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Research Article

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Investigating Thermophysiological Comfort Properties of Fabrics Used in Athlete Clothes

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Abstract

The main goal of this work was to study the influence of sportswear fabric properties on the thermophysiological comfort of athletes. Seven different yarn type fabric were produced with two different knitting structure as single jersey and mesh knitting. The weights of fabrics were tried to closer to each other as much as possible to see the effect of yarn type on air permeability, thermal resistance, water vapour resistance and moisture management properties of fabrics. It will be planned to use the mesh in combination with single jersey knitted fabrics in the future studies for production of athlete clothes. The highest air permeability, OMMC value was seen in TS TencelTM yarn knitted fabric and the lower water vapor resistance was seen in PM textured polyester mesh knitted fabric. Which means thermophysiological comfort properties of these fabrics are higher than the others and feels comfortable by the athletes according to objective test results. For this reason, TS TencelTM single jersey and PM coded Polyester mesh knitted fabric or their combinations can be preferred production of athlete clothes.

Keywords

Moisture management; Water vapour resistance; Thermal resistance; Air permeability

Introduction

In the last decades, the importance of functional clothing involving sport, outdoor and other protective garments has increased. For this reason, fabric breathability (moisture transmission and air permeability) and thermal properties should be improved to meet the requirements of athletes. The type of fibre (natural, synthetic or blend), the fabric structure (woven or knitted) and fabric constructions are important parameters that affect the thermal and breathability properties of sportswear fabrics. Thermal insulation, breathability and the heat and moisture transmission properties affect the comfort sensation from a physiological point of view.

Heat and moisture transmission from garment involves complex processes which are coupled with evaporation, condensation and sorption and desorption of moisture. Transfer of heat away from the body is affected by various factors including air movement, relative humidity, sunshine and clothing. Thermo-physiological properties of clothing are often assessed by the hotplate test, where the "breathability index" is the ratio between evaporative resistance and thermal insulation [1].

For sportswear physiological aspect is extremely important because of its major effect on the efficiency and performance of athletes. 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. Some studies about this subject were given in below:

Varshney et al. (2010) investigated the effect of linear densities and profiles of polyester fibres on the physiological properties of their fabrics. They founded that air permeability and moisture vapour permeability positively correlated with fibre decitex. Also, the use of non-circular polyester in place of a circular one augments the wickability of liquid water along with the permeability of air and moisture vapour through the fabrics [2].

Majumdar et al. (2010) investigated thermal properties of different knitted fabric structures made from cotton, regenerated bamboo and cotton-bamboo blends. The experiments were done by using air permeability, Alambeta and Permetest test devices. It was found that the thermal conductivity of knitted fabrics generally decreased as the proportion of bamboo fibre increases [3].

Wang et al. (2014) investigated evaporative cooling efficiency of one layer tight-fitting sportswear. For this reason, Coolmax®, merino wool, sports wool and cotton knitted fabrics were selected for the study. The results demonstrated that, for the sportswear materials tested, the real evaporative cooling efficiency linearly decreased with the increasing ratio of moisture being transported away from the skin surface to the clothing layer [4].

Atasagun et al. (2015) investigated the advantages of Viloft blends used for sportswear, taking into account objective measurements and subjective wear trials. The results showed that the mechanical properties of Viloft-blended fabrics have not been superior to commercial fabrics. Viloft/wool fabrics showing high thermal resistance and water vapour resistance have had poor transfer properties [5].

Özkan and Meriç (2015) investigated the thermal and moisture management properties of six different types of polyester knitted fabrics that are used in the production of summer cycling clothes. They found that warp knitted raschel fabric was more convenient for summer cycling clothing because of its good air permeability, low thermal resistance, low water vapour resistance and good moisture management properties [6].

Öner and Okur (2015) investigated the transfer properties of knitted fabrics which had 1 × 1 rib-knitted structure and which were systematically produced from 20 tex yarns made of natural, regenerated cellulosic, synthetic and functional fibres. The results showed that Polyester and Cotton/Coolmax fabrics with float structure had good liquid moisture transfer properties and high capillary absorption characteristics [7].

Hussein et al. (2015) studied comfort and mechanical properties of polyester/bamboo and polyester/cotton four different ratios blended knitted fabrics. The results showed that thermal resistance

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of P/C blended fabrics was reduced by an increase in the content of cotton in the fabric blend. Which means an increase in polyester content in the blend increases fabric thickness causing an increase in thermal resistance [8].

Chen et al. (2017) examined thermophysiological comfort properties of polyester weft-knitted fabrics for sports T-shirt. It was found that higher mass was associated with higher air resistance, higher porosity was associated with faster dry speed and faster vertical wicking rate was associated with shorter water absorption time for fabrics tested in that study [9].

Suganthi and Senthilkumar (2017) studied 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. The water vapour permeability of the bi-layer fabric increased with a decrease of thickness and presence of openness in the fabric. It was observed that moisture absorbency of bi-layer knitted structure increased with an increase of stitch density and tightness factor [10].

Degirmenci and Coruh (2017) investigated the effect of loop length and raw material on the air permeability and the bursting strength of plain knitted fabrics. The results showed that because of the cross section of the polyester yarn is more regular, maximum air permeability values are obtained in the fabric manufactured from polyester fibres [11].

The aim of this paper is investigating thermophysiological comfort properties of a group of fabric which can be used for the production of athlete clothes. The weights of fabrics were tried to closer to each other as much as possible to see the effect of yarn type on air permeability, thermal resistance, water vapour resistance and moisture management properties of fabrics. It will be planned to use the mesh in combination with single jersey knitted fabrics in the second stage of this work and to conduct a wear trial with the selected samples.

Material and Methods

Seven different types of knitted fabric were produced by a manufacturer with two different knitting structure as single jersey and mesh knitting. The properties of fabrics measured by standard methods are given in Table 1. Before the fabrics were used in the test, they were placed in a controlled room for 24 hours for conditioning. The air permeability properties of the fabrics were measured using an SDL Atlas air permeability instrument according to the EN ISO 9237 standard with a 100 Pa air pressure and a 20 mm^2 test area. A moisture management instrument (MMT) was used to measure the dynamic liquid transport properties of knitted samples. The moisture management properties were evaluated using a moisture management tester according to AATCC 195-2009 [12].

The thermal resistance and water vapour resistance properties of the fabrics were measured using an SDL Atlas Sweating Hot Plate instrument according to the EN 31092 and ISO 11092 standards with a plate the surface temperature of 35°C. The thermal resistance measurements were collected in a controlled room at a temperature of 20°C and a humidity of 65%. The water vapour resistance measurements were collected at a temperature of 20°C and a humidity of 40%. The porosity values of fabrics were calculated according to

$$\varepsilon = 1 - \left(\frac{\pi . d^2 l . C . W}{2t}\right)$$

where t is sample thickness (cm), 1 is the loop length (cm), d is yarn diameter (cm), C is the number of courses per cm and W is the number of wales per cm [13].

Results

Air Permeability

Air permeability is defined as the volume of air in litres which is passed through 100 cm^2 (10 cm × 10 cm) of the fabric in one minute at a pressure difference of 10 mm head of water [14]. Air permeability values of tested fabrics are compared in (Figure 1). TS, Tencel™ single jersey knitted fabric showed the highest air permeability value. We also know Tencel fibre has it is air conditioning naturally. POS1 and POS2 polyester knitted fabrics with different filament numbers showed the lowest air permeability values because these fabrics had the highest course and wale values. Also, POS1 coded fabric having higher filament number and lower density showed higher air permeability value than POS2. All the fabrics were produced with single jersey weave type (except PM fabric), so the important

Table 1: Fabric properties used in the experiment.*PS-Cotton Single Jersey, PPS-Cotton Polyester Single Jersey, POS1-Polyester Single Jersey (1), PM-Polyester Mesh Knitted, TS-Tencel Single Jersey, MS- Modal Single Jersey, POS2- Polyester Single Jersey (2).

Fabric Code	Composition (%) and Yarn Count	Knit	Wales-Courses (cm)	Density (g/cm³)	Loop Length (mm)	Thickness (mm)	Porosity (%)
PS	100% Cotton 19.68 Tex	Single Jersey	14-21	0.24	2.3	0.61	92.3
PPS	50-50% Cotton/Polyester 19.68 Tex	Single Jersey	15-19	0,25	2.15	0.57	92.7
POS1	91% Textured Polyester 9% Spandex 11.11/108 Tex Textured Polyester, 2.22 Tex Spandex	Single Jersey	16.5-26	0.28	2.12	0.48	91.4
PM	98% Textured Polyester %2 Polyester Trilobal 24.44/360 Tex Textured polyester, 2.22 Tex Polyester Trilobal	Mesh (Weft knitted)	13-17	0.23	2.17	0.62	93
TS	100% Tencel 19.68 Tex	Single Jersey	14-19.5	0.27	2.07	0.52	92.8
MS	94.5% Modal %5.5 Spandex 14.76 Tex Modal 2.22 Tex Spandex	Single Jersey	16-25	0.29	2.01	0.54	91.4
POS2	%92.5 Textured Polyester %7.5 Spandex, 11.11/96 Tex Textured Polyester 2.22 Tex Spandex	Single Jersey	16-28	0.30	2.21	0.51	91.2

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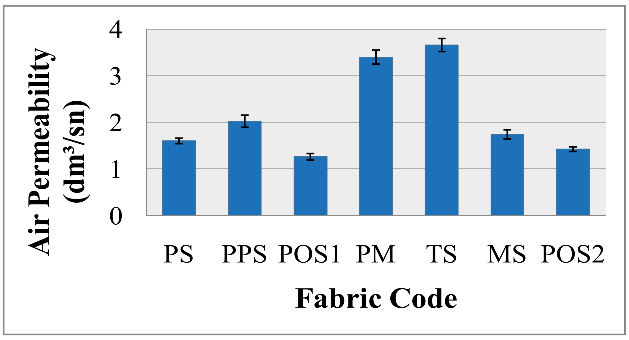

Figure 1: Air permeability values of the fabrics.

parameter is the yarn type and yarn count. The highest porosity value PM coded fabric showed the second highest air permeability value because of mesh knitting structure and low coarse and wale value. When we compare same yarn count PS cotton single jersey and PPS cotton-polyester single jersey knitted fabrics, polyester included PPS fabric showed higher air permeability value because of higher porosity value. Which supports previous studies, the more porosity the fabric, the more the permeable fabric is obtained [15] and air permeability is a function of knitted fabric thickness and surface porosity [16].

Moisture Management Test Device Measurements

The MMT is designed to sense, measure, and record the liquid moisture transport behaviours in multiple directions [17]. According to AATCC test method, 195-2009, wetting time (top-bottom), absorption rate (top-bottom), maximum wetted radius (top-bottom), spreading speed (top-bottom), accumulative one-way transport capacity index and overall moisture management capability of fabrics were measured by MMT. MMT grading scale was given in Table 2. The highest top wetting time value was shown in the highest courses and wales value POS2 coded fabric. Which means this fabric absorbs water solution slower than the other fabrics in the top surface. The second highest wetting time values both in the top and bottom surfaces were shown in PM, the highest thickness value polyester mesh knitted fabric (Figure 2). The lowest top wetting time means that moisture is absorbed faster by the material and transmitted to the outer surface of the fabric. The lowest wetting time values were shown in MS modal single jersey knitted fabric. The weight of tested fabrics are close to each other and their knits are the same (except PM). So we can say modal yarn absorbs the sweat solution more quickly than other fabrics and feels drier in the skin surface. Because modal fibers show a compact external structure with very small pores and some large pores towards the center, so, show more absorption and transfer of moisture [18].

Absorption Rate of Fabrics

The absorption rate is defined as the average moisture absorbency (%/sec) of the top and bottom surfaces of the fabric within the pumping time (20 sec) [19]. The absorption rate of fabrics used in the experiments was shown in (Figure 3). Bottom absorption rates of fabrics were higher than top absorption rates except for PS coded fabric. This means that the sweat solution absorbed by the top surface of the fabric did not accumulate on the top surface which was rapidly transferred to the bottom surface. If only a little sweat is transferred to the outer surface of a fabric, it still causes the collection of sweat on the skin surface and disturbs the wearer [20]. The highest bottom absorbency rate was seen in PM coded textured polyester mesh fabric which means sweat solution don't hold top surface of fabric, it transferred to bottom surface of fabric and feels drier in the skin. The lowest top absorption rate was measured in polyester fabric with POS2 code having the highest course and wale numbers.

Spreading Speed of Fabrics

Spreading speed is the speeds of the moisture spreading on the top and bottom fabric surfaces to reach the maximum wetted radius. The spreading speed of fabrics used in the experiments was given in (Figure 4). The highest bottom spreading speed value was found in the textured polyester mesh (PM) fabric sample which showing the highest bottom absorption rate. This fabric felt comfortable than the others because the skin surface felt drier than the other fabrics. Since the spreading speed values of PPS, POS1 and TS coded fabrics were in the range of 3-4, these fabrics showed fast spreading speed value according to MMT grading scale. PS coded cotton single jersey fabric

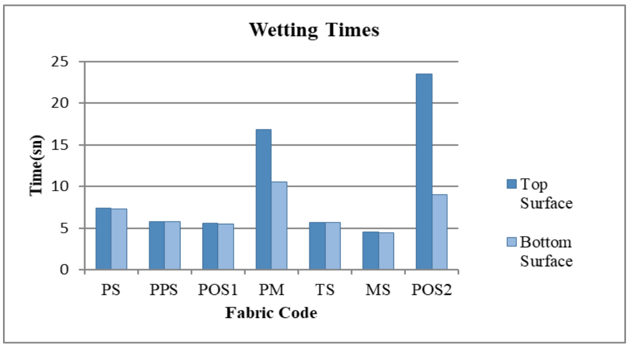

Figure 2: The wetting time values of fabrics.

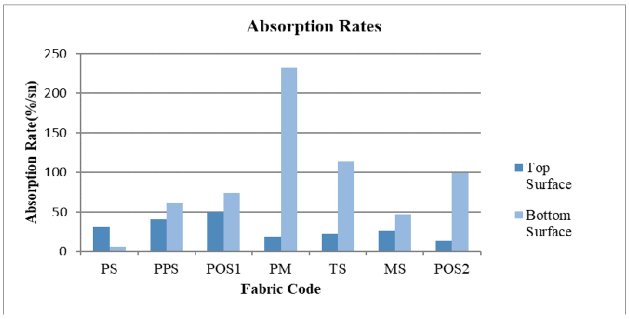

Figure 3: The absorption rate of fabrics.

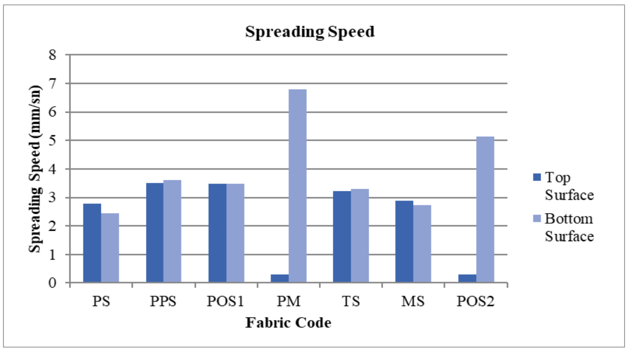

Figure 4: Spreading speed of fabrics.

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was showed the lowest bottom spreading speed value which means water solution was kept by the top surface of the fabric and a small amount of solution was transferred to the outer surface of the fabric. Because cotton keeps moisture well because of hidrofilic structure.

OWTC and OMMC Measurements of Fabrics

MMT grading scales were used to analyze the OMMC and OWTC values of fabrics (Table 2). Accumulative one-way transport index (OWTC) is the difference of the accumulative moisture content between the two surfaces of a fabric [21]. The means of highest OWTC value is the transfer of test solution from one side of the fabric to the other side very quickly. This property also affects the transfer of sweat in the skin surface to fabric outer surface. OWTC values of tested fabrics are given in (Figure 5). All the fabrics were showed perfect OWTC value according to MMT grading scale except PPS and POS1 fabrics. The highest OWTC values were obtained in PS, 30/1 Cotton yarn single jersey knitted fabric. On the other hand, the cotton-polyester knitted fabric of (PPS) the same yarn count of 30/1 showed a good OWTC value according to MMT grading scale. In this example adding polyester yarn to cotton decreased the OWTC value of fabrics.

Overall Moisture Management Capacity (OMMC) is an index to indicate the overall capability of the fabric to manage the transport of liquid moisture [22]. Overall moisture management properties of the tested fabrics are given in Figure 6. The highest OMMC value was seen in TS, highest air permeability value, 30/1 Tencel™ knitted single jersey fabric. Tencel has a very high absorption capability, a unique nanofibril structure and a very smooth surface. As a result, all these physiological functions are much more pronounced for TENCEL than for other cellulosic fibres [23]. The lowest OMMC value was observed

Table 2: MMT grading scale (MMT Test Device Manual, 2011).

Index	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Wetting Time (s)	≥ 120 No wetting	20-119 Slow	5-19 Medium	3-5 Fast	<3 Very Fast
Absorption Rate (%/s)	0-10 Very slow	10-30 Slow	30-50 Medium	50-100 Fast	>100 Very Fast
Max Wetted Radius (mm)	0-7 No wetting	7-12 Small	12-17 Medium	17-22 Large	>22 Very large
Spreading Speed (mm/s)	0-1 Very slow	1-2 Slow	2-3 Medium	3-4 Fast	>4 Very fast
OWTC (%)	<-50 Poor	-50 to 100 Fair	100-200 Good	200-400 Very good	>400 Excellent
OMMC	0-0,2 Poor	0,2-0,4 Fair	0,4-0,6 Good	0,6-0,8 Very good	>0,8 Excellent

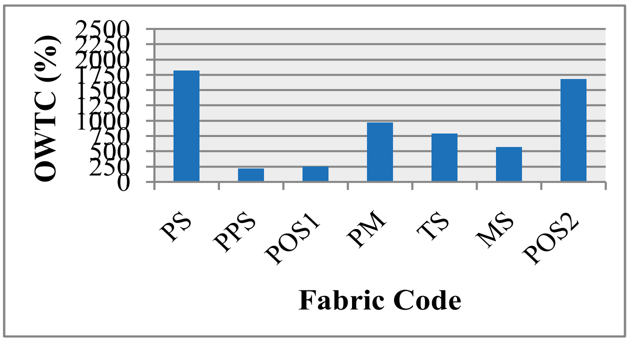

Figure 5: One-way transport index of the fabrics.

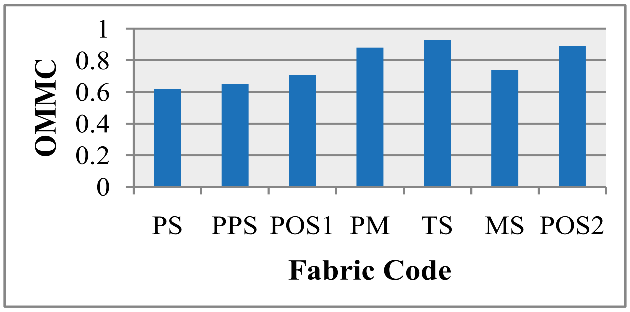

Figure 6: Overall moisture management properties of the fabrics.

in PS, which was the highest OWTC value, 30/1 Cotton knitted single jersey fabric. We can see the effect of yarn type on OMMC values of fabrics. The regenerated cellulose Tencel knitted fabric was showed the highest OMMC value than cellulosic cotton fibre. Cotton absorbs much less water than Tencel and Modal. If the same yarn count of PS and PPS fabrics are compared, polyester knitted PPS coded fabric showed the highest OMMC value than cotton knitted fabric because of capillarity of polyester yarn. The water molecules are not absorbed by the polyester fibers because of their hydrophobic characteristics on the other hand cellulosic fibers as cotton absorb the water easily with their polar groups but they keep liquid in their structure, which makes it difficult to transport liquid [24].

Thermal Resistance Measurements

The sweating guarded hot plate apparatus was used to measure the thermophysiological comfort of clothing, i.e. the thermal and vapour resistances of fabrics under steady-state conditions [25]. It simulates processes occurring next to the human skin–the transfer of heat and water vapour (sweat) from the skin, through the textile layers, to the environment [26]. Thermal resistance values of fabrics measured with Sweating Hot Plate device are shown in Figure 7. The highest thermal resistance value was seen in PPS coded cotton-polyester single jersey knitted fabric. Regarding the thermal properties of the tested samples in dry state, samples containing more PES fibres showed fairly lower thermal conductivity than the pure cotton samples [27]. For this reason cotton single jersey knitted fabric (PS) was showed second highest thermal resistance value. Because thermal conductivity of cotton is higher than polyester and normally there is a inverse relationship between thermal conductivity and thermal resistance of fabrics. Thermal resistance values of cotton and modal knitted fabrics were found close to each other. The lowest thermal resistance values were seen in POS2 textured polyester and TS Tencel knitted fabrics. POS1 and POS2 fabrics were of the same yarn count and knitting structure. But POS1 showed higher thermal resistance value most probably due to the lower density value. Because for same yarn knitted fabrics, there is a inverse relationship between fabric density and thermal resistance [20].

Water Vapour Resistance

The water vapour resistance represents the water vapour pressure difference between the two sides of the specimen divided by the resultant evaporative heat flux per unit area in the direction of the gradient in units of (m^2.Pa/W). The water vapour resistance is calculated according to:

$$R_{et}=\Delta\rho(A/H-\Delta He)$$

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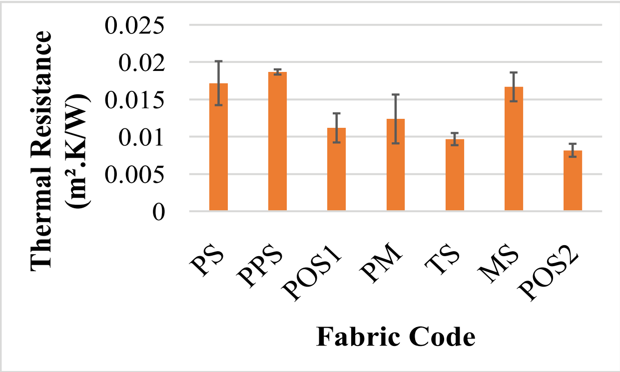

Figure 7: Thermal resistance of fabrics.

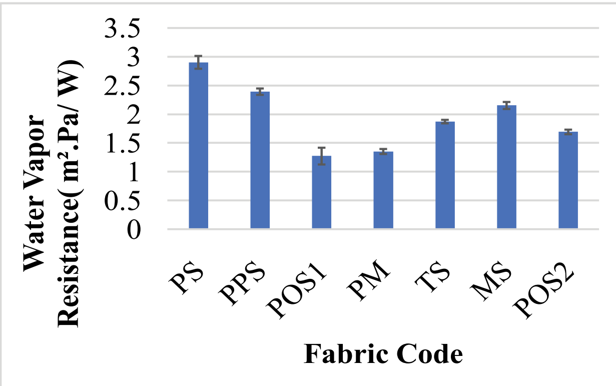

Figure 8: Water vapor resistance of fabrics.

Where ΔP is the difference in the partial pressure between the two sides of the specimen in Pa, A is the area of the measuring unit (plate) in m^2, H is the heating power supplied to the measuring unit (plate) in W and ΔHe- is the correction term in W [28].

The water vapour resistance values of fabrics measured with Sweating Hot Plate device are given in Figure 8. Water vapour resistance and permeability are inversely proportional to each other. Fabric characteristics and structure play a significant role on water vapor permeability. When comparing fabrics made of the same yarn, the water vapor transmission rate is primarily a function of fabric thickness and density. The highest water vapour resistance value was seen in PS, 30/1 Cotton knitted single jersey, one of the highest thickness value fabric meaning that, this fabric had the lowest water vapour permeability value. The second highest water vapour resistance was observed in the same yarn count PPS coded fabric sample.

Especially in sports clothes, highest water vapour permeability value is preferred. Because sporters must throw away the sweat from the skin surface and this is only possible with water vapour permeability characteristic of the fabric. The lowest water vapour resistance value was seen in the lowest thickness value POS1, textured polyester yarn knitted fabric. Also PM, textured polyester mesh knitted fabric showed low water vapour resistance value because of the mesh knitting structure. These results indicate that these fabrics can be used for active sports clothes because of water vapour permeability properties.

Conclusion

In this study, thermophysiological comfort properties of a group of samples were compared to use in production of athlete clothes. Firstly, air permeability, moisture management, thermal resistance and water vapour resistance of seven different fabrics were investigated. Five samples were chosen and produced to use in wear trials according to objective test results. MS coded modal single jersey fabric was not selected because of its high water vapor resistance and moderate air permeability values. Also, POS2 coded polyester single jersey fabric was not used in production of athlete clothes because of higher water vapour resistance value than POS1 coded fabric. PS and PPS coded fabrics were chosen because they are widely used in the market. The TS coded fabric selected because of highest air permeability and OMMC values. This means that this fabric structure absorbed the sweat solution more quickly and quickly transferred it to the other side of the fabric, making the user feel more comfortable. The PM coded fabric had mesh fabric structure and it was used in clothing experiments due to low water vapour resistance value. Because athletes must throw away the sweat from the skin surface during the activity and this is possible with low water vapour resistance of the fabric. It can be concluded that, Tencel single jersey and Polyester mesh knitted fabric or their combinations can be preferred to use in production of athlete clothes.

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