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INVESTIGATION OF THE EFFECT OF APPAREL FABRICS STRUCTURE ON AIR PERMEABILITY AND THERMAL COMFORT PROPERTIES

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Abstract : Fabric structure has a major effect on air permeability and thermal comfort properties of apparel fabrics. Air permeability and thermal comfort properties of apparel depend on fabric structural properties such as weave type, fabric thickness, weight, yarn density and cover factor. Thermal conductivity, thermal diffusivity, thermal absorptivity, thermal resistance and air permeability should be measured to test thermal comfort properties of fabrics.The purpose of this study is to investigate the effect of the apparel fabrics structure on air permeability and thermal comfort properties. For this reason, air permeability and thermal comfort properties of viscose / polyester blended woven fabrics of different structures which are widely used in apparel have been examined. According to the results, a negative correlation was observed between weight, thickness, cover factor and air permeability of the fabrics. A positive correlation was observed between weight, thickness, cover factor and thermal conductivity of the fabric samples. A positive correlation was observed between weight, cover factor and thermal absorptivity of the fabric samples. Also positive correlations were observed between thickness- thermal resistance and thickness- thermal diffusivity of the fabric samples.

Key Words: Apparel, weave type, thermal comfort, air permeability

Giysilik Kumaşların Yapısının Hava Geçirgenliği ve Termal Konfor Özellikleri Üzerine Etkisinin İncelenmesi

Öz: Kumaş yapısı, giysilik kumaşların hava geçirgenliği ve termal konfor özellikleri üzerinde önemli etkiye sahiptir. Hava geçirgenliği ve termal konfor özellikleri örgü tipi, kumaş kalınlığı, gramaj, sıklık ve örtme faktörü gibi kumaş yapısal özelliklerine bağlıdır. Termal iletkenlik, termal yayılma, termal absorptivite, termal direnç ve hava geçirgenliği kumaşların termal konfor özelliklerini test etmek için ölçülmelidir. Bu çalışmanın amacı, giysilik kumaşların yapısının hava geçirgenliği ve termal konfor özellikleri üzerine etkisini incelemektir. Bu sebeple, giysilerde çok kullanılan farklı yapılardaki viskon/polyester karışımlı dokuma kumaşların hava geçirgenliği ve termal konfor özellikleri incelenmiştir. Sonuçlara göre, kumaşların gramaj, kalınlık, örtme faktörü ile hava geçirgenlik değerleri arasında negatif korelasyon elde edilmiştir. Kumaşların gramaj, kalınlık, örtme faktörü ve termal iletkenlik değerleri arasında pozitif korelasyon bulunmaktadır. Kumaşların gramaj, örtme faktörü ve termal yayılma değerleri arasında pozitif korelasyon bulunmaktadır. Aynı zamanda, kumaşların kalınlık ile termal absorptivite ve termal direnç değerleri arasında da pozitif korelasyon bulunmaktadır.

Anahtar Kelimeler: Giysi, kumaş yapısı, termal konfor, hava geçirgenliği

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1.INTRODUCTION

Clothing manufacturers want fabrics pass from the garment production processes easily. These manufacturers also want that garments have a good appearance and a good wear comfort. The structural properties of the fabric affect the comfort characteristics of the fabric. The important properties are weave type, fabric thickness, yarn type, weight, density and cover factor. (Choudhuryn, Majumdar and Datta, 2011).

The resistance of a fabric to air permeability will depend on the fabric structural properties. The differences in the structural properties of fabrics lead to different permeability behaviors under the same environmental conditions (Turan and Okur, 2008; ISO 9237). Air permeability is very important for the thermal comfort of garments.

Fiber and yarn properties affect the thermal resistance of garments. The most important factor for determining thermal resistance of a fabric is thickness.

Since the stagnant air between two fabrics increases the thermal resistance or insulation, the garments made from two or three layered fabrics have high thermal resistances. (Sinclair, 2015).

Thermal comfort properties of fabrics, such as thermal resistance, thermal conductivity, thermal diffusivity and thermal absorptivity, are influenced by fabric structural properties such as yarn type, fabric thickness, weave type, weight, yarn density, surface treatment, air permeability, and surrounding temperature (Hes and Loghin, 2009).

Thermal conductivity coefficient (λ) presents the quantity of heat, which transitions from 1 m^2 of material through a distance of 1 m within 1 s to achieve a temperature difference of 1 K. The thermal conductivity of fabrics is generally between 0.033 and 0.01 W / mK.

Thermal absorptivity (b) of fabrics has been presented the thermal sensation (heat flow level) during short-term contact with a fabric surface of human skin (Hes and Loghin, 2009).

Thermal resistance (R) depends on fabric thickness and thermal conductivity. Thermal resistance is the capability of a material to stand heat flow. There are many studies investigating the effect of the fabrics structural parameters on the thermal properties of fabrics. The studies show that there is a high correlation between the thermal resistance of the fabric and its thickness, weight, cover factor and density (Fan and Hunter, 2009; Kanat, Özdil and Marmaralı, 2014).

Thermal diffusivity (A) measures the thermal energy carrying capacity according to the thermal energy storage capacity of a material. Thermal diffusivity explains how quickly a material reacts to a change in temperature. Higher thermal diffusivity is associated with faster heat diffusion (Eryürük, 2016).

Fabrics made from viscose rayon yarns are among the most preferred materials in apparel. Viscose woven fabrics have high drap ability and are widely used for apparel (Sinclair, 2015).

One of the most important characteristics of the fabrics that affect the thermal comfort properties of an apparel is its structural properties. Such parameters as thickness, weight, weave type, fabric cover factor and yarn density are the most effective parameters. The fabric weave type composes its thickness and weight properties and affect the air permeability and thermal insulation. (Marmaralı, Özdil and Retzschmar, 2007; Ravaldi and Valizadeh, 2011).

It is assumed that thickness is the most important geometric characteristic of fabrics that affect thermal insulation properties (Frydrych, Dziworska and Bilska, 2002; Matusiak and Sikorski, 2011; Kanat, Özdil and Marmaralı, 2014)

The purpose of this study is to investigate the effect of the apparel fabrics structure on air permeability and thermal comfort properties.

2.MATERIAL AND METHOD

2.1. MATERIAL

In this study, four types of woven fabrics with different structural properties which are widely used for apparel fabrics were measured. Structural properties of the fabric samples are given in Table 1.

Table1. Structural parameters of fabrics used

Fabric Code	Weave Type	Yarn Density (thread/cm)		Yarn Count (Ne)		Thickness (mm)	Weight (g/m^2)	Fabric Cover Factor
		Warp	Weft	Warp	Weft			
A1	Twill 3/1/1/1	42	27	28/1 Viscose	28/1 Viscose/PET 80/20	0.35	160	23.83
A2	Twill 3/1/1/1	33	27	28/1 Viscose	28/1 Viscose/PET 80/20	0.33	145	21.51
A3	Twill 2/1	43	27	28/1 Viscose	28/1 Viscose/PET 80/20	0.40	160	24.09
A4	Twill 2/1	35	27	28/1 Viscose	28/1 Viscose/PET 80/20	0.36	145	21.31

2.2. METHOD

In this study, air permeability and thermal comfort properties tests were made on the fabric samples. The ASTM D 3776-09a standard was used to measure the mass per unit area, and the ASTM D 3775-17 standard was used to measure the warp and weft density of the fabric samples (ASTM D 3776-09a; ASTM D 3775-17). Cover factors of the fabric samples were calculated according to the Peirce formulas (Peirce, 1937).

The warp and weft cover factor K_{wa} and K_{we} are defined at Equation (1) according to Peirce.

$$Kwa = \frac{3.3\ x\ n1}{\sqrt{Nm1}} \qquad Kwe = \frac{3.3\ x\ n2}{\sqrt{Nm2}} \tag{1}$$

n_1 = Warp yarn density (thread/cm)
n_2 = Weft yarn density (thread/cm)
N_1 = Warp yarn count (Nm)
N_2 = Weft yarn count (Nm)

The fabric cover factor K_f is defined at Equation (2) according to Peirce.

$$\mathrm{Kf} = Kwa + Kwe - \frac{Kwa\ x\ Kwe}{28} \tag{2}$$

Air permeability tests were made according to the ISO 9237 standard using an SDL Atlas Digital Air Permeability Tester Model M 021A. A 100Pa pressure drop was used to test air permeability. The test area was 20 cm^2 for all fabric samples.

The ALAMBETA device was used to measure thermal comfort properties and fabric thickness. The instrument simulates dry human skin (Hes and Loghin, 2009).

Measurement was performed under standard climatic conditions. For each fabric, five repetitions of the measurement were made, and the arithmetic mean was calculated from the individual measurement results.

Prior to the tests, all fabric samples were conditioned for 24 hours in standard atmospheric conditions (at a temperature of 20 ± 2 ° C and relative humidity of 65 ± 2%).

The results were evaluated statistically with using SPSS 14.0 program. Completely randomized single-factor (one way) multivariate analysis of variance (ANOVA) as a fixed model was applied to data. Student-Newman-Keuls (SNK) tests were used to compared the means. The treatment levels were marked in accordance with the mean values, and levels were marked with different letter (a, b, c and d) to show that they were significantly different.

The correlation coefficient was calculated between the values of the fabric structural properties and thermal comfort properties.

3. RESULTS AND DISCUSSION

The air permeability and thermal comfort properties values of the fabrics are given in Table 2-3.

Table 2. Air permeability values of fabrics

Fabric Code	Air Permeability ($l/m^2/s$)	% CV
A1	660.2	2.71
A2	1258.0	8.13
A3	501.4	6.68
A4	1276.0	3.30

Table 3. Thermal comfort properties test results for fabric samples

Fabric Code	Thermal Conductivity (W/m K 10^{-3})		Thermal Diffusivity (mm^2/s)		Thermal Absorptivity ($Ws^{1/2}/m^2$ K)		Thermal Resistance (m^2 K/W 10^{-3})	
	λ	% CV	A	% CV	B	% CV	R	% CV
A1	38.5	1.03	0.048	15.83	176.2	8.78	9.1	2.52
A2	35.5	2.22	0.044	13.18	168.2	4.01	9.2	4.23
A3	40.6	2.06	0.059	30.76	167.8	8.83	9.8	3.42
A4	35.8	3.43	0.058	14.48	149.4	7.48	10.1	6.73

Analysis of variance and Student-Newman-Keuls test results are given in Tables 4 and 5. The correlation coefficient values between the fabric structural and thermal comfort properties of fabrics are presented in Table 6.

Table 4. Statistical analysis (Analysis of variance and SNK test) results for air permeability

Anova and Student-Newman-Keuls Test Results		
Fabric Type	**Air permeability (l/mm^2/s)**	
	P/Sig.	**SNK**
A1	0.00*	660.2 b
A2		1258.0 c
A3		501.4 a
A4		1276.0 c

**: statistically significant ($P < 0.05$)*
(a), (b) and (c) represent the significantly different ranges according to SNK test.

Table 5. Statistical analysis (analysis of variance and SNK test) results for thickness and thermal comfort properties

Anova and Student-Newman-Keuls Test Results										
Fabric Type	**Thickness (mm)**		**Thermal Conductivity (W/mK 10^{-3})**		**Thermal Diffusivity (mm^2/s)**		**Thermal Absorptivity (Ws^{-}/mK$^{)}$**		**Thermal Resistance (m^{2}K/W 10^{-3})**	
	P/Sig.	**SNK**	**P/Sig.**	**SNK**	**P/Sig.**	**SNK**	**P/Sig.**	**SNK**	**P/Sig.**	**SNK**
A1	0.00*	0.35 a	0.00*	38.5b	0.04	0.048a	0.02	176.2b	0.00*	9.18 a
A2		0.33 a		35.5 a		0.044 a		168.2a		9.26 a
A3		0.40 b		40.6 c		0.059 a		167.8a		9.86 a
A4		0.36 a		35.8 a		0.058 a		149.4a		10.1 b

**: statistically significant ($P < 0.05$)*
(a), (b and (c) represent statistically difference ranges according to SNK test.

Table 6. Correlation coefficients between structural and thermal comfort properties of fabrics

	Air Permeability	**Thermal Conductivity**	**Thermal Diffusivity**	**Thermal Absorptivity**	**Thermal Resistance**
Weight	**- 0.986**	**0.933**	0.194	**0.671**	- 0.240
Thickness	**- 0.684**	**0.816**	**0.855**	- 0.095	**0.590**
Cover Factor	**- 0.995**	**0.952**	0.194	**0.684**	- 0.239

3.1. Factors Affecting Air Permeability of Fabrics and Clothing

A negative correlation was observed between weight, thickness, cover factor and air permeability of the fabrics, as shown in Table 6. The fabric structure affects the air permeability. As seen in Figure 1, the lowest air permeability was measured for fabric sample A3, while the highest air permeability was measured for fabric sample A4.

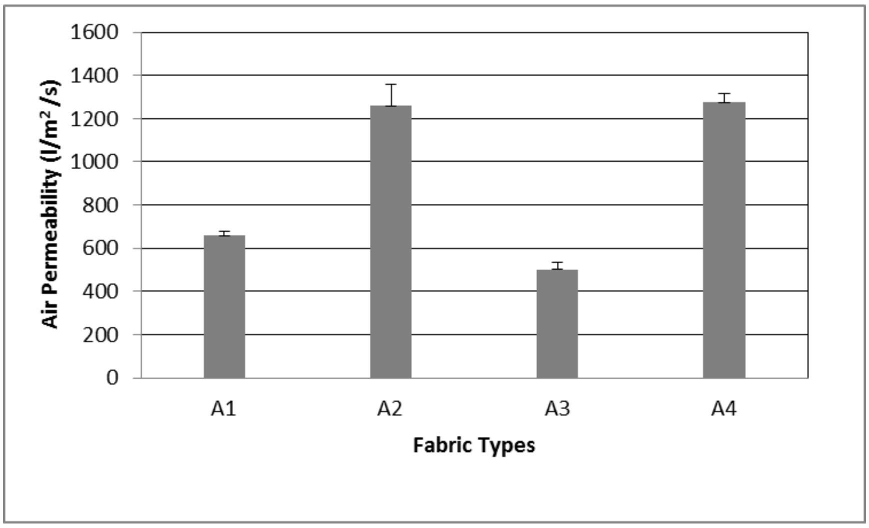

Figure 1:
Air permeability values of fabrics

Fabric samples A2 and A4 have lower warp density and higher air permeability than fabric samples A1 and A3, which have high warp density.

Thermal transmittance of the air is low. Stagnant air in the fabric structure can improve the insulation value of the material and keep the human body warm.

The resistance of a fabric and apparel to air permeability has depend upon fabric structural properties, especially yarn density and thickness (Sinclair, 2015). As the yarn density decreases, the porosity of the fabric will increase, so that the air permeability will increase.

The results of the ANOVA test in Table 4-5 indicated that there were statistically significant (5% significance level) differences between the fabric thickness and air permeability of various types of fabrics.

The SNK test results given in Table 4 indicated that the fabric samples had significantly different air permeability values. Fabric samples A2 and A4 verified the highest readings for air permeability. Experimental results showed that the effect of yarn density was observed to be significant for the air permeability of the fabric samples.

3.2. Factors Affecting Thermal Properties of Fabrics and Clothing

Thermal comfort properties of fabrics such as thermal conductivity, thermal diffusivity, thermal absorptivity and thermal resistance are influenced by fabric structural propertiess such as fabric thickness, weight, cover factor and yarn density.

Thermal conductivity demostrates the ability of a material to perform heat. Figure 2 shows thermal conductivity values of fabrics. For fabric samples, thermal conductivity was higher for A1 than A2 and higher for A3 than A4. The warp density, thickness and weight of fabric sample A1 were higher than A2, and the warp density, thickness and weight of fabric sample A3 was higher than A4. Higher density, thickness and weight of fabrics were correlated with higher thermal conductivity.

According to measure datas, the thermal conductivity values of the fabrics woven with twill weave vary between 35.5 and 40.6 W/mK 10^{-3}.Thermal conductivity values of viscose fibre is

62 mW/mK and polyester fibre is 140 mW/mK (Tian, Qu and Zhang, 2014; Morton and Hearle, 1986).

A positive correlation was observed between weight, thickness, cover factor and thermal conductivity of the fabrics, as shown in Table 6.

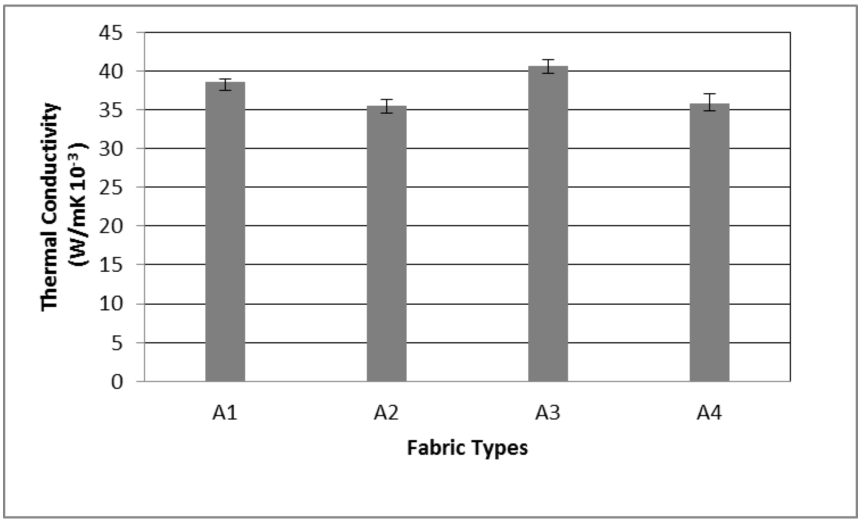

Figure 2:
Thermal conductivity values of fabrics

Figure 3 shows the thermal diffusivity test values of fabrics. Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure. Thermal diffusivity explains how quickly a material reacts to a change in temperature. For fabric samples, thermal diffusivity was higher for A1 than A2 and higher for A3 than A4. The warp density, thickness and weight of fabric sample A1 were higher than A2, and the warp density, thickness and weight of fabric sample A3 was higher than A4. Higher density, thickness and weight of fabrics were correlated with higher thermal diffusivity. A positive correlation was observed between thickness and thermal diffusivity of the fabrics, as shown in Table 6.

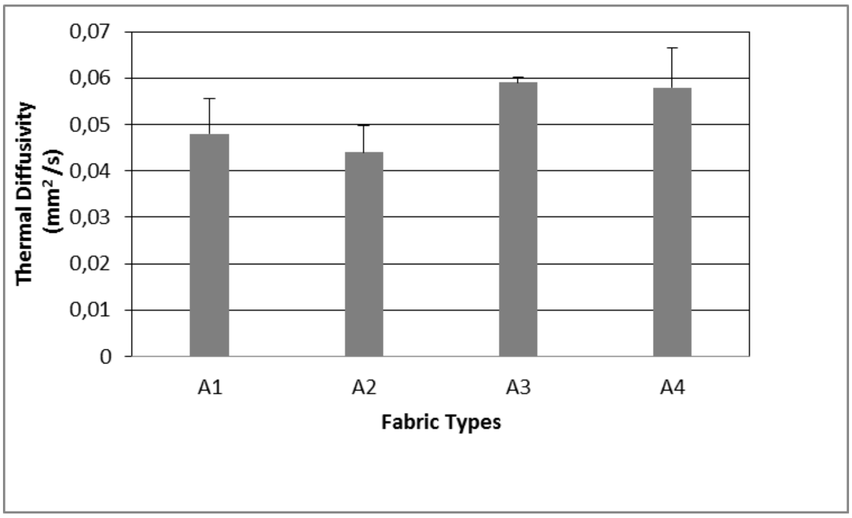

Figure 3:
Thermal diffusivity values of fabrics

Figure 4 shows the thermal absorptivity values of fabrics. The thermal absorptivity value gives the fabric a hot-cold feeling. According to the results, the thermal absorptivity of fabric sample A1 was higher than A2, A3 was higher than A4. The fabric samples with a higher thickness, cover factor and weight showed higher absorptivity values.

A positive correlation was found between the weight, cover factor and thermal absorptivity of the fabrics as shown in Table 6.

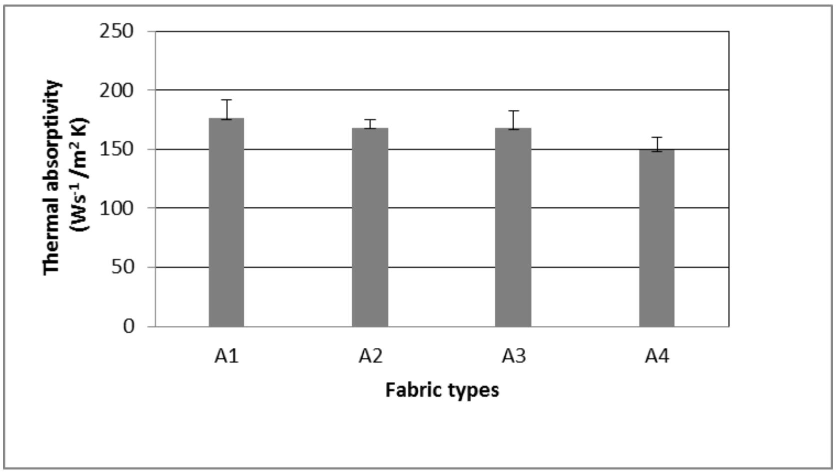

Figure 4:
Thermal absorptivity values of fabrics

Figure 5 shows the thermal resistance values of fabrics. If the thermal resistance of the fabric increases, the thermal insulation also increases. The thermal resistance of fabric sample A2 was higher than A1, and A4 was higher than A3. The fabric samples with higher density, thickness, cover factor and weight showed lower thermal resistance values.

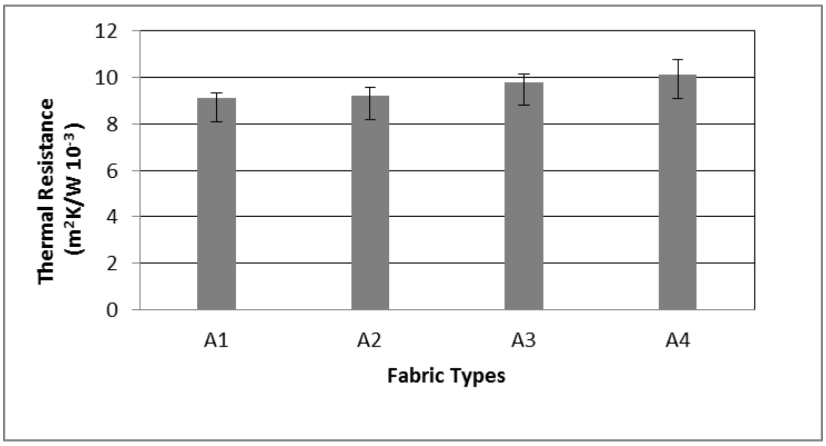

Figure 5:
Thermal resistance values of fabrics

Thermal resistance is a measurement of a material that indicates its ability to resist heat flow through it. The fabric structure properties influence heat and moisture transfer and thus thermal comfort properties. (Ho, Pan, Newton and Au, 1937).

As yarn density decreases in fabrics, the value of thermal resistance increases. This increase is observed because as the yarn density decreases, the amount of stagnant air in the fabric increases.

ANOVA test results in Table 5 indicated that; there were statistical (5% significance level) differences between the thickness and thermal comfort properties of fabrics.

4. CONCLUSION

The effects of apparel fabrics structure on their air permeability and thermal comfort properties are very important. Fabrics made from viscose rayon yarns are among the most preferred materials in apparel. Viscose woven fabrics have high drap ability and are widely used for apparel.

In this study, effect of fabric structure on air permeability and thermal comfort properties were investigated. For this reason, air permeability and thermal comfort properties of viscose / polyester blended woven fabrics of different structures which are widely used in apparel have been examined. The thermal comfort properties of fabric are affected by the thermal properties of the fibres forming the fabric.

Thermal comfort properties of fabrics, such as thermal resistance, thermal conductivity, thermal diffusivity and thermal absorptivity, are influenced by fabric structural properties such as yarn type, fabric thickness, weight, yarn density, surface treatment, air permeability, and surrounding temperature.

Statistical analysis was also conducted to identify relationships among the weight, thickness, cover factor and thermal comfort properties of fabrics.

According to the results, a negative correlation was observed between the weight, thickness, fabric cover factor and air permeability of the apparel fabrics.

A positive correlation was observed between the weight, thickness, cover factor and thermal conductivity of the apparel fabrics.

A positive correlation was observed between the weight, cover factor and thermal absorptivity of the apparel fabrics. Also a positive correlation was observed between the thickness and thermal resistance and diffusivity of the apparel fabrics.

The results showed that yarn density had an effect on air permeability and thermal comfort properties. Decreasing yarn density increased air permeability and thermal resistance.

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