Thermal comfort properties of summer and winter outerwear knitted fabrics

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Abstract:
Comfort is considered one of the most important properties required by the consumers when purchasing clothes. Thermal comfort can be divided into physiological and psychological ones. This study aimed to differentiate between different knitted structures that randomly selected from the Egyptian market in order to be used as summer and winter outerwear in terms of their thermal comfort. Thermal comfort was characterized in this study by air permeability, thermal conductivity, thermal resistance and water vapor transmission in the fabric. One-Way analysis was used to differentiate between knitted fabric samples. The findings of this study revealed that knitted fabric weight is the most influential factor on thermal comfort properties. With regard to summer and winter outerwear, there were significant differences among knitted fabric samples in terms of their thermal comfort properties.

Keywords:
Knitted Fabric, Thermal Comfort, Outerwear, Thermal Conductivity, Thermal Resistance, Water Vapor Transmission, Air Permeability.

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1. Introduction
When wearing clothes, good comfort, high quality and low price are importantly required by the wearers. Other parameters than touching, handling and seeing what are called comfort are expensively required by consumers to choose clothing to be worn appropriately [1]. Comfort is one of the most significant factors affecting the performance of apparel whether knitted or woven fabrics. Comfort can be divided into two main categories, namely psychological and physiological comfort. These two classes can be characterized as warmness, coolness, roughness and breathability [2, 3].

Thermal comfort refers to sensations of hot, cold, dry or dampness in clothes and is usually associated with environmental factors, such as heat, moisture, and air velocity [4]. Many properties of textile materials, such as water/moisture vapor transmission and air permeability, are important factors that affect the thermal comfort of textiles.

Woven and knitted fabric properties, especially comfort, were investigated in numerous papers [5-17]. In these research works, the effects of constructional parameters of woven and knitted fabrics on comfort and other physical properties were studied in details.

In their study of the effect of Kermel fiber content in cotton/nylon blended fabrics on thermal comfort properties, Ali Kakvan and co-workers [5] found that the content of Kermel fibers don't affect the thermal conductivity of the blended fabrics up to 40%. However blended fabrics containing 30% Kermel fibers gave the highest thermal comfort values. Adding Kermel fibers up to 10% decreases vertical wicking significantly. A content of 40% Kermel fibers in cotton /nylon blended fabrics leads to desirable thermal comfort properties. It was also found that increasing Kermel fibers diminished the water vapor resistance significantly up to 40% blending ratio.

The effect of cross sectional shape of polyester fibers on thermal comfort of woven polyester fabrics was examined extensively [6]. The findings of this study disclosed that polyester woven fabrics containing hollow polyester fibers increased thermal conductivity and thermal absorption values but decreased the values of air and water vapor permeabilities compared polyester fabrics containing solid fibers. Comfort characteristics of fabrics woven from different compact yarns were studied [9]. In this study compact yarns were spun from different spinning techniques. The results showed that fabrics woven from Elite compact yarns exhibited higher air permeability and slightly higher values of moisture vapor transmission rate compared fabrics woven from conventional spun yarns.

Hüseyin, et al. [10] investigated the thermal comfort properties of bamboo/cotton knitted fabrics. They found that comfort properties of bamboo/cotton fabrics rely mainly on fabric structure. Pique knitted fabrics were found to have higher air permeability values compared to

plain and double knit fabrics. It was also found that double knit fabrics contains 70% bamboo fibers have lower thermal resistance and lower water vapor resistance compared the other knit fabrics. Thermal insulation properties of woven fabrics were examined [12]. It was found that weft density and woven fabric structures play a vital role in determining the optimal values of the thermal insulation properties of the woven fabrics.

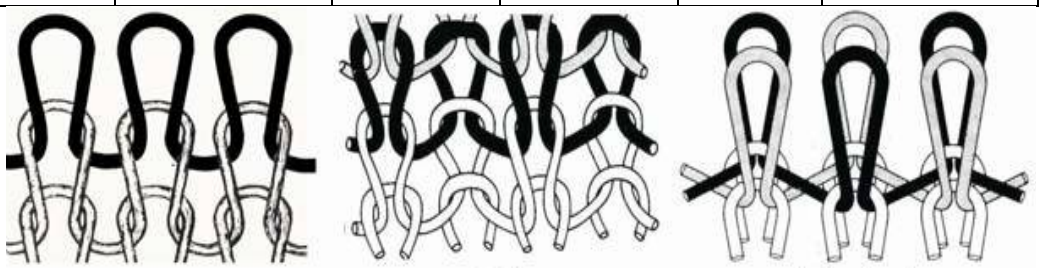
2. Experimental work

2.1- Materials

In this study, twelve knitted fabrics were selected randomly from the Egyptian market. Eight of these knitted fabrics were used as summer outerwear, while the rest of fabrics were used as winter outerwear. The fabric samples under study are all knitted from single Jersey, rib and Interlock structures that are shown in figure 1. The characteristics of selected knitted fabrics were listed in table 1.

Table 1: Characteristics of selected knitted fabrics.

Fabric code	Name	Knit structure	Yarn count (Ne)	Weight (g/m2)	Outerwear
A	Melton	Interlock	30/1	200	Summer
B	Melton	Interlock	24/1	295	Summer
C	Melton	Interlock	16/1	300	Summer
D	Parasola	Single Jersey	30/1	145	Summer
E	Parasola	Single Jersey	24/1	220	Summer
F	Single pique	Single Jersey	30/1	205	Summer
G	Double pique	Single Jersey	24/1	235	Summer
H	Rib	Rib	24/1	255	Summer
I	Derpie	Rib	20/1	375	Winter
J	Derpie	Rib	30/2	450	Winter
K	Rib	Rib	24/1	320	Winter
L	Melton	Interlock	30/2	340	Winter



Single Jersey **Rib** **Interlock**

Figure 1: Basic knit structures used in this study

2.2- Laboratory testing

Before testing, all fabric samples were conditioned in standard atmosphere for 24 hours at temperature 20^{o}C±2 and relative humidity 65%±2. Each fabric property was measured ten times and the average value was obtained.

The air permeability of knitted fabrics under study was measured according to standard test method ASTM D 737 – 96 using the Air Flow Tester of Model No. 9025 at 98 Pa air pressure. The relative water vapor transmission rate was also measured in accordance with standard test method ASTM D 1776 – 96 using Alambeta measuring instrument. Thermal conductivity and resistance were measured in accordance with standard test method ASTM D- using Alambeta measuring device.

2.3- Statistical analysis

In order to analyze the obtained experimental data, A Statistical Package for Social Students, namely SPSS Software Version 15 was utilized. One-Way analysis was used to detect the significance differences among the different fabric samples at 0.01 significance level.

3. Results and discussion

3.1- Air permeability

Air permeability is a hygienic property of textiles which influences the flow of gas from the human

body to the environment and the flow of fresh air to the body. Air permeability depends on fabric porosity, which means the number of canals in the textile fabric, its cross- section, and shape.

The values of air permeability of different knitted fabrics used for summer and winter wear were plotted in figures 2 and 3. The results of the statistical analysis listed in table 2 and 3 showed the significance difference among fabric structures with respect to air permeability values at significance level 0.01. It was also proved that the knitted fabric structure accounted for 99% of the effects on air permeability for summer and winter outer wears.

From figure 2 it can be seen that the weight of summer melton knitted fabric has a negative influence on air permeability. As the fabric weight increases the air permeability decreases. The same trend of the fabric weight was obtained to the rest of knitted structures. Parasola knitted fabrics of weight 145 g/m2 gave the highest value of air permeability compared to the other knitted structures.

Regarding winter wear knitted fabrics, it can be seen from figure 3 that for derpie lycra, the fabric weight has a negative effect on the values of air permeability. As the fabric weight increases the air permeability decreases. For winter outer wear fabrics, melton knitted fabrics of weight 340 g/m2 gave the highest air permeability value (36.5 cm3/cm2.sec) while derpie lycra of weight 450 g/m2 yields the lowest value of air permeability.

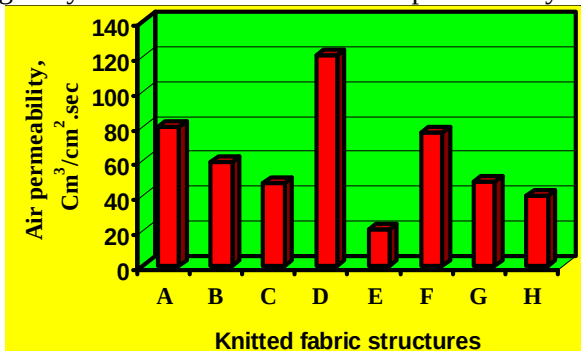


Fig 2: Air permeability of different knitted fabric structures for summer wear

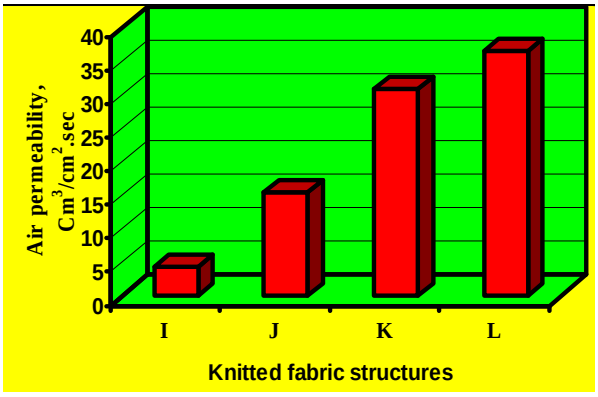


Fig 3: Air permeability of different knitted fabric structures for winter wear

Table 2: Analysis of variance for the effects of weft knitted structures on air permeability of summer wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	32715.6	7	4673.657	1302.67	0.000	2.31274
Within groups	114.808	32	3.58775			
Total	32830.4	39				

Table 3: Analysis of variance for the effects of weft knitted structures on air permeability of winter wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	3203.021	3	1067.674	2199.325	0.000	3.239
Within groups	7.76728	16	0.485455			
Total	3210.788	19				

3.2- Thermal resistance

Thermal resistance can be defined as the resistance of a piece of fabric and a layer of air next to it to dry or conductive heat loss during wearing. The experimental results of thermal resistance of summer and winter outer wear knitted fabrics were illustrated in figures 4 and 5 respectively. The Analysis if variance results which listed in tables 4 and 5 revealed that knitted fabric structures have a huge influence on the thermal resistance values at 0.01 significance level. It was also concluded that knitted structures accounted for 97% and 95% for the effects on thermal resistance values for summer and winter outer wear respectively.

Figure 4 illustrates the values of thermal resistance of summer outer wear knitted fabrics. By contrast to air permeability, fabric weight was found to have a positive influence on thermal resistance. As the fabric weight increases, the values of thermal resistance react in the same manner. Summer melton knitted fabric with higher weight depicted high thermal resistance compared to summer melton of lower weight. Also double pique knitted fabric exhibited higher

thermal resistance more than single pique knitted fabrics. Rib knitted structures showed moderate values of thermal resistance compared to the other knitted fabrics.

For winter outerwear knitted fabrics, it can be noticed from figure 5 that, for derpie lycra, fabric weight has a positive influence on fabric thermal resistance.

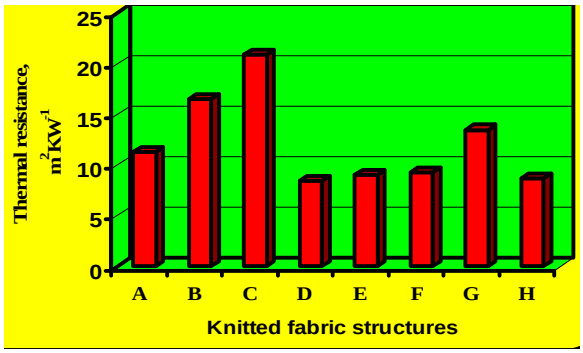


Fig 4: Thermal resistance of different knitted fabric structures for summer wear

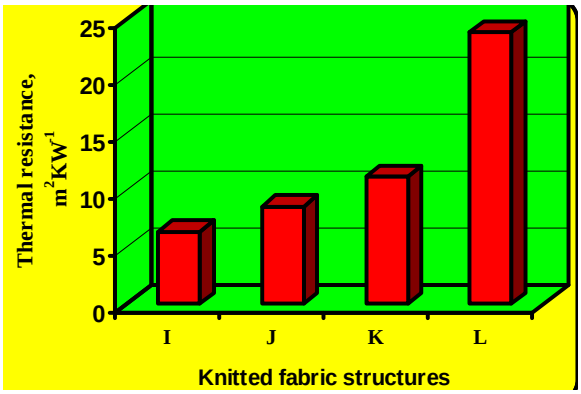


Fig 5: Thermal resistance of different knitted fabric structures for winter wear

As the fabric weight increases, thermal resistance follows the same trend. It can also be seen that melon knitted fabrics of weight 340 g/m2 showed highest values of thermal resistance compared to all winter outer wear knitted fabrics.

Table 4: Analysis of variance for the effects of weft knitted structures on thermal resistance of summer wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	1010.352	7	144.336	1961.52	0.000	2.313
Within groups	2.35468	32	0.073584			
Total	1012.707	39				

Table 5: Analysis of variance for the effects of weft knitted structures on thermal resistance of winter wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	925.072	3	308.357	5248.635	0.000	3.239
Within groups	0.94	16	0.059			
Total	926.012	19				

3.3- Thermal conductivity

Thermal conductivity, which is a reciprocal of thermal resistance, can be defined as the transmission rate of heat through a piece of fabrics next to human skin.

Experimental results of thermal conductivity for summer and winter outerwear knitted fabric wears were depicted in figures 6 and 7 respectively. The statistical analysis listed in tables 6 and 7 respectively showed that knitted fabric structure has a remarkable influence on the thermal conductivity values. It was also found that fabric knitted structures accounted for 95% and 98% of the effects on thermal conductivity of summer and winter wears respectively.

With respect to summer outerwear knitted fabrics, it can be seen from figure 5 that fabric weight has a negative influence on thermal conductivity. As the fabric weight increases, thermal conductivity of knitted fabrics decreases. The same result can be plied to all knitted structures. Rib knitted fabrics exihibted higher thermal conductivity values, whereas parasola fabric of weight 220g/m2 yielded the lower thermal conductivity values.

Regarding winter outerwear knitted fabrics, fabric weight has also a negative effect on thermal conductivity values. Derpie lycra of weight 375g/m2 gave the highest thermal conductivity values followed by derpie lycra of weight 450 g/m2 , rib lycra and melton respectively.

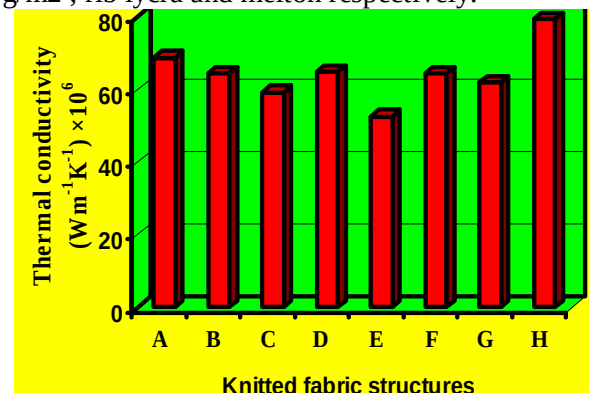


Fig 6: Thermal conductivity of different knitted fabric structures for summer wear

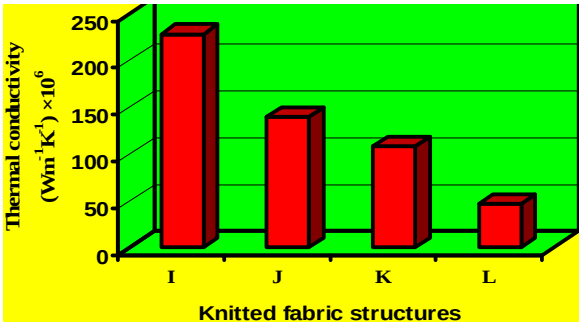


Fig 7: Thermal conductivity of different knitted fabric structures for winter wear

3.4- Relative water vapor transmission

Transmission of water vapor released from the human body through a worn fabric is referred to as relative water vapor transmission. It is also referred to as insensible perspiration. Water vapor transmission of summer and winter outerwear knitted fabrics were illustrated in figures 8 and 9 respectively. It was concluded from ANOVA results that knitted fabric structures have a considerable influence on the relative water vapor transmission at 0.01 significance level. It was also proved that kintted stryctyres accounted for 99% and 98% of the effects on relative water vapor transmission for summer and winter outerwear knitted fabrics.

For summer outerwear knitted fabrics illustrated in figure 8, it can be detected that fabric weight has a negative effect on water vapor transmission. As the fabric weight increases, the water vapor transmission decreases. Parasola knitted fabric of weight 145 g/m2 exhibited the highest values of water vapor transmission and melton knitted fabric if weight 35 f/m2 showed the lowest values of water vapor transmission.

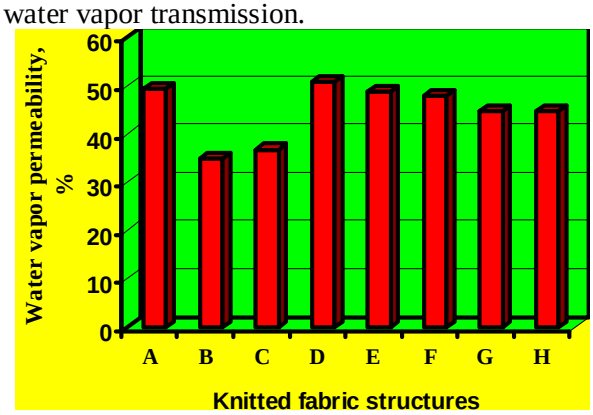


Fig 8: Water vapor permeability of different knitted fabric structures for summer wear

Regarding winter outerwear knitted fabrics, the fabric weight was found to have a negative influence on the water vapor transmission. The high water vapor transmission values accompanied ripe lycra of weight 320 g/m2 and lowest values was associated by drpie lycra knitted fabrics.

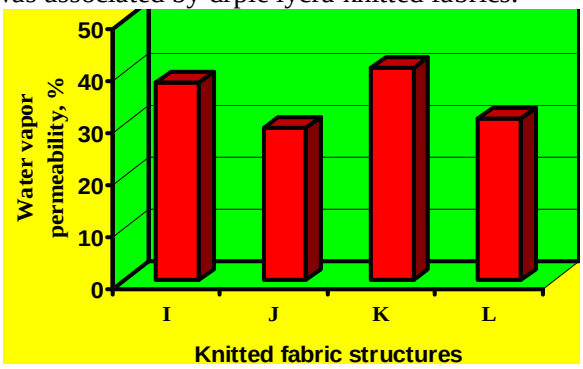


Fig 9: Water vapor permeability of different knitted fabric structures for winter wear

Table 6: Analysis of variance for the effects of weft knitted structures on thermal conductivity of summer wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	3389.255	7	484.179	165.652	0.000	2.313
Within groups	93.532	32	2.923			
Total	3482.787	39				

Table 7: Analysis of variance for the effects of weft knitted structures on thermal conductivity of winter wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	85890.99	3	28630.33	884.591	0.000	3.239
Within groups	517.8497	16	32.366			
Total	86408.84	19				

Table 8: Analysis of variance for the effects of weft knitted structures on water vapor permeability of summer wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	1219.43	7	174.204	919.890	0.000	2.313
Within groups	6.06	32	0.189			
Total	1225.49	39				

Table 9: Analysis of variance for the effects of weft knitted structures on water vapor permeability of winter wear

Source of Variation	SS	df	MS	F	P-value	F crit
Between groups	451.848	3	150.616	579.292	0.000	3.239
Within groups	4.16	16	0.26			
Total	456.008	19				

3.5- Quality assessment

To optimize knitted fabric properties, namely to select knitted fabrics which have the best properties , which in turn are more suitable for summer and winter outerwear, polar chart was developed. In polar chart, each diagram corresponds to one fabric structure. The diagram that has largest area its corresponding fabric will be suitable for outer wear. Figure 10 depicts the polar diagram for fabric codes A-D which intended to be used as a summer outerwear. From this chat it can be noticed that the diagram No. D corresponds to parasola of weight 145 g/m2 suits to summer wear.

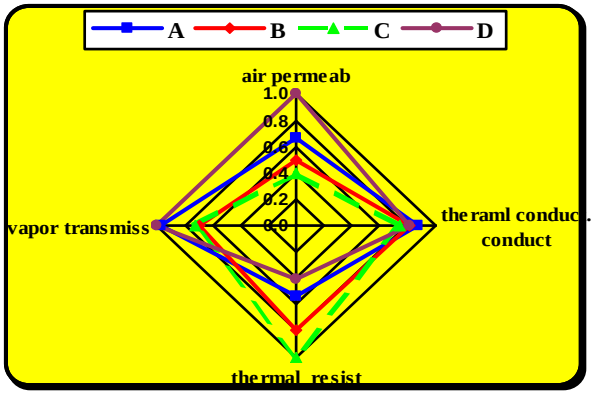


Figure 10: Polar diagram of knitted fabric codes A-D

Polar diagrams of fabric codes E-H was illustrated in figure 11. It can be noticed that fabric code, i.e single pique yield the largest area but still more less than parasola. Thus it was concluded that parasola knitted fabric of weight 145 g/m2 is the most suitable for summer outerwear.

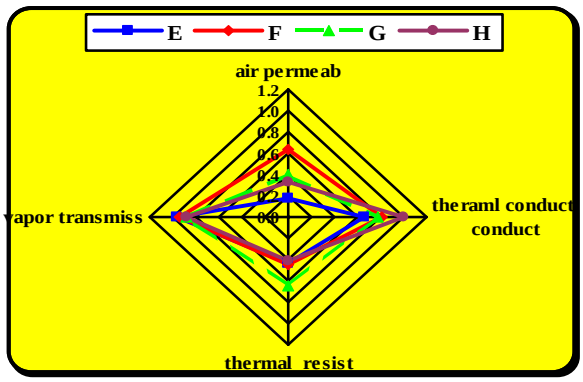


Figure 11: Polar diagram of knitted fabric codes E-H

Figure 12 portraits the polar diagrams for winter outerwear knitted fabrics of codes I-L. Fro this figure it can be seen that the largest area was associated with fabric code L, i.e. Melton of weight 340 g/m2. Thus this type of knitted fabric is the most suitable for winter outerwear.

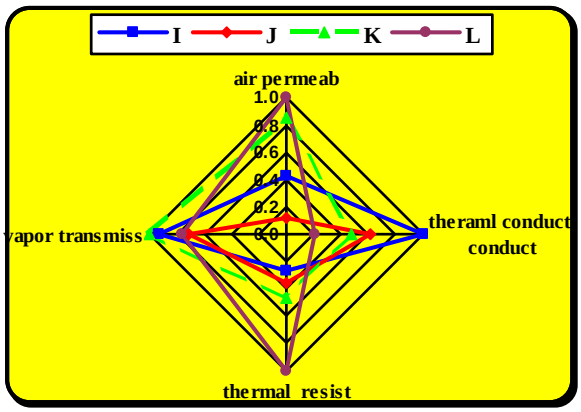


Figure 12: Polar diagram of knitted fabric codes I-.

4. 4- Conclusion

In this study, twelve knitted fabrics were selected randomly from the Egyptian market. Eight fabric samples were used as summer outerwear and four samples were used as summer outerwear. The main structures of these knitted fabrics mainly based upon single jersey, rib and interlock structures. The main objective of this study was to scrutinize thermal comfort properties of these knit structures. Thermal comfort throughout this work was characterized by air permeability, thermal conductivity, thermal resistance and water vapor resistance. One–Way analysis of variance was used to detect the significance difference among these knitted fabrics. The findings of this study can be sum up as follows:

- Statistical analysis showed a significance difference among knit structures with regard to their air permeabilities. Fabric weight has a negative influence on air permeability.
- Regarding summer outerwear, Parasola knitted fabrics of weight 145 g/m2 gave the highest value of air permeability compared to the other knitted structures.
- with regard to winter outerwear, melton of weight 340 g/m2 has the highest value of air permeability.
- It was proved that fabric weight has a negative influence on thermal conductivity. As the fabric weight increases, thermal conductivity of knitted fabrics decreases.
- It was found that Derpie lycra of weight 375g/m2 gave the highest thermal conductivity

with regard to summer outerwear.

- Fabric weight was found to have a positive influence on thermal resistance. As the fabric weight increases, the values of thermal resistance react in the same manner.
- Melton fabrics of weight 300g/m2 and 340 g/m2 respectively were found to have highest values of thermal resistance for summer and winter outerwear.
- Polar charts disclosed that the best knitted fabric samples suited to summer and winter outer wear were parasola of weight 145 g/m2 and melton of weight 340 g/m2 respectively.

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