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The Effect of Fabric Structure on Ventilation System of Clothing Comfort

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Abstract: ***Sportswear fabrics need to provide a comfortable environment for the wearer and consequently need to be able to handle moisture vapor and sweat produced by the body. Modern sportswear is usually made from synthetic fibers like polyester. To evaluate the effectiveness of ventilation systems in sportswear, four polyester fabrics different in their structure, open hollow mesh, flat mesh, open hollow micro mesh and closed hollow micro mesh. Tested for air permeability , thermal retention, water vapor, wettability, wicking and drying time, the fabric which have the best properties was used in three positions in T-shirt (armpit , chest and back). Four polyester knitted fabrics different in their structure, single jersey, interlock and rib, were tested for air permeability, thermal retention, water vapor permeability, wettability , wicking and drying time , and the fabric that have the best properties was used to make the T-shirt. Three Athletes undertook physical exercises, wearing this T-shirts, the amount of perspiration generated in three different positions (armpit , chest and back) were recorded for analysis. The results suggest that ventilation at the appropriate positions in the T-shirt could contribute considerably to use of breathable fabrics.***

Keywords: mesh, perspiration, moisture, Drying, ventilation

1. Introduction

There are many aspects required when designing clothing for sports [1] [2][3].

The protection functions from weather (wind, rain and snow, etc), The comfort function (thermo-physiological comfort, skin comfort, body movement comfort) the exercise function to assist improvement of athletic performance[4] [15] [16] [17]

The design of the clothing system utilizing the mechanisms of warmth and moisture transfer through a garments would have an influence.

Studies have considered many methods of ventilating systems such as Pit zips, Venting pockets, Venting back, venting structure fabrics;

1) Pit zips, opening utilizing the sleeve seam, side seam, and both sleeve and side seam.
2) Venting pockets are utilized as a part of jackets . Unzipping these pockets permits air movement between the body and surrounding atmosphere , the pockets having a penetrable mesh lining.
3) Venting back, generally has a fold covering a mesh lining part of the garment.
4) Venting structure fabrics, there are many structures of knitted fabrics, for example, mesh; these structures permit air movement between clothing and environment. Can put the texture in the clothing as indicated by area of sweating skin armpit , chest, back and abdomen. [5] [6] [7]

The polyester fabrics used has pore sizes from around 0.05 mm to 2.0 mm and weight range from 11 to 163 gm.

A breathable garment can regulate body temperature , enhance muscle performance and delay exhaustion. For example, cotton might be reasonable for low levels of action, but fabrics made of nylon or polyester is more qualified for high amounts of movement. They Absorb less water than cotton, however can wick dampness quickly through the fabric, Polyester has phenomenal protection from dirt, alkalis, decay, mold. Being solid, yet light weight, polyester has flexibility and an smooth feel these are immensely imperative qualities to buyers for a wide assortment outerwear and Recreational applications, air permeability is an important factor in such material. [8] [9] [10] [11] [12] [24]

When vapor goes through a material layer two procedures are included: dispersion and sorption desorption. Water vapor diffuses through a textile structure in two ways, straightforward dispersion through the air spaces amongst yarns and along the fiber itself. At a particular fixation slope, the dissemination rate along the material relies upon the porosity of the material and furthermore on the water. [13] [14] [15]

The variables related with knitted fabric's thickness and development decides dampness vapor transport properties, particularly in low thickness open material structures. Fiber-related elements, for example, shape and dampness retaining properties. [18] [24]

2. Experimental

This paper consists of two parts, **the first part:** The effect of ventilation through Four polyester fabrics were different in their structure, open holo mesh ,flat mesh, open holo micro mesh and closed holo micro mesh testing air permeability, thermal retention, water vapor , permeability , wettability ,wicking and drying time and choice the fabric which the best properties. The best fabric, used in three positions in three T-shirts, upper arm (position A), chest (position B) and back (position C), are shown in figure1. Four polyester fabrics were Different in their structure, single jersey, interlock and rib. Testing air permeability, thermal retention, water vapor permeability, wettability, wicking and drying time and choice the fabric which the best properties. The best fabric, used in made T-shirt. The specifications for nine samples polyester fabrics which use in T-shirt are shown in Table 1 and 2. figure (1) shows fabric physical properties. Sewing three T-shirts, No. 80 round needle with No. 120 polyester core spun thread was used.

Table 1: Fabric physical properties

No.		structure	Density		Weight g\m^2	Thickness m.m
			courses/ cm	Wales/ cm		
Fabrics For ventilation	1	Flat mech	52	36	1.49	0.656
	2	Open holo mesh	32	30	2.01	0.702
	3	Closed holo micro mesh	24	22	2.23	0.912
	4	Open holo micro mesh	32	21	2.08	0.871
Fabrics for T-shirt	5	Single jersy-1	34	30	1.54	0.542
	6	Interlock-1	33	25	1.64	0.598
	7	Interlock-2	40	28	1.88	0.532
	8	Single jersy-2	42	32	1.48	0.45
	9	rib	28	18	2.35	0.632

Figure 1.. Shows the knitted polyester fabrics structures.

Figure 2: Three different positions of ventilation system in T-shirt

The second part: Three Athletes with good physical condition who consistently take part in physical exercises, for example, running. Practice exercises while wearing these T-shirts. Their normal properties appear in Table 2. The activity routine comprised of 30 minutes resting to equilibrate to the surrounding atmosphere, 10 minutes exercise and 5 minutes resting after the activity. Preceding the activity schedule, and towards the end of the 30 minutes resting period, absorbent papers of size 90 cm2 were appended to the subjects to gauge the rate of sweat.

The amount of perspiration generated during exercise was measured by weighing the absorbent papers and T-shirt before and after the exercise.

Table 2: Mean features of the Athletes.

No. Athletes	Age(years)	Weight(kg)	Area(m^2)
3	28-35-45	80±5	1.990±0.045

2.2 Measurements [19]

2.2.1 Weight of fabric

2.2.2 Thickness of fabric.

2.2.3 Air permeability of textile fabric.

Air permeability is described as the rate of air flow passing perpendicularly through a known area, under a prescribed air pressure differential between the two surfaces of a material. Tests were performed according to standard A.S.T.M- D 737, using a Textest FX-3300 air permeability tester. The air pressure differential between the two surfaces of the material was 100 Pa

2.2.4 Thermal retention

Thermal properties were evaluated using according to standard ISO 11092:2014. In all cases, the measuring head temperature was, approximately, 32°C and the contact pressure 200 Pa.

2.2.5 Moisture Management[20]

For liquid transport within fabrics, two phenomena must be accounted for – wettability and wickability.

Wettability Test

Expresses the rate of water diffusing in the fabric surface and represents fabric's instantaneous water absorbency and transferring ability. The fabric samples were placed flat on a hydrophobic board with the outer surface facing down. The diffusion area (m.m2) was measured 30 seconds after dripping 0.2 ml of water, using a precise dropper whose tip was 10 mm above the fabric surface. The measurement was repeated at five different points and the average of the diffusion area (m.m2) was taken to indicate the diffusion ability of the fabrics.

Wicking Test

Expresses fabric's ability to move sweat away from the skin to the outer surface of the fabric, where it evaporates. The apparatus used to determine the transverse wicking consists of a horizontal glass plate fed from below with water through a capillary tube coming from a reservoir placed on an electronic balance. The sample was placed on the glass plate and was held in contact with it applying another glass plate on top of it. The changing weight of the reservoir is measured by an electronic balance to determine the rate of liquid uptake by the material. [22]

2.2.6 Water Vapor Permeability

Tests were performed according to standard ISO 11092:2014, when vapor passes through a textile layer two processes are involved: diffusion and sorption desorption.

At a specific concentration gradient, the diffusion rate along the textile material depends on the porosity of the material and also on the water vapor diffusivity of the fiber. Diffusivity of the material increases with the increase in moisture regains. [22] [23]

2.2.7 Drying Time

The drying time is mainly dependent on how much water is absorbed by the fabric and therefore by fabric thickness (23, 24). In this test, fabrics were cut into square samples of 10x 10 cm2, placed on a horizontal surface and wetted with 1 ml of distilled water dropped onto it using a precise dropper whose tip was 10 mm above the fabric surface. The remaining water ratio (RWR) and the drying time of fabrics were assessed. In order to determine the drying rate, the fabrics were weighted in the dry state (dry weight- Wf) and immediately after wetting (wet weight at the initial stage - W0). The change in weight (Wi) was measured at 10,20 and 30minute intervals and the remaining water ratio (%) was then calculated, for each interval, using the following equation:

$$RWR = \frac{W_i - W_f}{W_0 - W_f} 100\%$$

The remaining water ratios were used to express the drying ability of the fabrics as wetted by sweat.

All tests were carried out in National Institute for Standards after the samples were Conditioned under standard atmospheric conditions(temperature 20 ± 2°C, 65 ± 2% relative humidity), according to standard ISO 139:1973. [7] [23] An exploratory data analysis containing central tendency and dispersion statistics was performed with the purpose of identifying outliers, normal behavior of the measured properties and also the homogeneity of variances. Then, analysis of variance was made using ANOVA procedure.

3. Results and Discussion

Results of experimental examination on the produced samples are presented in the following tables and graphs. Results were statically analyzed for data listed, table 3.

Table 3: The Measurements for fabrics

samples		*air permeability ($cm^3/cm^{2/}sec.$)*	*thermal retention (clo)*	*W.V.P ($pa.m^2 w$-1)*	*Wettability (Min.)*	*Wicking (c.m)*	
						warp	*weft*
Fabrics For ventilation	1	164.4	18.1	2.7	00:19.6	1.6	1
	2	169.8	19.1	2.9	00:09.5	6	4.8
	3	67.58	14.1	2.1	08:49.4	1	0.4
	4	151.4	16	2.5	04:06.1	1.3	1
Fabrics for T-shirt	5	163	11.9	2.3	00:06.0	6	5.1
	6	148	10.5	2.1	00:14	5	4
	7	96	7.3	2	00:26.0	4	3.1
	8	208	3.4	1.1	30:23.6	0	0
	9	70.02	18.2	2.7	00:06.9	8.5	6.8

3.1 Air permeability of textile fabric

The results obtained with respect to air permeability of fabrics are represented in figure (3), Fabrics for ventilation, these results follow the order: 2>1> 4> 3.

It can be noticed that Flat mech has the highest air permeability that could be probable due to the less compact structure of another fabrics. While Closed holo micro mesh structure is less air permeable than Flat mech structure because the spaces of Flat mech probably due to the lowest thickness and weight of fabrics. Structure are more than that of Closed holo micro mesh structure, flat mesh, this is most Fabrics for T-shirt, These results follow the order: 9> 5> 6> 7>8. It can be noticed that Single jersy-2 has the highest air permeability that could be probable due to the less compact rib structure of another fabrics. While structure is less air permeable. The air permeability is generally higher for Single jersy-2; this is most probably due to the lowest thickness and weight of fabrics.

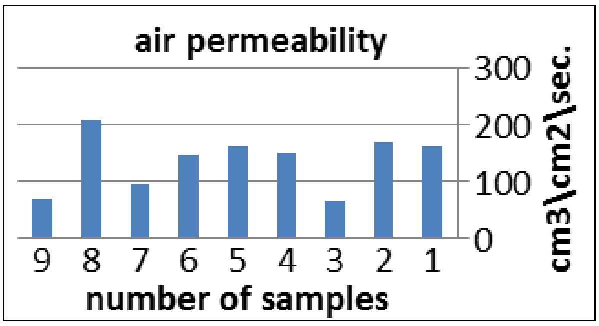

Figure 3: The relationship between structure and air permeability of fabrics.

3.2 Thermal retention

The results obtained with respect to thermal retention of fabrics are represented in figure (4), Fabrics For ventilation, these results follow the order: 2>1> 4> 3.flat mesh structure has the least thermal retention; it can transfer the heat away from the body when exercising. Fabrics for T-shirt, These results follow the order: 9> 5> 6> 7>8. It can be noticed that Single jersy-2 has the highest thermal retention when compared with another fabrics. This behavior is in a great extent influenced by the fabric structure and the fabrics with the lowest thickness and weight.

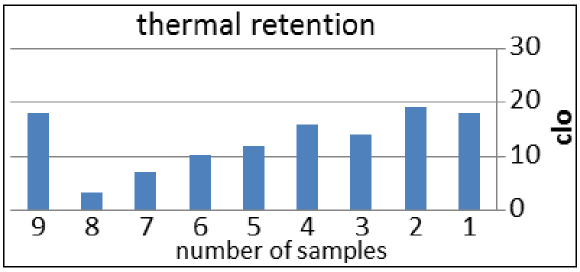

Figure 4: The relationship between structure and thermal retention of fabrics

3.3 Moisture Management

Moisture Management For liquid transport within fabrics, wetting is usually used to describe accounted for – wettability and wickability the change from a solid–air interface to a solid–liquid interface. Wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. As Capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system. Many test methods have been developed to measure liquid water absorbency and water vapor transport in fabrics. These methods measure different aspects of moisture management characteristics of fabrics.

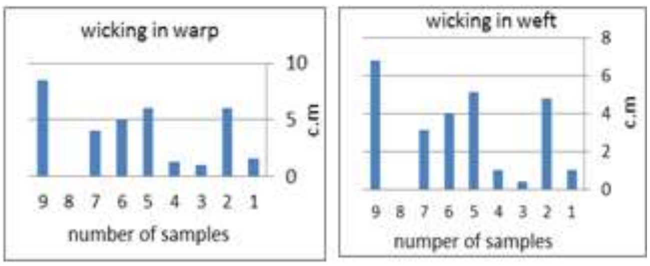

Figure 5: The relationship between structure and wicking of fabrics in warp and weft

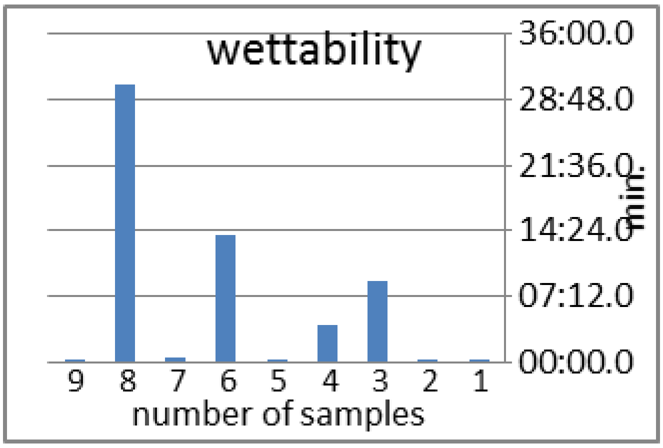

Figure 6: The relationship between structure and wettability of fabrics

3.3.1 Wicking Ability

As illustrated in Figure 5, flat mesh structure fabrics have higher wicking than another fabric. Fabrics For ventilation, these results follow the order: 1> 2> 4> 3. His behavior is in a great extent influenced by the fabric structure and the fabrics with the lowest thickness and weight. Moreover, the initial rate of water up-take in flat mesh wicking is generally higher for flat mesh structure fabrics than for another fabric.

Fabrics for T-shirt, These results follow the order: 9> 5> 6> 7>8. It can be noticed that Single jersy-2 has the highest wicking ability when compare with another fabric.

3.3.2 Wettability Test

The results obtained with respect to thermal retention of fabrics are represented in figure 6, Fabrics For ventilation, these results follow the order: 3> 4> 1> 2.flat mesh structure the take low time for absorption drop of water. Fabrics for T-shirt, These results follow the order: 8> 7> 6> 5>9. It can be noticed that Single jersy-2 has the highest time for absorption drop of water. When compare with another fabric. This behavior is in a great extent influenced by the fabric absorption drops. Moreover, open structure absorb water in low time.

3.3.3 Water Vapor Permeability

As illustrated in Figure 7, flat mesh structure fabrics have higher water vapor permeability than another fabric. Fabrics For ventilation, these results follow the order: 2>1> 4> 3. His behavior is in a great extent influenced by the fabric structure and the fabrics with the lowest thickness and weight. Moreover, open structure of flat mesh decreases the resistance to vapor flow through the fabric surface, which allow transmission water vapor permeability. Fabrics for T-shirt, These results follow the order: 9> 5> 6> 7>8. It can be noticed that Single jersy-2 has the highest transmission water vapor permeability when compare with another fabric.

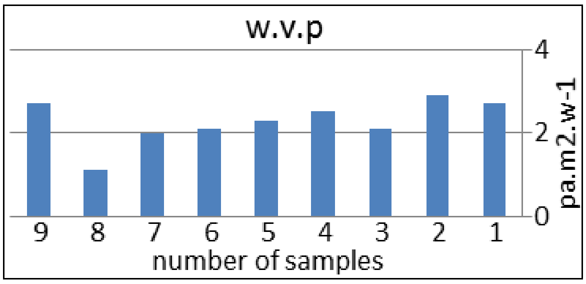

Figure 7: The relationship between structure and water vapor permeability of fabrics

3.4 Drying Time

The evaporation curve presented in Figure 8 and table 4. Demonstrate that the drying rates of Flat mesh structure is higher and the drying times (0% remaining water ratio) Lower than another fabric. As in diffusion ability, which increase the rate of capillary.

The water transmission to the fabric surface and release from it. All the fabrics, around 73-97 % of the remaining water ratio after 10 minutes, around 40-92 % of the remaining water ratio after 20 minutes, around 32-85 % of the remaining water ratio after 30 minutes. Fabrics for ventilation, these results follow the order: 2>1> 4> 3. His behavior is in a great extent influenced by the fabric structure.

Fabrics for T-shirt, These results follow the order: 9> 5> 6> 7>8. It can be noticed that Single jersy-2 has the lower the drying time (0% remaining water ratio). When compare with another fabric. Namely thickness and mass per unit area, seem to have affected the drying ability of fabrics (higher drying ability corresponds to structures with the lowest thickness and mass per unit area and lower drying ability to structures with the highest thickness).

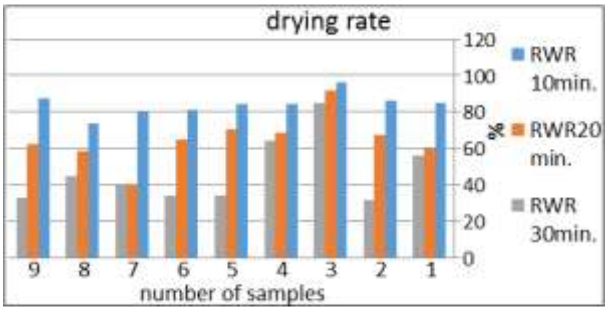

Figure 8: The relationship between structure and the drying times of fabrics

Table 4: The Measurements for the drying times (0% remaining water ratio) of fabrics

Samples	RWR 10min%	RWR 20min%	RWR 30min%
1	85.11	59.57	55.81
2	86.05	67.44	31.91
3	96.47	91.76	84.71
4	84.44	68.8	64.44
5	84.09	70.45	34.04
6	81.39	65.11	34.09
7	80.85	40.43	39.53
8	73.91	58.71	45
9	87.5	62.5	32.61

The first part presents, a quantitative study of various comfort related properties carried out on Four fabrics were different in their structure, open holo mesh, flat mesh, open holo micro mesh and closed holo micro mesh, and aiming at the selection the air permeability, thermal retention, water vapor permeability, wettability ,wicking and drying time and choice the fabric which the best properties. The best structure fabric is open mech used in three positions in T-shirt show figure 2.

Four polyester fabrics were different in their structure, single jersey, interlock and rib. Choice the structure fabric which the best properties. The best structure fabric is single jersy-2, used in made T-shirt .then, open mesh and single jersey structure the best choice. Design of the mesh allows us to vary the porosity of mesh and netting properties to meet highly specific applications. We can tighten the loops to create a filter fabric that allows water and air to pass through while capturing tiny particulates.

We can use high elongation yarns to make fabrics with significant stretch and recovery.

The second part presents, the results obtained for the amount of perspiration produced during the Exercise- are shown in table 6 The total perspiration measured is the total amount of sweat absorbed by the single jersey T-shirt and absorbent papers. The analysis of variance is listed in table 6. upper arm opening gave rise to considerably more sweat than chest opening and back opening. This was expected following the fabric test results detailed and the findings of previous research conducted into the effect of fabric properties on sweat generation.

It is interesting to note that the position of back opening has no effect on reducing the perspiration rate for three athletes, although the existence of an opening does result in a reduction in sweat rate. This is perhaps due to the fact that data are based on the amount of perspiration measured after a whole exercise (10, 20 and 30 minutes exercise, five minute resting period). If the amount of sweat was recorded just after the exercise, rather than after the resting period, the experiment results were analyzed using he calculations used followed ANOVA procedure. Two factors were used for the analysis: the three locations of openings in T-shirt, upper arm (A), chest (B) and back (C), for three athletes and the time (10, 20 and 30 minutes exercise, five minute resting period) intervals between the start of the exercise and the measurements of skin perspiration rate are shown in table 5. Indication this P-value=0.996602435 for Sample, P-value=0.999999997 for Columns and P-value=1 for Interaction.

The first point to note is the effect of fabrics used on the change in Perspiration rate skin. Owing to the open mech structure was expected to provide better comfort. During the exercise, especially at the beginning of the exercise, although after about ten minutes of exercise differing average skin Perspiration was noted ($p < 0.1$). This phenomenon is mainly dependent on the fabrics' ability to transfer water vapor property.

The changes of Perspiration before and after exercise, especially the effect of opening during the resting period, seemed to affect the subjects comfort. the rating difference between before and after the exercise T-shirt.

This effect is not apparent at the beginning of the exercise routine, but differing average Perspiration was noted when wearing T-shirt after about 20 and 30 minutes into the exercise ($p < 0.1$).

Table 5: Analysis of variance for perspiration rate before and after exercise

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	1.00	2	25.50	0.00	1.00	3.07
Columns	442.94	9	49.22	0.01	1.00	1.96
Interaction	60.08	18	3.34	0.00	1	1.69
Within	899,171.23	120	7,493.09			
Total	899,725.25	149				

Table 6: The results obtained for the amount of perspiration produced during the Exercise.

			Weight (gm)									
				Athlete 1			Athlete 2			Athlete 3		
		opening Placement	Before Exercise	After 10 min.	After 20 min.	After 30 min.	After 10 min.	After 20 min.	After 30 min.	After 10 min.	After 20 min.	After 30 min.
First T-Shirt	First T- shirt	opening in Chest	191	191.5	198	210	191.7	197.7	208	191.6	199	211
	Chest (Paper)	opening in Chest	2.7	3	3.03	3.11	3.4	3.6	4.2	3.2	3.5	3.6
	Back (Paper)	opening in Chest	2.7	3.75	4.75	4.88	3.8	4.3	5	3.9	4.6	4.9
	Right armpit (Paper)	opening in Chest	2.7	4	4.6	4.8	4.1	4.8	5.5	4.2	4.9	5.2
	Left armpit (Paper)	opening in Chest	2.7	4.2	4.7	5.05	4.1	4.9	5.6	4.2	4.8	5.3
Second T-Shirt	Second T- shirt	opening in Back	191	193.6	198.5	203	194	199	206	194.2	200	209
	Chest (Paper)	opening in Back	2.7	3.47	5.4	7.6	4.4	5.6	7.8	3.5	5.3	7.7
	Back (Paper)	opening in Back	2.7	3.27	5	6.4	3.6	4.4	6.6	3	4.8	6.8
	Right armpit (Paper)	opening in Back	2.7	4.8	5.6	7.1	5.2	5.6	7.2	3.9	5.6	7.5
	Left armpit (Paper)	opening in Back	2.7	4.9	5.6	7.2	5.2	5.7	7.2	3.8	5.7	7.5
Third T-Shirt	Third T- shirt	opening in armpit	191	194	195	197	194.6	196	200	197	198	200
	Chest (Paper)	opening in armpit	2.7	3.7	4.4	4.9	3.9	4.8	5.3	4.3	4.6	5.8
	Back (Paper)	opening in armpit	2.7	3.9	4.9	5.9	4.3	5	5.8	4.4	5.1	6
	Right armpit (Paper)	opening in armpit	2.7	3.3	3.5	3.7	3.5	3.9	4	3.7	4	4.2
	Left armpit (Paper)	opening in armpit	2.7	3.4	3.5	3.7	3.6	3.9	4.1	3.6	4	4.2

4. Conclusions

From this research it is shown that both ventilation system, Properties and structures of fabrics can contribute to comfort feeling in T-shirt when T-shirt is worn for activities. During the exercise, the best structure fabric is open mech in air permeability, thermal retention, water vapor permeability, wettability , wicking and drying time.

The design of the openings in T-shirt has an effect on the total amount of sweat absorbed Upper arm opening has the greatest effect on reducing the perspiration rate for athletes followed by chest opening and back opening.

The results for the period of exercise, however, do suggest that the provision of ventilation at appropriate positions in T-shirt could contribute considerably to Perspiration of the use of hi-tech fabrics. Skin sweat at the upper arm was greater than at other parts of the body where measurements were taken at the start of the exercise. This suggests that an opening upper arm may be the most effective way of creating ventilation. Although several T- shirt manufacturers incorporate a ventilation system around the upper arm, it is not the most popular position to open during exercise. It is recommended, however, to consider engineering a design.

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