Investigation of the Some Performance Properties of Knitted Fabrics which are Produced by Soybean and Organic Cotton Yarn

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ABSTRACT

INVESTIGATION OF THE SOME PERFORMANCE PROPERTIES OF KNITTED FABRICS WHICH ARE PRODUCED BY SOYBEAN AND ORGANIC COTTON YARN

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With increasing of life standards not only using properties but also comfort properties get important. Since the perception of comfort is something subjective, the need of ability to define comfort with measurable quantities, so as to have clear definitions.

Comfort is an important aspect on textile production but it is difficult to determine an exact comfort level; however there are certain fabric properties which are known to be related with sensorial comfort hence those properties may be measured for a comfort evaluation. So, to provide comfort properties new fiber types have been developed. In this study soybean and organic cotton were selected because of their increasing attention at comfort area.

Comfort is discussed in three categories: physical, psychological and physiological. In this project, physiological comfort concerned with thermal balance of human body was investigated.

In this thesis work air permeability, wicking ability, water vapor permeability and thermal comfort behavior of fabrics were tested. Raw material (fiber type) and yarn count were variable in this study. Each of them was analyzed. According to test results and statistical analysis it was observed that these properties affect the comfort properties of fabric and the best yarn number were found by using these test according to raw material. The soybean and organic cotton fabric were compared according to these tests.

Key words: Thermal comfort properties, thermal resistance, thermal conductivity, thermal absorbtivity, air permeability, water vapor permeability, wicking ability, soybean yarn, organic cotton yarn.

ÖZET

SOYA VE ORGANİK PAMUK İPLİKLERİNDEN ÖRÜLMÜŞ KUMAŞLARIN BAZI PERFORMANS ÖZELLİKLERİNİN KARŞILAŞTIRILMASI

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Yaşam standartlarının yükselmesi ile kumaşların konfor özelliği önem kazanmıştır. Konfor algı açısından öznel olduğu için ölçülebilir testlerle tanımlanmaya ihtiyacı vardır.

Konfor tekstil üretiminde önemlidir fakat gerçek konfor değerini hesaplamak zordur. Böyle olmasına rağmen bazı kumaş özellikleri hissel konfor ile ilgili olduğundan bu özellikleri ölçerek konfor değeri ölçülebilir hale getirilir. Kumaşların konfor özellikleri açısından yeni elyaf çeşitleri geliştirilmiştir. Bu çalışmada, soya ve organik pamuk ipliğinden örülmüş kumaşlar incelenmiştir. Bu lif tiplerinin seçilmesinin sebebi, konfor açısından dikkati çeken özelliklere sahip olmalarıdır.

Konfor fiziksel, fizyolojik ve psikolojik konfor olmak üzere üç ayrı alanda incelenir. Bu çalışmada fizyolojik konfor incelenmiştir.

Bu çalışmada kumaşların hava geçirgenliği, kılcallık, su buharı geçirgenliği ve ısıl konfor özellikleri test edilmiştir. Değişken olarak elyaf çeşidi ve iplik numarası belirlenmiştir. Test sonuçlarına ve yapılan istatistiksel analize göre kumaşların konfor özellikleri üzerindeki etkisi incelenmiş ve yapılan çalışmaya göre üreticiler için en iyi performans özelliği gösteren elyaf çeşidi ve iplik numarası belirlenerek soya ve organik pamuktan yapılan kumaşlar karşılaştırılmıştır.

Anahtar kelimeler: termal konfor, termal direnç, termal iletkenlik, termal absorbtivite (soğurma), hava geçirgenliği, su buharı geçirgenliği, kılcallık, soya ipliği, organik pamuk ipliği.

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CHAPTER 1
INTRODUCTION

1.1 Introduction

Clothing is important for human life. Firstly clothing is a layer to protect the body from cold, hot, chemical and microbiological substance.

But at the new world, the clothing not only is used to protect the body against to environment. For this comfort is the most important for customers during the selection of garments so the customers play the most important role about the increasing the clothing research.

Comfort of apparel can be defined through the experience of a person. Comfort is a subjective criterion. But, it can be quantified in an objective manner in terms of the properties of non-sensorial comfort characteristics. Thermal equilibrium and moisture position are the most important comfort criteria for apparel. Comfort depends on various factors including the type of the material, method of construction of textile substrate, feeling of the wearer, impacts due to climatic condition of the environment and its variation. Comfort can also be changed by finishing treatments to the fabric.

New world people change their living and working condition. People prefer lightweight and healthcare garments. Besides synthetic fibers, manufacturers have started to use regenerated fibers due to their comfort. For this reason, organic cotton and soybean fiber are used newly by the customers.

Organic Cotton is the cotton that is grown without using any chemical fertilizer or pesticide on it; "Vegetable cashmere" is a common nickname for soy-based fabric, a softer, more luxurious (and more expensive) alternative to organic cotton. Soybean fiber is a renewable resource and a byproduct of the food industry. Some soy fibers are organic while others are not, but all soy fibers are better for the environment than most fabrics. Vegetable cashmere is rich with 45% protein content in the fiber. It is said to contain 18 kinds of active minerals which aid in bio-chemistry when naturally absorbed through the skin [1].

The main aim of this study is to present a comparative analysis of thermal insulation properties such as thermal conductivity, thermal absorbtivity, thermal resistance and others for fabrics made of organic cotton and soybean yarns, and also to study the influence of the yarn count on thermal properties. For this, air permeability, water vapor permeability, longitudinal wicking, and thermal comfort were tested and analyzed.

If we look at the previous work, there are no comparative studies on thermal comfort of knitted fabrics produced by soybean and organic cotton yarns. This study is important for the literature.

1.2 Comfort related fibers

Researching the alternative sources for fibers is important due the concerns on the future price and availability of both the natural and synthetic fibers in current use. Although more than 50% of the 70 million tons of fibers consumed annually in the world are from petroleum based resources, limited efforts are made to find alternative sources to replace at least a part of the synthetic fibers [2].

The cultivation of natural fibers such as cotton is also declining due to farmers shifting to crops such as corn and soybeans that are being used for bio-fuels and are easier to grow and provide a better economic return than fiber crops. These limitations on the price and availability of the natural and synthetic fibers will inevitably make finding alternative sources for fibers a necessity in the near future [2].

About 220 million tons of soybeans and an equivalent amount of byproducts (straw) are produced in the world every year. Although soybean straw is an inexpensive, abundant and annually renewable source suitable for producing technical fibers, no previous reports are available on studying the suitability of using soybean straw for fibers or other industrial applications. Also, there is very limited literature available on the composition, structure and properties of the soybean straw and especially on the properties of cellulose in the straw. Using soybean straw as a source for fibers will not only add value to the soybean crops but also provide a sustainable source for fibers. However, it will be necessary to develop appropriate fiber production conditions and understand the structure and properties of the soybean straw fibers in order to utilize the soybean straw for various industrial applications. The major cereal crops in the world, corn, wheat, rice, soybeans and sorghum have annual world production of 700, 630, 619, 214 and 58 million tons, respectively. This means an availability of about 220 million tons of byproducts that are suitable for fiber production [2].

In this study, organic cotton and soybean fiber were investigated. Now we will explain these types of fibers below:

1.2.1. Cotton

The earliest evidence of using cotton as a textile fiber is from India and the date assigned to this fabric is 3000 B.C. There were also excavations of cotton fabrics of comparable age in Southern America. Cotton cultivation first spread from India to Egypt, China and the South Pacific. Even though cotton fiber had been known already in Southern America, the large scale cotton cultivation in Northern America began in the 16th century with the arrival of colonists to southern parts of today's United States. The largest rise in cotton production is connected with the invention of the saw-tooth cotton gin by Eli Whitney in 1793. With this new technology, it was possible to produce more cotton fiber, which resulted in big changes in the spinning and weaving industry, especially in England. Today, cotton is grown in more than 80 countries worldwide [3].

Cotton is a vegetable fiber obtained from the mature capsule of the cotton plant, a shrub about 40 cm high, with leaves and flowers of a red or yellow color (see Figure 1.1). When the flower is fecundated it loses its petals and within 25 days a capsule surrounded by a leaf called bract grows. The capsule is sustained by a cup and has a drop shape rounded at the lower extremity. Inside the capsule there are from five to eight seeds on which the fiber developed. When the capsule is mature it opens into four parts showing the cotton ball. On the same plant the maturation of the capsules does not occur simultaneously, therefore more passages are required for the harvest of the cotton. The harvest is carried out a week after maturation. The first operation after harvesting is husking, which permits the removal of the fibers from the seeds. Then the cotton is carded and combed so as to eliminate all the impurities. 4000 fibers is the seed average. Staple length = 1/8" - 2.5" (0.32 - 6.35cm) - for manufacturing yarns, fabrics, 7/8" - 11/4" (2.22 - 3.18cm) is standard [3].

Figure 1.1 Photographs of growing of cotton fibers [3]

The length is the most important attribute of the fiber. In this regards, cotton is divided into two large categories: long fiber cottons (long staple), which measures more than 28 mms and amongst which Sea Island in the United States holds the record and the Egyptian Makò and Sakellaridis which arrive at and sometimes overreach 50 mms, and short fiber cotton (short staple), that do not reach the length of 18 mms and that derive from the Asian regions; there is also an intermediate category of cottons whose fiber length is included between 18 and 28 mms, such as those from the United States Uplands and which constitute the grand mass of the world production, 60% and more [3].

Cotton, as a natural cellulosic fiber, has a lot of characteristics, such as [4];

- Comfortable Soft hand

- Good absorbency
- Color retention
- Prints well
- Machine-washable
- Dry-cleanable
- Good strength
- Drapes well
- Easy to handle and sew

1.2.2. Organic Cotton

Organic cotton has been produced for centuries, but it was first officially certified in 1989/90 by Turkey, followed by the USA. Other common names used for organic cotton, particularly at the beginning of production, are green cotton, biological cotton and environment-friendly cotton. There are places where no insecticides or synthetic fertilizers are used to grow cotton, but production is not sold as organic because it lacks certification. In order to claim that cotton is organic and receive a premium price, cotton production must be recognized as organic by a certifying organization. Organic cotton is grown without pesticides and insecticides, furthermore organic cotton seeds are not genetically modified. For organic cotton cultivation only methods and materials that have a low impact on the environment are used (organic farming). Though organic cotton farming replenishes and maintains soil fertility. Organic cotton cultivation reduces the use of toxic and persistent pesticides and fertilizers and builds biologically diverse agriculture. Also farmers of organic cotton and their families profit, because water remains clean and less diseases and toxication appears form organic cotton farming. By that, Organic cotton agriculture protects the health of people. It also protects the planet by reducing the overall exposure to toxic chemicals from synthetic pesticides. These can end up in the ground, air, water and food supply, and are associated with health consequences, from asthma to cancer [5].

Many allergies are a direct result of chemicals in cotton fibers we either wear, or sleep on. Non-organic cotton is produced in a way that causes great damage to the environment. It cannot be sustained without high levels of synthetic fertilizers and pesticides. Pesticides kill, cause serious disease in human, and can be fatal to farmers and farm workers who spray them on the crop. Toxic chemical residue remains in industrially treated fibers, in our clothing and bedding. Persistent contact with the skin can aggravate a variety of allergies and allergic symptoms, especially for those with asthma and multiple chemical sensitivities. Eliminating the usage of these chemicals, not only benefit the surrounding environment, but also benefits users. And, major usage of the cotton seeds is for making oil and cattle feed. Hence if not directly, indirectly we tend to consume the cotton with its contents [5].

Production of organic cotton could be given as follows [5]**;**

- Synthetic Fertilizers like Urea, DAP, NPK cannot be used.
- Synthetic pesticides like - herbicides, insecticides, fungicides etc are not to be used.
- Prevent spray drift from the surrounding fields - used border framing.
- No use of genetically modifies organisms such as BT Cotton
- Crop rotation is a must - No repeat crop in the same field for 2 subsequent years and or intercropping.
- Proper maintenance of records and documents for certification

Organic Cotton can rightly be called the most skin friendly, most soothing and absolutely harmless natural fiber. While conventional cotton can sometimes be irritating to new born skins, Organic Cotton is never. It is the ideal material for protecting and cleaning new born babies, making clothes, bandages, covering and cleaning wounds, making baby crib beddings and baby clothes, towels and thousands of such things. It can also be safely used in surgeries where contamination from any source can be fatal. Organic Cotton Seed Oil, a bi-product of Organic Cotton, has wide uses in snacks and in feed for livestock [5].

Table 1.1 shows a comparative study of cultivation techniques adopted in cultivating conventional Non Organic Cotton and Organic Cotton.

That conventional cotton has better quality than organic cotton, but in fact, it is just the other way round. Organic cotton is of far better quality than non organic cotton. When you tell them this, they will raise another point. They will say that conventional cotton farming gives more production. That was true even a few years ago, but not now. It is true that cotton is very prone to infestation and fungal infections and even a few years back, the conventional cotton growers who used lots of synthetic insecticides, pesticides, fungicides and fertilizers, naturally enjoyed more production That was then when advanced techniques of organic farming were limited to researches. Now the scenario has changed. Egypt, a major cotton producing nation, has done a miracle. By implementing advanced organic farming techniques, it has cut down its usage of artificial fertilizers and pesticides by more than ninety percent (90%) and yet achieved a growth of thirty percent (30%) in production [5].

Table 1.1 Comparative of conventional non organic cotton and organic cotton [5]

Conventional Cotton Farming	**Organic Cotton Farming**
Land is not detoxified	Land is invariably detoxified
Artificial/chemical fertilizers are used	Organic fertilizers/compost/manure is used
Artificial/chemical pesticides & insecticides are used	Organic/herbal pesticides and insecticides are used. Bio-controlling of insects/pests is also done.
Seeds are treated with fungicides & insecticides	Seeds are not treated
Mono crop culture is practiced	Crop rotation is practiced
Genetically Modified Organisms are used	Genetically Modified Organisms are not used
Soil lacks organic matter & cannot retain water & a lot of irrigational water goes wasted/drained out	Soil has more water retention capacity due to presence of organic matter & water is least wasted
Weeds are destroyed using herbicides/weedicides	Weeds are manually or mechanically removed
Has fatal affects on many friendly small animals & insects like owls, snakes, earthworms, frogs etc.	Does not affect their habitat. Rather, it encourages their dwelling.
Adversely affects ecological balance, both due to deforestation & extensive use of toxic chemicals	Affects adversely (as trees or forests are cleared for making space for farming), but not that much.
Chemical defoliation	Defoliation is seasonal/natural or by water control

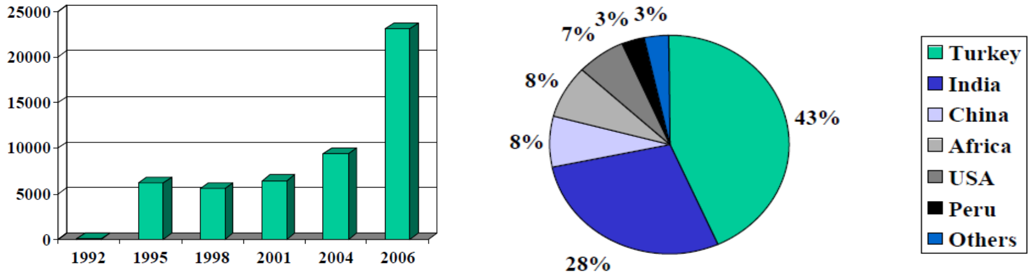
The only thing that goes against organic cotton is its price. It is costlier than conventional cotton. This is because of lesser production of organic cotton and higher prices of organic fertilizers, pesticides and fungicides. Organic cotton farming also calls for more manual labor than the conventional one. But seeing the rate at which production of organic cotton is increasing and more and more farmers taking to organic farming, situations will change and prices will surely go down very soon. More the production and more the demand the lesser per unit production cost and lesser the prices. There is one more problem and that is that Organic Cotton goods are not available in as many colors as the conventional cotton goods are. This is because there are not many shades of organic colors to color the Organic Cotton with and using artificial colors and dyes on it is out of question [5].

Here is a list of certifiers on organic cotton goods [5];

- Global Organic Textile Standards (GOTS)
- USDA National Organic Program (NOP)
- European Organic Regulations (EU 2092/91)
- Export Certificates for Japan (JAS Equivalent)
- Indian National Programme for Organic Production (NPOP).
- Quebec Organic Reference Standard (CAAQ)
- Bio Suisse Standards
- IOFAM Basic Standards
- ECOCERT

If we look at the organic cotton production, organic cotton production is concentrated in Turkey (10,000 tons of fiber; 43% of total production) and India (6,500 tons of fiber; 28%), where growth has recently also been most spectacular (see Figure 1.2 b). Together they now produce more than 70% of the world organic cotton supply. Other relevant producers in terms of volume are China (1,750 tons; 8%) and the United States (1,500 tons; 7%).The African countries together accounted for about 1,800 tons of fiber in 2006, or 8% of total production, mainly in Uganda and the United Republic of Tanzania, 14 but also in Egypt and in French speaking West Africa (Mali, Burkina Faso, Benin) [6].

Production of organic cotton has increased enormously over the last few years (see Figure 1.2. a). Global organic cotton production jumped by more than fifty two percent (53%) in 2006-2007 over that in 2005-2006 and then amazingly by almost one hundred and fifty two percent (152%) in 2007-2008. That amounts to 145,872 Metric Tons or 668,581 Bales grown in 24 countries, with India topping other nations. Among others, the specialty of Indian organic cotton is that all the cotton is hand picked. The major organic cotton producing nations are listed in descending order of the amount of organic cotton they produced, as; India, Syria, Turkey, China, Tanzania, United States of America, Uganda, Peru, Egypt, and Burkina Faso [5].



a. trade worldwide
(in tons of fiber 1992–2006)

b. trade per production area
(in tons of fibre, 2006)

Figure 1.2 Organic cotton productions [5, 6]

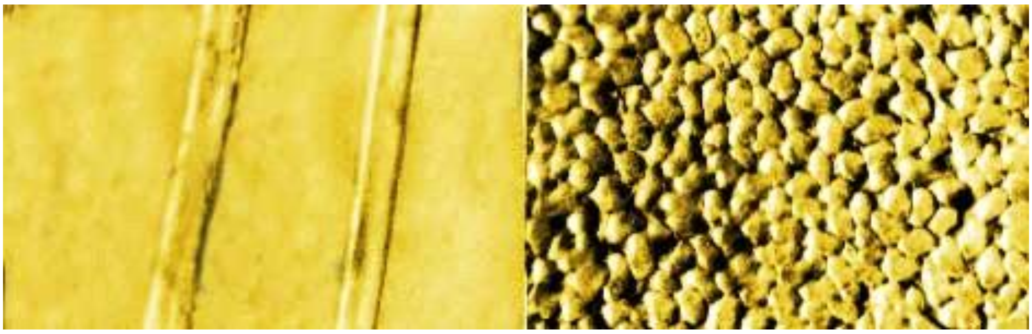
1.2.3. Soybean Fiber

Soybean fiber was invented by Henry Ford in 1937, and was termed as "Soy Wool". Until 1960, Soybean was being manufactured in Poland. This fiber was reinvented in 1998 and was promoted in 2000. At presents, it can be made from waste products of the soy bean food industry [7].

Soybean protein fiber is the only renewable botanic protein fiber we can touch today. SPF shown in Figure 1.3 is a unique active fiber. Its 16 amino acids are healthy and nutritional to people's skin. Its moisture absorption, ventilation, draping and warmth cover the superior performances of natural fibers and synthetic ones [3].

If we look at the general information about soybean fiber construction;

- The content of protein in the fiber is up to 45%
- Soybean protein contains 18 kind of active materials which are necessary to human body
- The presence state of protein: hinge type and covered type
- Cross section of fiber is like dumbbell
- Vertical shear of fiber has longitude grooves
- Peninsula-like frameworks spread equably on the surface of fiber [3].



a. Vertical shear of SPF b. Cross section of SPF

Figure 1.3 Vertical shear and cross section of SPF under electron microscope [3]

Soybean fiber has the softness and smoothness of cashmere, but doesn't cause hazard to the environment. Its products are degradable by landfill back to the earth. This fiber comes from soybean, a plant massive in sourcing and rich in nutrition. People usually eat soybean but now are able to wear it [3].

Taking natural soybean as raw material, the soybean protein fiber is high garde fiber for textile with different length and specifications after using new technology of bioengineering to abstract globules from soybean meal, make purified globules to change space structure, make it into protein spinning liquid with certain concentration, spin it into 1.27-3.3dtex of single fiber by the instrumentality of wet spinning technology after maturation and stabilizing performance of fiber with chemical connection, cremation, thermoform and cutting. The soybean protein fiber is also called s "healthy and comfortable fiber in new century" and "artificial cashmere" by expert in textile industry. Because the main raw materials of which are from natural soybean meal, the raw material is in abundance and can be recycled, it will not cause predatory exploitation for resources. During the production process of soybean protein fiber, the subsidiary materials and auxiliary agent are in noxious, most auxiliary agent and semi-finished fiber can be recycled. The bean dregs of which after abstracting protein can be used as fertilizer, so the production process will not pollute environment. The appearance of soybean protein fiber has filled up a blank in textile material development of our country [8].

Fabrics from this fiber have the following features [9]:

- Cashmere feel: The fabric made of Soybean Protein Fiber is soft, smooth, light. It has cashmere feel, but smoother than cashmere.
- Dry and comfort: the moisture absorption of soybean fiber is similar to that of cotton fiber, but its ventilation is more superior to that of cotton.
- Luxuriant appearance: Soybean Protein Fiber fabric has joyful silky luster with perfect drape and elegant;
- Good color fastness: Its color is quite fresh and lustrous with active dyes while quite stable in the sunshine and perspiration. Compared with silk products, the problem of freshness of color and stability of dying is solved.
- Anti-ultraviolet: Its anti-ultraviolet property is superior to cotton fiber, much more superior than viscose and silk.
- Good mechanical property: Breaking strength of the single soybean protein fiber is over 3.0cNdtex, which is higher than that of wool, cotton and silk and only lower than that of polyester fiber of high intension.
- Function of Health: Soybean Protein Fiber possesses many amino acids necessary to human's body, so it has exceptional function of health.
- Skin Evaporation: Its amino acid can activate the collagen protein in the skin, resist tickling and evaporate the skin.

If we look at the soybean fabric according to fashion aspect we can say that; Soy has the most luxurious appearance of all plant fibers. Fabric is soft, smooth and light. It has fantastically elegant draping abilities, making it a very flattering choice. It has a soft feel of cashmere. It is easy to care for, no dry cleaning necessary [10].

Also soybean fabric show perfect properties about environment;

Soy is a natural by-product of normal food production - soybeans, tofu, soy milk. It is a renewable resource, which can be grown organically and is naturally biodegradable. It requires no pesticides to grow and is often used to sow fields to replenish nutrients in the soil. Manufacturing is done through wet-spinning. The liquid soy is solidified to make soybean fiber. The final product, the fiber is then used to create sustainable clothing. The remaining raw material, bean dregs, after having their protein extracted, can be used as feed or fertilizer. All auxiliaries used in production of soybean fiber are of a harmless nature, and they are recyclable making the production process a closed end process [10].

Now, there are some properties of SPF as shown below apparently so we learn characteristic of the soybean fiber. Physical parameters of SPF are shown in Table 1.2. These properties are important for general information about production condition**.**

Table 1.2 Physical parameters of SPF [3]

No.	Items	Unit	Certified Product
1	Bias of linear density	%	+10.0&-10.0
2	Bias of length	%	+9.0&-9.0
3	Breaking strength	cN/ dtex	=>2.5
4	CV value of breaking strength	%	<=20
5	Rate of over-length fiber	%	<=1.00
6	Over-length fiber	Mg/100g	<=100
7	Defects	Mg/100g	<=350
8	Number of crimp	No/25mm	<=7

Table 1.3 shows a comparison of soybean with major fiber classes. Soybean fiber was compared with mostly used fibers, such as; cotton, viscose, silk and wool.

The crimp ratio, residual crimp ratio and elastic recovery rate of soybean fiber were tested, as illustrated in the following Table 1.4.

Table 1.4 shows that the crimp ratio of soybean fiber is only 1.65%, while the common value of other chemical fiber is 10-15%. Therefore the cohesion force of soybean fiber is rather small and anti-slipping agent is necessary in spinning. The residual crimp ratio is only 0.88%, while the common values of other chemical fibers are 10%, which means that the crimp of soybean fiber is easy to unwind and the crimp stability is poor. The elastic recovery rate of soybean fiber is 55.4%, which is also lower than the common values of other chemical fibers (70-80%). Therefore the elastic property of soybean fiber is poor. The shrinkage rate of soybean fiber in

Table 1.3 Comparisons SPF with other fibers [3]

Property		SPF	Cotton	Viscose	Silk	Wool
Breaking strength (CN/dtex)	Dry	3.8-4.0	1.9-3.1	1.5-2.0	2.6-3.5	0.9-1.6
	Wet	2.5-3.0	2.2-3.1	0.7-1.1	1.9-2.5	0.7-1.3
Dry breaking extension (%)		18-21	7-10	18-24	14-25	25-35
Initial modulus (kg/mm^2)		700-1300	850-1200	850-1150	650-1250	
Loop strength (%)		75-85	70	30-65	60-80	
Knot strength (%)		85	92-100	45-60	80-85	
Moisture regain (%)		8.6	9.0	13.0	11.0	14-16
Density (g/cm^3)		1.29	1.50-1.54	1.46-1.52	1.34-1.38	1.33
Heat endurance		Yellowing and tackifing at about 120° C (Bad)	Becoming brown After long time Processing at 150° C (Excellent)	Strength down after longtime processing at 150° C (Good)	Keep stable When temperature <=148° C (Good)	(Good)
Alkali resistance		At general level	Excellent	Excellent	Good	Bad

Acid resistance	Excellent	Bad	Bad	Excellent	Excellent
Ultraviolet resistance	Good	At the general level	Bad	Bad	Bad

Table 1.4 The crimp ratio of soybean fiber [3]

Crimp ratio / %	1.65	GB/T14338-1993
Residual crimp ratio/ %	0.88	GB/T14338-1993
Elastic recovery rate/ %	55.4	GB/T14338-1993

boiling water is %2.2 and dry heat air is %2.3. The heat shrinkage rate of soybean fiber is rather great, and soybean fiber has no obvious melting point. The fiber strength decreases largely, and the color becomes pale yellow at 160° C; and at 200° C, the color becomes deep yellow; at 300° C, the fiber begins to carbonize, and the color becomes brown. Therefore the temperatures of dyeing and setting of soybean fabric are preferred ***not to exceed 100° C***. If the setting temperature is 110° C, the fabric handle becomes hard. At this time, the fabric handle can only be improved by the washing of soap bath above 60° C. The soybean fiber has good light fastness property and good resistance to ultraviolet radiation, which is better than cotton, viscose and silk [3].

The comparison of antistatic property of soybean fiber and other fibers is shown in the following Table 1.5.

It is obvious that the mass specific resistance of soybean fiber is similar with silk, and lower than other man-made fibers. It can be said that the soybean fiber has good antistatic effect, which is beneficial to the textile fabrication and wearing property [3].

Table 1.5 Comparison of antistatic property of soybean fiber and other fibers [3]

Fiber	Mass specific resistance
Cotton	6.8
Wool	8.4

Silk	9.8
viscose	7.0
PA	9-12
PE	8.0
PE (de-oiled)	14
PAN	8.7
PAN (de-oiled)	14
Soybean fiber	10.33

The resistance properties of soybean fiber, wool, silk and cotton to acid, alkali and fungus were compared, as given in Table 1.6.

Table 1.6 Resistance properties of soybean fiber, wool, silk and cotton [3]

Fiber Property	Wool	Soybean fiber	Silk	Cotton
Resistance to acid	Resistant to thin- acid (good)	Resistant to thin- acid (good)	Resistant to thin- acid (good)	Resistant to thin-acid, not resistant to hot thin-acid (relatively good)
Resistance to alkali	Resistant to thin-alkali (soda), not resistant to caustic soda.	Resistant to thin-alkali (soda), not resistant to caustic soda.	Resistant to thin-alkali (soda), not resistant to caustic soda.	Resistant to caustic soda.
Resistance to moth / fungus	Resistant to fungus, not resistant to moth	Resistant to moth and fungus	Resistant to fungus, not resistant to moth	Resistant to moth, not resistant to fungus

The table above indicates that the resistance properties to alkali and acid of soybean fiber are the same as those of wool and silk. The resistance to fungus of soybean fiber is also the same as that of wool and silk. And the resistance to moth of soybean fiber is better than that of silk, wool and cotton [3].

Soybean products have the following applications:

- Apparel
- Bedding
- T-Shirts, pullovers and sweaters, socks etc…

1.3 Purpose of This Thesis

Good fabric appearance and clothing comfort are important criteria for consumer. At the future new natural healthy and ecological textile products gain importance. Comfort is affected by air permeability, water vapor permeability and thermal conductivity, thermal resistance, thermal absorbtivity and wicking ability.

At this study, thermal comfort properties of knitted fabrics which are produced by new natural fibers such as soybean and organic cotton were observed. Naturally, this observation was performed after some operations. Firstly, soybean yarns were taken from Hayteks Textile and organic cotton yarns were taken from Başyazıcıoğlu Textile. Three different yarn numbers of each sample were knitted in Selçuk İplik A.ş. By the experimental studies, effect of yarn number and fiber type on comfort properties was analyzed. The experimental set up was including air permeability, water vapor permeability and thermal behavior of samples. The results were discussed and analyzed statistically.

The aims of this study are;

- to investigate and compare of the some performance properties of knitted fabrics which are produced by soybean and organic cotton yarn.

- to present a comparative analysis of thermal comfort properties such as thermal conductivity, thermal absorbtivity, thermal resistance and others for fabrics made of organic cotton and soybean yarns.
- to determine the effect of fiber type and yarn number on comfort properties of the knitted fabrics produced by soybean and organic cotton yarn.

Material Type (two kinds): 100 % soybean and 100% organic cotton yarn

Yarn Number (three level): Ne 20/1, Ne 30/1, Ne 40/1

These six yarns were knitted on sample circular knitting machine produced by IPM by İpekçioğlu Faycan CKM-1-S

The following properties of fabrics were tested;

1. Air permeability
2. Water vapor permeability
3. Thermal conductivity
4. Thermal resistance
5. Thermal absorbtivity
6. Wicking ability

The air permeability tests were done on six samples by using the air permeability test instrument and water vapor permeability and wicking ability tests were done on six samples in Textile Engineering Department of University of Gaziantep. Thermal resistance, thermal conductivity and thermal absorbsivity tests were done at Czech Republic.

1.4 Importance of the thesis

This study was supply basic information and recommendation to textile and clothing industry which plans to use the new generation natural fibers that are claimed to show excellent comfort properties. Besides, a literature review on comfort was ensuring a reference for comfort researchers.

1.5 Structure of Thesis

Chapter 2 includes the information about comfort. Thermal resistance, thermal conductivity, thermal absorbtivity, air permeability water vapor permeability and wicking ability were reviewed.

In Chapter 3; two different yarns with three yarn count were used. 100% soybean yarn and 100% organic cotton yarn with three different yarn numbers were used. The yarn numbers of soybean yarns are Ne 20/1, Ne 32/1, and Ne 40/1. The yarn numbers of organic cotton yarns are Ne 20/1, Ne 30/1, and Ne 40/1. Fabric structural characteristics, air permeability, thermal resistance, thermal conductivity, thermal absorbtivity, water vapor permeability, wicking ability testing methods were given in Chapter 3.

In Chapter 4; results of the tests were given and discussed. According to the test results air permeability, thermal resistance, thermal conductivity, thermal absorbtivity, water vapor permeability, wicking ability and fabric structural characteristics of knitted samples were examined and discussed. Soybean yarns and organic cotton yarns were compared with each other. Minitab statistical program was used for analyzing the test results.

Lastly in Chapter 5; conclusion of thesis was given.

CHAPTER 2

COMFORT

2.1 Introduction

Comfort is a complex and nebulous subject that is very difficult to define. Many researches have investigated about comfort definition. Some of them are Fourt and Hollies surveyed the literature and found that comfort involves thermal and non-thermal components and is related to wear situations such as working, non-critical and critical conditions. The physiological responses of the human body to a given combination of clothing and environmental conditions are predictable when the system reaches a steady state. It can be calculated from knowledge of easily measured factors, such as the thermal resistance and moisture resistance of the clothing, the climatic conditions, and the level of physical activity [11].

Slater [12] defined comfort as 'a pleasant state of physiological, psychological, and physical harmony between a human being and the environment. Slater identified the importance of environment to comfort and defined the three types named.

Physiological comfort is related to the human body's ability to maintain life, psychological comfort to the mind's ability to keep it functioning satisfactorily with external help, and physical comfort to the effect of the external environment on the body.

It has been recognized for a long time that it is difficult to describe comfort positively, but discomfort can be easily described in such terms as *prickle, itch, hot,* and *cold.* Therefore, a widely accepted definition for comfort is 'freedom from pain and from discomfort as a neutral state' [13]. Further, the psychological and physiological states have a number of aspects:

- Thermo physiological comfort - 'attainment of a comfortable thermal and wetness state; it involves transport of heat and moisture through a fabric'.
- Sensorial comfort - 'The elicitation of various neural sensations when a textile comes into contact with skin'.
- Body movement comfort - 'Ability of a textile to allow freedom of movement, reduced burden, and body shaping, as required'.
- Aesthetic appeal - Subjective perception of clothing to the eye, hand, ear, and nose, which contributes to the overall well-being of the wearer [13].

In all these definitions, there are a number of essential components [14]:

Comfort is related to subjective perception of various sensations.

- Comfort involves many aspects of human senses, such as visual (aesthetic comfort), thermal (cold and warm), pain (prickle and itch), and touch (smooth, rough, soft, and stiff).
- The subjective perceptions involve psychological processes in which all relevant sensory perceptions are formulated, weighed, combined, and evaluated against past experiences and present desires to form an overall assessment of comfort status.

- Body-clothing interactions (both thermal and mechanical) play important roles in determining the comfort state of the wearer.
- External environments (physical, social, and cultural) have great impact on the comfort status of the wearer.

2.2 Classification of comfort

Comfort can be classified as: psychological, physical, and physiological.

2.2.1 Psychological comfort

Comfort, in the end, is the psychological feeling or judgment of a wearer who wears the clothing under certain environmental conditions. Pontrelli developed a Comfort's Gestalt [15] in which the variables influencing the comfort status of a wearer were listed comprehensively. The variables were classified into three groups: physical variables of the environment and the clothing; psycho-physiological parameters of the wearer; and psychological filters of the brain. The Gestalt indicates that the comfort status of a wearer depends on all these variables and their interactions [14].

The flow chart for the subjective perception of comfort is given in Figure 2.1. This chart illustrates the processes of how the subjective perception of overall comfort is formulated. The physical processes provide the signals or stimuli to the sensory organs of the human body, which will receive them, produce neuro physiological impulses, send these to the brain, and take action to adjust sweating rate, blood flow, and sometimes heat production by shivering. The brain will process the sensory

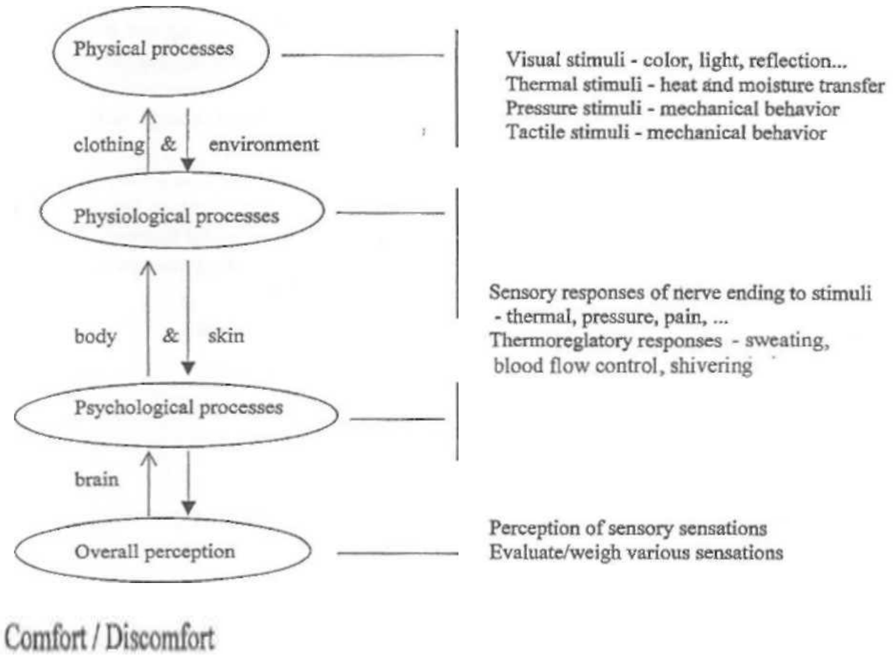


Figure 2.1 Formulation processes of the subjective perception of comfort [14]

signals to formulate subjective perception of various individual sensations, and further evaluate and weigh them against past experience and desires, which is influenced by many factors such as physical, environmental, social and cultural surroundings, and state of being [14].

The psychology of comfort is the study of how the brain receives individual sensory sensations, and evaluates and weighs the sensations to formulate subjective perception of overall comfort and preferences which become our wear experience and influence our further purchase decisions [14].

Human perception of clothing and external environment involves all the relevant senses and has formed a series of concepts that we use to express these perceptions to each other. To understand the psychological processes we need to measure these perceptions in subjective ways. A subjective measure is the direct measure of the opinion of a person, which is the only factor of interest in carrying out the measurements. Since there are no physical instruments to measure what a wearer is thinking or feeling objectively, the only way to obtain the subjective perceptions is by use of psychological scaling. With psychological scaling, the process of making judgments is based on the scales of individual words or language that we collect from experience and share with peers throughout life [14].

Slater pointed out a number of problems with subjective measurements. Firstly, measurements rely completely on the honesty of human subjects. Secondly, there exist wide variations in subjective opinions inhuman beings, which demand a large number of measurements to obtain satisfactory precision. Thirdly, there are great difficulties in carrying out statistical analysis on subjective data because subjective answers are not real numbers, and the mental calibration used by each respondent may not be the same. Finally, there are inconsistencies in subjective data, as the opinion of individual respondents is influenced by a large number of psychological, physiological, social, and environmental factors [15].

Despite the difficulties involved, scientific psychology has been developed for over 100 years to study the behavior of humans [16]. A great deal of work has been done in the field of psychological scaling, which has developed psychological laws, experimental techniques, and mathematical methods to handle the data from subjective responses [17]. Many researchers have applied the psychological scaling techniques to study clothing comfort.

Hollies summarized six essential elements in psychological scaling [18]:

- Commonly recognized attributes to measure.
- Language (terms) to describe these attributes.
- Assignment of a scale to indicate the level of attributes.
- A rating panel to apply the rating scale to attribute measurement.
- Appropriate data handling.

Hollies found that strong sensations were experienced when mild or heavy sweating occurred, and during modest excursions of warming or chilling following the inception of sweating [18]. By repeating experiments, Hollies et al obtained a list of sensory descriptors that were generated by asking the participants to describe the sensations they experienced. The list of sensations included the descriptors *snug,* *loose, heavy, lightweight, stiff, staticky, non-absorbent, cold, clammy, damp, clingy, picky, rough, and scratchy* [19].

In a study of fabric hand, Howorth and Oliver asked 25 participants to rank 27 fabrics and describe their reasons. Twenty-one descriptive terms and their frequency of use were obtained. Through factor analysis, they derived seven descriptors for fabric hand/ *smoothness, softness, coarseness, thickness, weight, warmth, and stiffness* [20, 21].

For evaluating men's winter suiting fabrics, David *et al* generated lists of 'bipolar descriptors' by discussing them with each judge. The descriptors from all the judges were collated and listed, and were then associated with the' Standard Definitions of Terms Relating to Textiles'. However, each individual judge had the choice of using his/her own list of descriptors. For each judge, an individual list of fourteen bipolar descriptors was produced. After eliminating the pairs of words that did not give useful contribution by analyzing the data from subjective evaluation, seven pairs of descriptors were identified: *coarse—fine, stiff -pliable, rough—smooth, harsh—soft, cool—warm, hard—soft, and rusty—quiet* [22].

In developing the methodology for evaluation of fabric handle, Kawabata and Niwa generated sensory descriptors by letting a panel of expert judges (the Hand Evaluation and Standardization Committee) judge fabric handle and asking them the reasons for their decisions. They identified terms such as KOSHI *(stiffness),* NUMERI *(smoothness'),* and SHARI *(crispness)* as 'primary-hand' expressions [23].

Li [24] carried out an investigation on the psychological sensory responses to clothing of consumers living in different countries. A survey was conducted in three countries: Britain, China, and USA. Twenty-six sensory descriptors were selected: *snug, loose, stiff, lightweight, staticky, nonabsorbent, sticky, heavy, cold, damp, clammy, clingy, picky, rough, scratchy, cool, hot, soft, warm, wet, prickly, itchy, chill, sultry, tickling, and rangy.* Altogether, 465 observations were made. Using analysis of variance and non-parametric analysis of differences, it was found that the ratings of most of the sensory descriptors were significantly different between three types of clothing: summer wear, winter wear, and sportswear, at $p < 0.01$ level.

Differences in the ratings of most sensory descriptors were significantly different between Chinese and British respondents for summer wear, but not for winter wear and sportswear. No significant differences in ratings of the sensory descriptors were found between male and female respondents [14].

Fritz argued that consumers have their internal scales and concepts in evaluating fabric quality. Consumers themselves know best and they are capable of making objective, quantitative, and repeatable assessments of their sensations. Researchers should try to discover the consumers' desires in the performance of products. Therefore, sensory descriptors should be derived from consumers instead of experts or researchers. Fritz reported the usage of a repertory semantic differential grid to define product attributes using descriptive adjectives, by focus group study. For example, the polar pairs of descriptors for toweling fabrics include *soft-harsh, smooth-rough, cool-hot, light-heavy, fine-coarse, crisp—limp, clammy-absorbent, atural-synthetic, sheer—bulky, clingy—flowing, crushable-resilient, lacy-plain, drapable—rigid, scratchy-silky,* and *stiff-soft [25].*

2.2.2 Physical comfort

In studying the physical factors determining the comfort performance of textiles, it is concluded that heat transfer between man and his environment, together with the movement of moisture for insensible heat transfer, constitutes the major comfort - maintaining mechanism. Depending on the particular functional requirements of garments, the parameters which can be evaluated for physical aspects of comfort are conductivity, water-vapour resistance, air-permeability, moisture-holding ability, wind resistance, abrasion resistance etc [14].

It is obvious that comfort involves a complex combination of properties, both subjective and physical. There is general agreement that the movements of heat, moisture and air through a fabric are the major factors governing comfort, but some of the subjective factors such as size, fit and aesthetic behavior like softness, handle and drape are obviously very important in the textile field [26].

The physical processes that generate those stimuli include heat transfer by conduction, convection and radiation, moisture transfer by diffusion, sorption, wicking and evaporation, and mechanical- interactions in the form of pressure, friction, and dynamic irregular contact. Comprehensive research has been carried out to study the mechanisms of heat and moisture transfer processes in clothing in the past few decades. However, the mechanisms of the mechanical interaction between clothing and the body have not been investigated so thoroughly [14].

2.2.3 Thermal physiological comfort

Clothing must protect the human body against climatic influence, environmental conditions and physical activities. In such a way, the body's thermal balance is achieved and a microclimate which is perceived to be comfortable is created next to the skin. In other words, an important task of clothing is to support the body’s thermoregulatory system to keep its temperature within a median range, even if the external environment and physical activities change in a much broader range [14].

An understanding of the role of clothing in the thermal balance of the human body and thermal comfort under steady-state conditions has been developed over the past few decades, and this has been widely used in the clothing industry and the heating-ventilating industry. The human body is rarely in a thermal steady state, but is continually exposed to transients in physical activity and environmental conditions. Hygroscopic fibers such as wool and cotton absorb moisture vapor from ambient air when humidity rises, and release heat. Similarly, when the humidity falls, moisture is released, and heat is taken up by the fibers. Under transient conditions, this sorption behavior of fibers can play an important role in the heat exchange between the human body and the environment, and in thermal comfort perceptions [14].

Yaglou and Miller defined 'effective temperature' as an index of warmth perception when a human body is exposed to various temperatures, humidity, and air movements. The scale of effective temperature was determined by the temperature of still, saturated air which was felt as warm as the given conditions. For instance, any ambient condition has an effective temperature of 60°F when it is perceived as warm as still air saturated with water vapor at 60°F. Effective temperature was adopted by the American Society of Heating and Ventilating Engineers as the operating scale for establishing comfort charts for clothed sedentary individuals exposed to a variety of temperatures, relative humidities, and wind velocities [27].

Rohles[28] derived an equation using multiple regressions to predict thermal sensations after an exposure of three hours:

$$Y = 01509\, T_{ab} + 0.01 H_a - 8.3719 \tag{2.1}$$

Where is Y the thermal sensation on the scale of 1=cold, 2=cool, 3=slightly cool, 4=comfortable, 5= slightly warm, 6=warm, and 7=hot; T_{ab} is the dry bulb temperature in $^\circ F$; and H_a is the relative humidity in percent.

Gagge at al [29] studied the sensory comfort and thermal sensations of resting-sitting, unclothed subjects, and compared them with the associated physiological responses under steady-state and transient conditions of 12-48 °C. When exposed to steady cold and warm environments, thermal comfort and neutral temperature sensations lay between 28-30 °C when no physiological temperature regulatory effort was needed. Discomfort perception was related to lowering average skin temperature toward cold environments and increased sweating towards hot environments.

The same conclusion was drawn for transient changes - when the subjects were exposed from comfortable to uncomfortable, neutral to cold, and neutral to warm. Thermal discomfort was found to be an excellent stimulus for behavioral activity by man. Thermal sensation gave man an early anticipatory drive for conscious action to change his body's microclimate rather than depend on natural, but short-term, thermal protection by sweating, vasodilatation, or vasoconstriction and shivering [14].

Gagge et al. [30] reported a study on comfort, thermal sensations, and associated physiological responses during exercise at various ambient temperatures. The authors concluded that, after 30-40 minutes of steady exercise, temperature sensations from cool to hot/were mainly correlated with skin and ambient temperatures; warm discomfort was related to skin sweating and skin conductance. During steady state exercise, perception of temperature was dominated by sensory mechanisms in the skin, while warm discomfort was mainly determined by thermoregulatory mechanisms. The comfort and thermal sensations during thermal transients caused by the rise in metabolic rate at the start of exercise were correlated with the initial rise in mean body temperature.

Hensel [31], and Carterete and Friedman [32, 33] pointed out the physiological basis of thermal comfort, and the difference between thermal comfort and temperature sensations. Temperature sensations are mainly derived from cutaneous thermo receptors, which are used to judge the thermal state of objects or the environment. Thermal comfort and discomfort reflect a general state of the thermoregulatory system, which is the integration of afferent signals from both cutaneous and internal thermo receptors. Therefore, the measurements of temperature sensations and of thermal comfort need to be distinguished. McNalla [34] used two separate scales to study thermal sensations and thermal comfort, as summarized in Table 2.1.

Table 2.1 Thermal sensations and thermal comfort [14]

Scales for Thermal Comfort and Thermal Sensations	
Thermal sensations	**Thermal comfort**
1.very cold	1.uncomfortably cold
2.cold	2.colder than comfortable
3.cool	3.much cooler than comfortable
4.slightly cool	4.slightly cooler than comfortable
5.neutral	5.comfortable
6.slightly warm	6.slightly warmer than comfortable

7.warm	7.much warmer than comfortable
8.hot	8.hotter than comfortable
9.very hot	9.uncomfortably hot

Thermal comfort –related fabric properties are widely investigated and could be given under various topics.

2.2.3.1 Thermal insulation

The thermal-insulation property of a textile fabric has been defined by Miller [35] as its ability to resist the transmission of heat by all modes. G.d. Morris [36] also defined thermal insulation as the effectiveness of a fabric in maintaining the normal temperature of the human body under equilibrium conditions.

The most important thermal property in most apparel applications is insulation against heat flow. The measure of the insulation of a material is its thermal resistance. It is defined as the temperature difference between, the two faces divided by the heat flux, and has units of Km^2/W. The magnitude of the heat flux at a point is inversely proportional to the thermal resistance of the material, that is, the higher the resistance, the lower is the heat loss [37].

There are two specially named units of thermal resistance the tog and the clo.

The tog is defined as one-tenth of the ratio of with temperature difference across a fabric or other material or assembly of materials to the resulting rate of heat flow in watts per square metre. i.e., a thermal resistance of 1 tog corresponds to a heat transfer of 10 Wm^2 per degree C temperature difference. i.e. [37]

$$10\ \text{togs} = 1\left(\frac{\deg ree\ C}{\text{watts/metre}^2}\right)\ ,$$

$$1\text{tog} = 0.418\ {}^\circ C\ s\ m^2 cal^{-1} = 0.567\ {}^\circ F\ h\ ft^2\ Btu^{-1} \tag{2.3}$$

The tog is a physical unit of thermal resistance defined in terms of measurable physical quantities. The warmth of clothing fabrics, quilts, and other textile products is measured in togs.

One tog is the thermal resistance of a fabric for a conventional man's suiting or of a blanket of a medium quality. The higher the tog value, the greater is the thermal insulation provided. The thermal resistance of several layers of clothing or bedding in calm air can be obtained by adding the values for each layer. Typical tog values for a range of fabrics are shown in Table 2.2 [37].

Table 2.2: Typical tog values for a range of fabrics [37]

Typical Thermal –resistance Values For Clothing and Furnishing Fabrics	
Fabric or Article	**Thermal resistance value(tog)**
Shirtings	0.1
Suitings	1
Sweaters	1
Carpets	2
Curtains	0.2
Sheets	0.2
Blankets	1
Continental quits	10

The clo unit of insulation is defined as a mean thermal resistance of $0.155^{\circ}Cm^{2}W^{-1}$. It is also the insulation required to keep a resting man (producing heat at the rate of 1 met ($58W^{-2}m$) comfortable in an environment at 21°C with air movement of 0.1 m s-1 and relative humidity not over 50%, with a body metabolism of 50 $kcal\ m^{2}/h$. It can therefore be visualized as roughly the insulation of indoor clothing [37].

Two types of measurement of clo are possible and should be distinguished from each other in discussion, as follows [37].

(a) Thermal resistance, from thickness:

Clo=1.6x (thickness in cm)= 4x (thickness in inch)

This includes air spaces up to 5 mm or 0.2 in. The maximum insulation for some materials may approach 2 clo/cm, but the factors above are representative of good clothing.

(b) Thermal resistance physically measured:

$$clo = 0.155^{\circ}Cm^2/W \quad = 0.18^{\circ}Cm^2h/kg\,cal \quad \text{or}$$

$$1\ clo = 0.648^{\circ}Cm^2s/cal \ = 0.0880\ ^{\circ}Fft^2h/\text{Btu} = 1.55\ \text{tog} \tag{2.4}$$

Many research have been done about the clo and comfort, some of them are shown below;

Holcombe and Hoschke investigated the relationship between the thickness and thermal resistance of textile fabrics is examined with particular reference to underwear structures, and the influence of domestic washing on this relationship is demonstrated. The thermal resistance of these low density fabric constructions is determined primarily by fabric thickness, and other parameters such as fiber type and construction have a minor but significant influence [38].

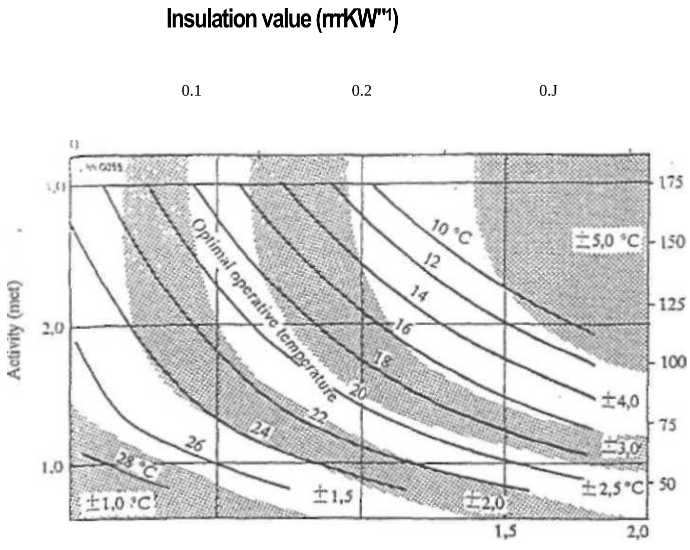
Fanger [39] developed a mathematical model to define the neutral thermal comfort zone of men in different combinations of clothing and activity levels. Mean skin temperature and sweat secretion rates were used as physical measures of comfort. Based on Fanger's work, the American Society of Heating, Refrigerating and Air Conditioning Engineers developed generalized comfort charts and indices of thermal sensation for predicting comfort acceptance under different combinations of clothing insulation, metabolic level, air temperature, and wet-bulb temperature (or radiant temperature).

Fanger presented an international standard dealing with thermal comfort, ISO 7730, and discussed the philosophy and the scientific basis behind this standard [40]. It aimed to specify conditions that would be acceptable in thermal comfort to a given percentage of the population. In the standard, thermal comfort was defined as the condition of mind that expresses satisfaction with the thermal environment. Dissatisfaction, which may be caused by warm or cool discomfort for the body in general, is expressed by the PMV and PPD indices. PMV index is the Predicted

Mean Vote, which is used to predict the thermal sensation for the body as a whole on a seven-point scale, from cold to hot. PPD index is the Predicted Percentage of Dissatisfaction. The ISO standard recommended a PMV within the range of-0.5 to +0.5, meaning that the PPD should be lower than 10%. When PMV is zero, the optimal operative temperature is achieved, this being a function of activity and clothing [14].

Figure 2.2 shows the operative temperature, defined as the uniform temperature of an enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment. For normal practical applications, the operative temperature is roughly equal to the mean value of mean radiant and air temperatures [14].

The curves show the optimal operative temperature which satisfies most people in given clothing and in a given activity in Figure 2.3. The shaded areas show the acceptable ranges around the optimal temperature. The metabolic rate can be estimated from physical activities, as shown in Figure 2.3, while the thermal insulation of clothing (clo) can also be estimated from the type of clothing showing in Figure 2.4. Using the metabolic rate and clothing clo values, the optimal effective temperature and its tolerance limit can be estimated from Figure 2.4 [14].



Clothing (clo)

Figure 2.2 Optimal operative temperatures [14]

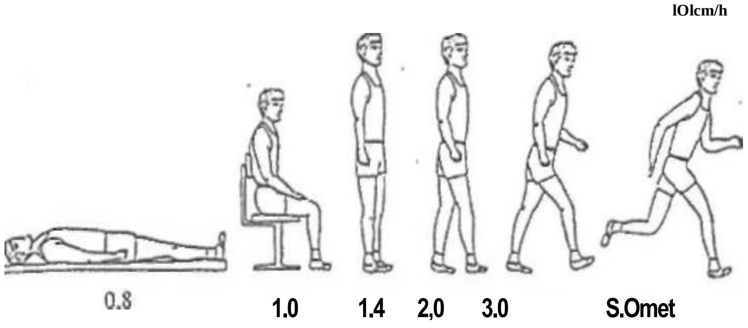


Figure 2.3 Metabolic rates of physical activities [14]

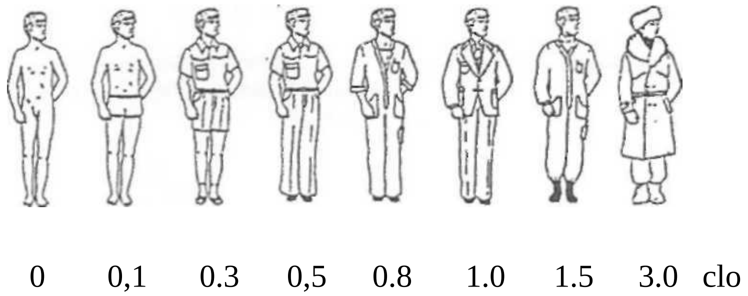


Figure 2.4 Thermal insulation of typical clothing [14]

Gagge et al., as a rational starting basis, developed an environmental temperature scale based on the heat exchange equations during the passive state and the effect of physiological regulatory controls. The temperature scale used the Humid Operative Temperature **(**T_{oh}**),** defined as the temperature of an imaginary environment to which the body would lose the same heat by radiation, convection and evaporation as it would in the actual environment. A new 'effective temperature' scale was also constructed for a sedentary, normally clothed (0.6 clo**)** subject, on the basis of loci of constant wettedness caused by regulatory sweating [14].

Gagge [41] defined three rational temperature indices: Standard Operative (T_{so}), Standard Humid Operative (T_{soh}), and Standard Effective **(SET)** Temperatures, in terms of average skin temperature, skin wettedness, and the associated heat transfer coefficients. Generally speaking, T_{so} is an index of thermal stress caused by the environment; T_{soh} is an index of thermal strain caused by T_{so}**;** and SET is an index temperature, describing the dry bulb temperature of the standard environment at 50% r.h. that causes the same heat exchange for the same T_{so} skin wettedness, and average skin temperature [14].

Gagge et al. proposed another new Predicted Mean Vote index, designated PMV*, by simply replacing the operative temperature, T_o in Fanger's Comfort Equation with **SET.** Gagge pointed out that Fanger's PMV is primarily based on heat load; it is not sensitive to changes in relative humidity or vapor pressure, nor to the vapor permeability of clothing worn. By defining PMV with SET instead of T_o the new PMV (PMV*) is able to respond to the thermal stress by heat load, the heat strain by changing humidity of the environment, and the vapor permeability of the clothing worn [14].

2.2.3.2 Thermal conductivity

Conduction occurs when heat moves through a medium. The rate at which this occurs is proportional to the thickness of the material, the cross-sectional area over which it travels the temperature gradients between its surfaces and its thermal conductivity.

Thermal conductivity is another familiar term applied to materials that conduct heat. In physics thermal conductivity, is the property of a material that indicates its ability to conduct heat. Thermal conductivity is defined as the heat flux divided by the temperature gradient where heat is transferred by conduction only and has units of W/mK. It gives the rate of flow of heat by conduction through unit area of material of unit thickness when a difference in temperature of one degree Celsius exists between its opposite faces. Since the purpose of clothing in the present context is to restrict the flow of heat from the body to its environment, materials having low thermal conductivities are required [37].

Thermal conductivity coefficient λ presents the amount of heat, which passes from 1 m^2 area of material through the distance 1 m within 1 s and create the temperature difference 1 K. The highest thermal conductivity exhibit metals, whereas polymers have low thermal conductivity, ranging from 0,2 to 0,4 W/mK. Thermal conductivity of textile structures generally reaches levels from 0,033 to 0,01 W/mK. Thermal conductivity of steady air by 20°C is 0,026 W/mK while thermal conductivity of water is 0,6 W/mK, which is 25 times more. That is why the water presence in textile materials is undesirable [42].

If we look at the measurement of thermal conductivity, there are two methods to measure thermal conductivity; these are steady-state and transient techniques. A steady-state technique is a measurement that the temperature does not change with time. This makes the constant signal. The disadvantage is that a well-engineered experimental setup is needed. The Divided Bar (various types) is the most common device for this method.The transient techniques show a measurement during the process of heating up. The advantage is that there are quickly measurements. Needles are used for this methods (inserted into samples or plunged into the ocean floor). The measurement result of thermal conductivity is based on Equation (2.1)

$$\lambda = \frac{Q}{F\tau\frac{\Delta T}{\sigma}} \qquad W/mK \tag{2.5}$$

Where Q represents amount of conducted heat, F shows area through which the heat is conducted, τ is time of heat conducting, ΔT denotes drop of temperature, σ is the fabric thickness.

Extensive research has been carried out on the thermal behavior of textile materials.

Lamb investigated the heat loss from a ventilated clothed body. They noted that heat transfer depends on air velocity and fabric permeability. Farnworth and Dolhan used a sweating hot plate method to detect the rate of heat loss through cotton and polypropylene underwear. They concluded that the pattern of heat loss for polypropylene and cotton was different, but not sufficiently so, to affect the wearer's thermal state. Schneider worked on the thermal conductivity of textile fabrics containing water. They showed that under moist conditions wool fabric had better insulating properties than porous acrylic, cotton and polypropylene. Gibson examined the influence of air permeability on heat and water vapor transport through woven and nonwoven fabrics. From this study, it has been pointed out that the air permeability of fabric becomes particularly important in the situation of an air space between fabric and sweating skin simulating surface. The study by Woo pointed out that conduction is the dominant heat transfer mechanism for most non-woven fabrics. Fiber fineness es and fabric thickness have a significant influence on thermal conductivity, especially for low-density nonwoven fabrics. Jirsak et al. developed dynamic and static methods for measuring the thermal conductive properties of textile materials. They pointed out that thermal conductivity measured by the dynamic method is generally higher and more unstable than that of the static method, probably because of the thermal convection due to the thermal gradient within the fabric. They recommended static methods for porous media such as textile materials [43].

The relationship between fabric properties and thermal conductivity of various jute/cotton blended knitted fabrics has been studied. The experimental result shows that lower thermal conductivity noticed at higher jute blend proportions. The thermal conductivity reduces with increasing fabric thickness. It also reveals that fabric air permeability and tightness factor values influences the thermal conductivity of jute/cotton blended knitted fabrics [44].

2.2.3.3 Thermal absorbtivity

Thermal absorption is a surface property, and therefore the finishing processes can change it. This parameter allows assessment of the fabric’s character in the aspect of its ‘cool warm’ feeling. Fabrics with a low value of thermal absorption give us a ‘‘warm’’ feeling.

Warm-cool feeling means the feeling we get when the human skin touches shortly any object, it was found, that this parameter characterizes well the transient thermal feeling which we get in the moment, when we put on the undergarment, shirts, gloves or other textile products. Since this feeling strongly affects the choice of people when buying the clothes or garments, the objective assessment of this feeling became very important in the last decade [45].

The first instrument, which was able to evaluate the warm-cool feeling of fabrics objectively, was developed by Yoneda and Kawabata in 1983. They have introduced the maximum level of the contact heat flow $q_{\max}$ (W/m^2K) as a measure of this transient thermal characteristics, and Kawabata has published the first objectively determined values describing the thermal-contact properties of textile fabrics. Their instrument, called Thermo-Labo, was commercialized [45].

He developed in 1986, another instrument for the objective evaluation of warm-cool feeling of fabrics, but of different concept, was completed at the Technical University in Liberec. This computer controlled semi-automatic instrument called ALAMBETA calculates all the statistic parameters of the measurement and exhibits the instrument auto-diagnostics, which avoids faulty instrument operation. The whole measurement procedure, including the measurement of thermal conductivity λ, thermal resistance r, level of heat flow $q_{\max}$, sample thickness and the results evaluation, lasts less than 3 -5 min. As the objective measure of warm-cool feeling of fabrics, so called thermal absorptivity b $(Ws^{1/2}/m^2K)$ was introduced [45].

Provided that the time τ of thermal contact between human skin and a fabric is short, textile fabric was idealised to a semi-infinite body of thermal capacity ρ_c (J/m^3) and initial temperature t_2. Transient temperature field between human skin (characterised by a constant temperature t_1) and a fabric is then given by the following partial differential equation.

$$(\frac{\partial t}{\partial \tau}) = a(\frac{\partial^2 t}{\partial x^2}) \qquad (2.7)$$

and can be used for the calculation of the initial level of heat flow q passing between the skin (characterised by a constant temperature t_1) and textile fabric according to the next equation, whose derivation for the boundary condition of 1st order is similar to derivation of the Equation (1.8):

$$q_{dyn} = b(t_1 - t_2)/(\pi\tau)^{1/2} \tag{2.8}$$

Thus derived thermal absorbtivity b $(Ws^{1/2}/m^2K)$ is given by the following relation:

$$b = (\lambda\rho_c)^{1/2} \tag{2.9}$$

Where ρ_c (J/m^3) is thermal capacity of the fabric and the term b presents thermal absorbtivity of fabrics. The higher is thermal absorbtivity of the fabric; the cooler is its feeling. In the textile praxis this parameter ranges from 20 $Ws^{1/2}/m^2K$ for fine nonwoven webs to 600 $Ws^{1/2}/m^2K$ for heavy wet fabrics [42].

Coolness to the touch of smooth, lightweight fabrics is enhanced by fibers with high moisture sorption capacity such as wool. Subjective trials to assess the coolness of fabrics in wool, cotton, polyester, and a wool/polyester blend are done under controlled environmental conditions. In paired comparisons, subjects choose the fabrics with higher moisture sorption capacity more frequently as cooler as the difference in the capacity of the two fabrics increases. Laboratory measurements show a correspondingly greater temperature drop at the skin surface during contact with the more absorptive fiber. This enhanced cooling is associated with the desorption of moisture that takes place as fabrics move toward the skin through a changing humidity environment [46].

As it can be seen, the level of thermal absorptivity depends neither on the temperature gradient between the fabric and skin, nor on the measurement time. This value just depends on the contact pressure, which also correspond to the real situation. The pressure is adjustable [45].

2.2.3.4 Air permeability

Air permeability of a fabric is defined as the amount of air, passed over a surface under a certain pressure difference in a unit time. This value has significance with respect to the usage area. Since knitted fabrics have a loop structure, they have more pores than woven fabrics, so, in general, air permeability of knitted fabrics is higher than the woven fabrics having same weights. The experiment of determination of air permeability that defines the properties of keeping warm, protection against the wind, breathability etc. of knitted fabrics used as clothing, is very important [47].

Air permeability describes the property of fabric to let through air. In outdoor clothing it is important that air permeability is as low as possible because it should function as a wind protection. Air permeability of a fabric is a measure of how well it allows the passage of air through it. The ease or otherwise of passage of air is of importance for a number of fabric end uses such as industrial filters, tents, sail cloths, parachutes, raincoat materials, shirtings, down proof fabrics and airbags. It can also be used to provide an indication of the breathability of weather-resistant and rainproof fabrics [48].

Construction factors and finishing techniques can have an effect upon air permeability by causing a change in the length of airflow paths through a fabric. Fabrics with different surface textures on either side can have a different air permeability depending upon the direction of air flow [49].

Air permeability ($air\ per$) is defined by the equation:

$$air\ per = \frac{V}{F\tau(\Delta p)} \qquad dm^3/m^2s \tag{2.10}$$

where
V - capacity of the flowing medium,
F - the area through which the medium is flowing,
τ - time of flow,
Δp - drop in pressure of the medium.

The air permeability of a fabric can influence its comfort behavior in several ways.

In the first case, a material that is permeable to air is also, in general, likely to be permeable to water, in either the vapour or the liquid phase. Thus, the moisture-vapour permeability and the liquid-moisture transmission are normally closely related to air permeability [48].

In the second case, the thermal resistance of a fabric is strongly dependent on the enclosed still air, and this factor is in turn influenced by the fabric structure, as also is the air permeability. A very open cloth can inflict serious wind chill problems on the wearer in cold climates with a breeze blowing and may thus affect survival chances in extreme cases [48].

Finally, a highly air-permeable fabric may be sheer or have as very open structure, so that aesthetic factors such as modesty, dimensional stability, drape, handle etc may result in discomfort of a psychological or physical nature in the wearer. Although air permeability in itself is merely another effect, rather than a cause, associated with such manifestations of discomfort, it can nevertheless provide a convenient and readily measured way of quantifying the likely behaviour of a fabric in these other areas [48].

Air permeability is normally measured on apparatus designed to force air through the test specimen in a reproducible manner, usually classified into two types. In one system, the pressure difference between the opposite faces of a test specimen is fixed, and measurement is made of the resulting air-flow thro' the material. In the other type, the rate of movement of air thro' the fabric is adjusted to a fixed value and the pressure difference that must be developed across the fabric in order to maintain this air-flow is then measured [49].

2.2.3.5 Moisture-vapor transmission

In clothing, moisture vapor transmission as a measure of breathability has showed a greater comfort for wearers of clothing for outdoor activity.

Water vapour transmission is essential in determining the breathability of clothing and textiles in outdoor wear as well as in indoor wear. A breathable textile allows extra heat loss by evaporation of moisture through the clothing layers. If clothing layers are impermeable the moisture is captured between skin and clothing and heat is accumulated in the body. As a consequence, heat and moisture build up, causing discomfort, wet skin and skin abrasion [48].

The water vapor permeability of different clothing systems can be directly compared in term of i_m values on the condition their thermal resistances are of the same values. Goldman defined evaporative transmissibility as the ratio of permeability index to total insulation (i_m / clo). It is an indicator of obtainable proportion of the maximum sweat evaporative cooling in a specific environment without the presence of air current. Thus, evaluation of the insulation and evaporative impedance of a clothing system is able to accurately estimate the relative advantages of the clothing as compared with another, with regard to the thermal protection or strain when the clothing is worn [50].

The report by McCullough and Rohles revealed that evaporative transmissibility (i_m / clo) was helpful to compare the ensembles with different insulation values. Two jacket ensembles with different insulation, which shared the same evaporative transmissibility, would allow the same heat exchange between the body and the surrounding in the same environments at the same activity levels [50].

It is easy for clothing materials with high evaporative transmissibility value (i_m / clo) to transport heat by means of both convective heat transfer and evaporative cooling. Whereas,in high humidity and at low air speed, the evaporative cooling is less important and the thermal resistance becomes the most important variable [50].

Another common expression of water vapour permeability is index of water permeability (I_w). It was defined as the ratio of steady-state evaporative rate through ensemble in watts to steady-state evaporation of nude subject in watts. I_w was utilized by Henane et al. to assess physiological strain resulting from clothing worn by the armored vehicle crew under warm conditions. It indicated the ratio of real skin evaporation through clothing to total evaporation of nude subject with high environmental evaporative power. In comparison with i_m index, which was biophysical parameter measured under static conditions and underestimate the evaporation through clothing, I_w was likely to overestimate the evaporation through clothing due to lower insulation and higher permeability index resulting from wind movement. The I_w index could be useful in ranking the physiological strains due to wearing special protective clothing under warm conditions [50].

There are various techniques to measure MVTR, ranging from gravimetric techniques that measure the gain or loss of moisture by mass, to highly sophisticate instrumental techniques that in some designs can measure extremely low transmission rates. Note that special care has to be taken in measuring porous substances such as fabrics as some techniques are not appropriate. Likewise for very low levels, many techniques would not have the resolution to provide a reliable result. There are numerous standard methods described in ISO, ASTM, BS, DIN etc, and quite often industry specific. Instrument manufacturers will often be able to provide test methods developed to fully exploit the specific design which they are selling [51].

The condition under which the measurement is made has a considerable influence on the result.Both the temperature of and humidity gradient across the sample need to be measured, controlled and recorded with the result. An MVTR result without specifying these conditions is almost meaningless. Certainly no two results should be compared unless the conditions are known. The most common international unit for the MVTR is $g/m^2/day$. In the USA, $g/100in^2/day$ is also in use, which is approximately 1/15 of the value of $g/m^2/day$ units. (More precisely, the ratio is 1/15.500031 or very close to 2/31.) Typical rates in aluminium foil laminates may be as low as 0.001 $g/m^2/day$, whereas the rate in fabrics can measure up to several thousand $g/m^2/day$. Often, testing is conducted on a sheet of material. Calculations based on that can be useful when designing completed structures (packages, clothing, etc). Seams and seals are also very important to end-use performance; performance verification and validation of complete containers or irregular objects is often recommended[51].

The movement of water vapor of a fabric depends on the micro porous structure of fabrics. The factors affecting moisture vapor permeability are the effect of fabric structure and properties, finishing treatments, texturising, different yarn twists, blending and mechanical treatments.

2.2.3.6 Capillarity and Wicking

In general, wicking takes place when a liquid travels along the surface of the fiber but is not absorbed into the fiber. Physically, wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. This type of flow in any porous medium, caused by capillary action, is governed by the properties of the liquid, liquid-medium surface interactions, and geometric configurations of the pore structure in the medium [52,53].

Liquid properties such as surface tension, viscosity, and density, as well as the surface wetting forces of the fibers are known or can be experimentally determined, but the pore structure of a fibrous medium is complicated and much more difficult to quantify. The complexity of a fabric structure makes it impossible to measure an accurate pore structure. Furthermore, movement and interaction of a liquid through pores can cause both shifting of fibers and changes in pore structure [52, 53].

According to Harnet and Mehta [54], “wick ability is the ability to sustain capillary flow,” whereas wettability “describes the initial behavior of a fabric, yarn, or fiber when brought into contact with water.” While wetting and wicking are still argued to be separate phenomena, they can be described by a single process – liquid flow in response to capillary pressure [55].

More completely, in the absence of external forces, the transport of liquids in a porous media is driven by capillary forces that arise from the wetting of the fabric surface. Because capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system. Hence, they are coupled and one cannot occur in the absence of the other [56].

The spontaneous flow of moisture or wicking occurs due to a pressure differential or capillary action. Capillary action or, capillarity, can be defined as the macroscopic motion or flow of a liquid under the influence of its own surface and interfacial forces. The primary driving forces responsible for the movement of moisture along the fabric are the forces of capillarity. Capillarity describes the phenomenon when liquids in narrow tubes, cracks, and voids take on motion caused by the surface tension of the liquid [56].

Capillarity is based on the intermolecular forces of cohesion and adhesion. If the forces of adhesion between the liquid and the tube wall are greater than the forces of cohesion between the molecules of the liquid, then capillary motion occurs. This flow is similar to other types of hydraulic flow in that it is caused by a pressure difference between two hydraulically connected regions of the liquid mass. The direction of flow is such as to decrease the pressure difference [57].

Flow would cease when the pressure difference became zero. According to the laws of capillarity, fluid flow would be faster in a void with a large capillary radius than that in one with a small radius. Though that may be true, the smaller radius capillary can transport moisture to a greater height as illustrated in Figure 2.5.

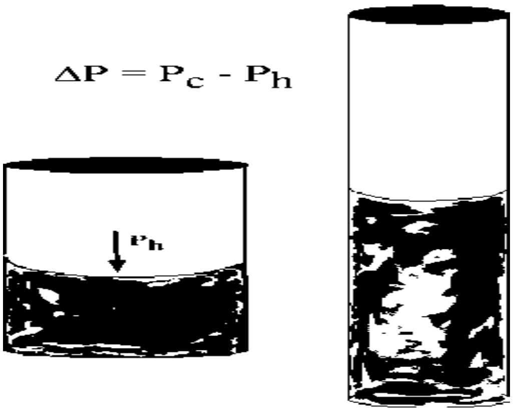


Figure 2.5 Illustration of capillary rise in different size pores

The two fundamental properties used to predict overall wicking performance in a fabric is capillary pressure and permeability. The capillary pressure is the primary driving force responsible for the movement of moisture along a fabric. The magnitude of capillary pressure *Pc* can be expressed by the Laplace equation:

$$P_c = 2\gamma \cos\theta / R \tag{2.11}$$

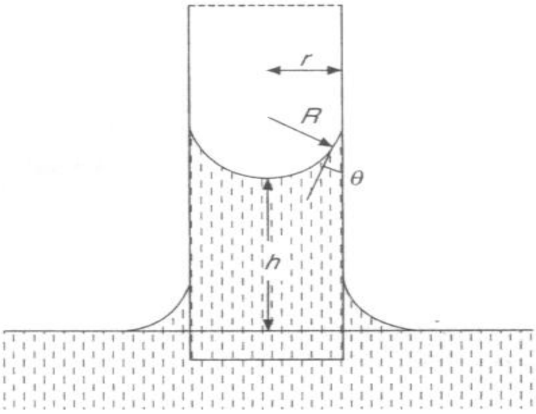


Figure 2.6 Wicking in a capillary [58]

where γ is the liquid surface tension, θ is the contact angle of the liquid with the substrate, and *R* is the effective capillary radius [58].

The other fundamental property, permeability, is the term used for the conductivity of the porous medium with respect to permeation by a Newtonian fluid [59]. In general, permeability is a quantitative measure of the ability of a porous medium to conduct fluid flow and is considered the one of most important physical properties of that porous medium. Permeability is related to the pore sizes and their distribution since the distribution of the sizes of entrances, exits, and lengths of the pore walls make up the major resistances to flow. Greenkorn [60] states that "the permeability is the single parameter that reflects the conductance of a given pore structure."

Though there are several methods to solve for the permeability in porous media, they usually involve a non wetting liquid or air be forced through the substrate. This through-plane permeability does not accurately define the property of the medium to wick moisture. To assess wicking, one must be able to calculate an in-plane, non forced permeability. This type of permeability quantitatively helps to define how a fabric can wick moisture.

Based on the extent of interactions with fibers, wicking processes can be divided to four categories [56].

(i) *Wicking of a liquid, no significant diffusion into the fiber surface,* e.g. hydrocarbon oil wicking into a polyester fabric at ambient temperature; capillary penetration is the only process operating;

(ii) *Wicking accompanied by diffusion of the liquid into fibers or into a finish on the fiber, e.g.* water wicking in a cotton fabric and diffusing into fibers, water wicking into a soil-release treated polyester fabric, and diffusing into the finish. Two simultaneous processes are operating - capillary penetration and diffusion of the liquid into the fibers;

(iii) *Wicking accompanied by adsorption on fibers, e.g.* an aqueous surfactant solution wicking into a polyester fabric. Several processes are operating simultaneously - capillary penetration of the liquid, diffusion of the surfactant in the liquid, and adsorption of the surfactant on fibers.

(iv) *Wicking involving adsorption and diffusion into fibers, e.g.* an aqueous surfactant solution wicking into a cotton fabric. Several processes are operating simultaneously - capillary penetration, diffusion of the liquid into the fibers, diffusion of the surfactant in the liquid, and adsorption of the surfactant on fibers.

There are two main types of wicking tests;

1. Longitudinal wicking tests
2. Horizontal wicking tests

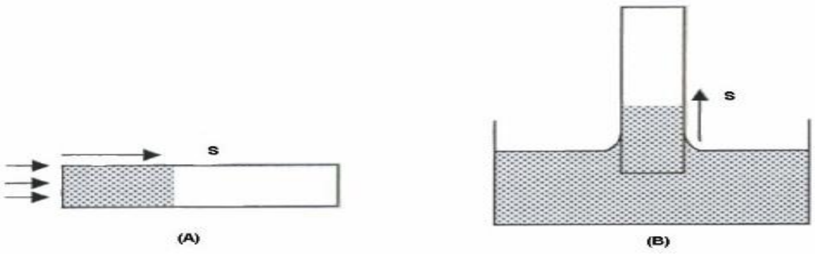


Figure 2.7 Horizontal wicking test and longitudinal wicking test

Wicking is common practice to use in-plane wicking measurements to evaluate the absorbing power or liquid transport capabilities of fibrous sheet materials. Most versions of the test methods used for this purpose start out by dipping one end of a sheet into a liquid and monitoring its subsequent upward movement into the sheet, either by following the position of the liquid front (rate of liquid travel) or by gravimetric or volumetric changes. If the upward distance traveled by the liquid becomes long enough, there will be a noticeable effect of gravity on the flow rate [61].

Equilibrium will happen when the capillary action is balanced by gravity, i.e. by the weight of the raised liquid [56, 62]. Moreover, water uptake in a vertically shows a gradient distribution pattern, with a saturated zone near the water-fabric interface followed by diffused and steadily distributed zones [63]. During vertical upward wicking, the flow of liquid is unsteady due to gravity effects. At the onset of absorption in a vertical capillary system, the absorbed liquid is relatively close to the liquid source, and the effect of gravity can be neglected in this situation. However, at a longer period of time (or upward wicking distance), gravity plays an increasingly important role.

Hsieh and Yu [64] have described a gravimetric measurement for wetting and transport in woven fabrics. Hsieh [64] discussed capillary theory for this gravimetric method. Initially, when the liquid contacts the fabric, the capillary pressure is greater than the weight of the liquid in the fabric and the liquid continues to rise. The liquid stops rising at the equilibrium height (h_{eq}), when capillary forces are balanced by the weight of the liquid. Upon reaching equilibrium, the force detected by the balance reading (ΔB_{eq}) becomes constant, indicating stabilization of the wetting and wicking processes. The balance reading after separating the fabric from the liquid (ΔB_{eq}) indicates the amount of liquid retained by the fabric (W_t). The fabric wetting force (F_w) is decoupled as:

$$F_w = (\Delta B_{eq} - W_t)g \tag{2.12}$$

The fabric wetting contact angle (θ) is calculated as:

$$\theta = \cos^{-1}(F_w / P\gamma) \tag{2.13}$$

where P is the fabric-liquid perimeter, which can be estimated from the force measured in hexadecane as:

$$P = F_w / \gamma hexadecane \tag{2.14}$$

Ravichandran *et al.* [65] described a method for measuring vertical wicking. Samples were marked 1.27 cm from the top and bottom of the fabric strip and hung vertically from a cross-bar into a dilute aqueous solution of *Procion Red HE-3B*. Wicking distances corresponding to five minutes were measured for all samples except those treated with anthranilic acid. Samples treated with anthranilic acid were measured for wicking after three minutes because they wicked so rapidly and were not long enough for a five-minute test.

Liquid penetration into a piece of polyester nonwoven fabric hung vertically above the liquid was studied theoretically and experimentally by Kurematsu and Koishi [66]. The phenomena of liquid ascent were analyzed using Washburn's equation [67], which rarely indicated the effect on the fiber bed structure such as porosity and specific surface. Heights of liquids ascending in polyester nonwoven fabric can be calculated with the improved Kozeny-Carman's equation, for fluid flow through a porous media, including a term for the capillary force between two parallel surfaces of the nearest fibers in three fiber orientating models of polyester nonwoven fabric. Theoretical ascending heights for carbon tetrachloride, ethyl alcohol, rc-butyl alcohol, n-decyl alcohol, toluene, cyclohexane, and diglycidylether bisphenol A (epoxy resin) appear to be in fair agreement with the experimental heights determined by taking into account liquid evaporation.

Miller *et al.* [62] presented theoretical and experimental cases of downward and upward wicking. The equations describing these two processes have somewhat different forms. The results indicate that downward wicking can produce an essentially constant feed rate over a very long time period, whereas upward wicking rates decrease continuously with time but never actually reache zero. According to them, if it is necessary to bring about complete filling of all the available free volume within a porous sheet, the best way is to test under downward wicking.

There are many factors affecting the wicking, if we classes the factors some we can found three important classes, these are; fiber, yarn and fabric structure.

A knitted textile fabric is constructed with a single yarn or set of yarns moving in only one direction. Instead of two sets of yarns crossing each other as in weaving, the single knitting yarn is looped through itself to make a chain of stitches. Because of its construction, a knitted fabric is not a completely solid structure, but is complex and porous in shape. The complex contours formed by the fibers in the yarn and the yarns in the fabric constitute the boundaries of the channels along which moisture flows [68].

It has been reported that the most important mechanism of fabric wicking is the motion of liquid in the void spaces between the fibers in a yarn. Due to the laws of capillarity, the much larger pores between yarns do not contribute much to the long-range motion of liquid. It has also been concluded by Minor *et al* .that yarn intersections act as new reservoirs, and feeds all branches equally [68]. This finding will become increasingly important when different types of knit structures are compared.

It has been theorized by many researchers that the flow of a fluid in a fabric is largely governed by the network structure of the fabric [70-71] and not due to the fiber type [71, 72]. In any system where capillarity causes relative motion between a solid and a liquid, the shape of the solid surfaces is an important factor, which governs the rate and direction of liquid flow [68]. The rate of travel of liquid water is governed by the fiber arrangement in yarns which control capillary size and continuity [71]. To assume that fiber type does not contribute to capillary flow is not an entirely true statement, because fiber type also contributes to the overall structure. Fiber type, under certain circumstances, can drastically change the structure of the yarn, in turn changing the wicking properties of the fabric. For example, changes in fiber properties when wet can significantly affect liquid movement and retention behaviors through fiber swelling.

Fiber swelling not only increases liquid retention in the fibers at the expense of the capillary liquid capacity in interfiber pores, but also complicates the pore structure. This swelling of the fibers can cause bottlenecking or the closing off of capillaries, which in turn causes the flow in those capillaries to be slow or even stop. It is well known that this type of response to moisture is prevalent in yarns made of cellulosic fibers. Also, yarns spun with natural fibers have very irregular capillaries due to various factors such as fiber roughness, cross-sectional shape and length [69].

It can be generalized that the requisites for a good wicking fabric include stiff fibers, uniformity of structure, and resistance of the structure to collapse. Also, the fibers should not be swollen by the liquid being wicked [70].

CHAPTER 3

MATERIALS AND METHOD

3.1. Introduction

100% Soybean yarn and 100% organic cotton yarn with three different yarn number were used. The yarn numbers of soybean yarns are Ne 20/1, Ne 32/1, and Ne 40/1. The yarn numbers of organic cotton yarns are Ne 20/1, Ne 30/1, and Ne 40/1.

Organic cotton yarns are taken from Başyazıcıoğlu Textile Mills at Kayseri. Soybean yarns are obtained from Hayteks Textile Mills at Ankara. The sample fabrics using these six yarns were knitted on sample circular knitting machine in Selçuk Tekstil / Gaziantep.

The air permeability tests were done on six samples by using the air permeability test instrument in Textile Engineering Department of University of Gaziantep. Also water permeability and wicking tests were done on six samples in here.

Thermal comfort tests were done at Technical University of Liberec, Czech Rebuclic. These were thermal resistance, thermal conductivity and thermal absorbtivity.

Fabric properties were analyzed and calculated in the Textile Engineering Department of University of Gaziantep. Fabric thickness, fabric density, fabric weight were calculated by manually at laboratory condition.

3.2. Materials

3.2.1. Yarns

Table 3.1 shows yarn type and count which were used in the study.

Table 3.1 Yarn type and yarn count

Material (Yarn Type)	Yarn Count (Ne)
100% Soybean	20/1
100 % Soybean	32/1
100% Soybean	40/1
100% Cotton (organic)	20/1
100% Cotton (organic)	30/1
100% Cotton (organic)	40/1

3.2.2. Knitting machine

All yarns were knitted using the sample knitting machine. The machine specifications were given in Table 3.2.

Table 3.2 Machine Specification

Machine manufacturer	Ipm by ipekçioğlu faycan CKM-1-S
Machine type	Circular knitting machine
Types of bed	Single bed
Fein(gauge)	16 E
Diameter(inch)	3,5
Number of needles	195
Direction of machine rotation	Counter clock wise

3.2.3. Knitted samples

Six samples were collected in two groups:

1. Group samples: 100% Soybean knitted fabric (Table 3.3)

Table 3.3 1.Group samples: 100% Soybean knitted fabric

Number	**Fabric Code**	**Yarn Count(Ne)**	**Fabric Composition (100%)**
1.Sample	1-A	Ne 20	(100%) Soybean knitted fabric
2. Sample	2-A	Ne 32	(100%) Soybean knitted fabric
3.Sample	3-A	Ne 40	(100%) Soybean knitted fabric

2. Group samples: 100% Organic cotton knitted fabric (Table 3.4)

Table 3.4 2.Group samples: 100% Organic cotton knitted fabric

Number	**Fabric Code**	**Yarn Count(Ne)**	**Fabric Composition (100%)**
1.Sample	1-B	Ne 20	(100%) Organic cotton knitted fabric
2. Sample	2-B	Ne 30	(100%) Organic cotton knitted fabric
3.Sample	3-B	Ne 40	(100%) Organic cotton knitted fabric

For vertical wicking test two samples of each fabric were taken and tested, so 12 samples were obtained.

3.3. Test Instruments and Methods

Air permeability ($air\ per$), water vapor permeability (VWP), wicking and thermal comfort tests (Thermal conductivity (λ), Thermal resistance (r), and Thermal absorbtivity (b)) was done on samples.

3.3.1. M021A SDL ATLAS Air Permeability Tester

The Digital Air Permeability Tester M021A given in Figure 3.1 accurately and swiftly determines the resistance of fabrics (woven, knitted, and non-woven textile materials) to the passage of air (air flow) under constant pre-set air pressure while clamped in the test rig of selected test head/area [73].

The specimen is loaded to the test area of the instrument easily by means of a clamping lever. By pressing down the clamping arm to start the test, a powerful muffled vacuum pump draws air through an interchangeable test head with a circular opening. The pre-selected test pressure is automatically maintained and, after a few seconds, the air permeability of the test specimen is digitally displayed in the pre-selected unit of measure. By pressing down the clamping arm a second time the test specimen is released and the vacuum pump is shut off. Sample Holders. A $200\ cm^2$ test head is included with the instrument [73].

Figure 3.1 M021A SDL ATLAS Air permeability tester [73]

5 sq. cm test area, 20 sq. cm test area, 25 sq. cm test area, 38 sq. cm test area, 50 sq. cm test area, 100 sq. cm test area.

M021A Air Permeability Tester was used in the study. ASTM D737-75(1980) standard test method was used for air permeability of textile fabrics. The samples were placed on head of tester which had $20\ cm^2$ area and air was passed with 100

Pa. The values were recorded by computer system. The test was employed on each sample for 10 times. After 10 times, the average value was taken [73].

A circle of fabric is clamped into the tester and through the use of a vacuum; the air pressure is made different on one side of the fabric. Airflow will occur from the side with higher air pressure, through the fabric, to the side with the lower air pressure. From this rate of air flow, the air permeability of the fabric is determined. Sample Preparation was done by following procedure;

1. When cutting specimens, avoid wrinkles, folds or creases.

2. Avoid getting oil, water, grease, etc. on the specimens when handling.

3. For scientific testing, 10 samples are used.

5. Use specimens representing a broad distribution across length and width, preferably along the diagonal of the fabric [73].

3.3.2. ALAMBETA

The apparatus used in this study enables the measurement of the following thermal parameters as shown in Figure 3.2: thermal conductivity, thermal absorbtivity, thermal resistance and sample thickness.

The Alambeta basically simulates the dry human skin and its principle depends in mathematical processing of time course of heat flow passing through the tested fabric due to different temperatures of bottom measuring plate (22°C) and measuring head (32°C) [74].

When the measurement starts, the measuring head down and touches the planar measured sample which is located on the instrument base under the measuring head. In this moment, the surface temperature of the sample suddenly changes and the instrument registers the heat flow course. Simultaneously, sample thickness is measured. All the data are then processed in the computer according to an original programming. [74]

Figure 3.2 Computer controlled instrument ALAMBETA for fast measurement of thermal insulation and thermal contact properties of flat textiles. [74]

The simplified scheme of the instrument is shown on Figure 3.3. The principle of first version of this instrument depends in the application of ultra thin heat flow sensor 4, which is attached to a metal block 2 with constant temperature, which differs from the sample temperature. When the measurement starts, the measuring head 1 containing the mentioned heat flow sensor drops down and touches the planar measured sample *5*, which is located on the instrument base 6 under the measuring

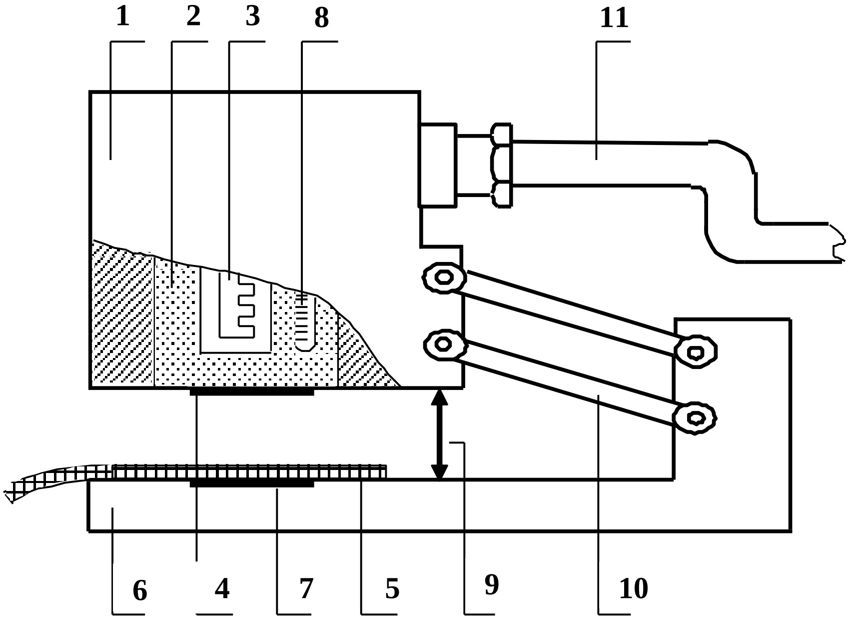


Figure 3.3 Schematic of Alambeta Instrument [75]

head. In this moment, the surface temperature of the sample suddenly changes and the instrument computer registers the heat flow course. Simultaneously, a photoelectric sensor measures the sample thickness. All the data are then processed in the computer according to an original programming, which involves the mathematical model characterising the transient temperature field in thin slab subjected to different boundary conditions [74]. To simulate the real conditions of warm-cool feeling evaluation, the instrument measuring head is heated to 32ºC (see the heater 3 and the thermometer 8), which correspond to the average human skin temperature, while the fabric is kept at the room temperature 22ºC. Similarly, the time constant of the heat flow sensor, which measures directly the heat flow between the automatically moved measuring head and the fabrics, exhibit similar value (0,07 sec), as the human skin.. Thus, the full signal response is achieved within 0,2 sec. The validity of thermal absorptivity as a new warm-cool feeling parameter of fabrics was confirmed by several tests where the results of relative subjective feeling of 100 persons were compared with the values of thermal absorptivity found by means of the ALAMBETA instrument, see in [75]. Within various research projects the thermal-insulation and thermal-contact properties of all common textile products were experimentally investigated.

3.3.3 Water Vapor Permeability Test

Water permeability test was done at laboratory condition by using BS7209 standard test method. Three samples fabric were taken from each main six fabric samples. So, eighteen samples were available. First of all samples were prepared according to standard. The samples were cut at 14 cm and 14.8 cm. Eighteen glass cases were used and the cases were filled with distillated water and the cases were covered and the space between fabric and water was 10 mm. Prepared glass cases were weighted and waited at laboratory condition for 24 hour. After 24 hour the cases were weighted again. The difference showed the amount of water permeability ratio. The water permeability ratio was calculated by using this equation. The unit was $gm^2 / hour$.

$$WVP = 24 * M / (A * t) \qquad (2.1)$$

Where M represents the mass difference, A is area of samples and t denotes passed time.

3.3.4. Vertical Wicking Test:

Tests were done by using DIN 53924 standard conditions. Two samples of each of six main samples were prepared at the same area. Length and width of samples were 8x1 inch. We had 12 samples. A glass case was filled with diluted water and each sample was immobilized on the glass case by using an apparatus and contacted with diluted water in the glass case only at 1 cm. After $2,5,10, \text{and} 15\, \text{minutes}$ the samples were get out of and the wetted area was measured by using ruler and the values were recorded.

3.3.5. Fabric Properties

Fabric thickness, fabric weight and density were measured by manually at laboratory condition according to TS7128-ENISO5084 standard condition. First of all fabric thickness and weighs were measured for each samples. According to thickness and weight values, density was calculated as; (fabric weight / fabric thickness).

3.4. Statistical Analyses

For statistical analysis of results and to derive regression models between comfort properties and fabric structural characteristics, the demo programming of Minitab was used. In statistical analysis, Mallows' Cp, named for Colin Mallows, is often used as a stopping rule for various forms of stepwise regression. Mallows proposed the statistic as a criterion for selecting among many alternative subset regressions [76]. It is oversimplified to think that the "best" model is the minimized of Cp. The “s” (square root of Mean Squared Error) is the error standard deviation. A good model should have small s, and Mallows' Cp, close to the number of predictors plus the constant contained in the model [76].

The Best-Subsets Regression tables (coefficient tables) were given to list the estimated coefficients for the predictors of each response (either comfort or structural property). Linear regression examines the relationship between a response and predictor(s) . When the best subsets of each predictor(s) and response pair according to Cp and s values were obtained, we tried to determine whether or not the observed relationship between the response and predictors was statistically significant. For this, we need to [77]:

- Identify the coefficient p-values: The coefficient value for P (p-value) tells you whether or not the association between the response and predictor(s) is statistically significant [77].
- Compare the coefficient p-values to our level: If the p-value is smaller than the level we have selected, the association is statistically significantly. A commonly used a-level is 0.05 [77].

P-Regression was used to test the hypothesis that all the coefficients in the model are zero (non-significant). A smaller p-value than a pre-selected level (0.05) implies that at least one coefficient in the model is not zero (significant) [77].

CHAPTER 4

RESULT AND DISCUSSION

4.1. Air Permeability

The experimental study was carried out on raw material samples. Table 4.1 and Figure 4.1.show the air permeability test results. The fifteen tests of each sample were done and the average values were taken with calculation CV%.

The results show as the yarn fineness increase and the fabric thickness decrease, air permeability values increase, respectively. The samples of soybean fabrics have better air permeability than that of organic cotton.

Table 4.1 Air permeability of the samples

Fabric Samples	Air Permeability (mm/s)	CV (%)
1-A	1912,00	5,00
2-A	3010,00	10,09
3-A	3698,66	7,67
1-B	2018,00	12,24
2-B	2126,00	11,58
3-B	3326,00	8,07

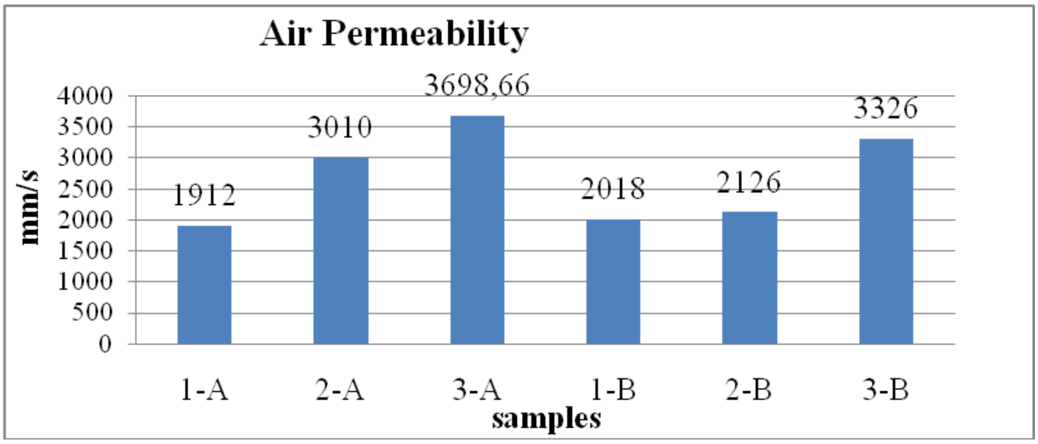


Figure 4.1 Air permeability test results

4.2. Results of the Alambeta

The thermal comfort tests on samples were done at Technical University of Liberec, Czech Republic. The thermal resistance, thermal conductivity, thermal absorbsivity were measured by using Alambeta instrument that mentioned at materials and instruments part given in Table 4.2.

Table 4.2 Alambeta test result

FABRIC CODE	$r*10^3 (m^2W/K)$ Thermal resistance	$\lambda*10^3 (W/mK)$ Thermal conductivity	$b*10^3 (Ws/m^2K)$ Thermal absorbtivity
1-A	12,335	38,1	90,5
CV (%)	12,28	1,4	2,5
2-A	10,382	36,6	89,3
CV (%)	3,38	0,6	5,5
3-A	9,565	34,5	77,7
CV(%)	2,88	4,2	5,6
1-B	11,007	42,7	94,3
CV (%)	4,72	2,6	0,7
2-B	10,696	40,2	87
CV (%)	3,60	2,4	7,7
3-B	9,0909	37,4	71,4
CV (%)	1,49	1,4	3,2

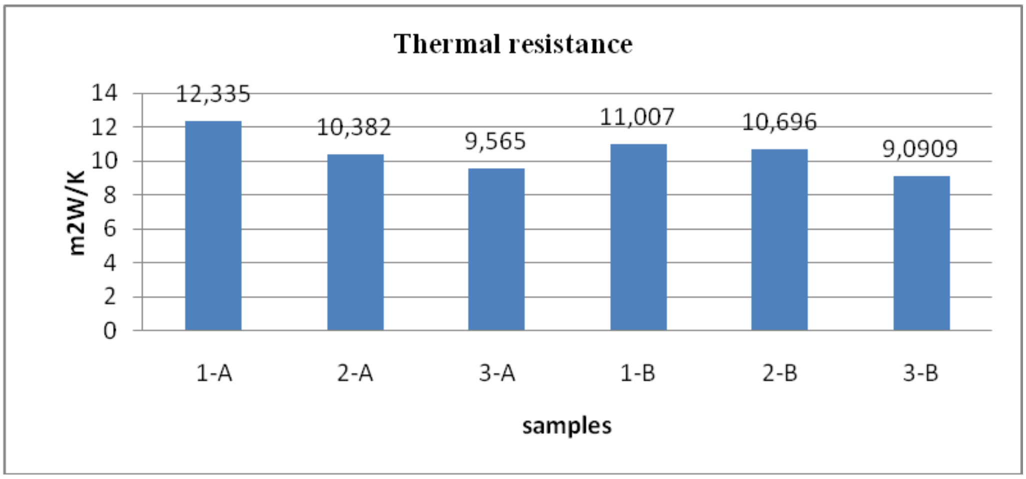


Figure 4.2 Thermal Resistance Test Result

The results show as the fabric thickness decreases, thermal resistance also decreases. The samples of soybean gave generally higher thermal resistance values. (Figure 4.2) Figure 4.3 illustrates that organic cotton yarns have high level thermal conductivity than soybean yarns. Also, coarse yarns show better thermal conductivity than finer yarns. Heavier fabrics that contain thinner air layer have higher thermal conductivity.

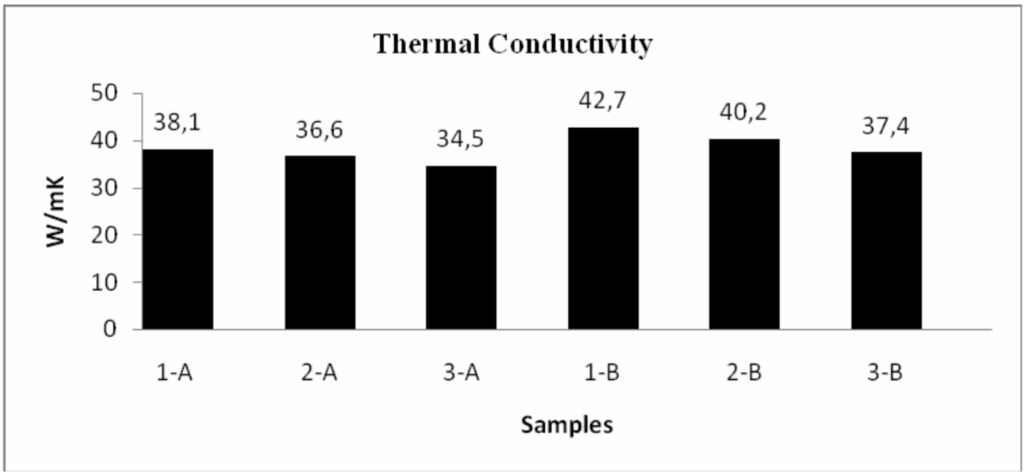


Figure 4.3 Thermal Conductivity Test Result

Figure 4.4 represents that coarse yarns show better thermal absorbtivity than finer yarns. Also, soybean yarns show high level thermal absorbtivity than cotton(organic)yarns generally. Only Ne 20 cotton yarn was higher than Ne 20 soybean yarn.

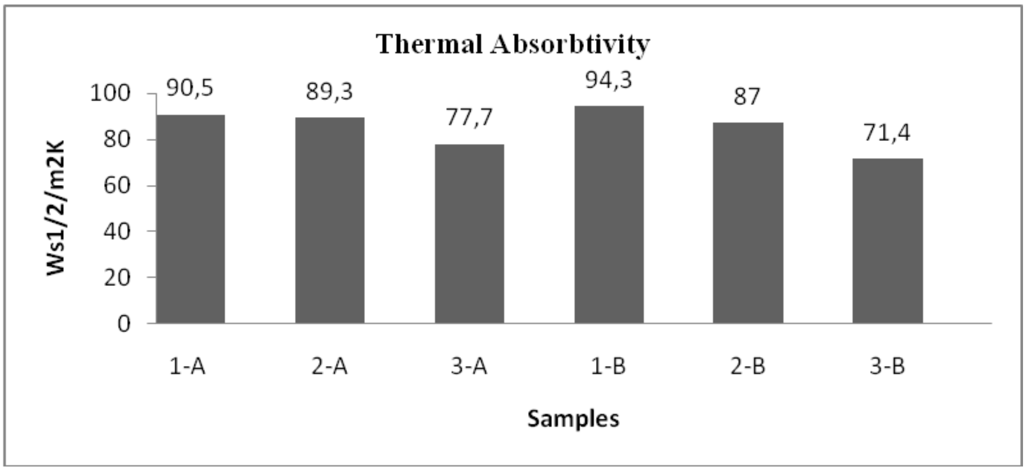


Figure 4.4 Thermal Absorbtivity Test Result

4.3. Fabric Structural Characteristics

Fabric structural characteristics are given in Table 4.3. Fabric densities of soybean yarns were lower than organic cotton yarns generally.

Table 4.3 Fabric Structural Characteristics

Samples	Weight(g/m2)	CV(%)	Thickness (mm)	CV(%)	Density(g/cm3)	CV(%)
1-A	139,43	1,97	0,47	3,22	0,295	2,92
2-A	100,10	1,02	0,38	3,01	0,261	3,37
3-A	82,08	6,37	0,33	1,73	0,246	5,76
1-B	141,39	2,35	0,47	2,43	0,299	1,16
2-B	116,47	4,53	0,42	1,35	0,272	3,67
3-B	78,47	4,15	0,34	2,94	0,230	3,81

4.4. Vertical Wicking

Longitudinal wicking tests carried out supplied the information of liquid rise on the fabrics in lengthwise direction in a short period of time.

Longitudinal wicking test results were given below in Table 4.4. It can be seen that all types of soybean yarns show higher wicking level than all types of organic cotton yarns. And also, if we look at the yarn count Ne 20 yarn count shows the maximum height among other yarn count for both yarn types. Then, if we compare the separately, Ne 20 soybean yarns show the maximum wicking level among the fabrics tested (Figure 4.5).

Table 4.4 Wicking Test Result

samples	After 2 min(cm)	After 5 min(cm)	After 10 min(cm)	After 15 min(cm)
1-A	6,35	9,95	13,15	15,85
2-A	5,9	9,25	11,95	14,25
3-A	5,7	9,1	11,6	14,1
1-B	5,85	9,25	11,4	13,5
2-B	4,7	8,2	10,9	13,25
3-B	3,6	6,5	10,5	12,25

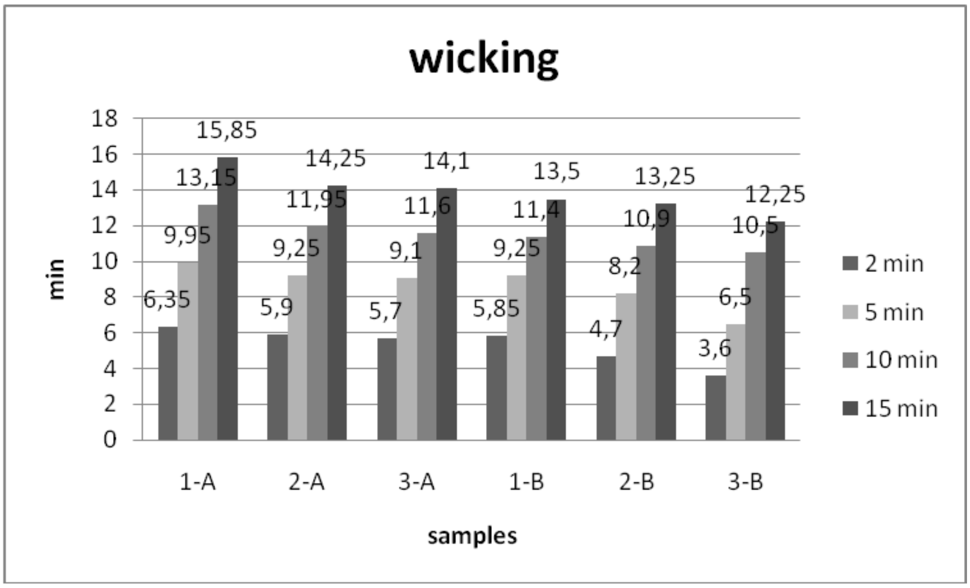


Figure 4.5 Wicking Test Result

4.5. Water Vapor Permeability

It is obvious from both Table 4.5 and Figure 4.6 that soybean yarn the best level was obtained at Ne 32 soybean yarn and Ne 40 cotton (organic) yarn.

Table 4.5 Water Vapor Permeability Test Result

Water Vapor Permeability		
Fabric Code	WVP(g/m2day)	CV(%)
1-A	649,94	0
2-A	682,43	20,2
3-A	541,61	6,9
1-B	610,,27	3,89
2-B	600,95	5,58
3-B	685,31	13

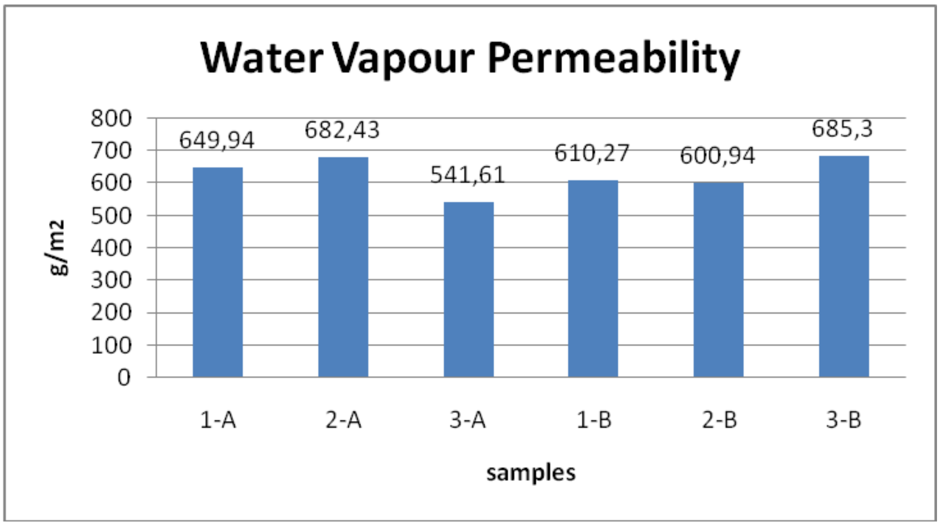


Figure 4.6 Water vapor permeability test result

4.6. Minitab results

4.6.1. Air permeability

When the air permeability of samples were analyzed with the other comfort properties (thermal conductivity, thermal absorstivity, thermal resistance, wicking and WVP values.) the lowest Cp and s values were obtained by the contribution of thermal conductivity and thermal resistance.(Table 4.6) So we concluded that air permeability of the samples was strongly related with thermal conductivity and resistance.

Table 4.6 Best Subsets Regression of Air Permeability

Best Subsets Regression:
Predictors: thermal conductivity(λ) ; thermal absorbsivity(b); thermal resistance(r); wicking; water vapor permeability(WVP)
Response: Air permeability

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	λ	b	r	wicking	WVP
1	50,7	47,6	32	480,62			X		
2	**85,5**	**83,6**	**1,5**	**269,23**	**X**		**X**		
3	87,1	84,3	2,1	263,37	X		X	X	
4	87,1	83,2	4	272,42	X	X	X	X	
5	87,2	81,8	6	283,33	X	X	X	X	X

Thus, the regression equation was obtained between air permeability and thermal conductivity and thermal resistance as following:

$$air\ per = 10734 - 115 * \lambda - 356 * \mathrm{r} \tag{4.1}$$

The regression Equation 4.1 shows that there is an inverse relation between air permeability and thermal conductivity and also thermal resistance. P-values of the regression equation and analysis of variance were given in Table 4.7 and Table 4.8.

Table 4.7 Regression Analysis of air permeability

Regression Analysis: air per versus; thermal conductivity; thermal resistance

Predictor	coef	SE Coef	T	P

Constant	10734,3	897,8	11,96	0,000
λ	-114,51	19,09	-6,00	0,000
r	-355,99	49,13	-7,25	0,000

Table 4.8 Analysis of Variance of air permeability

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	2	6412300	3206150	44,23	0,000
Residual Error	15	1087288	72486		
Total	17	749588			

Table 4.7 illustrated the contribution of thermal conductivity and thermal resistance of whole samples on air permeability is significant.

When the air permeability was analyzed with fabric structural properties (yarn count, thickness, weight and fiber density), we found that the best subset regression was between air permeability and only fabric thickness (Table 4.9). Since, the contribution of fiber density can be neglected; we concluded that the variation in fiber type (soybean or organic cotton) was not significantly important selecting criteria on air permeability. Air permeability can be adjusted strongly by the changes at fabric thickness.

Table 4.9 Best Subsets Regression of air permeability

Best Subsets Regression

Predictors : yarn count(Ne); Thickness; fiber density, weight

Response : air permeability

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ne	Thickness	Fiber density	weight
1	**82,3**	**81,2**	**0,6**	**288,35**		**X**		
2	83,7	81,6	1,3	285,04		X	X	

3	80,5	80,5	3,2	293,66		X	X	X
4	84,2	79,3	5	302,35	X	X	X	X

Thus, the regression equation was obtained between air permeability fabric thickness as following:

$$air\ per = 6696 - 10119 * \text{thickness} \tag{4.2}$$

The regression Equation 3.2 shows there is an inverse relation between air permeability and thickness.

P-values of the regression equation and analysis of variance were given in Table 4.10 and Table 4.11.

Table 4.10 Regression Analysis of air permeability

Regression Analysis: air per versus; Thickness				
Predictor	coef	SE Coef	T	P
Constant	6696	480,6	13,93	0,000
Thickness	-10119	1175	-8,61	0,000

Table 4.11 Analysis of Variance of air permeability

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	1	6169243	6169243	74,2	0,000
Residual Error	16	1330345	83147		
Total	17	7499588			

Table 4.10 showed the contribution of thickness on air permeability was significant and important for both soybean and organic cotton samples.

4.6.2. Thermal Conductivity

When the thermal conductivity(λ) of samples were analyzed with the other comfort properties (thermal conductivity, thermal absorstivity, thermal resistance, wicking and WVP values.) the lowest Cp and s values were obtained by the contribution of thermal absorbsivity, thermal resistance and air permeability (Table 4.12). So we concluded that thermal conductivity of the samples was strongly related with thermal absorbsivity, thermal resistance and air permeability.

Table 4.12 Best Subsets Regression of thermal conductivity

Best Subsets Regression:

Predictors: thermal absorbtivity(b), thermal resistance(r) , wicking and water vapor permeability(WVP)

Response :thermal conductivity

Vars	**R-Sq**	**R-Sq(adj)**	**Mallows Cp**	**S**	**b**	**r**	**air per.**	**wicking**	**WVP**
1	36,8	32,9	27,3	2,8023	x				
2	70,6	66,7	7,2	1,9753		x	x		
3	**81,5**	**77,5**	**2,1**	**1,6222**	**x**	**x**	**x**		
4	81,6	76	4	1,6769	x	x	x	x	
5	81,6	74	6	1,7444	x	x	x	x	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the thermal conductivity and thermal absorbsivity, thermal resistance and air permeability.

Thus, the regression equation was obtained between air permeability and thermal conductivity and thermal resistance as following:

$$\lambda = 58,6 + 0,189 * \mathrm{b} - 2,31 * \mathrm{r} - 0,00465 * \mathrm{air\ per} \tag{4.3}$$

The regression Equation 4.3 shows there is a direct relation between thermal absorbsivity and inverse relation with thermal resistance and air permeability.

P-values of the regression equation and analysis of variance were given in Table 4.13 and Table 4.14.

Table 4.13 Regression Analysis of thermal conductivity

Regression Analysis: thermal conductivity versus thermal absorbsivity; thermal resistance; air per

Predictor	Coef	SE Coef	T	P

Constant	58,568	9,043	6,48	0,000
b	0,18924	0,06592	2,87	0,012
r	-2,3114	0,4236	-5,46	0,000
air per.	-0,0046455	0,0009959	-4,66	0,000

Table 4.14 Analysis of Variance of thermal conductivity

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	3	162,116	54,039	20,54	0,000
Residual Error	14	36,84	2,631		
Total	17	198,956			

Table 4.13 showed the contribution of thermal absorbsivity, thermal resistance and air permeability on thermal conductivity were significant and important for both soybean and organic cotton samples.

When the thermal conductivity was analyzed with fabric structural properties (yarn count, thickness, weight and fiber density), we found that the best subset regression was between thermal conductivity and fabric thickness, weight and fiber density. The contribution of fiber density, weight and thickness are significant (Table 4.15). We concluded that the variation in fiber type (soybean or organic cotton) was important selecting criteria on thermal conductivity. Thermal conductivity can be adjusted strongly by the changes at fiber type.

Table 4.15 Best Subsets Regression of thermal conductivity

Best Subsets Regression: **Predictors:** Ne; Thickness; Fiber Density; weight **Response** :Thermal conductivity									
Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ne	Thickness	Fiber density	weight	
1	41,3	37,7	12,6	2,7009		x			
2	63,3	58,4	4,6	2,2061		x	X		
3	**70,5**	**64,2**	**3,4**	**2,0463**		**x**	**X**	**X**	

4	71,3	62,5	5	2,0953	x	x	X	X	

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the thermal conductivity and fabric thickness, weight and fiber density as following:

$$\lambda = -6{,}81 + 126 * \text{thickness} + 12{,}6 * \text{fiber density} - 0{,}215 * \text{weight} \tag{4.4}$$

The regression Equation 4.4 shows there is a direct relation between fabric thickness and fiber density and inverse relation between fabric weights.

P-values of the regression equation and analysis of variance were given in Table 4.16 and Table 4.17.

Table 4.16 Regression Analysis of thermal conductivity

Regression Analysis: thermal conductivity versus thickness; density; weight				
Predictor	Coef	SE Coef	T	P
Constant	-6,808	9,009	-0,76	0,462
Thickness	126,27	51,01	2,61	0,027
Density	12,576	4,822	2,61	0,021
Weight	-0,2155	0,1163	-1,85	0,085

Table 4.17 Analysis of Variance of thermal conductivity

Analysis of Variance					
Source	DF	SS	MS	F	B
Regression	3	140,336	46,779	11,17	0,001
Residual Error	14	58,62	4,187		
Total	17	198,956			

The lowest P values were seen at thickness and fiber density so it is obtained that the contributions of fabric thickness and also fiber density on thermal conductivity are stronger and fabric thermal conductivity depends on raw material.

Tables 4.16 showed the contribution of thickness and density on thermal conductivity were significant and important for both soybean and organic cotton samples.

4.6.3. Thermal Resistance

When the thermal resistance(r) of samples were analyzed with the other comfort properties (thermal conductivity, thermal absorstivity, wicking and WVP values.) the lowest Cp and s values were obtained by the contribution of thermal conductivity, wicking and air permeability (Table 4.18). So we concluded that thermal resistances of the samples were strongly related with thermal conductivity, wicking and air permeability.

Table 4.18 Best Subsets Regression of thermal resistance

Best Subsets Regression:

Predictors: thermal conductivity(λ); thermal absorbtivity(b); air per; wicking; water vapor permeability(WVP)

Response :thermal resistance(r)

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	λ	b	air per.	wicking	WVP
1	53	50,1	32,4	0,93882					
2	77,8	74,8	10	0,66698	X		X		
3	**87**	**84,2**	**2,9**	**0,52833**	**X**		**X**	**X**	
4	87,8	84,1	4	0,53019	X	X	X	X	
5	87,9	82,8	6	0,55117	X	X	X	X	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the thermal resistance and thermal conductivity, wicking and air permeability.

Thus, the regression equation was obtained between thermal resistance and thermal conductivity wicking and air permeability as following:

$$\mathrm{r} = 16{,}2 - 0{,}180 * \lambda - 0{,}00170 * \text{air per} + 0{,}410 * \text{wicking} \qquad (4.5)$$

The regression Equation 4.5 illustrates there is an inverse relation between thermal conductivity and air permeability. And direct relation between wicking.

P-values of the regression equation and analysis of variance were given in Table 4.19 and Table 4.20.

Table 4.19 Regression Analysis of thermal resistance

Regression Analysis: thermal resistance versus ;thermal conductivity, air permeability, wicking				
Predictor	Coef	SE Coef	T	P
Constant	16,201	3,761	4,31	0,001
λ	-0,18036	0,05141	-3,51	0,003
air per	-0,0017016	0,0002839	-5,99	0,000
wicking	0,4101	0,1303	3,15	0,007

Table 4.20 Analysis of Variance of thermal resistance

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	3	26,1215	8,7072	31,19	0,000
Residual Error	14	3,9079	0,2791		
Total	17	30,0293			

When the thermal resistance was analyzed with fabric structural properties (yarn count, thickness, weight and fiber density), we found that the best subset regression was between thermal resistance and fabric weight and fiber density. The contribution of fiber density and weight are significant (Table 4.21). We concluded that the variation in fiber type (soybean or organic cotton) was important selecting criteria on thermal resistance. Thermal resistance can be adjusted strongly by the changes at fiber type.

Table 4.21 Best Subsets Regression of thermal resistance

Best Subsets Regression: **Predictors:** Ne; Thickness; Fiber Density; weight **Response :**thermal resistance								
Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ne	Thickness	Fiber density	weight
1	65,3	63,1	7,8	0,80751				X
2	**77,7**	**74,8**	**1,9**	**0,66757**			**X**	**X**
3	78,8	74,3	3,3	0,67406		X	X	X
4	79,2	72,9	5	0,69239	X	X	X	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the thermal resistance and fabric weight and fiber density.

Thus, the regression equation was obtained between the thermal resistance and fabric weight and fiber density as following:

$$r = 11{,}9 - 4{,}37 * \text{fiber density} + 0{,}0431 * \text{weight} \tag{4.6}$$

The regression Equation 4.6 shows there is a direct relation between fabric weight and inverse relation between fiber densities.

P-values of the regression equation and analysis of variance were given in Table 4.22 and Table 4.23.

Table 4.22 Regression Analysis of thermal resistance

Regression Analysis: thermal resistance versus; density; weight				
Predictor	Coef	SE Coef	T	P

Constant	11,919	2,152	5,54	0,000
fiber density	-4,366	1,506	-2,9	0,011
Weight	0,043092	0,006264	6,88	0,000

So the lowest P value was seen at weight variable. So we can say that there is the best relationship between thermal resistance and weight. And also selection of fiber type affects the thermal resistance of fabric.

Table 4.23 Analysis of Variance of thermal resistance

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	2	23,345	11,672	26,19	0,000
Residual Error	15	6,685	0,446		
Total	17	30,029			

Tables 4.22 showed the contribution of weight and density on thermal resistance were significant and important for both soybean and organic cotton samples.

4.6.4. Thermal Absorbtivity

When the thermal absorbtivity of samples were analyzed with the other comfort properties (thermal conductivity, thermal resistance, wicking and WVP values.) the lowest Cp and s values were obtained by the contribution of thermal conductivity, wicking (Table 4.24). So we concluded that thermal absorbtivity of the samples were strongly related with thermal conductivity and wicking.

Table 4.24 Best Subsets Regression of thermal absorbsivity

Best Subsets Regression:

Predictors: thermal conductivity(λ); thermal resistance(r); air per; wicking; water vapor permeability(WVP)

Resistance: thermal absorbtivity(b)

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	λ	r	air per.	wicking	WVP
1	49,3	46,1	9,1	6,181			X		
2	**69,6**	**65,6**	**1,8**	**4,9426**	**X**			**X**	

3	73,2	67,5	2,2	4,8036	X	X		X	
4	73,5	65,3	4,1	4,9601	X	X		X	X
5	73,7	62,7	6	5,1443	X	X	X	X	X

So we selected the thermal conductivity and wicking for equation.

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the thermal absorbtivity and thermal conductivity, wicking.

Thus, the regression equation was obtained between thermal absorbtivity and thermal conductivity and wicking as following:

$$b = -34{,}5 + 1{,}64 * \lambda + 4{,}12 * \text{wicking} \qquad (4.7)$$

The regression Equation 4.7 shows there is a direct relation between thermal conductivity and wicking.

P-values of the regression equation and Analysis of variance were given in Table 4.25 and Table 4.26.

Table 4.25 Regression Analysis of thermal absorbtivity

Regression Analysis: thermal absorbtivity versus; thermal conductivity;wicking				
Predictor	coef	SE Coef	T	P
Constant	-34,47	20,58	-1,68	0,115
Λ	1,6406	0,3523	4,66	0,000
Wicking	4,123	1,025	4,02	0,001

Table 4.26 Analysis of Variance of thermal absorbtivity

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	2	839,45	419,73	17,18	0,000
Residual Error	15	366,45	24,43		
Total	17	1205,9			

The lowest P value was seen on thermal conductivity. So we can say that there is best relationship between thermal absorbtivity and thermal conductivity.

When the thermal absorbtivity was analyzed with fabric structural properties (yarn count, thickness, weight and fiber density), we found that the best subset regression was between thermal absorbsivity and yarn count (Ne). The contribution of yarn count was significant (Table 4.27). We concluded that the variation in yarn count (soybean or organic cotton) was important selecting criteria on thermal absorbsivity. Thermal absorbsivity can be adjusted strongly by the changes at yarn count.

Table 4.27 Best Subsets Regression of thermal absorbsivity

Best Subsets Regression:

Predictors: Ne; Thickness; Fiber Density; weight

Response : thermal absorbtivity

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ne	Thickness	Fiber density	weight
1	**68,7**	**66,7**	**1,3**	**4,8594**	**X**			
2	70,7	66,7	2,3	4,8568	X			X
3	72,1	66,1	3,6	4,9041	X	X		X
4	73,4	65,2	5	4,9709	X	X	X	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the thermal absorbtivity and yarn count. Thus, the regression equation was obtained between the thermal absorbsivity and yarn count as following:

$$b = 110 - 0{,}827\ Ne \quad (4.8)$$

The regression Equation 4.8 shows there is an inverse relation between thermal absorbsivity and yarn count.

P-values of the regression equation and analysis of variance were given in Table 4.28 and Table 4.29.

Table 4.28 Regression Analysis of thermal absorbtivity

Regression Analysis: thermal absorbsivity versus; Ne

Predictor	coef	SE Coef	T	P
Constant	110,391	4,39	25,15	0,000
Ne	-0,8273	0,1397	-5,92	0,000

Table 4.29 Analysis of Variance of thermal absorbtivity

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	1	828,08	828,08	35,07	0,000
Residual Error	16	377,82	23,61		
Total	17	1205,9			

Table 4.28 showed the contribution of yarn count on thermal absorbtivity were significant and important for both soybean and organic cotton samples.

4.6.5. Wicking

When the wicking of samples were analyzed with the other comfort properties (thermal conductivity, thermal resistance, thermal absorbsivity, air permeability and WVP values.) the lowest Cp and s values were obtained by the contribution of thermal absorbsivity, thermal resistance and air permeability (Table 4.29). So we concluded that wicking of the samples was related with thermal absorbtivity, thermal resistance and air permeability.

Table 4.30 Best Subsets Regression of wicking

Best Subsets Regression:

Predictors: thermal conductivity(λ), thermal absorbtivity(b); thermal resistance(r); air permeability; water vapor permeability(WVP)

Response : wicking

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	λ	b	r	air per	WVP
1	53	50,1	3,4	0,83026			X		
2	57,3	51,6	3,8	0,81761			X	X	
3	**65,2**	**57,8**	**2,9**	**0,76388**		**X**	**X**	**X**	

4	67,5	57,5	4,1	0,76657		X	X	X	X
5	67,7	54,2	6	0,79556	X	X	X	X	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the wicking and thermal absorbsivity, thermal resistance and air permeability.

Thus, the regression equation was obtained between the wicking and thermal absorbsivity, thermal resistance and air permeability as following:

$$\text{Wicking} = -\,1{,}80 + 0{,}0554\ b + 0{,}795\ r + 0{,}000965\ \text{air per} \qquad (4.9)$$

The regression Equation 4.9 shows there is an inverse relation between wicking and thermal absorbsivity, thermal resistance and air permeability.

P-values of the regression equation and Analysis of variance were given in Table 4.31 and Table 4.32.

Table 4.31 Regression Analysis of wicking

Regression Analysis: wicking versus; b; r; air per				
Predictor	coef	SE Coef	T	P
Constant	-1,795	4,258	-0,42	0,68
b	0,05539	0,03104	1,78	0,096
r	0,7952	0,1995	3,99	0,001
air per	0,000965	0,000469	2,06	0,059

Table 4.32 Analysis of Variance of wicking

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	3	15,3169	5,1056	8,75	0,000
Residual Error	14	8,1692	0,5835		
Total	17	23,4861			

Table 4.30 shows there is inverse ratio between wicking and other three parameters. And also we can see there is best relationship between wicking and thermal resistance because P value become zero nearly.

When the wicking of the samples was analyzed with fabric structural properties (yarn count, thickness, weight and fiber density), we found that the best subset regression was between wicking and fabric thickness and fiber density. The contribution of fabric thickness and fiber density were significant. We concluded that the variation in fabric thickness and fiber density (soybean or organic cotton) were important selecting criteria on wicking (Table 4.33). Wicking can be adjusted strongly by the changes at fabric thickness and fiber type.

Table 4.33 Best Subsets Regression of wicking

Best Subsets Regression:
Predictors: Ne; Thickness; Fiber density, weight
Response :wicking

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ne	Thickness	Fiber density	weight
1	59,8	57,3	141,9	0,76816			X	
2	**96,5**	**96**	**1,6**	**0,23448**		**X**	**X**	
3	96,6	95,8	3,3	0,24017		X	X	X
4	96,6	95,6	5	0,24606	X	X	X	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the wicking and fabric thickness, fiber density Thus, the regression equation was obtained between the wicking and fabric thickness and fiber density as following:

$$\text{Wicking} = 22{,}0 + 12{,}1\ \text{Thickness} - 9{,}37\ \text{Fiber Density} \quad (4.10)$$

The regression Equation 4.10 shows there are an inverse relation between wicking and fiber density and direct relation with fabric thickness.

P-values of the regression equation and analysis of variance were given in Table 4.34 and Table 4.35.

Table 4.34 Regression Analysis of wicking

Regression Analysis: wicking versus; thickness; density				
Predictor	coef	SE Coef	T	P
Constant	22,0071	0,7892	27,88	0,000
Thickness	12,0847	0,9653	12,52	0,000
Density	-9,3718	0,5319	-17,62	0,000

Table 4.35 Analysis of Variance of wicking

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	2	22,661	11,331	206,09	0,000
Residual Error	15	0,825	0,055		
Total	17	23,486			

Table 4.34 showed the contribution of fabric thickness and fiber density on air wicking were significant and important for both soybean and organic cotton samples.

The P values of both are zero. It means that there is strong relation between them.
And also we can say that fiber type is important for wicking analysis.

4.6.6. Water Vapor Permeability

When the water vapor permeability of samples were analyzed with the other comfort properties (thermal conductivity, thermal resistance, thermal absorbsivity, air permeability and wicking values.) the lowest Cp and s values were obtained by the contribution of air permeability and wicking (Table 4.36). So we concluded that water vapor permeability of the samples were related with air permeability and wicking.

Table 4.36 Best Subsets Regression of water vapor permeability

Best Subsets Regression:

Predictors: thermal conductivity(λ); thermal absorbsivity(b); thermal resistance(r); air permeability(air per); wicking

Response : water vapor permeability

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	λ	b	r	air per	wicking
1	8,3	2,6	-1	103,32	X				
2	**13**	**1,4**	**0,3**	**103,91**				**X**	**X**
3	14,9	0	2	106,38		X		X	X
4	15	0	4	110,33		X	X	X	X
5	15,1	0	6	114,76	X	X	X	X	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the water vapor permeability and air permeability and wicking .Thus, the regression equation was obtained between the as following:

WVP = 1180 – 0,0523 air per - 27,8 wicking (4.11)

The regression Equation 4.11 shows there is an inverse relation between water vapor permeability and air permeability and wicking. But also we can see that there is weak connection between them.

P-values of the regression equation and Analysis of variance were given in Table 4.37 and Table 4.38.

Table 4.37 Regression Analysis of water vapor permeability

Regression Analysis: WVP versus; air per; wicking

Predictor	Coef	SE Coef	T	P
Constant	1180,3	373,4	3,16	0,006
air per	-0,05234	0,04091	-1,28	0,22
wicking	-27,83	23,12	-1,2	0,247

Table 4.38 Analysis of Variance of water vapor permeability

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	2	24287	12143	1,12	0,351
Residual Error	15	161960	10797		
Total	17	186247			

When the water vapor permeability of the samples was analyzed with fabric structural properties (yarn count, thickness, weight and fiber density), we found that the best subset regression was between water vapor permeability and yarn count, fabric weight and fiber density. The contribution of fabric weight, fiber density and yarn count were significant (Table 4.39). We concluded that the variation in fabric weight, yarn count and fiber density (soybean or organic cotton) were important selecting criteria on wicking.

Table 4.39 Best Subsets Regression of water vapor permeability

Best Subsets Regression

Predictors: Ne; Thickness; Fiber Density; weight

Response :Water vapor permeability

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ne	Thickness	Fiber density	weight
1	10,2	4,5	3,6	102,26			X	
2	16	4,8	4,4	102,13	X		X	
3	**31,7**	**17,1**	**3,3**	**95,312**	**X**		**X**	**X**
4	13	13	5	97,605	X	X	X	X

After that regression analysis was done and the regression equation was obtained. The regression equation showed the relationship between the water vapor permeability and fabric weight, yarn count and fiber density Thus, the regression equation was obtained between the water vapor permeability and fabric weight, yarn count and fiber density as following:

$$WVP = 2065 - 31{,}7\ Ne + 427\ \text{Fiber Density} - 9{,}49\ \text{weight} \tag{4.12}$$

The regression Equation 4.12 shows there are an inverse relation between water vapor permeability and yarn count and weight and direct relation with fiber density. So we can say that fiber type is important for water vapor permeability.

P-values of the regression equation and analysis of variance were given in Table 4.40 and Table 4.41.

Table 4.40 Regression Analysis of water vapor permeability

Regression Analysis: WVP versus; Ne; density; weight				
Predictor	Coef	SE Coef	T	P
Constant	2065	1015	2,03	0,061
Ne	-31,68	16,21	-1,95	0,071
Fiber density	427,5	225,7	1,89	0,079
Weight	-9,491	5,288	-1,79	0,094

Table 4.41 Analysis of Variance of water vapor permeability

Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	3	59066	19689	2,17	0,137
Residual Error	14	127181	9084		
Total	17	186247			

CHAPTER 5

CONCLUSION

The object of this study was to investigate comfort properties of knitted fabrics which were made of soybean and organic cotton yarns besides analyzing their fabric structural properties.

For this study, %100 soybean and %100 organic cotton yarns were used with three different yarn counts. Fiber type and yarn count were taken as variables. The yarns were knitted by using sample knitting machine and all of them were tested to see the affect of fiber type and yarn count on comfort properties of fabric.

Thermal comfort properties (thermal resistance, thermal conductivity and thermal absorbtivity), air permeability, water vapor permeability and wicking abilities of samples were examined to evaluate the comfort related abilities of fabrics studied and categorical variables and other fabric parameters effective on these properties were tried to be found out.

It is clear from the results that air permeability of fabrics and fabric thickness were correlated with each other. Air permeability increased with decreasing fabric thickness.

If we look at the literature survey [47, 48] knitted fabrics have a loop structure, they have more pores and so, in general, air permeability of knitted fabrics are higher than woven fabrics. So we can say that fabric structure is important parameter for air permeability. A very open cloth can inflict serious wind chill problems on the wearer in cold climates with a breeze blowing and may thus affect survival chances in extreme cases. The samples of soybean fabrics gave better air permeability than cotton (organic) fabrics because of soybean yarn is thinner than organic cotton yarn so soybean fabrics have more open structure than organic cotton fabrics.

If we look at the thermal resistance test results; as the fabric thickness decreases thermal resistance also decreases. If a thermal resistance property is needed, fabric thickness parameters must be considered.

Literature survey shows that that the thermal resistance of a fabric is strongly dependent on the enclosed still air, and this factor is in turn influenced by the fabric structure. According to Holcombe and Hoschke [38] the thermal resistance of low density fabric constructions was determined primarily by fabric thickness, and other parameters such as fiber type and construction have a minor but significant influence.

Also, the samples of coarse yarns showed better thermal conductivity than finer; and organic cotton samples had high level thermal conductivity than soybean samples. For thermal comfort, the clothing is to restrict the flow of heat from the body to its environment; materials having low thermal conductivities are required.

The study by Woo [43] pointed out that fiber fineness and fabric thickness have a significant influence on thermal conductivity. The heat transfer characteristics of fabric are more influenced by the fabric’s structural features such as thickness, air volume fraction and bulk density of fabric, rather than fiber type. According to Lamb [43] the heat transfer depends on air velocity and fabric permeability.

If we analyze the thermal absorbtivity we obtained that coarse yarns show high level thermal absorbtivity than finer yarns. We concluded that the variation in yarn count (soybean or organic cotton) was important selecting criteria on thermal absorbtivity. According to regression equation [4.7] the thermal absorbtivity of the samples were strongly related with thermal conductivity and wicking and there is a direct relation between thermal conductivity and wicking.

According to literature survey [45] the higher is thermal absorbtivity of the fabric; the cooler is its feeling. This value just depends on the contact pressure, which also correspond to the real situation.

If a manufacturer wants to produce a garment which is used on summer days, fabric should show good wicking ability and air permeability. For wicking ability fiber type and fabric thickness are significant. According to results coarse yarns show better wicking ability than finer.

The regression equation [4.9] showed that wicking of the samples was related with thermal absorbtivity, thermal resistance and air permeability. There is an inverse relation between wicking and thermal absorbtivity, thermal resistance and air permeability.

Literature survey [68] shows that during vertical upward wicking, gravity plays an increasingly important role. There are many factors affecting the wicking, these are; fiber, yarn and fabric structure. A knitted fabric is not a completely solid structure, but is complex and porous in shape. The complex contours formed by the fibers in the yarn and the yarns in the fabric constitute the boundaries of the channels along which moisture flows. Due to the laws of capillarity, the much larger pores between yarns do not contribute much to the long-range motion of liquid. It has also been concluded by Minor, yarn intersections act as new reservoirs, and feeds all branches equally.

Wicking analyzing showed that soybean samples had better wicking ability than organic cotton samples because of fiber type can change the structure of the yarn, in turn changing the wicking properties of the fabric. For example, changes in fiber properties when wet can significantly affect liquid movement and retention behaviors through fiber swelling. Also, yarns spun with natural fibers have very irregular capillaries due to various factors such as fiber roughness, cross-sectional shape and length. For a good wicking fabric include stiff fibers, uniformity of structure, and resistance of the structure to collapse. Also, the fibers should not be swollen by the liquid being wicked [70].

According to water vapor permeability test result we concluded that water vapor permeability of the samples was related with air permeability and wicking. The regression [4.11] showed that there was an inverse relation between water vapour permeability and air permeability and wicking. We concluded that the variation in fabric weight, yarn count and fiber density (soybean or organic cotton) were important selecting criteria on wicking. The regression equation [4.12] showed there were an inverse relation between water vapor permeability and yarn count and weight and direct relation with fiber density. So we can say that fiber type is important for water vapor permeability. The movement of water vapor of a fabric depends on the micro porous structure of fabrics. The factors affecting moisture vapor permeability are the effect of fabric structure and properties, finishing treatments, texturising, different yarn twists, blending and mechanical treatments.

If we compare the soybean and organic cotton yarns; the soybean samples were better than organic cotton samples at air permeability and the most suitable yarn count was Ne 40. Also soybean samples were better at thermal resistance and the most suitable yarn count was Ne 20.

Also, soybean samples were better at thermal absorbtivity and the best yarn count was Ne 20. The soybean samples were better than at wicking ability and the best yarn count was Ne 20. At water vapor permeability the best yarn count was Ne 32.

Organic cotton samples were better than soybean at thermal conductivity and the best yarn count was Ne 20. At water vapor permeability, the best yarn count for organic cotton yarn was Ne 40.

According to above mentioned analysis fiber type is important selecting criteria when considering thermal conductivity, wicking and water vapor permeability; but not important selecting criteria for thermal resistance, thermal absorbtivity and air permeability. Yarn count is significantly important for thermal absorbtivity and water vapor permeability parameters.

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