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Thermal properties of different kinds of polyester knitted fabrics

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Thermal comfort behavior of four different types of polyester yarn single jersey knitted fabric has been studied. Spun, micro denier, continuous filament and hollow polyester yarns of 2 linear densities (106 denier and 177denier) have been used to prepare single jersey fabrics with three loop lengths (0.26 cm, 0.28 cm and 0.3 cm). The air permeability of continuous filament and micro denier yarn knitted fabrics is found to be higher than that of the spun yarn knitted fabrics. It is observed that 106 denier (0.3 cm loop length)micro denier fabric has the highest air permeability while 177 denier (0.26 cm loop length) spun yarn fabric shows the lowest air permeability, as compared to other fabric samples. Comparatively, the low air permeability characteristics are shown for coarser spun yarn fabric than the finer microdenier fabric. A significant difference is observed in water permeability among spun yarn, continuous filament yarn and micro denier yarn knitted fabrics at both linear densities of the yarn. The spun yarn of 177denier single jersey fabric has higher water vapour permeability and the continuous filament yarn fabric of 177 denier has lower water vapour permeability. The thermal conductivity value of 106 denier continuous filament polyester fabric is higher while that of microdenier polyester is lower. The statistical analysis shows significant difference between two different yarn linear densities and three different loop lengths of polyester yarn fabrics. Besides, different yarn and different count have impact on the comfort properties of single jersey fabrics.

Keywords: Knitted fabrics, Micro denier polyester, Polyester, Single jersey fabric, Thermal comfort

1 Introduction

Clothing plays a dynamic role in the process of thermoregulation as it modifies heat loss and moisture loss from the skin[1]. Comfort is one of the very important fabric properties, apart from mechanical and dimensional properties. Clothing comfort is mainly associated with thermal comfort[2]. The total thermal comfort of a clothing depends on the movement of heat, air, and moisture[3,4]. The process of heat transfer occurs due to the combined effect of conduction, convection and radiation of entrapped air through the fabric. Most importantly, the transfer of heat mainly occurs due to thermal conduction with in significant loss of convection and radiation. The total heat transmitted through the fabric depends on the heat conduction through air gaps in the fibre content[5]. The clothing comfort includes all the properties, such as thermal properties, aesthetic properties, psychological comfort and body movement. Knitted fabrics possess good comfort properties, as they allow water vapour transmission from the body along with stretch and ease of movement. To make knitted fabric more comfortable, changes have been made in the yarn parameters linear density and twist, knitting factors (CPI, WPI and loop length) and finishing process.

The comparative study on the thermal conductivity of different types of polyester knitted fabrics revealed that fabric structure, fibre content, and finishing treatments significantly affect the thermal properties. The fabric structures with higher density and tighter interlocking loops exhibited lower thermal conductivity, indicating better thermal insulation performance. Additionally, the addition of special finishing treatments, such as surface coatings or coatings with insulating materials further enhanced the thermal resistance of the polyester fabrics[6]. The thermal comfort properties of polyester single jersey knitted fabrics were studied and it was found that fabric parameters, such as yarn type, stitch density, and fabric weight influenced the thermal insulation and air permeability. Fabrics with higher stitch density exhibited improved thermal insulation, while fabrics with lower fabric weight and higher air permeability enhanced moisture management, leading to better thermal comfort for the wearer[7]. The effect of weft knitted fabric

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structure on the thermal properties of polyester blends was also studied. They observed that different stitch patterns had varying effects on thermal conductivity, thermal resistance, and heat retention. Fabrics with tighter stitches and higher loop density demonstrated lower thermal conductivity and improved heat retention, suggesting better thermal performance for polyester blended knitted fabrics[8]. The thermal conductivity of polyester fleece fabrics for outdoor apparel was studied. Their research indicated that fabric thickness, pile height, and fibre composition significantly influenced thermal insulation and heat transfer properties. Thicker fabrics with higher pile height and higher polyester content demonstrated improved thermal insulation, making them suitable for cold weather outdoor applications[9]. The study on thermal properties of polyester rib knitted fabrics concluded that different rib structures influenced thermal resistance, thermal conductivity, and heat retention capabilities. Fabrics with smaller rib widths and higher rib densities exhibited higher thermal resistance, indicating better insulation. The findings suggest that optimizing rib structures can enhance the thermal performance of polyester rib knitted fabrics[10]. They studied the effects of fabric parameters on the thermal conductivity of polyester interlock knitted fabrics and found that yarn type, loop length, and fabric weight had a significant impact on thermal performance. Polyester interlock fabrics with longer loop lengths, higher yarn thickness, and higher fabric weight exhibited lower thermal conductivity, indicating better thermal insulation properties[11]. The thermal properties of flame-retardant polyester knitted fabrics and concluded that flame-retardant additives affect the thermal behavior, heat transfer, and flammability of the fabrics. The inclusion of flame-retardant additives in polyester fabrics led to increased thermal resistance, reduced heat transfer, and improved flame resistance, making them suitable for applications requiring enhanced thermal protection[12].

Many good comfort properties are possessed by the knitted fabrics. Knitted fabrics have very good stretch and ease of movement, and this allows for transmission of water vapour from the body. Permeability is defined as *fabric's ability to transport moisture through itself, and is determined by a combination of sizes of spaces within it and the connections between the spaces.* One of the main comfort properties is the air permeability. Different aspects, such as thickness of fabric, fabric cover factor, twist of yarn, porosity, different weave pattern, different type of finishes and fabric coating affect the air permeability. The thermal conductivity of different types of polyester knitted fabrics revealed that fabric structure, fibre content, and finishing treatments significantly affect the thermal properties. The study on thermal comfort properties of polyester single jersey knitted fabrics showed that fabric parameters, such as yarn type, stitch density, and fabric weight influence the thermal insulation and air permeability. Fabrics with higher stitch density exhibited improved thermal insulation, while fabrics with lower fabric weight and higher air permeability enhanced moisture management, leading to better thermal comfort for the wearer. The fabric parameters also affect the thermal conductivity of polyester interlock knitted fabrics. It is found that yarn type, loop length, and fabric weight had a significant impact on thermal performance. Polyester interlock fabrics with longer loop lengths, higher yarn thickness, and higher fabric weight exhibited lower thermal conductivity, indicating better thermal insulation properties. Several researches have been investigated and carried out on the thermal comfort properties of knitted fabric[6-8].

In this research, the effects of various yarn parameters (like count) and knitting factors (CPI, WPI, loop length) on comfort properties of the knitted fabric have been studied.

2 Materials and Methods

2.1 Materials

Four different commercially available polyester yarns (spun, micro denier, continuous and hollow) of two different linear densities (106 denier and 177 denier) were obtained from different resources. Circular knitting machine with 21-feed, KNITMAC 24E gauge, 16 inches' cylinder diameter with positive storage feeder and 27 rpm velocity as a special attachment was used to produce single jersey knitted fabrics. Also, 0.26 cm, 0.28 cm and 0.3 cmloop lengths were used for all the fabric samples.

2.2 Methods

The structural and physical properties of fabric like mass per unit area (ASTM D 3776), thickness (ASTM D 1777), wales per unit length & courses per unit length [(ASTM D 3887: 1996 (RA 2008)] and loop length (ASTM D 3887) were evaluated (Table 1). Mass per unit area and fabric thickness at different places of the fabric was measured with the help of Shirley thickness gauge. Fabric of 10 cm × 10 cm sample size were cut for measuring the mass per unit area of the knitted fabrics. The sample was weighed

Table 1 — Physical properties of continuous filament, spun, micro denier and hollow fibre polyester knitted fabrics

Sample	Denier	Loop length cm	Fabric thickness mm	Wales per inch	Courses per inch	Mass per unit area, GSM
Continuous filament polyester(CF)	106	0.26	0.623	31	34	123.5
		0.28	0.617	29	31	114.2
		0.3	0.587	26	30	110.4
	177	0.26	0.633	29	36	124.2
		0.28	0.620	28	34	119.5
		0.30	0.591	26	31	118.5
Spun polyester (Spun)	106	0.26	0.637	31	36	126.3
		0.28	0.631	27	34	123.5
		0.30	0.578	25	32	110.5
	177	0.26	0.647	32	34	135.5
		0.28	0.634	29	31	132.6
		0.30	0.598	25	33	109.6
Micro denier polyester (MD)	106	0.26	0.623	33	32	126.5
		0.28	0.619	31	33	125.6
		0.30	0.598	30	35	126.5
	177	0.26	0.635	31	28	122.6
		0.28	0.615	27	34	120.2
		0.30	0.585	25	34	115.3
Hollow fibre polyester (HF)	106	0.26	0.634	30	36	126.1
		0.28	0.625	27	35	122.5
		0.30	0.598	26	31	109.6
	177	0.26	0.645	31	37	120.6
		0.28	0.631	30	34	114.5
		0.30	0.602	27	33	109.8

using electronic balance and the value was multiplied by 100. Twelve courses of the loop length unravelled and the total length was measured. The average loop length or stitch length calculation was done by using the formula: [(total length × no. of wales)/12]. The loop shape factor was calculated by the ratio of courses/inch and wales/inch. As per ASTM D 1777-07, thickness of the fabric was calculated for each specimen at 10 different places and the average was calculated for further analysis. As per ASTM D-3776 -96, mass per unit area of fabric was calculated by using a standard cutter and the average value of five samples was reported. Textest FX 3300 (Textest Instruments AG, Schwerzenbach, Switzerland) air permeability tester was used to measure air permeability of the fabric at a pressure of 100 Pa (ASTM D737).The water vapour permeability on a Permetest instrument (Sensora Company, Liberec, Czech Republic) was measured according to ISO 11092. The Alambeta instrument (Technical University of Liberec, Liberec, Czech Republic) was used to measure thermal conductivity values. According to ISO 11092, the fabric is kept between the hot and cold plates in this instrument. Standard atmospheric conditions [21 ± 1 °C (70 ± 2°F) and 65 ± 2% relative humidity (RH)] as recommended by ASTM D 1776 and standard practice for conditioning and testing textiles was maintained while taking measurements. Ten readings were taken for each of the knitted fabrics and the average value was calculated. In order to make statistical comparison, analysis of variance method (ANOVA) was used for the test results of the fabrics produced by spun polyester yarn, continuous filament polyester yarn, and micro denier polyester with two different counts respectively. The significant '*p*'values obtained were compared, and considered significant if the value is equal to or less than 0.05.

3 Results and Discussion

3.1 Fabric Physical Properties

Table 1 shows that when linear density increases, the thickness and weight of fabric increase. Also, with the increase in loop length, there is a decrease in the thickness and weight of the fabric samples. These results are in agreement with the findings of Frydrych *et al*.[9] and Majumdar *et al*.[10]. Knitted fabric thickness mainly depends on the yarn linear density, structure of the fabric and loop closeness in the fabric. Fabric structure, yarn linear density and different properties of knitted fabrics structure affect the GSM of fabric. As the fabric density increases, the weight of the fabric also increases. For the same yarn linear density, if there is an increase in the stitch length, the structure of the fabric becomes loose, resulting in lower GSM of the fabric. Table 1 also shows that the fabric thickness decreases when the loop length increases. This is also predicted by Prakash and Ramakrishnan[11], as there is an increase in the loop length, there is a decrease in the fabric thickness. It is revealed that with an increase in loop length, the GSM of the fabric and the fabric thickness for the same yarn linear density get reduced.

3.2 Air Permeability

The air permeability values of spun yarn, continuous filament yarn and micro denier yarn knitted fabrics of both 106 denier and 177 denier are shown in Fig. 1. There is a noteworthy difference in the air permeability of different linear densities of spun yarns, continuous filament yarns, micro denier yarn and hollow fibre yarn polyester knitted fabrics and also in the air permeability values of different loop lengths. It is noticed that the air permeability of spun yarn knitted fabrics is lower than those of the micro denier and hollow fibre yarn knitted fabrics. It is observed that 177 denier spun yarn fabric of 0.26 cm loop length has the lowest air permeability, while 106 deniermicro denier yarn fabric of 0.3 cm loop length has the highest air permeability. The fabric made from continuous filament polyester yarn has higher inter yarn space in the fabric, which results in higher air permeability as compared to spun polyester fabric. Spun yarn fabric is a coarser yarn fabric, resulting in low air permeability value because of less inter yarn spaces. Thickness and the mass per square meter of fabric have impact on the air permeability of the fabric. The air permeability value is higher when the fabric thickness and fabric weight are lower[12]. Table 2 reveals a significant difference in air permeability of all different types of polyester single jersey knitted fabrics having different linear densities and loop lengths.

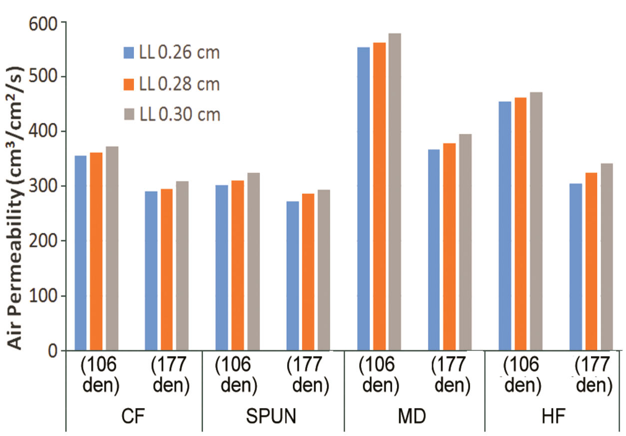

Fig. 1 — Air permeability of polyester knitted fabric.

One of the important comfort aspects of textile material is air permeability. It is the transfer of air flow from the human body surface to the environment. It also allows the passage of fresh air into the body. The value of air permeability is different for different fabric samples and loop lengths. As the fabrics become looser, the value of air permeability increases. It is shown in Table 1 that the thickness and weight of the fabric decrease with larger loop length fabric. All these results contribute to the higher air permeability value. Moreover, higher air permeability value is due to the increased loop length, which causes a loose fabric surface. As the yarn becomes finer, the pores between the loops of the fabric get larger and hence air permeability gets increased accordingly. The spun polyester fabric of count 177 denier and loop length 0.26 has the highest fabric thickness. There is also an increase in the air permeability value, as the stitch length increases. The fabric compactness decreases, with the increase in the loop length which leads to the decrease in the total number of stitches. Figure 1 clearly indicates that for a coarser yarn fabric, the air permeability value islower when compared with the finer yarn fabric. Moving across the range from 0.26cm to 0.3cm loop length, it is clear that the increase in loop length

Table 2 — Statistical comparison of air permeability of fabric samples

Source of variation	Sum of square value (SS)	Degree of freedom (df)	Mean square value (MS)	F-value	p-value	F crit
Loop length	192634.95	7	27519.28	1986.87	7.022×10^{-20}	2.76
Types of yarn	2134.75	2	1067.37	77.06	2.77×10^{-8}	3.73

*Significant for α = 0.05.

increases the air permeability. On the other hand, due to the micro spaces in the fibre structure in the microdenier fibre, the air permeability values become higher. These findings are also reported by Majumdar *et al.*[10] that micro fibre yarns have smaller diameters than other polyester yarns of the same count. The results show that the thickness of the fabric has a significant effect on the values of air permeability for the different polyester knitted fabrics. As the thickness is increased the value of air permeability tends to decrease, irrespective of the type of fibre.

3.3 Thermal Conductivity

Another important and intrinsic properties of the fabric is thermal conductivity which is the ability to conduct heat in the fabric. Type of fibres, type of fabric structures and the amount of entrapped air determine the fabric thermal property. Therefore, the thermal conductivity of the fabric is higher for coarser fabric, because of the entrapped air in it[13]. Figure 2 shows the thermal conductivity values of all the knitted fabrics of both 106 denier and 177 denier. Table 3 shows a significant difference in thermal conductivity of all different types of single jersey knitted fabrics, having two different linear densities and three loop lengths. Hollow fibre polyester fabric of 106 denier(0.3cm loop length) has high thermal conductivity value and continuous filament polyester fabric of 177 denier (0.26 loop length) has low thermal conductivity value. Afzal *et al.*[1]reported that the courses per inch, wales per inch and mass per unit

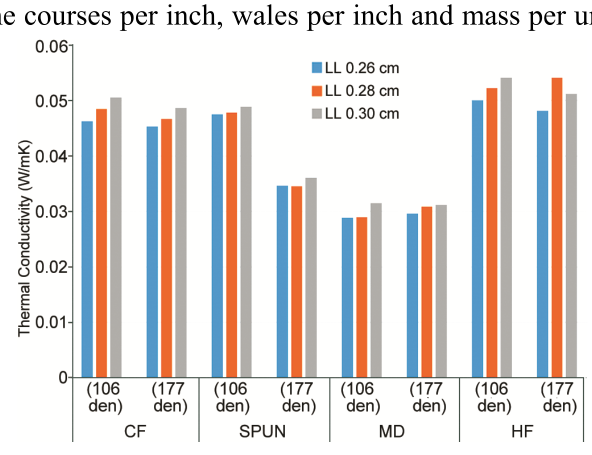

Fig. 2 — Thermal conductivity of polyester knitted fabrics.

area of the fabric have a direct effect on the thermal conductivity of the fabric. When there is a decrease in compactness of the fabric, thickness and areal density of the fabric, there is an increase in the thermal conductivity of the fabric. This is due to the consistent decrease in thickness, wales per inch, courses per inch of the fabric, which results in loose fabric structure[14]. Compared to other fabrics used widely, polyester fabric has higher thermal conductivity[15] with decreased fabric thickness[16,17]. Figure 2 shows that with the decrease in loop length, thermal conductivity value decreases. The compactness of the fabric decreases with the increase in loop length due to the decreasing fibres content in the structure of the fabric. Similarly, longer loop length creates more porosity in the fabric and there is a decrease in the areal density and the fabric thickness (Table 1). Therefore, higher loop length decreases the thermal conductivity of the fabric. It is revealed by Pac *et al.*[18] that different fabric types made of similar fibre can affect heat transfer changes. It is clear from Fig. 2 that the lower thermal conductivity value is due to the increase in yarn linear density.

3.4 Water Vapour Permeability

The water vapour permeability values of spun yarn, continuous filament yarn, hollow fibre and micro denier yarn knitted fabrics of both 106 denier and 177denier are shown in Fig. 3. From Table 4 (ANOVA analysis), it is observed that the water vapour permeability values have a significant difference among the spun yarn, continuous filament yarn, micro denier yarn and hollow fibre polyester knitted fabrics and between the linear density and between the loop lengths. The water vapour permeability is higher for the hollow fibre yarn of 177 denier (0.30cm loop length) single jersey fabric and is lower for the spun yarn fabric of 177 denier (0.26cm loop length) than all other fabrics.

Relative water vapour permeability of fabric is defined as the capability to transfer the vapour from the surface of the body. If the fabric tends to have higher thermal resistance, the heat generated by the body will not be dissipated. There will be a higher resistance to moisture for heat transfer that causes a

Table 3 — Statistical comparison of thermal conductivity of fabric samples

Source of variation	Sum of square value (SS)	Degree of freedom (df)	Mean square value (MS)	F-value	p-value	F crit
Loop length	0.00176	7	0.000251	583.97	3.62×10^{-6}	2.76
Types of yarn	2.98×10^{-5}	2	1.49×10^{-5}	34.60	3.82×10^{-6}	3.73

*Significant for α = 0.05.

Table 4 — Statistical comparison of water vapour permeability of fabric samples

Source of variation	Sum of square value (SS)	Degree of freedom (df)	Mean square value (MS)	F-value	p-value	F crit
Loop length	166838.62	7	23834.08	442.39	2.50×10^{-15}	2.76
Types of yarn	3969.08	2	1984.54	36.83	2.60×10^{-6}	3.73

*Significant for α = 0.05.

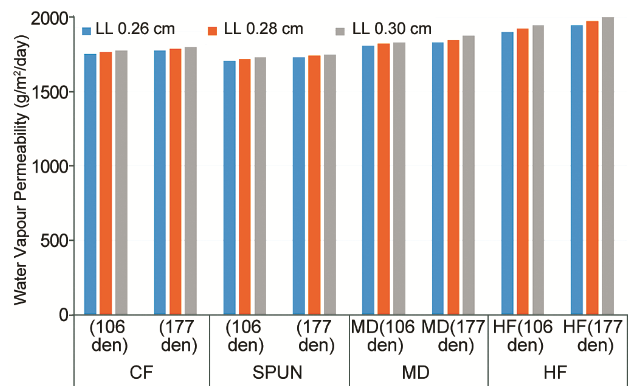

Fig. 3 — Water vapour permeability of polyester knitted fabrics

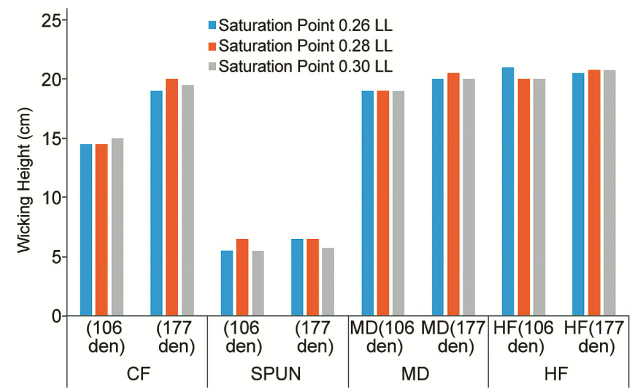

Fig. 4 — Wicking of 0.26 LL, 0.28 LL and 0.30 LL polyester fabric.

sense of uncomforting. Figure 3 represents the water-vapour permeability value of the different polyester yarn fabrics and it is perceived that as the loop length increases, the water-vapour permeability value also increases. It is well-known that the water vapour permeability is higher for continuous filament polyester fabric than the spun polyester fabric. This is due to the channelled structure of continuous filament of polyester. The hollow fibre yarn fabric of 177 denier (0.30cm loop length) has higher water vapour permeability that can be contributed to the lower GSM of fabric and the fabric thickness, which results in easy transmission of the water vapour through the fabrics. Large-porous structure of the constituent fibres contributes to the water-vapour permeability of fabric material. It is also clear that when there is an increase in the linear density, the water-vapour permeability value gets increased. The water-vapour permeability and the air permeability results are more similar though the effect is a little less in case of the former. Prahsarn *et al.*[19] associated certain fibre-related factors such as fibrecross-sectional shape, moisture absorption properties and thickness of the fabric to the water vapour transmission rate.

3.5 Wicking

The fabrics were tested for vertical wicking (BS 3424) characteristics. To analyse the wicking behaviour, ten samples (20 cm × 2 cm) were taken, tested and their average values were calculated. To hold the fabric sample, a stand arrangement is used, where one end (upper) of the fabric was clipped and the other free end (lower) was suspended vertically down with 2cm of the fabric immersed inside a beaker of distilled water. At the start, after a minute the vertical movement of the water was observed. Due to the capillary action, the water transportation took place in the fabric. Later on, for every 5 min up to 30 min, the water height movement is measured in the fabric samples till its saturation level. The rate of vertical water movement by capillary action was tested. Figure 4 shows the wicking heights of all the fabric samples, analysed with the wicking time from 5 min to 30 min. The water spreading rate by capillary action was tested. Initially, the wicking height was faster in the continuous filament and micro denier yarn knitted fabric, and then there is a gradual increase in the height at every 5 min time interval. The wicking rate is found slower for spun yarn fabric. Hollow fibre polyester fabric of 177 denier (0.29 cm loop length) has the maximum wicking height and the spun yarn fabric of 106 denier (0.26 cm loop length) has the lowest wicking height.

Figure 4 also reveals that the coarser yarn fabric wicking height is comparatively higher than that of finer yarn fabric. This is due to the higher capillary action of the coarser fabric caused by the greater number of fibres in the cross-section. Similarly, coarser fabric shows higher wicking ability of the fabric due to the greater thickness of the fabric[20]. Continuous filament polyester has a proper channelled structure that results in higher wicking behaviour as compared to the spun polyester fabric. The channel structure facilitates the easy transportation of the water through the fabric[21]. There is an increase in the wicking length continuously with the increase in stitch length. Longer loop length of single jersey fabric lengths improves the wick ability of the fabric. This results in a lower tightness factor and increased porosity size. So, it is clear that there is an improved wick ability, with the increase in the loop length. It was also investigated by various researchers that wicking depends on one of the factors, i.e. tortuosity of fabric[20-23] and the factor was combined in single jersey knitted fabric[24].

3.6 Data Analysis: Variance Statistics

ANOVA statistical summary results show that the effect of different linear density and loop length on thermal comfort properties is mostly statistically significant. According to Tables 2-4, it is clear that all the variables are significant at 95% confident level.

4 Conclusion

Spun yarns, continuous filament yarns, micro denier yarns and hollow fibre polyester yarn single jersey fabric of both the linear densities have been investigated for the thermal comfort properties of fabric having all the three loop lengths. The properties of yarn and the fibre distribution within the yarn, the different loop lengths and the yarn linear densities affect the air permeability, water vapour permeability, thermal conductivity and wicking of the fabrics. The 106 denier micro denier yarn knitted fabrics (0.3cm loop length) have higher air permeability values and 177 denier spun yarn knitted fabrics (0.26cm loop length) have lower air permeability. There is an increase in the thermal conductivity value of the 106 denier (0.3cm loop length) hollow fibre polyester fabric. The decreased thermal conductivity value is obtained for the continuous filament polyester fabric of 177 denier (0.26cm loop length). Comparatively, hollow fibre single jersey fabric of 0.3cm loop length and 177 denier has higher water vapour permeability and the continuous filament yarn fabric of 177 denier (0.3cm loop length) shows lower water vapour permeability. The wicking height is found maximum for 0.28cm loop length and 0.3cm loop lengths (177 denier) hollow fibre single jersey fabrics and lower for 0.26cm loop length (106 denier) spun yarn fabric.

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