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Development of sportswear with enhanced moisture management properties using cotton and regenerated cellulosic fibres

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The effect of fibre composition on moisture management properties and peak heat flux (q_{max}) values of one commercial sport garment and six knitted fabrics (sportswear), composed of 100% polyester, 100% cotton, 100% modal, and blend of polyester with cotton and modal, have been investigated. The moisture management properties are assessed by using the moisture management tester, and the feeling of coldness or warmth is assessed by measuring q_{max} value on KES-F7 Thermo labo II. Blending polyester fibre with cotton and modal has improved moisture management properties of the fabrics in comparison to 100% polyester fabric. q_{max} study also indicates that polyester/cotton and polyester/modal blend fabrics are cooler as compared to 100 % polyester fabric.

Keywords: Cotton, Modal, Moisture management testing, Peak heat flux, Polyester, Sportswear, Warm-cool feeling

1 Introduction

There has been an enormous market growth for sportswear over the last 20 years. The sportswear market comprises around 45% of the global sports equipment, sport apparel and footwear market. The sportswear categories account for a sales value of approximately US$265 billion in 2015 as reported in Euromonitor International (2016)[1.] Sports participation rates and activities have increased in major markets in recent years, with some of the key activities being fitness, gym and running. However, there are many sporting activities that show researchers with opportunities for development of sportswear. As per the market demand, sportswear can be categorized into four groups, viz performance sportswear, basic sportswear, sports leisurewear and sports- fashion clothing. Performance sportswear is highly technical-oriented clothing which enhances the performance with special functionality. It is produced in lowest volume and highest price range, whereas basic sportswear is cheaper and more stylish while retaining as many of the material attributes as possible. Sports leisurewear is replica of performance sportswear, worn at home and is sold in higher volume at much smaller price[2, 3].

In recent years, development in active sportswear fabrics has been progressing to perform high functions and to achieve comfort. Comfort may be defined as a pleasant state of psychological, physiological and physical harmony between a human being and the environment. Wear comfort of active sportswear can be divided into four different aspects, namely thermo physiological comfort, sensorial/tactile comfort, mobility/dexterity comfort and psychological comfort[4,5]. Thermo-physiological wear comfort is concerned with the heat and moisture transport properties of clothing and the way it helps the clothing to maintain the heat balance of the body during various level of activity[6]. An important function of cloth is to supply a maximum of wearing and thermal comfort to human bodies, and to protect the wearer from external environmental elements and climatic conditions such as cold and warm conditions, rain, snow and wind and that it is crucial for the human body to maintain a core temperature of around 37°C (ref. 7). Clothing materials should thus have a high moisture retention capacity and high moisture transportation properties to maintain constant temperature humidity between skin and fabric. This is based on the fact that the moist fibres can act as a heat reservoir[8]. Thermal comforts imply the maintenance of body temperature within relatively narrow limits. Under the conditions where thermal comfort cannot be achieved by the human body's own ability (i.e. body temperature regulation), such as very cold or hot weather, clothing must be worn to support its

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temperature regulation by resisting or facilitating heat exchange between the human body and the environment[9]. Thermal comfort of a garment depends on the wickability, air permeability and heat transfer. It is necessary for the garment to have good insulation as well as ability to absorb moisture by capillary action away from the skin because moisture transport and quick drying behaviour of textiles depends mainly on the capillary capability and moisture absorbency of fibres[10]. When fibre absorbs moisture, heat is released and hence water absorbency of fabric is an important factor that affects the thermal and sensorial comfort. Thus, the final thermo-physiological comfort is given by two principal components[12], viz (i) thermal resistance in wet state and active cooling resulting from moisture evaporation from the skin and its passage through the garment, and (ii) direct evaporation of sweat from the fabric surface[11,12]. During sport activity human body generates heat quickly due to faster metabolism and then body's cooling mechanism attempts to dissipate this extra heat by producing perspiration. Perspiration should be readily taken away from the skin to the outer atmosphere before it accumulates on skin for maintaining cool and dry condition to make the sport person comfortable and to enhance their performance during sport activity[13,14].

There are numbers of textile fibres that are currently used in sportswear, both natural and synthetic, but sportswear market is dominated by specialty polyester. Unfinished polyester fibre is hydrophobic and has much lower absorption capacity than cotton and modal, but its wicking rate, although slow as compared to some other synthetic fibres, is faster than that of cotton. Polyester fibre is low cost and has excellent washing and wearing properties. Hence, it's a major constituent in sportswear. Commercially available polyester garments to be used next to skin are usually chemically treated to improve its wicking ability. This is achieved by applying hydrophilic finishing to polyester filament. The resulting hydrophobic core and hydrophilic surface allow moisture to migrate along the outer surfaces of filament without being into the core[15].

Knitted fabrics are widely used in sportswear due to their excellent stretch and recovery, porosity, air permeability, softness and warmth. In last few years, knitted fabrics are gaining interest due to their simple production technique, low cost, high level of clothing comfort and wide range[16]. They also offer good freedom of movement, shape retention and tailored fit. With possibility of numerous combinations of fabric construction and yarns used, knitted fabric are considered ideal for sportswear, such as t-shirts[17].

It is evident that fibre type, yarn properties, fabric structure and finishing treatments affect the clothing comfort. The use of blended fibre combinations in sportswear has grown in the past decade, as brands attempt to improve function and comfort using different fibre blends. The use of blending technologies and the array of fibres available for sportswear will continue to provide a source of innovation for sportswear products. Therefore, the present study aims to investigate the thermo-physiological comfort properties, namely moisture management and q_{max} values of commercial garment and six knitted fabrics developed for sportswear application, which are composed of 100% polyester, 100% Modal, 100% cotton and their blends[16,17].

2 Materials and Methods

2.1 Materials

Polyester (75 den, 150 den Micro PET filament), modal (40s Ne), and cotton (40s Ne) were combined in different proportions for fabric development. Modal fibre used in this study was procured from Birla Cellulose, Aditya Birla Group. Polyester filaments used for the study were obtained from Reliance Industries and cotton was purchased from local supplier. Three single jersey fabrics composed of 100% modal, 100% cotton and 100% polyester (150 den) and three plaited blend fabrics of 75den PET/40s cotton, 75den PET/ 40s modal, 60s Ne modal/40s Ne cotton were developed at Textile Research & Application Development Centre (TRADC), Birla Cellulose, Grasim Industries Ltd. One commercial single jersey garment made up of 100% polyester micro filament yarn (82 den PET) was also considered for technical analysis. All seven fabrics including one commercial garment purchased from specialty sportswear store were selected for this study. All testing was carried out in a conditioning room, under the environmental conditions (21±1°C and 65±2% RH) according to ASTM D 1776. The moisture management properties of all seven fabrics were tested and evaluated by using the Moisture Management Tester (MMT) according to the AATCC Test Method 195-2009, and feeling of coldness or warmth was assessed by measuring 'q_{max}' value (peak heat flux) on KES-F7 Thermo labo II. The composition and physical properties of commercial and developed fabrics are presented in Table 1.

2.2 Moisture Management Properties

Fabric liquid moisture transport properties in multidimensions, called moisture management properties, significantly influence human perceptions of moisture sensation. Moisture management tester (MMT), developed by SDL Atlas to evaluate textile moisture management properties, was used. This method can be used to quantitatively measure liquid moisture transfer in one step in a fabric in multiple directions. Moisture spreads on both surface of the fabric and transfer from one surface to the opposite. Here, ten indices are introduced to characterize the liquid moisture management properties of fabric. Electrical conductivity changes are measured as the test solution migrates across the top of, through, and across the bottom of the test specimen. Factors affecting this movement include fabric water repellency, water resistance, and water absorption, along with the fibre and yarn wicking properties. Perspiration is mimicked with TM 195. The results obtained with this test method are based on water resistance, water repellency and water absorption characteristics of the fabric structure, including the fabrics' geometric and internal structure and the wicking characteristics of its fibres and yarns.

Ten indices of the MMT, used to characterize the moisture management properties of a fabric, are as mentioned below:

(i) Wetting time top (WT_t)
(ii) Wetting time bottom (WT_b)
(iii) Top absorption rate (MAR_t)
(iv) Bottom absorption rate (MAR_b)
(v) Top maximum wetted radius (MWR_t)
(vi) Bottom maximum wetted radius (MWR_b)
(vii) Top spreading speed (SS_t)
(viii) Bottom spreading speed (SS_b)
(ix) Accumulative one-way transport capacity (OWTC)
(x) Overall moisture management capability (OMMC) [13,18]

The OWTC is the difference in accumulative moisture content between the two surfaces of the fabric. The OWTC reflects the one-way liquid transport capacity from the top (inner) surface to the bottom (outer) surface of the fabric. The OMMC is an index indicating the overall capacity of the fabric to manage the transport of liquid moisture, which includes following three aspects:

(i) average moisture absorption rate at the bottom surface;
(ii) one-way liquid transport capacity;
(iii) maximum moisture spreading speed on the bottom surface[15, 19, 20]

According to AATCC Test Method 195-2009, the indices are graded and converted from value to grade based on a five grade scale (1-5): 1–poor, 2–fair, 3– good, 4–very good and 5– excellent. Table 2 shows the range of values converted into grades[15].

Table 1 — Fabric specifications

Fabric code	Fabric	Knit type	Stitch length mm	Aerial mass g/m^2	Wales/inch	Courses/inch
A	Commercial garment 100% polyester (82 den micro filament yarn)	Single jersey	2.8	130.6	52	111
B	100 % PET (75 den micro filament yarn)	Single jersey	2.6	88	28	58
C	100% Modal (40s Ne)	Single jersey	2.6	82	30	54
D	100% Cotton (40s Ne)	Single jersey	2.6	90	28	61
E	75 den Micro polyester/ 40s Ne cotton (35/65)	Plaited	2.8	147	28	51
F	75 den Micro polyester/ 40s Ne modal (35/65)	Plaited	2.8	145	32	51
G	60s Ne Modal/ 40s Ne cotton (50/50)	Plaited	2.8	151	30	51

Table 2 — Grading of MMT indices[20]

Index	Grade				
	1	2	3	4	5
Wetting time, s					
Top	≥120 (No wetting)	20-119 (Slow)	5-19 (Medium)	3-5 (Fast)	< 3 (Very fast)
Bottom	≥120 (No wetting)	20-119 (Slow)	5-19 (Medium)	3-5 (Fast)	<3 (Very fast)
Absorption rate, %/s					
Top	0-10 (Very slow)	10-30 (Slow)	30-50 (Medium)	50-100 (Fast)	>100 (Very fast)
Bottom	0-10 (Very slow)	10-30 (Slow)	30-50 (Medium)	50-100 (Fast)	>100 (Very fast)
Max wetted radius , mm					
Top	0-7 (No wetting)	7-12 (Small)	12-17 (Medium)	17-22 (Large)	>22 (Very large)
Bottom	0-7 (No wetting)	7-12 (Small)	12-17 (Medium)	17-22 (Large)	>22 (Very large)
Spreading speed mm/s					
Top	0-1 (Very slow)	1-2 (Slow)	2-3 (Medium)	3-4 (Fast)	>4 (Very fast)
Bottom	0-1 (Very slow)	1-2 (Slow)	2-3 (Medium)	3-4 (Fast)	>4 (Very fast)
OWTC	<-50 (Poor	-50-100 (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)

2.3 q_{max} Measurement

The sensation of coldness or warmth when skin touches a fabric is referred to as the "coldness and warmth feeling." The feeling of coldness or warmth will vary depending on the amount of heat transferred from the skin to the fabric. This device measures that feeling by evaluating the "q_{max}" value (peak heat flux). q_{max} was measured on KES-F7 (Thermolabo II). The Thermolabo II consists of (i) a guarded hot plate (BT-Box) with 5cm×5cm area, (ii) T-box which is essentially a copper plate with a known thermal capacity insulated on all sides except front face, and (iii) water box which can be maintained at any temperature by circulating water trough it.

q_{max} can be measured both with and without constant temperature base. The present study employed insulated condition for measuring q_{max}. The T-box was heated to about 30˚C by keeping it over hot BT-Box. The T-box was then quickly placed over the fabric, which was kept over a constant temperature of 20˚C. The maximum heat flux flowing between the T-Box and the fabric surface was detected by the electronics of the instrument. The experiment was carried out in controlled atmosphere (65±2% RH and 27±1˚C temp.)[19, 20].

3 Results and Discussion

3.1 Moisture Management Properties

The moisture management properties of the fabrics (in grades) are given in Table 3 and each index is discussed separately.

3.1.1 Wetting Time

Figure 1(a) shows the wetting time grade of top and bottom of seven fabrics. Wetting time is the time in seconds taken by a water drop for initial wetting of the fabric. It indicates the time period in which top and bottom surfaces of the test specimen begin to wet after the start of the test. Top fabric surface refers to that side of the fabric which initially comes in contact with test-water drop and represents the side that would come in contact with the skin of a wearer.

It can been seen that in non-blended fabric, 100% PET has medium wetting time grade at top and slow wetting time grade at bottom and it is the lowest as

Table 3 — MMT results (in grades) of sample fabrics

Fabric	WT_t	WT_b	MAR_t	MAR_b	MWR_t	MWR_b	SS_t	SS_b	OWTC	OMMC
Commercial garment (CG)	4	4	4	3	4	4	4	5	3	3
100% PET	3	2	4	5	1	1	1	1	1	2
100% Modal	5	5	3.5	3.5	5	5	5	5	1.5	2.5
100% Cotton	5	5	3.5	3.5	5	5	5	5	1.5	2.5
PET/Cotton	4	5	2	3	4	5	5	5	5	5
PET/Modal	4	5	3	3	4	5	5	5	5	5
Modal / Cotton	4.5	5	3	2.5	4	4	4.5	5	3.5	3.5

Wetting time top (WT_t), Wetting time bottom (WT_b), Top absorption rate (MAR_t), Bottom absorption rate (MAR_b), Top maximum wetted radius (MWR_t), Bottom maximum wetted radius (MWR_b), Top spreading speed (SS_t), Bottom spreading speed (SS_b), Accumulative one-way transport capacity (OWTC), and Overall moisture management capability (OMMC).

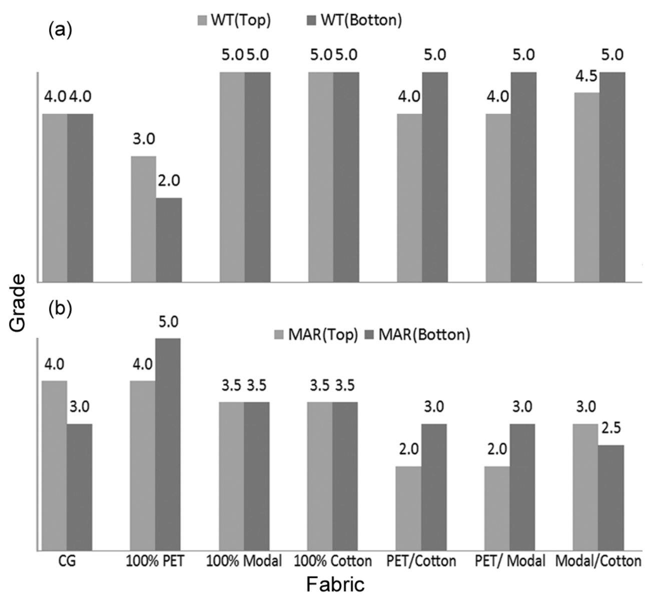

Fig. 1 — Wetting time (a), and absorpation rate (b) grades of top and bottom of fabrics

compared to other fibres. This is because polyester is a hydrophobic fibre with very low moisture regain properties. 100% Modal and 100% cotton has very fast wetting time grade both at top and bottom surfaces as these are hydrophilic fibres with high moisture regain. Wetting time at top and at the bottom is the same for 100% Modal and 100% cotton fabric.

While considering blended materials, like PET/cotton, PET/ modal and modal/cotton, wetting time grade both at top and bottom drastically changes from medium to fast wetting time as compared to 100% PET. Among the blended fabrics both PET/cotton and PET/ modal show very fast wetting time grade both at bottom and top. Modal/cotton blend fabric shows very fast wetting time grade both at top and bottom surface. Commercial garment shows fast wetting time grade at top and bottom surfaces, because commercial sports garments are generally finished with hydrophilic finishes. As compared to blended fabric, commercial garment shows similar wetting time grade at top as that of PET/cotton and PET/modal blends but bottom wetting time grade is low as compared to that of PET/cotton and PET/ modal fabrics. Comparison between 100% PET and PET blended with cotton and modal demonstrates that blending PET with modal or cotton improves its top as well as bottom wetting time significantly.

3.1.2 Maximum Absorption Rate

Absorption rate is the average speed at which the test-water drop is absorbed by the fabric after initial wetting. The absorption rate is related to the tendency of fabric to allow sippage of water through the inter-yarn, inter-fibre and intra-fibre spaces.

Figure 1(b) shows mean grade of moisture absorption rate of seven specimens on the top and bottom surfaces during the rise of water content respectively. In non blended fabric, 100% PET, 100% cotton and 100% modal have medium absorption rates at top and bottom surfaces. Commercial garment have fast absorption rate at top and medium absorption rate at bottom. PET/ cotton and PET/modal blend fabrics show slow absorption rate at top and medium absorption rate at bottom surfaces, whereas modal/cotton blend fabrics show medium absorption rate at top as well as at bottom surface. PET blended with cotton or modal shows faster absorption rate at bottom as compared to top surface, and this can help to take moisture away from inner layer of fabric (next to skin) to outer layer.

3.1.3 Maximum Wetted Radius

Figure 2(a) shows mean grades of the maximum wetted radius at top and bottom surfaces of 7 fabrics including one commercial garment. Maximum wetted radius (MWR_t and MWR_b) is defined as the maximum

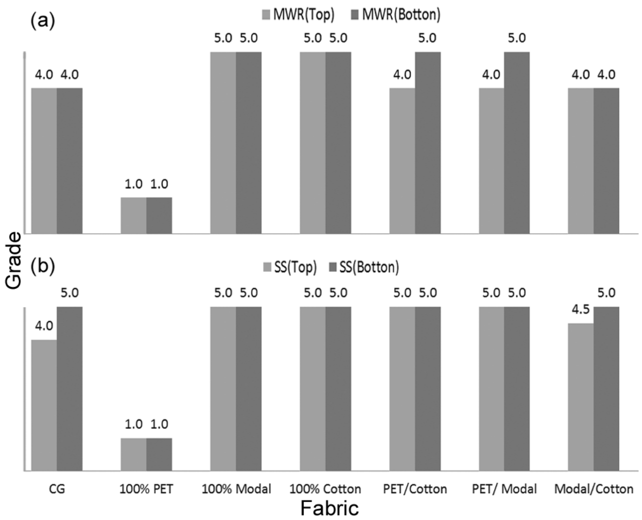

Fig. 2 — Maximum wetted radius (a), and spreading speed (b) grades of top and bottom fabrics

wetted ring radius at the top and bottom surfaces respectively. In non blended fabrics, 100% cotton and 100% modal fabrics show very large wetted radius both at top and bottom surfaces, while 100% PET shows no wetting at top and bottom surfaces. Commercial garment shows large wetted radius both at top and bottom surfaces. So, the results indicate that 100% PET has no wetting but wetting radius of PET can be enhanced with the help of hydrophilic chemical finishing as high wetted radius is obtained for commercial garment which is also made up of 100% PET. In blended fabrics, PET/cotton and PET/modal blends show large wetted radius on top surface and very large wetted radius on bottom surface. Modal/cotton blend fabric shows very large wetted radius both at top and bottom surfaces. On comparing MWR_t and MWR_b, 100% PET and PET blended fabrics demonstrate that blending PET fibre with cotton or modal fibre improves 100% PET fabric's top and bottom maximum wetted radius.

3.1.4 Spreading Speed

Figure 2(b) shows the mean grade of spreading speed at top (SS_t) and bottom (SS_b) surfaces of the seven fabrics. The SS_t and SS_b are defined as the accumulative spreading speed from the centre towards the maximum wetted radius. In non blended fabric, 100% PET has very slow spreading speed both at top and bottom surfaces. 100% Cotton and 100% modal show very fast spreading speed both at top and bottom surfaces. Commercial garment also shows fast spreading on top surface and very fast spreading on bottom surface. This may be because of the hydrophilic finishes. For commercial garment spreading speed of bottom surface (outer surface) is more than that of top surface (next to skin surface). This indicates that the sport garment has to be designed in such a way that moisture should spread faster and quicker on outer surface than on inner surface. Comparison between 100% PET and PET blend with cotton and modal fabrics demonstrates that blending PET with cotton or modal improves spreading speed of polyester top and bottom surfaces many fold, showing better performance than commercial garment and hence making these blends more suitable for sports garment. Modal/cotton blended fabric also shows very fast spreading speed at top and bottom surfaces.

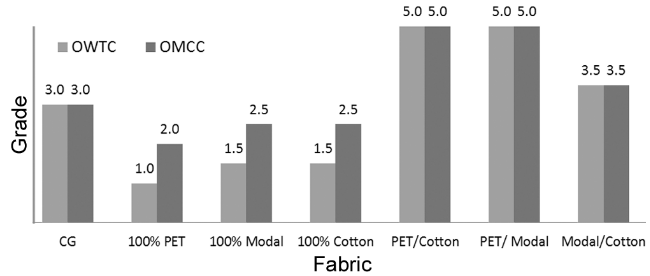

Fig. 3 — Accumulative one way transport index and overall moisture management capacity grade of fabrics

3.1.5 Accumulative One Way Transport Index

Figure 3 indicates mean grade of accumulative one way transport index for all seven fabrics. In non blended fabric, 100% PET has poor one way transport capacity whereas 100% cotton and 100% modal have fair one-way transport capacity. Commercial garment has medium OWTC. PET/cotton and PET/modal fabrics show excellent one way transport index grade, whereas modal/cotton blended fabric also shows very good one way transport index grade. Comparison between 100% PET fabric and PET blend with cotton and modal fabrics demonstrates that the blending of cotton or modal fibre with polyester fibre improves 100% polyester fabric's one way transport capability from poor to excellent, making it more suitable for sportswear application. Even modal/cotton blend fabric also shows very good one way transport index grade and these fabrics can also be used for sportswear application.

3.1.6 Overall Moisture Management Capability

Figure 3 also indicates overall moisture management capability of seven fabrics under study. In non blended fabrics, 100% PET fabric has fair

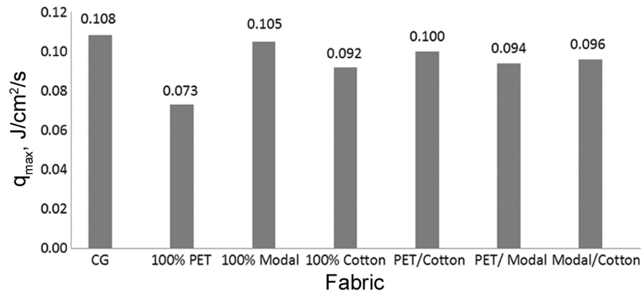

Fig. 4 — q_{max} values of fabrics

OMMC, whereas 100% modal and cotton fabrics have good OMMC grade. Commercial sports garment also has good OMMC grade. OMMC values of PET/cotton and PET/ modal fabrics are excellent. OMMC grade of modal/cotton blend fabric is also very good. Comparison between 100% PET fabric with PET/cotton and PET/modal fabrics demonstrate that blending PET with cotton and modal fibre improves 100% polyester fabric's OMMC significantly, thus indicates that blending cotton or modal with PET makes it more suitable for sportswear application without using any hydrophilic chemical finishes. Even modal/cotton blended fabric also has good OMMC and it can also be used for sportswear application.

3.2 q_{max} Measurement

q_{max} is the feeling of coolness or warmth. It means the feeling we get when a human skin touches an object. It is measured as the maximum amount of heat flow between the body and the fabric (Watt/m^2.). The higher the value, the cooler we feel. On the Kawabata System, q_{max} is the peak value of heat current measured immediately after the heat stored on a pure copper plate travels to a fabric when the plate touches the surface of the fabric. It reproduces the warm/cool feeling (transient hear transfer) experienced when a human finger touches an object.

Figure 4 indicates q_{max} values for seven fabrics under study. The result obtained indicates that 100% PET has low q_{max} values compared to 100% modal and 100% cotton fabrics. 100% Modal fabric has highest q_{max} value among these non blended fabrics. The result obtained indicates that modal fabric is 44% cooler compared to polyester and 14% cooler compared to cotton fabric. Commercial garment has q_{max} value of 0.108. In blended fabrics, PET/cotton and PET/ modal has q_{max} value of 0.094 and 0.100 respectively, this indicates that q_{max} value of PET can be significantly improved by blending it with cotton or modal fibres.

4 Conclusion

PET/ cotton, PET/modal fabrics show higher spreading speed of fabric bottom surface and excellent one way transport index and overall moisture management capability. Combining polyester fibre with cotton or modal produces fabrics with better moisture management properties than 100% polyester. q_{max} study indicates that PET/cotton and PET/ modal blend fabrics are cooler compared to 100 % polyester fabric. Therefore, polyester if blended with cotton or modal can be used effectively for sportswear application. Combination of cotton and modal also gives good moisture management fabric with good q_{max} values offering a suitable alternative to polyester in sportswear application.

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