(REFEREED RESEARCH)

THERMAL COMFORT PROPERTIES OF COTTON KNITTED FABRICS IN DRY AND WET STATES

KURU VE ISLAK DURUMLARDA PAMUKLU ÖRME KUMAŞLARIN ISIL KONFOR ÖZELLİKLERİ

Nida OĞLAKCIOĞLU
Ege University
Textile Engineering Department
e-mail: nida.gulsevin@ege.edu.tr

Arzu MARMARALI
Ege University
Textile Engineering Department

ABSTRACT

In recent years the importance of clothing comfort properties became one of the most important feature of the fabrics and many of the studies are devoted to measurements of thermal properties. However in many of these researches, the thermal comfort characteristics of fabrics were investigated only in dry state. The aim of this study is to characterize thermal comfort properties of garments with analyzing thermal properties after sweating. For this aim thermal conductivity, thermal absorptivity and thermal resistance values of fabrics, knitted with different types of cotton yarn, were tested in both dry and wet states. The results indicate that there is not any significant difference between thermal comfort properties of the fabrics knitted with carded and combed yarns, whereas mercerization process affected to these properties significantly. After wetting, all fabric structures indicate cooler feeling and lower thermal insulation.

Key Words: Knitted fabric, Moisture absorptivity, Thermal absorptivity, Thermal comfort, Thermal resistance.

ÖZET

Giysi konforu son yıllarda kumaş özellikleri için en önemli nitelik olmaya başlamış ve ısıl özelliklerin ölçümünü kapsayan birçok çalışma gerçekleştirilmiştir. Ancak bu çalışmaların büyük bir bölümünde ısıl özellikler sadece kuru durumda incelenmiştir. Bu çalışmanın amacı, terleme sonrasındaki ısıl özellikleri analiz ederek giysilerin ısıl konfor özelliklerini karakterize etmektir. Bu amaçla farklı pamuk iplikleri ile örülen kumaşların hem kuru hem de ıslak durumlar için ısıl iletkenlik, ısıl soğurganlık ve ısıl direnç değerleri test edilmiştir. Sonuçlar karde ve penye iplikler ile örülen kumaşların ısıl konfor özellikleri arasında önemli bir farkın olmadığını, diğer yandan merserizasyon işleminin bu özellikleri önemli seviyede etkilediğini göstermektedir. Tüm kumaş numuneleri ıslandıktan sonra soğuk his ve düşük ısıl izolasyon özelliği sergilemektedir.

Anahtar Kelimeler: Örme kumaş, Nem soğurganlığı, Isıl soğurganlık, Isıl konfor, Isıl direnç.

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1. INTRODUCTION

Clothing comfort, which can be defined as a state of well being and comfortable feeling, is very important especially for next-to-skin garments. This parameter entails three main considerations: psychological, sensorial and thermo-physiological (1). The thermo-physiological (thermal) comfort, which is the subject of this research, depends on thermal, moisture and air permeability properties.

The main function of the garments is to constitute a regulation system for keeping body temperature at the mean value even if outer atmospheric conditions and physical activities change. Human has a very effective temperature regulatory system, which ensures that the body's core temperature is kept at approximately 37°C. During heavy activities the body produces lots of heat energy and the body temperature increases. Given a set metabolic rate, the body must reject heat at the proper rate in order to maintain thermal equilibrium. When the body becomes too warm, first the blood vessels vasodilate, increasing the blood flow through the skin and subsequently sweating begins. Sweating is an effective cooling tool, because the energy required for the sweat to evaporate is taken from the skin. Therefore the garments should allow the perspiration to pass through; otherwise it will result in discomfort (2, 5). That's why thermal comfort properties of the fabrics are very important for high levels of body comfort.

Researchers have identified the seven major determinants of thermal comfort response (2):

1. Air (dry-bulb) temperature
2. Humidity
3. Mean radiant temperature
4. Air movement
5. Clothing
6. Activity level
7. Rate of change of any of the above

As any one of these variables changes, the others need to be adjusted to maintain the thermal equilibrium between heat gain and heat loss in order for a person to continue to feel comfortable. The clothing can be accepted the most determinant factor for comfort. If the garment has a high level of heat transfer capacity, it will help to balance thermal equilibrium of body and especially for active or sports wear moisture management is as important as heat transfer (2).

Kawabata and Yoneda were the first researchers to express the warm-cool feeling numerically. They designed the Thermo-Labo, the first instrument which is able to evaluate thermal contact property objectively and introduced the maximum level of the contact heat flow q_{max} (W/m^2K) as a measure of transient thermal characteristics (3).

Then starting from the ideas of Kawabata, Hes introduced another parameter called thermal absorptivity to evaluate the warm-cool feeling. This parameter is the objective measurement of warm-cool feeling and determines the contact temperature of two materials and (4). It can be expressed as:

$$b = (\lambda\, \rho\, c)^{1/2}, \; (W\, s^{1/2} / m^2 K) \qquad [1]$$

where:

λ: Thermal conductivity (W/m K)
ρ: Fabric density (kg / m^3)
c: Specific heat of fabric (J / kg K)

If the thermal absorptivity of clothing is low, it gives a warmer feeling at first contact (5). The better feeling depends on customer: for instance in cold regions warmer feeling is demanded, whereas in hot summer days cooler clothing is preferred (6).

This equation only applies for the short initial time of thermal contact between the skin and the fabric. For longer contact times exceeding a few seconds the heat flow q loses its dynamical (transient) character and its level falls the steady-state level (7). In that case the parameter of thermal resistance takes an important role for thermal characteristics. Thermal resistance is an indication of how well a material insulates and under a certain climate condition if the thermal resistance of clothing is less, the heat energy will gradually reduce with a sense of coolness (8). This parameter is connected with thermal conductivity and fabric thickness by the equation given below:

$$R = h / \lambda, \; (m^2\, K / W) \qquad [2]$$

where:

h: Fabric thickness (m)
λ: Thermal conductivity (W/m K)

For textile materials, still air in the fabric structure is the most important factor for thermal conductivity and so for thermal resistance values, as still air has the lowest thermal conductivity value compared to all fibers (λ_{air} = 0.025) (9, 10). Therefore as the amount of entrapped air in the structures increases, the fabric provide high thermal insulation with lower thermal conductivity values.

Various researchers made investigations in order to increase comfort properties of garments. The common results are that comfort properties are effected significantly from fiber types (11-13) (natural, regenerated, synthetics, engineered and etc.), yarn parameters (14-17) (yarn count, twist factor, spinning method etc.) and fabric characteristic (16, 18-22) (tightness, weight, thickness, structure etc.). Also it is reported that the environmental conditions and activity level of wearers influence perceived comfort (22). However in many of these researches, the thermal comfort characteristics of fabrics were investigated only in dry state. But after heavy activities or in hot weather in order to maintain thermal balance the body begins to sweat and till that time the fabric touches wetted skin. As known an important aspect of the warm-cool feeling evaluation is the change of this feeling when textile products get wet (6, 23).

In order to investigate warm-cool feeling after sweating, thermal absorptivity values in wet state can be used to evaluate moisture absorptivity of fabrics. In this method certain amount of liquid drop onto the interface fabric which placed between the measured fabric sample and the centre of the measuring head. The liquid is more or less taken away into the fabric by absorption in a few second. In the case of low absorption, the thermal capacity of the interface fabric is kept rather high due to the higher relative moisture. So the thermal absorptivity results remain significantly high. This means that the moisture absorptivity of the tested fabric is poor. Unlike this when the liquid is rapidly distributed through the whole thickness of the tested fabric, the interface fabric becomes almost completely dry and the instrument shows a lower level of the thermal absorptivity. This indicates good moisture absorptivity, which is a required property for the sensation of comfort in a fabric in a wet state (6, 23).

The aim of this research is to characterize the thermal comfort properties of knitted fabrics by analyzing thermal absorptivity and thermal resistance parameters in both dry and wet states. For this aim, single jersey structures were knitted with different types of cotton yarns (carded, combed, mercerized and plied yarns) and thermal comfort properties (thermal conductivity, thermal resistance and thermal absorptivity) were compared between dry and wet states. Also the effects of yarn types of thermal comfort properties were investigated.

2. MATERIAL AND METHOD

In order to search the thermal comfort properties of the knitted fabrics in dry and wet state, different cotton yarn types were used (Table 1). All the samples were knitted with single jersey structure on circular laboratory sample knitting machine. The thermal comfort properties (thermal conductivity, thermal absorptivity and thermal resistance) of fabrics were measured on Alambeta instrument. All measurements were performed under the standard atmospheric conditions (20±2°C temperature, %65±4 relative humidity).

For wet state measurements, Coolmax® fabric was used to simulate wetted skin. 0.5 ml of water (containing detergent) was injected onto its surface and waited for 1 minute for the liquid had been uniformly distributed within a circle of 45-50mm. When this interface fabric wetted, it was turned down and inserted into the space between the measured sample and the centre of the measuring head of the instrument. Three measurements were done for each sample and than mean values were calculated.

Evaluation of the test results was made using statistical software. To determine the statistical importance of the variations, ANOVA tests were applied. To deduce whether the parameters were significant or not, p values were examined. If "p" value of a parameter is greater than 0.05 ($p > 0.05$), the parameter will not be important and should be ignored (Table 2).

3. RESULTS AND DISCUSSION

The thermal comfort properties of the experimental fabrics in dry and wet states are given in Table 1.

Table 1. Thermal comfort properties of tested fabrics in dry and wet states

Material Type	Yarn count (Ne)	Twist coefficient (α_m)	Tightness factor (K)		Thermal conductivity (W/m K)	Thickness (m)	Thermal resistance (m^2 K/W)	Thermal absorptivity ($Ws^{1/2}/m^2K$)
100%Co-Carded	30/1	3.7	11.5	Dry	0,0399	0,00083	0,0207	85,23
				Wet	0,1087	0,00151	0,0139	356,67
100%Co-Combed	30/1	3.7	11.0	Dry	0,0400	0,00082	0,0206	93,67
				Wet	0,1038	0,00167	0,0162	386,00
100%Co	56/2	3.9	11.7	Dry	0,0379	0,00076	0,0201	84,20
				Wet	0,1020	0,00140	0,0137	358,00
100% Mercerized Co	56/2	4.0	11.4	Dry	0,0392	0,00072	0,0184	89,70
				Wet	0,1060	0,00123	0,0116	386,00
100%Co – Single yarn	30/1	3.8	11,6	Dry	0,0385	0,00075	0,0194	87,13
				Wet	0,1020	0,00130	0,0127	368,00
100%Co – Double plied yarn	30/1x2	3.8 (for single yarn)	12,3	Dry	0,0602	0,00160	0,0266	121,67
				Wet	0,1240	0,00215	0,0172	380,00

Table 2. p values of variance analysis for thermal comfort parameters

Source		thermal conductivity	thickness	thermal resistance	thermal absorptivity
Material	Carded-Combed	,356	,282	,496	,062
State	Dry-Wet	,000 *	,000 *	,007 *	,000 *
Process	Mercerize	,003 *	,000 *	,008 *	,002 *
State	Dry-Wet	,000 *	,000 *	,000 *	,000 *
Material	Single-Double plied	,000 *	,000 *	,000 *	,000 *
State	Dry-Wet	,000 *	,000 *	,000 *	,001 *

* significant for α= ,05

The p values which show that the parameters have an important effect or not on thermal properties of the fabrics are given in Table 2.

The thermal contact properties of all common textile products were experimentally investigated within various researches. It was found that the practical values of the thermal absorptivity of dry fabrics range from 20-300 ($Ws^{1/2}$/K m^2) and these values increase between 150 and 300 ($Ws^{1/2}$/K m^2) when the fabrics get wet (6, 23). Similarly to previous researches the results of this study showed that the thermal absorptivity values were between 250 and 300 in wet state and increased about 300% compared to dry state (Figure 1). On the other hand it was found that thermal resistance values decrease over 30% after wetting (Figure 2). An interesting point related to our samples is that all measured fabrics exhibit similar thermal resistance and thermal absorptivity values regardless of material type.

The changes in thermal comfort parameters can be explained with the increment of thermal conductivity after sweating (Table 1, Equations 1 and 2). As mentioned before (6, 23) since the thermal conductivity of water is much higher than fibers and the entrapped air in the textile structure, fabrics moistened by sweat give higher thermal conductivity values compared with the dry state (Figure 3).

The statistical analysis and comparisons for different yarn types showed that (Table 2, Figure 1, Figure 2 and Figure 3):

- There are not any significant differences in thermal conductivity, thermal resistance and thermal absorptivity values between the fabrics knitted with carded and combed yarn.
- Thermal conductivity values of the mercerized fabrics are higher whereas the thermal resistance values are lower than untreated fabrics. Because mercerizing treatment results in the swelling of the cell wall of the cotton fiber and this causes increases in the surface area and reduces air gaps in the yarn structure. On the other hand mercerized fabrics provide higher thermal absorptivity and so give cooler feeling at first contact. This situation can be explained by the higher contact area with the smooth surface structure of fabrics after mercerization process. As mentioned before (16) heat conduction transfer is higher in smoother surfaces and so they give cooler feelings.
- The fabrics knitted with double plied yarns have higher thermal conductivity values than knitted with single yarns. In this fabric structure the air gaps are less because of higher fabric density. So thermal conductivity of fabrics knitted with double plied yarns will be high. Another result of this structure is higher absorptivity and cooler feeling. Despite the increase in thermal conductivity values, the thermal resistance values of these fabrics increase as well. This contradiction can be explained with the high thickness of double plied yarn fabrics (Equation 2).

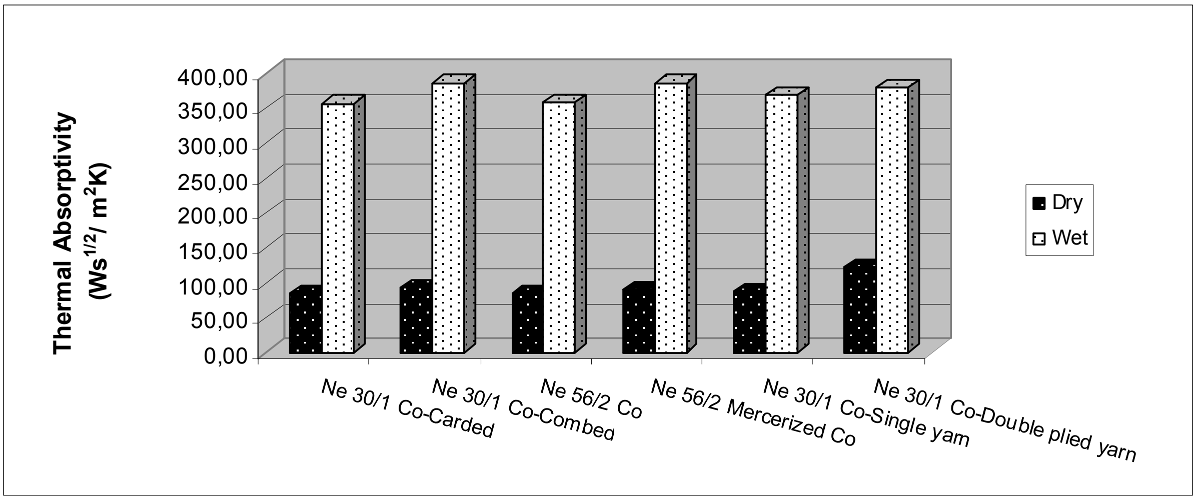

Figure 1. Thermal absorptivity in dry and wet states

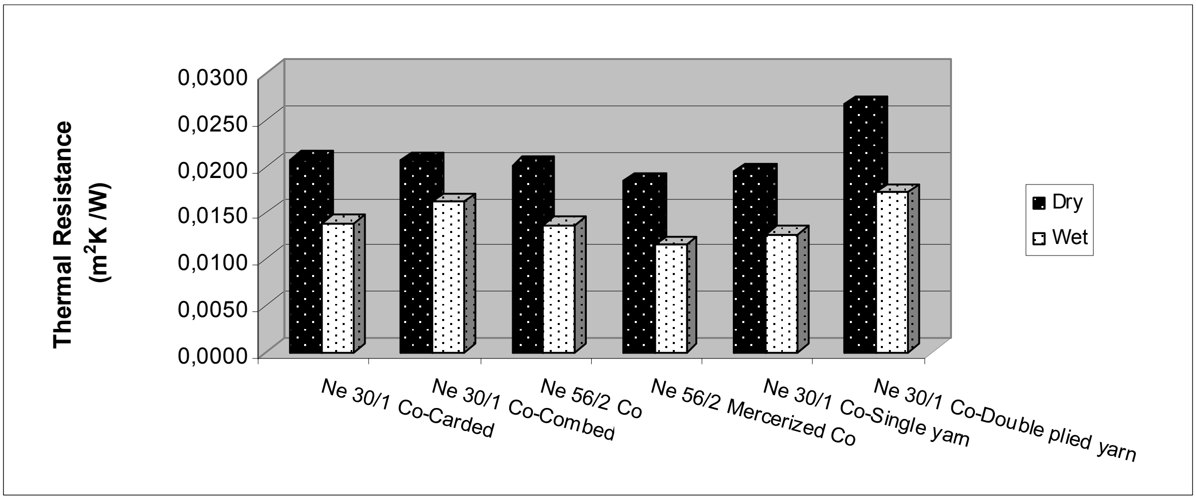

Figure 2. Thermal resistance in dry and wet states

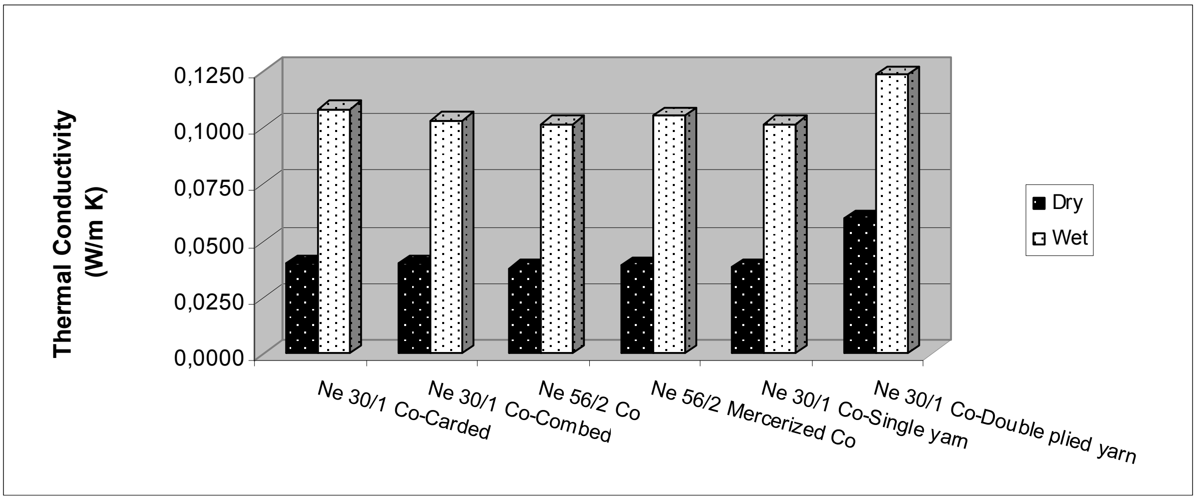

Figure 3. Thermal conductivity in dry and wet states

4. CONCLUSION

In this research the thermal resistance and thermal absorptivity characteristics of fabrics, knitted with different yarn types, were investigated. The fabrics were tested both in dry and wet states in order to determine the comfort properties of fabrics before and after sweating. The results were analyzed statistically and compared according to yarn type in dry and wet state. It was found that the wetted fabrics indicate lower thermal insulation and cooler feeling. Therefore it is recommended to determine the thermal comfort properties of garments in both dry and wet states in order to choose the best one according to end use, especially for active or sports wear. Another result is that the thermal resistance decreases and thermal absorptivity increases with a sense of cooler feeling with mercerization process. So the use of mercerized yarns is more suitable for summer days. Besides, the using of double plied yarns increases thermal resistance of the fabrics whereas the fabrics knitted with these yarns give cooler feeling. However there is not any significant difference between thermal comfort properties of the fabrics knitted with carded and combed yarns.

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