SEPTEMBER 2021 Ph.D. in Textile Engineering ESİN BABALIK

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A NEW APPROACH TO SPORTS CLOTHING PRODUCTION BY POLYPROPYLENE FIBER

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ESİN BABALIK

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Ph. D. Thesis

in

Textile Engineering

Gaziantep University

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Esin BABALIK

ABSTRACT

A NEW APPROACH TO SPORTS CLOTHING PRODUCTION BY POLYPROPYLENE FIBER

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Polypropylene (PP) which belongs to polyolefin fiber family has been used in carpet and packing industry and characterized with its well-known resilience, shape retention tendency, low density, low price, high tenacity and easy process ability. The previous studies showed that PP also had superior wicking ability, high air permeability and soft handle, which are important needs for sports clothing. Therefore, a comprehensive study would allow evaluating PP as fiber alternative to cotton or polyester (PET) in sports clothing industry.This thesis is built on a content which basically consists to evaluate the thermal and mechanical properties of PP knitted fabrics with that of cotton and PET fabrics to find out whether PP would be an alternative for sports clothing. This study covered the usage of different denier of PP continuous filament yarns with low density, different knitting patterns and mixture of PP with cotton and PET in the various samples. The measurements on thermal and mechanical comfort-related properties were statistically analyzed and advantages of PP fiber over cotton or PET were monitored. 100% PP sports clothing samples were produced and wear trials were performed by the volunteers under determined conditions.

Key Words: Polypropylene, Cotton, Polyester, Knitted Fabric, Mechanical Comfort, Thermal Comfort, Sportwear.

ÖZET

SPOR GİYİM ÜRETİMİNE POLİPROPİLEN LİFİ İLE YENİ BİR YAKLAŞIM

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133 Sayfa

Poliolefin elyaf ailesine ait olan polipropilen (PP) lifi , halı ve ambalaj endüstrisinde kullanılmasına rağmen iyi bilinen esnekliği, şekil tutma eğilimi, düşük yoğunluğu, düşük fiyatı, yüksek mukavemeti ve kolay işlenebilirliği ile karakterize edilmektedir. Daha önce yapılan çalışmalar, PP'nin spor giyim için önemli ihtiyaçlar olan üstün fitilleme kabiliyetine, yüksek hava geçirgenliğine ve yumuşak tutuşa sahip olduğunu göstermiştir. Bu nedenle, kapsamlı bir çalışma, spor giyim endüstrisinde PP'nin pamuk veya polyestere (PES) alternatif bir elyaf olarak değerlendirilmesine olanak sağlayacaktır. Bu tez, temel olarak PP örme kumaşların termal ve mekanik özelliklerini pamuklu ve PES kumaşların özellikleriyle değerlendirmek ve PP'nin spor giyim için bir alternatif olup olmayacağını belirlemekten oluşan bir içerik üzerine inşa edilmiştir. Bu çalışma, çeşitli numunelerde düşük yoğunluklu, farklı örgü desenlerine ve PP ile pamuk ve PES karışımına sahip farklı denye PP sürekli filament ipliklerin kullanımını kapsamıştır. Termal ve mekanik konforla ilgili özelliklerle ilgili ölçümler istatistiksel olarak analiz edildi ve PP elyafın pamuğa veya PES'e göre avantajları izlendi. %100 PP spor giyim numuneleri üretilmiş ve belirlenen koşullar altında gönüllüler tarafından giyim denemeleri yapılmıştır.

Anahtar Kelimeler: Polipropilen, Pamuk, Poliester, Örme Kumaş, Mekanik Konfor, Termal Konfor, Spor Giyim.

''Dedicated to my son Uygar Tanur BABALIK

from the beginning to the end...''

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C	Celsius
M_n	Net metabolic heat
Q	Heat lost through the clothing
H	Heat lost through thermal transfer
E	Heat lost through evaporation (mass transfer)
M	Metabolic rate
W	External work
C	Heat loss by convection
C_k	Heat loss due to respiration
C_{res}	Heat loss due to respiration
R	Heat loss by radiation
E_{res}	Evaporate heat loss due to respiration
E_{sk}	Heat loss by evaporation from the skin
f_{cl}	Clothing area factor (clo)
h_c	Coefficient of convection heat transfer (W/m^2K)
T_{cl}	Clothing surface temperature (^0C)
T_a	Ambient air temperature (^0C)
σ	Stefan Boltzman Constant (5,67 x 10^{-8} W/m^2K^4)
ε_{cl}	Emmissivity of the clothing
T_r	Radiant temperature (^0C)
Q	Heat

$\boldsymbol{L}$	Unit thickness
A	Unit area
$\boldsymbol{\Delta T}$	unit temperature gradient
λ	Thermal conductivity
R	Thermal resistance
H	Fabric thickness
B	Thermal absorptivity
ρ	Fabric density
c	specific heat of fabric
γ_{sv}	Interfacial tensions between solid/vapor
γ_{sl}	Interfacial tensions between solid/liquid
γ_{lv}	Interfacial tensions between liquid/vapor
W_P	The work of penetration
r	Capillary radius
ΔP	Laplace pressure
RH	Relative humidiy
m_{ua}	Mass per unit area ($g/m)^2$
a	Specimen area (m^2)
m	Mass of specimen (gr)
WT	Wetting Time
WTt	Wetting Time top surface
WTb	Wetting Time bottom surface
AR	Absorbtion Rate
ARt	Absorbtion Rate top surface

ARb	Absorbtion Rate bottom surface
MWR	Maximum Wetted Radius
MWRt	Maximum Wetted Radius top surface
MWRb	Maximum Wetted Radius bottom surface
SS	Spreading Speed
SSt	Spreading Speed top surface
SSb	Spreading Speed bottom surface
AOTI	Accumulative One-Way Transport Index
OMMC	Overall Moisture Management Capability
Pa	Pascal
K	Constant
C_{total}	Total Comfort
$C_{physical}$	Physical (Mechanical) Comfort
$C_{thermal}$	Thermal Comfort

LIST OFABBREVIATIONS

USD	United States Dollar
PP	Polypropylene
PET	Polyester
ANOVA	Analysis Of Variance
SNK	Student Newman Keuls
TUBITAK	Türkiye Bilimsel Ve Teknolojik Araştirma Kurumu
SS21	Spring Summer 2021
CPI	Course Per Inch
WPI	Wales Per Inch
UV	Ultraviolet
USA	United States of America
US	United States
PTFE	Polytetrafluoroethylene
ISO	International Organization for Standardization
BS	British Standards
Ne	British yarn count
WCI	Wet Comfort Index
Tex	Yarn Count
Pa	Polyamide
CF	Continued Filament
AATCC	American Association of Textile Chemists and Colorists
ASTM	American Society for Testing and Materials
GSM	Grams Per Square Meter
TS EN	Turkish Standards English
DC	Dimensional Change

MMT	Moisture Management Tester
BMI	Body Mass Index
TCV	Total Comfort Value
PMV	Predicted Average Feeling

CHAPTER I

INTRODUCTION

The global competition in fashion and apparel industry is forcing the manufacturers to find new market areas or applications. Sport clothing market is estimated to have revenue of 150 billion USD and fiber technology is one of the most important growth areas of that huge market. Today, synthetic fibers with enhanced mechanical properties than that of natural fibers have been widely used in sports clothing area. The so-called comfort fibers which ensure increased thermal comfort sensation of the wearers have been preferred due to better moisture and water vapour management properties. Polypropylene (PP) which belongs to polyolefin fiber family has been used in carpet and packing industry and characterized with its well-known resilience, shape retention tendency, low density, low price, high tenacity and easy process ability. The previous studies showed that PP also had superior wicking ability, high air permeability and soft handle, which are important needs for sports clothing. Therefore, a comprehensive study would allow evaluating PP as fiber alternative to cotton or polyester (PET) in sports clothing industry.

The thesis is built on a content which basically consists to evaluate the thermal and mechanical properties of PP knitted fabrics with that of cotton and PET fabrics to find out whether PP would be an alternative for sports clothing. The study will cover usage of different denier of PP continuous filament yarns with low density, different knitting patterns and mixture of PP with cotton and PET in the various samples. The measurements on thermal and mechanical comfort-related properties will be statistically analyzed and advantages of PP fiber over cotton or PET will be monitored. 100% PP sports clothing samples will be produced and volunteers will wear under determined conditions and a survey will be performed. [1-3]

This study was named 'A New Approach to Sports Clothing Production by Polypropylene Fiber' and it consists of 8 chapters. Chapter 1 explains the reasons for the starting point of the study and the next sections of the study.

In the second chapter, the aim of this study and the questions that are likely to be searched for during the experiment are included. Throughout the study, these questions have been tried to be answered and guidance has been made through these questions.

In the third chapter, firstly, the information obtained as a result of an overview of the sportswear market is given. In line with this information, literature survey has been made. With the researches, short information about fiber type and fabric construction to be used is given. Mechanical, psychological and thermal comfort aspects are tried to be explained by giving information about clothing comfort which is the general scope of the thesis. Brief information is given about thermal comfort properties of textile products.

In the fourth chapter, the selection of the materials used in the study and their preparation are explained. The knitting reports of 54 dissimilar of knitted fabrics that used in the study are given and the mixing conditions of these fabrics are indicated. The test standards used for the tests and test methods applied to fabrics were specified. The test procedures were explained and the averages of the results of the tests were listed.

In the 5th Chapter, the results of the tests are arranged. Multi-axis graphical drawings were realized by normalizing the test results of the tests determining mechanical and thermal comfort properties. The multi-axis graphs of mechanical comfort components and the multi-axis graphs of thermal comfort components were examined separately. According to these results fabrics were determined.

In the 6th Chapter, statistical analysis was performed using ANOVA. F statistical values and SNK analyzes were calculated for each fabric type. As a result of these analyzes performed for each fabric construction, cause and effect relations related to comfort properties are indicated with numerical values.

In Chapter 7, 3 different fabric constructions which give the best multi –axis graphic value and display numerical values are selected. Samples of these selected knitted constructions with 3 different types of fibers (cotton, PET, PP) and wear trials were carried out. Knowledge about whether numerical values can be provided in practice.

In the last chapter, Chapter 8, the outcomes obtained throughout the study were evaluated. As a result of these evaluations, the final report of the project was presented and an opinion was expressed about the works that could be done in the future.

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CHAPTER II

PURPOSE OF THE STUDY

One of the most important textile product development areas for near future; sports textiles which are a sub-branch of technical textiles. Nowadays, people have started to do more sports and sports clothes are needed by a wider audience besides professional athletes. In the first stages of sports textiles, only the work and applications made for professional athletic clothes can be seen in the clothes intended for daily use today. After the adaptation of sports garments to daily life, the need to produce these products at affordable costs and retail prices without sacrificing comfort features, as well as the need for diversity resulting from the increase in demand, has led to the search for new raw materials.

Polypropylene fiber has reached the second fiber position after polyester in the synthetic fiber sector with the production volume reached in the last 10 years. Polypropylene is consumed extensively in Turkey; almost 45% of this consumption is due to the production of machine made carpets. The easy-to-clean structure of the fiber and its high wrinkle resistance have led to intensive use in carpets produced for indoor and outdoor areas. In addition, low costs, easy processability, low densities, high strength and excellent chemical resistance of polypropylene fibers can be listed as other reasons for their preference in the carpet sector. Polypropylene fiber is cheap and lightweight, fiber and its yarn production is easy, recycling is also expected to increase the use in the clothing industry due to the advantages, such as sportswear fabrics, which are produced from blends of polypropylene with other fibers, have started to find a place in the market. In addition, it is understood that the fabrics produced from polypropylene fiber will be a good alternative in sportswear sector if liquid water conduction (capillary, wicking), high water vapor and air permeability properties, easy maintenance properties such as dirt-repellent, easy cleaning, abrasion resistance, good wrinkle resistance are added.

The main aim of the project is to survey the suitability of using polypropylene fibers in the fabrics used in sportswear by evaluating the thermal and mechanical comfort properties based on the changing fashion and clothing need values. Whether polypropylene fibers can be used as an alternative to polyester fibers in terms of comfort properties will be examined within the scope of this project. The blends were prepared as cotton and polypropylene blends as an alternative to the most commonly used cotton fiber and polyester fiber blends in sportswear. The blends were made in fabric construction. Continuous filament polypropylene yarns with different thicknesses to meet the cotton polyester blends and cotton fibers were mixed in different constructions according to yarn counts. Thermal, mechanical, and psychological comfort properties of fabric will be analysed in this thesis.

The objectives that are tried to be elaborated in this thesis are:

1. Investigation of mechanical and thermal comfort properties of polypropylene knitted fabrics and determination of whether these fibers can be alternative to polyester.
2. Thermal and mechanical comfort properties of cotton / polyester blends commonly used in sportswear industry and cotton-polypropylene blended fabrics expected to be an alternative.
3. Selection of fabrics with high thermal and mechanical comfort as a result of examinations and applying clothing tests to these fabrics under appropriate conditions.

2.1. Research questions

At the beginning of this thesis, firstly, fiber blend ratios and fabric constructions will be decided. By comparing the mechanical and thermal comfort properties of the fabrics to be manufactured, the most suitable fabric mixture and construction will be tried to be determined in commercial sportswear market.

For this purpose, the following questions should be asked for guidance:

1. What are the fiber properties used and needed in the sportswear market?
2. What are the fabric properties to be used for sportswear?

3. What fiber blend ratios can be used in practice?

4. What is the most suitable fabric structure for sports?

5. Which thermal and mechanical comfort test methods are used to determine fabric comfort properties?

6. Can the fabric and fiber / fiber blend that provide the best value for the work result meet the commercial need?

The wear comfort of the sportswear is related to the liquid moisture transfer ability of fabric. Especially transporting sweat from the human body to the environment is important for comfort of the wearer. Becuse of that reason the wearer will feel dry. In this situation, according to the aim of the study, the fabric should be a moisture-management fabric.

The wear comfort of the fabric is related to mechanical (sensorial) comfort, such as not itching or being too rigid. Fabric which is used for sportswear should have good stretch and recovery performance to ensure that clothing does not restrict body movement and performance. [4]

CHAPTER III

LITERATURE SURVEY

3.1. An overview of the Sportswear Market:

"Wear for sports" or "activewear" by definition is about functionality, comfort and safety with the specification developed and designed to deliver a product that responsive to needs of the sportsman and sportswoman. Activewear is no more only occasional need of all types of modern customers; it is also a fashion statement. For last couple of years, active wear is not only sports performance outfit that you see at gyms and yoga classes, it has also become an important part of weekend daily outfits and street fashion. In line with this, considering this growth in the market in terms of new fashion fabrics, affordable versions for current fabrics and additional performance fabrics has been occured. Customers are keen on innovative sportswear fabrics to meet their needs.

Nowadays, with the effect of fashion on sports clothing, it is seen that interest in innovative products, sportswear and performance fabrics continues to increase in parallel with the trend of healthy living. Sportswear is located in a rapidly growing market with its adaptability to fashion, performance effect and functionality. Sustainability and adaptability are two important key items for SS21 trends and furthermore. Therefore a new fabric offers supporting these are also becoming even more important form as market.

Sportswear is a global phenomenon, according to Euromonitor; as reported in *Retail Week*, the sportswear market represented $282 billion worldwide in 2014, a 7% increase on the previous year and outpacing the growth of broader apparel, which stands at 5.8% of the market. [5, 6]

The customers to purchase sportswear can be grouped into the specific purposes: firstly to actively participate in sports, secondly to wear sportswear for fashion and thirdly to wear it for leisure and comfort (See Figure 1.1). Each item of sportswear in a consumer's wardrobe may have a different function. [7]

Figure 1.1 Function of sportswear [7]

One of the factors that affect the preferences of sports wearers is to be directed to one's needs, habits and pleasures. When we examined the current trends, the term "luxury athletic" often appears. Luxury athletic products have all kinds of comfort, convenience, thermal properties and air permeability. Sports activities should be done more efficiently and effectively, as well as sportswear should be aesthetic, visual and design aspects. However, form as sportswear fashion market, researches on affordable fabrics with this higher comfort, convenience, thermal properties and air permeability performances, becomes very important.

In the concept of luxury athletic, sportswear products are used in daily wear as well as sports activities. Showy and fancy products are outstanding. The global patterns in trims are interpreted with modern technology. There is a young and bold approach in which people can easily express themselves and aim to make an impact. This encourages creativity, individuality and the creation of more heterogeneous collections.

The "all-inclusive" approach is another trend approach. In this approach gender, beauty, race and cultural discrimination are challenged and clichés disappear. Creativity and imagination are intrinsically linked to destruction and reconstruction. How we dress and what style we have; an objection, protest and an escape process.

The impact of current trends on the design of active wear products the liberal and rebellious effect is remarkable. The boundaries between Sportswear and casual wear disappear.

As a result of trend analysis, it has been seen there 5 sensory activities are stated in changing sports activities profile. As a result, sportswear expectations are increasing. The concept high performance fabrics and sportswear, ‘’ touching the senses’’ concept gains importance in designs.

Knitted fabrics have become more preferred in the market with their low cost, easy production techniques, wide production range and high comfort values. Knitting is a process of fabric formation that involves the inter-looping of yarn in a series of connected loops by means of needles. As known, knitted fabrics have excellent comfort properties. They are stretched and compatible with body movements. Beside those specialities, they have also good handling and easy transferring of the water vapor from the body. These specialities make the knitted fabrics; give the priority for using them for sports, casual wear and underwear. Knitted structures offer several advantages. In general, they provide comfort to the wearer with their physical properties such as easy stretching, elasticity, softness and adaptability to body movements. Knitted fabrics offer a soft handling, good feeling and freshness. For this reason, knitted fabrics have long been preferred as fabrics in many types of clothing. Efforts have been made to make knitted fabrics more comfortable by incorporating different fibers, altering yarn parameters, like twist, bulk, count, and finishing treatments, and knitting factors, like stitch length, CPI (course per inch), WPI (wales per inch) and fabric weight,and by adopting new or different finishes [8]

A new focus on the development of bio-smart fabrics and the interaction between fabric and leather products are being developed and performance and comfort are being improved. The increase in ‘’value added’’ performance characteristics becomes important.

Desired properties of fabrics used in active wear and sportswear products; breath capability, heat and humidity management / control, windproof, waterproof, quick-drying, UV protective, antibacterial and antimicrobial, blood flow improving structure, muscle supportive, performance optimizer.. etc. Between fabric and leather structures that enhance interaction increase the sports performance of the end consumer. Developing and changing fashion trends also affect active and sportswear products. Product diversity, aesthetics and functionality are increased by using different fibers and new knitting structures.

A new approach in sports and active wear is using wool fiber in high performance knitted fabrics. Wool fiber and its blends are used in creative designs in the field of sports and daily wear because of the wool fiber properties which are moisture regulation, breathable structure, UV protection, washability, soft texture.. etc. Feeling comfortable and good, with soft touch, the use of wool and blended qualities is becoming widespread. Besides, the use of tencel, carbon and polypropylene fibers is gaining importance.

3.2. Fibers for Sportswear

Fiber is generally defined as flexible, macroscopically homogeneous materials with a large length / diameter ratio. In order for a material to be a fiber, it is assumed that the length / diameter ratio must be 100. The fibers are separated into two main groups: man-made fibers and natural fibers. Natural fibers are inherently inherent in fiber geometry and can often be used for textile purposes by simple mechanical and chemical pretreatments such as cleaning like cotton, silk wool linen angora etc. In the case of man-made fibers, the synthesis of the polymer from which the fiber is made and the shaping of the fiber into the polymer takes place through human labor. These polymers, which are given artificial or natural fiber geometry, have more than half of the world fiber consumption. [9, 10]

The performance of sportswear is affected by the fabric used in manufacturing and, accordingly, by the structure of the fiber used in fabric manufacturing. Sportswear should have some attributes, such as providing functional support, increasing the performance, protecting the wearer, offering fashion and wearer comfort. As sportswear becomes lighter and more breathable, it becomes more flexible, fit, and strength. The most important factor that fibers contribute toward wearer comfort and thermal balance leading to a suitable microclimate next to the skin. Fibers influence the total comfort of the wearer, mainly in providing a balance between heat loss and perspiration of the body.

Fibres used in sportswear and functional clothing are multidimensional and require a number of characteristics apart from possessing a length-to-width ratio for making a yarn. In the fibre manufactury, these parameters that influence performance fiber shape, fiber fineness, molecular structure and finishing applications. [11,12]

The main properties of fibers used in sportswear include: durability, lightness, extensibility, colorfastness, dimensional stability, washability, absorbency, high moisture recovery. In order to provide these properties, it has become popular to use phase change materials recently. Hence, textile fibres contribute toward moisture control, thermal regulation and breathability, cooling effects, softness, stretch and UV (ultraviolet) protection.

Synthetic fibres are found in countless applications in apparel and functional clothing due to mechanical and chemical properties compared to natural fibres. [12] In the past, cotton was widely preferred for a wide range of garments until the advent of synthetic fibres such as polyester, acrylic, nylon, polypropylene, etc. During the 1970s use of polyester fibres in sportswear predominated, continuing in the 1980s and 1990s. Polyester is preferred in sportswear because it is lightweight, cheap to produce, dye-fast, durable, easy to care for, quick drying, hydrophobic in nature and has wicking ability. In addition, the polyester filament fabrics can be given hydrophilic coating. Hence, polyester fibre-based fabrics with their hydrophobic cores and hydrophilic coatings can wick moisture away from its contact with the skin to outer surface to environment. Polyester is often blended with other natural fibres, mainly to extract its benefits to maintain moisture management and durability.[11-14]

The fibers, yarns and post-production finishing processes used in fabric manufacturing directly affect the fabric performance. It is aimed to benefit from the advantages of each fiber used by mixing different fiber types. thus, it is tried to be eliminated from the disadvantages of other fibers. As a result, the appearance, performance, durability, comfort, cost and maintenance of the fabric can be improved with these blends. Typical blending includes polyester/cotton, polyester/viscose, cotton/Lycra, nylon/Lycra, wool blends, wool/acrylic, Merino etc.

With the progress of technology in textiles, it is observed that the thermal comfort properties of the fabrics used increase as well as the mechanical and dimensional properties. It has become possible to provide higher comfort properties by using different fiber blends. Blending the fibers contributes to the aesthetic properties of the fabric as well as the comfort properties. Thus, it is aimed to benefit from the good properties of each fiber component in blends made with natural and artificial fibers. Thus, it is tried to obtain more balanced mixtures by combining mechanical and comfort features. With the product outputs obtained, both the product range expands and more diverse products emerge in marketing. [15].

3.2.1. Cotton:

Cotton is the most important among vegetable fibers. Like every vegetable fiber, the main component of cotton fiber is cellulose, the most abundant polymer in nature.

Cotton accounts for about 35% of world fiber consumption and is one of the most important textile fibers in the world. Cotton is grown in about 80 countries on earth, but only two thirds of the world's cotton production is provided by China, India and the United States. The USA, which ranks third after China and India in the world cotton production rankings, meets approximately one third of the world cotton exports and is the leading country in export [16].

Due to its fiber structure, cotton fiber has a flexible, easily bendable and twistable structure, soft touch. It has no allergic effect and is hygienic. Sweat absorption and air permeability is high. Because of these properties, it is among the most consumed fibers in the field of clothing.

3.2.2. Polyester:

Polyester was synthesized by British researchers J.R. Whinfield and J.T. Dickonson in 1941 as polyethylene terephthalate. This is called Terylene. In America, in 1953, Dacron called polyester fiber was produced. Although the starting materials are different, Dacron and Terylene have essentially the same chemical structure and the polymer of both is polyethylene terephthalate. As a result of the work of other countries began to be marketed under different trade names, all of these were called ‘polyester fibers by the recommendation of the US Federal trade commission. [9]

Polyester fibers can be used with 100% composition or blended. Polyester fiber is used in textile, carpet, swimwear, cord fabric, curtain, rope, underwear, shirts, such as the production of many products. It is a synthetic fiber that stands out with the use of cotton as a mixture. It is generally used in the production of clothing such as blouses and shirts by mixing with ½ ratio cotton fiber.

3.2.3. Polypropylene

Polyproylene was first produced by G. Natta, following the work of K. Ziegler by the polymetization of polyproylene monomer in 1954. [17] Polypropylene is one of the low density polymers (0.90 g / cm^3). It does not contain moisture due to high crystallinity and polar group. Resistance to chemicals is good, but under the influence of sunlight is degraded. Therefore, prior to extrusion, stabilizers that absorb ultraviolet rays are introduced into the polymer in the molten state. [9-10]

Polypropylene fibers; low weight, soft touch, low crease ability, effective heat - moisture management and breathability, dirt repellency, water repellency, high resilience, antibacterial, antiallergic, UV resistance gain by using UV additive many techniques such as strengthening of flammability during yarn production feature. In addition to its technical properties, polypropylene fibers are 100% degradable and are important structures in environment friendly production approach. Besides, low energy and water use in its production.

When the latest developments are followed, new generation moisture controlled fabrics, a microcirculation that makes it easier to absorb and expel moisture from the body technologies. Ducts in the fabric before body moisture becomes sweat through the body. Structural properties of polypropylene fiber can meet the expected breathability, heat-moisture transmission and comfort characteristics expected from sportswear. Sportswear products using polypropylene fibers provide performance improvement.

Polypropylene fiber is made by melt-spinning polypropylene. Polypropylene is obtainedby the polymerization of propylene monomer. Polypropylene fiber has the small specific gravity of 0.91 and is lightest among synthetic fibers. It possesses high tensilestrength, and its material (propylene) costs are lowest. Polypropylene drawbacks are being unable to be dyed and being less heat-resistant, in addition to an insufficientresistance to light. Polypropylene fiber is relatively environmentally friendly. Polypropylene fiber hardly generates harmful substances when burnt because it consists of only carbon and hydrogen. Recycling of the polypropylene is very easy because its molecular structure is simple. During the manufacturing of the polypropylene uses less energy if we compare with the other synthetic fibers manufacturing. Although polypropylene fiber still has a small use of percantage in the general textile market, it has an increasing use of percantage in the sportswear market. The polypropylene fibers have very low moisture absorbency whereas excellent wicking ability. As polypropylene does not wet out, its thermal insulation is retained during and after severe activity. Also polypropylene is a very lightweight fiber. Fabric made from polypropylene may shrink if washed at high temperature. The finishing proceses for the polypropylene is also more difficult than the other fibers. [18].

3.3. Literature Survey and A Brief Intro to Clothing Comfort :

With the developing world conditions, the expectations of the end consumer from the products used have changed. Dressing is no longer just a cover-up, and end users are required to meet their physical, social and psychological expectations in their routines throughout the day, as well as being in line with their appearance and status. In line with this demand, the concept of comfort has gained meaning and has been the subject of many studies. These researches are aimed at defining comfort and determining the conditions under which the user feels good.

Many researchers have presented different definitions for clothing comfort. In order to be considered comfortable, warnings about environmental factors such as ambient temperature, wind speed humidity, and light must be transmitted to the brain. The feeling of discomfort felt by any of these factors, depending on our clothes or psychological state, eliminates comfort. It is easily expressed in a few words, such as uncomfortable, irritating, cold-hot feeling, pain, stinging, itching, wetness and excessive sweating in clothing. For this reason, the most accepted definition for comfort is expressed as a natural situation, which is uncomfortable and free from pain ’. [19, 20, 21]

Comfort, which is defined as a pleasant state of psychological and physical harmony between a human being and environment, became the most important feature along with the development of textile technology. [22]

Hollies and Fourt [23] in the work of comfort, thermal (thermal) and non-thermal components (surface character, mechanical finishing processes, drape ability, sewn ability, electrostatic properties, etc.), including the user's status (operating status, various activities, etc.) and environmental conditions. Accordingly, the physiological responses of the human body to certain clothing and environmental conditions can be used to define comfort, but the environment must be at rest in order to make this definition. This is calculated by measuring factors such as thermal resistance, moisture resistance of the garment, climate conditions of the environment, and activity level of the user. Hes [24] described comfort as the complex effect of heat / moisture transfer properties and mechanical properties of fabrics and garments. The physical properties of the garment, such as the force that comes into contact with the body, the deformability of the garment, the stiffness, stiffness, softness perceived when the fabric is touched, have an effect on the comfort assessment [25].

In all these definitions, there are a few important parts. These;

• Comfort relates to the senses of various senses and is subjective. The physical aspects of comfort are related to human perception and subjective feelings of discomfort and/or pain. The factors that determine physical comfort are associated with the senses: touch, sight, hearing, taste, and smell. Touch plays a key role in people’s use of textiles and clothing, together with vision (quite often) and smell (to a lesser extent and in specific cases).

• Comfort includes various aspects of the human sense, such as visual (aesthetic comfort), thermal (cold and hot), pain (stinging and itching), and touch (smooth, rough, soft, hard).

• Subjective feelings include psychological processes. This means that the person evaluates the present situation from past experience in order to define the comfort conditions he / she wants. Body-clothing interactions (both thermal and mechanical) play an important role in defining the user's comfort state. From a psychological point of view, comfort reflects the individual requirements of people for clothing design, fabrics design, and colors to ensure convenience and confidence in various activities. In this sense, textiles are others (i.e., liking), and the need to express individuality or to ensure anonymity and privacy.

• External environmental conditions (physical, social, cultural) are very effective on user comfort. According to these definitions, the perception of comfort is a complex process that involves many stimuli from the garment and external environmental conditions, which go to the brain through neurons and are resolved there. The physiological comfort of an individual is associated with maintaining the heat balance between the production of heat by the body and the heat losses. Subjective factors that determine physiological comfort are thermal perceptions of individual sensory perceptions and physical activity. [2, 21, 26]

The factors related to textiles and clothing that determine human comfort are summarized in Table 3.1. [26]

Table 3.1 Factors Related to Textiles and Clothing that Determine Human Comfort [26]

		Human Comfort	
	Physical	Physiological	Psychological
Depends on	Touch	Thermal Perception	Texture
	Sight	Sense Perception	Color
	Smell	Movement	Design

3.3.1. Perception of comfort:

Human perception of clothing comfort is an interaction between physical, physiological and psychological factors with the surrounding environment when wearing a garment. Comfort is a multidimensional and complex phenomenon. Subjective perception of comfort involves complicated processes in which a large number of stimuli from clothing and external environments communicate to the brain through multi-channels of sensory responses to form subjective perceptions. These perceptions involve a psychological process 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. [27]

The grouping of variables called Comforts Gestalt that affect a user's comfort state is given below:

1. Physical variables of the environment and the clothing,
2. Psycho-physiological parameters of the wearer, and
3. Psychological filters of the brain. [28]

The flow chart for the subjective perception of comfort illustrates the process of how the subjective perception of overall comfort is formulated (Fig 3.2). 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 this to the brain, and take action to adjust sweating rate, blood flow, and somet imes heat production by shivering. The brain will process the sensory 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. [27]

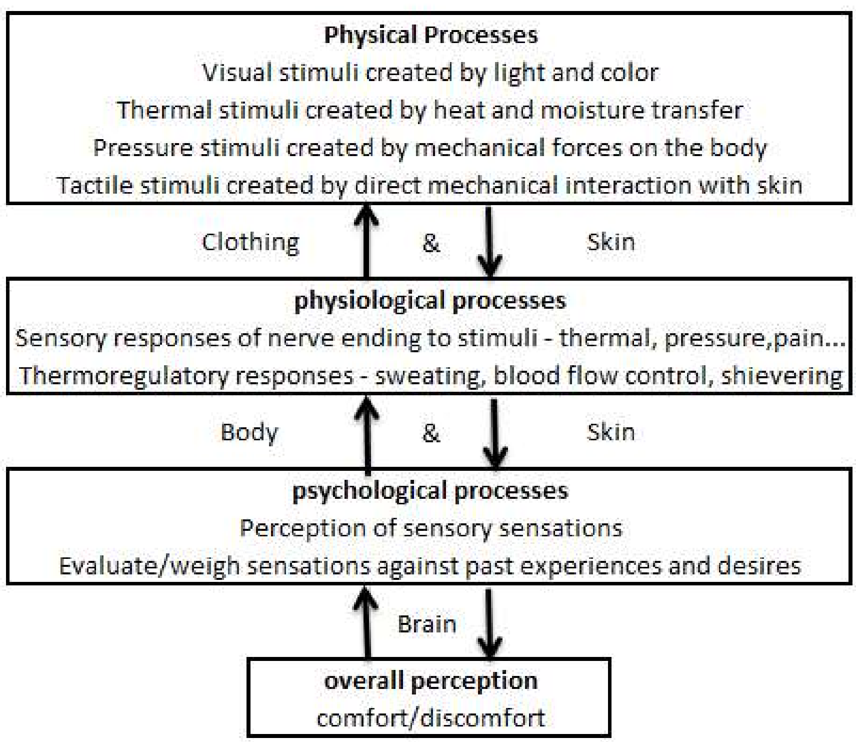


Figure 3.2 Subjective perception of comfort [27]

3.3.2. Clothing Comfort:

In clothing comfort, the most important factor is the movement of heat and moisture (liquid and vapor) through clothing to maintain the thermal equilibrium between human body and the environment. According to Goldman, there are four primary factors in clothing comfort, i.e. function, feel, fit and fashion. The function related to clothing comfort parameters are thermal and moisture (liquid and vapor) transmission, water absorbency, drying behavior, etc. the thermal transmission is a linear function of fabric thickness and relatively independent of fiber characteristics. Thus thermal transmission can be controlled by modification of yarn and fabric structures. Moisture vapor permeability also controls thermal characteristics by evaporative cooling phenomenon. The water transmission in liquid form, i.e. wicking, depends mainly on the type of fiber, weave structure of fabric and the finishes applied to the fabrics. The absorbency of water depends on fiber type, finishes, weave and design of fabric. Although the wicking is important, the amount of liquid that can be bottled away from the skin is also very important. The drying behavior depends on the type of fiber, fabric and design of fabric.

The clothing comfort related to feel are broadly divided into two distinct areas, namely the feel of clothing when held between the thumb and the fingers and the feel of clothing by the wearer when worn in contact with skin. Fit may incorporate factors from fashion, including concepts that may be diametrically opposed to comfort. The clothing fashion is related with the psychological comfort. [29,30]

Comfort in terms of clothing, psychological and physiological not to be affected as, to feel comfortable in ourselves. [31] Besides, a covered body can feel all climate factors. When somebody wears a cloth, body starts to produce heat and moisture. These products will stay at the air layer between the cloth and the body and affect the microclimate and determines the feeling of comfort sense. According to Yoo at al [32] the factors that affect the microclimate can be seen on Figure 3.3.

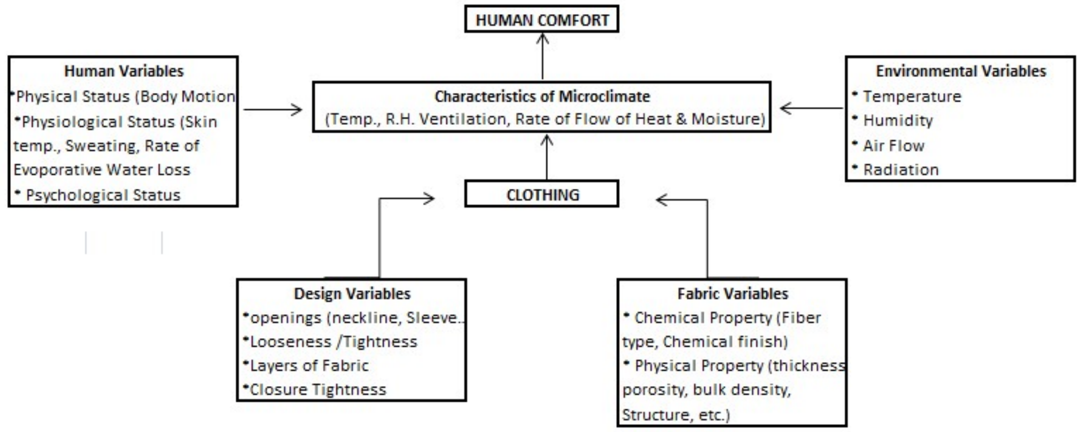


Figure 3.3 Factors that affect microclimate:

Three aspects of clothing comfort are:

1. Thermal comfort (thermo-physiological comfort) – attainment of a comfortable thermal and wetness state, it involves transport of heat and moisture through fabric.
2. Sensorial comfort (mechanical or tactile comfort) – the elicitiation of various sensations when a textile comes into contact with skin
3. Body movement comfort – ability of a textile to allow freedom of movement reduced burden, and body shaping, as required. [27]

Physical comfort is largely a subjective factor, although influenced by receptors that are universal to the human body. Individuals have varying levels of sensitivity. Providing physical comfort is a problem of the engineering and artistic aspect of the production of textiles and clothing.

Psychological comfort that is not less subjective depends mainly on the design, fashion trends, and other factors, mostly related to art.

Physiological comfort, although again dependent on individual reactions and perceptions, is related strongly to the design and production of textiles and clothing in the engineering aspect: from the selection of materials and the yarn production, fabric manufacturing through weaving knitting. [26]

3.3.2.1. Physical (Mechanical/Sensorial) Comfort:

Physical comfort of clothing is based on human sensation to clothing material. Clothing is a second layer of the skin and there are a lot of responses between skin and cloth. Human skin contyains specialised sensory receptors to detect various external stimuli. Physical comfort is a variation of the sensed stimulis. Different type of stimuli, that may be thermal may be physiological, or may be mechanical, when actually you wear clothing. And, ultimately it gives overall tactile response. Taking everything into consideration; there are three main stimulis:

1. Mechanical contact with external objects
2. Temperature changes due to heat flow to or from body
3. Damaging traumatic and chemical insults.[27 – 29]

As a result of these main stimulis feeling softness of the fabric, movement freedom, itching or adhesion because of the wet fabric are the some definiton of the physical feeling. The fabric properties that determine these sensations are surface smoothness, weight, softness, density and rigidity. [19]

According to Li, pyhsical comfort is the allowance of free movement of a textile product or taking the hape of the body when requested and not put too much load on the body. [20]

Comfortable clothing is fitting to body, gives soft feeling and non-itching. Fiber, yarn and fabric structural properties fabric, finishing, coating, lamination etc. processes are effective on physical comfort perception. [23] Softness is considered the opposite of fabric stiffness and is one of the most used terms to describe physical comfort. Hollies and Fourt [23], the most important feature that gives a soft feeling in clothes is thin, long fiber use.

Gamsworthy et al. Willis and Li's research is related to the stinging sensation fiber diameter, fabric thickness and fabric surface. showed high correlation with roughness. Investigations on the stinging sensation caused by the feeling of discomfort caused by the fiber ends exiting the garment / fabric surface. It shows that garment stiffness fiber diameter and breaking load, fabric compressibility and fabric friction physical comfort with the determination of these properties. estimates that can be made [20].

Uneven and squeaky fabric causes physical discomfort important sensory properties. The friction between the fabric and the skin and forcing mechanical interaction between the skin and cloth, garment smoothness, smoothness and squeakiness determines the state. The friction between the skin and the fabric has a smooth surface. As the moisture content of the skin increases, the resulting adhesion effect increased friction and force acting on the skin; because of comfortable clothing at low humidity level, as the moisture level increases (sweating) can be described as uncomfortable [20].

Gun et al. [7] studied the properties of fabrics made from 50/50bamboo/cotton yarns and compared them with fabrics made from 50/50 viscose/cotton and 50/50 modal/cotton yarns. The study compared the weight per unit area, thickness, bursting strength, air permeability and pilling of the fabrics, and it was found that fabric weight, thickness and air permeability was independent of fiber type.

3.3.2.2. Psychological Comfort:

When clothing and psychology come together, it is considered how much the user's expectations and emotions overlap with clothing. Many people in various positions and different statuses in the social atmosphere seek to adapt their clothes to the current situation. Psychological comfort in clothing is an expression of how much the user's expectations and feelings are met by the fabric or clothing. When the garment comes into contact with the body, it makes you feel what it feels, what it calls, how it looks to the eye. What makes the garment feel in contact with the body, how it feels and how it looks, forms the questions of psychological comfort. [2, 23]

Parameters such as fashion, beautiful appearance (aesthetics, color), ease of use, continuity of the product after washing, emotional and physical satisfaction of the user are included in psychological comfort. The factors that affect them are physiological comfort in the direction of economic resources, traditional usage patterns (effects of cultural assets on fashion), religions and habits, social status, social class differences and fashion directing authorities. [34]

Psychologically human, skin temperature is between 33 and 35 ^{0}C and the skin feels sweaty and comfortable. For this reason, users' comments are important in assessing comfort. Since objective evaluation is difficult to perform, it has become possible to compare and discuss subjective and objective measurements under the same conditions. Questionnaires for psychological comfort and psychological scales are used to examine users' opinions about clothes.

For this;

1. Determination of the property to be measured
2. Determination of the terms of this feature
3. Establishing the terms violence scale
4. Receiving data
5. Objective comparison of assessments by scale

Fritz's seven-degree scale to examine fabric attitude is given in the Table 3.2 below. [35]

Table 3.2 Fritz's seven-degree scale to examine fabric attitude

	Extremely	Very Much	Some What	Neither Both	Some What	Very Much	Extremely	
Soft	3	2	1	0	1	2	3	Harsh
Smooth	3	2	1	0	1	2	3	Rough
Cool	3	2	1	0	1	2	3	Hot
Light	3	2	1	0	1	2	3	Heavy
Fine	3	2	1	0	1	2	3	Coarse
Crisp	3	2	1	0	1	2	3	Limp
Clammy	3	2	1	0	1	2	3	Absorbent
Natural	3	2	1	0	1	2	3	Synthetic
Sheer	3	2	1	0	1	2	3	Bulky
Clingy	3	2	1	0	1	2	3	Flowing
Crushable	3	2	1	0	1	2	3	Resilient
Lacy	3	2	1	0	1	2	3	Plain
Drapable	3	2	1	0	1	2	3	Rigid
Scratchy	3	2	1	0	1	2	3	Silky
Stiff	3	2	1	0	1	2	3	Soft

Ruckman et al. investigated the effect of ventilation on outerwear jackets and used two types of jackets for this. One of them is made of a fabric laminated with PTFE.

The other type of jacket is a polyurethane coated jacket. 6 male subjects in a controlled climatic environment used for clothing trials. The subjects were wearing these jackets during their daily routine exercise and skin temperatures were measured at 4 different points and the amount of sweating was measured. For this purpose, the following scale (Fig. 3.4) was used to determine the thermal sensation and moisture sensation. It has been determined that fabric plays a very important role at rest. One of the jackets was found to give a higher feeling of discomfort compared to the other. [36]

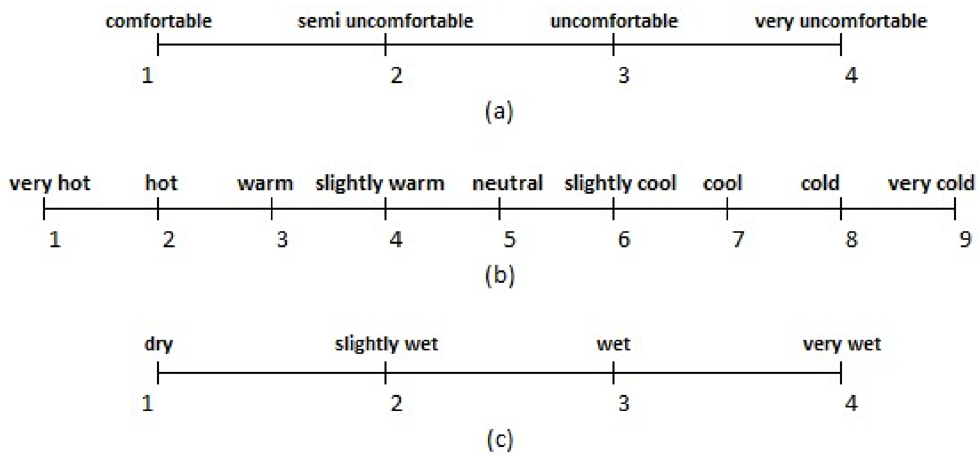


Figure 3.4 Ruckman's Scale for determination of thermal sensation and moisture sensation [36]

3.3.2.3. Thermal Comfort:

Thermal comfort is defined in ISO 7730 as "the mental condition that expresses *satisfaction* with the surrounding environment" [37]

Thermal comfort of clothing system is associated with the thermal balance of the body and its thermoregulatory responses to the dynamic interactions with the clothing and the environment.[29]

According to Fanger (1972), there is an analytical equation of thermal comfort. This equation involves different variables such as clothing, metabolism and environmental parameters like temperature, humidity, airflow velocity. etc. He defined the four essential conditions for an individual to be in a state of thermal comfort as follows:

- The body is in thermal equilibrium.
- Sweat is within comfortable limits.
- The average skin temperature is within comfortable limits.
- There is no local discomfort. [38]

The human body can be seen as a thermal system with its environment. Due to worn clothing, a human body is isolated in different proportions from the environment. The basis for the insulating effect is the thin layers of air embedded in the layers of clothing.

A thermal system is said to be at neutral state when it is in thermal balance with its surroundings. For the human body this translates to the situation in which all internally generated metabolic heat is fully transferred to the surroundings and physiological regulatory mechanisms like sweating and shivering are turned off. [39] Thermo-physiological comfort is about how clothing transmits heat from the body or transmits heat from the environment to the body. Actually, thermo-physiological comfort is associated with the thermal balance of the human body, which strives to maintain a constant body core temperature of about 37^0C and rise or fall of $\pm 5^0$C can be fatal. [29]

During the sitting activity, human metabolism generates heat. Human body needs to release the heat from the body. Heat transfer occurs from the higher temperature to the lower temperature. The heat transfer is completed when the balance occurred. Our clothes are insulates and they make the rate of heat release is slower. The retention or release of body heat is a prime requirement of clothing. Environment, conditions, metabolic rate, clothes have an interrelationship for clothing comfort.

The interaction between the environment and the human body is a complex and precise process. Usually not only one but two or more textile layers act as a barrier between the body and the environment—indoor or outdoor. Meanwhile, the thermoregulatory system is influenced by the task being performed. This complex process is presented in Figure 3.5. [26]

Upon analysis of the process of heat transfer from the environment to the body, it is obvious that the interaction between the outside air and the textile layer(s) is a physical process of heat exchange on the basis of the existing temperature gradient. More complex is the interaction between the textile in its role of a protective barrier and the body. This process includes two parts:

• *Textile–skin* interaction, which again is a purely physical process

• *Skin–core body* interaction, which is a physiological process convection due to the circulating fluids inside the body. Hereinafter, the control of the heat flow is carried out by physiological reactions such as sweating, metabolism, and vasomotor action [40].

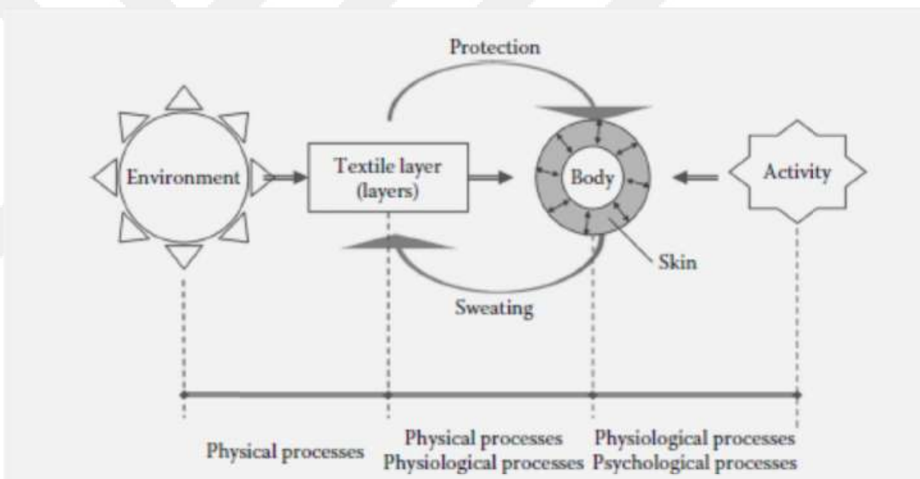


Figure 3.5 Effect of the environment on the body [23]

Clothing comfort is determined by the thermal regulation between the skin and the clothing. It is therefore necessary for a garment to be able to maintain a balance between internal and external temperature in order to be comfortable. Thermal comfort depends on the balance in temperature. The human body sweats to keep this temperature in balance. Sweat evaporates. This is the method that the body naturally uses to keep itself comfortable. It is also important for the clothing to be able to absorb the sweat of the body and vaporize it.

The human body has a complex mechanism for temperature control, which has to balance both heat production and heat losses. The heat is generated continuously as a result of the metabolism of all body cells, but it changes with the activity of the glands and the internal organs, as well as the action of the muscles, which movement (i.e., shivering) is one of the effective ways of the body to increase the heat generation. [26]

It is a known fact the evaporation reduces the temperature and ultimately skin will be cooled down and thermal balance will be achieved. Barker (2002) explains Woo and Barker model which is used to heat and moisture vapor transfer, which occurs simultaneously. This model is written as:

$$M_n = Q = H + E \tag{3.1}$$

Where:

M_n= Net metabolic heat which must be dissipated
Q= Heat lost through the clothing
H= Heat lost through thermal transfer
E= Heat lost through evaporation (mass transfer)

Woo and Barker (1988) calculates a comfort range with heat generated. The model is based on the first criterion of clothing comfort which holds that the net metabolic heat generated (M_n) must be dissipated through garments worn (Q). [34,41]

According to Layton, thermal comfort is a combination of clothing, climate and physical activity. When human eat, the chemical energy is converted to the work and heat. Produced heat transferred from the body's skin to the environment. On a steady-state heat balance, the heat energy produced by the metabolism equals the rate of heat transfer from the body by conduction, cnvection, radiation, evaporation and respiration. [29, 35]

Heat Loss Mechanism:

The human body is found in thermal equilibrium at normal environmental standards. It is known that the steady-state heat balance condition of human metabolism system produce energy of heat. This heat energy should be equal to the transferred heat from the body. Any activity in metabolism returns outside the body as convection, radiation and conduction. According to basic thermodynamic rules, the general heat balance equation is expressed by below (Equation 3.2):

$$M\text{-}W = C + C_k + C_{res} + R + E_{res} + E_{sk} \qquad (3.2)$$

M : Metabolic rate (M is determined by metabolic activity)

W : external work (W is so small. Generally ignored)

C : heat loss by convection

C_k : heat loss by conduction

C_{res} : heat loss due to respiration

R : heat loss by radiation

E_{res} : evaporate heat loss due to respiration

E_{sk} : heat loss by evaporation from the skin

Heat losses during clothing can be associated with the heat transfer processes on below:

• *Conduction*: When we contact a hot object with a cold object, the transfer of heat to the cold object is called conduction. When it is considered as textile, it is the mechanism of heat loss due to the contact between the dressed clothing and the skin or the contact between two different fabric layers. The outer layer of the fabric is always colder than the inner layer. The rate of the heat loss is influenced by the nature of the cloth. Heat losses by conduction increase when the colder surface is wet. In general, conduction accounts for 2%–3% of total heat losses in dry conditions. The conduction heat loss is usually insignificant. [26, 29]

• *Convection*: Heat transfer by convection refers to heat loss in the air layer between the skin and the textile surface closest to it. This heat loss occurs from the inner layer to the outer layer. Heat losses from the body by convection are associated with the removal of the layer of warm air between the body and the textile layers. Heat transfer by convection from the human body to the environment is expressed as follows (Equation 3.3) :

$$C = f_{cl} \,.\, h_c \,.\, (T_{cl} - T_a) \qquad (3.3)$$

C : Convection

f_{cl} : Clothing area factor (clo)

h_c : coefficient of convection heat transfer (W/m^2K)

T_{cl} : Clothing surface temperature (^0C)

T_a : Ambient air temperature (^0C)

The heat transfer coefficient (h_c) depends on air velocity so the rate of the convection heat losses related too. Indoor environment, the velocity of the air is so small and caused by the movement of the body. Heat losses by convection are important because of the presence of wind in the outdoor environment. Value of the h_c can be calculated with Equation 3.4 approximately:

$$h_c = 12.1 \;.\; V_a^{\;0,5} \tag{3.4}$$

• *Radiation*: Heat loss through radiation deals with heat losses to a colder environment than the body. It therefore depends on the average temperature of the environment, the temperature of the garment surface, and the environment and garment properties. Heat loss by radiation between the environment and the body is expressed as follows (Equation 3.5) :

$$R = \sigma \;.\; \varepsilon_{cl} \;.\; f_{cl} \;.\; F_{vf} \;[\; (\; T_{cl} + 273.15)^4 + (T_r + 273,15)^4 \;] \tag{3.5}$$

σ : Stefan Boltzman Constant ($5,67 \times 10^{-8}$ W/m^2K^4)

ε_{cl} : Emmissivity of the clothing

f_{cl} : Clothing area factor (clo)

F_{vf} : View factor between the body and surrounding surface

T_{cl} : Clothing surface temperature (^0C)

T_r : Radiant temperature (^0C)

• *Evaporation*: When we sweat, our body produces heat energy to remove sweat from our skin. The heated sweat evaporates and the heat loss in the form evaporation takes place. This is not directly related to the clothing characteristics. Evaporation always constitutes a rejection of heat from body.

• *Respiration*: This is the mechanism of heat losses from lungs, related to warming of the inhaled colder air, which is then exhaled. [26, 29]

Heat Generation Mechanism of the Body:

In order to counterbalance the heat losses, the body must produce an equal amount of heat so as to stay active despite the temperature of the environment. The thermal productivity of the body varies from person to person depending on the activity performed, as well as from age to age. Many factors, such as age, health, weight, activity degree, have an effect on the heat production of the human body.

A function of the human body is to produce heat. The ability of the body to produce temperature may vary according to many factors such as age, food intake and activity. When the body produces too much heat, this heat will disturb the human body if it cannot be transferred. There are two ways to remove this excess heat: the skin and the respiratory system. In the respiratory system, heat and moisture are excreted from the lungs. With the skin, heat and moisture balance is achieved by heat transfer. In other words, our body is a thermal staged system. In order to achieve this, both moisture transfer and heat transfer take place in our body. [27, 29, 35]

The mechanisms used by the body to produce heat are as follows:

• *Metabolism*: Biochemical reactions appear in the body and the heat is produced as a by-product.

• *Physical activity*: Muscles generate heat during physical work. Most of body's heat is produced by this mechanism.

• *Shivering*: Heat is generated via uncontrolled quivering of the muscles in cold environment that increases the heat production. The effect of this mechanism is limited to a few hours because of depletion of glycogen stores (the muscle *fuel*) and the appearance of fatigue.

Concerning the factors that influence the heat production in the body, two groups can be distinguished.

• Factors important for body's heat production:

- Food intake
- Metabolism, determined mainly by the activity

- Glycogen store
- Fluid balance

• Factors important for body's heat retention (and tolerance to cold environment):

- Thermal insulation of the textiles/clothing
- Size and shape of the body: body surface to body volume ratio
- Layer of fat under the skin
- Sorption abilities of the textiles
- Temperature of the environment

Thermophysiological comfort, as part of the overall comfort of the person, is assessed by various sensory signals that are processed by the brain. Two main sensations can be distinguished: *temperature* and *humidity* (Table 3.3).

Table 3.3 Sensations of the person related to thermophysiological comfort [26]

Sensation	Integral Result of	Sensation	Sensory Signal From
Temperature sensation	Sentation for temperature	Cold /Warm	Skin
	Speed of temperature changes	Speed of cooling / warming	
Moisture Sensation	Sensation of temperature changes	Increased speed of cooling	No Special sensors
	Tactile sensors	Wet Skin, drops of sweat	

The thermal discomfort associated with the presence of a sensation for moisture is much more discussed than the discomfort preconditioned by cold indoor environment. Clothing or textiles can further increase the discomfort due to the moisture that appears because of the imbalance between the generated (or absorbed) heat by the body and heat losses. The following aspects related to the sensation of moisture should be taken into account:

- Water vapor or sweat is transported from the moist skin surface to the nearest textile layer (which can be part of clothing, furniture fabric, bedding, etc.). As a result, the friction coefficient *textile–skin* is changed, which provokes as a rule an unpleasant sensation in contact.

- Being wet due to the convective moisture transport or the diffusive transfer to the environment, the textile layer cools fast and provokes unpleasant sensation of wetness in case of direct contact with skin (cold sensation).

3.4. Important textile properties for thermal comfort:

The thermal comfort properties of textile materials have come into sharp focus in the textile research work of recent times. Properties like thermal resistance, thermal conductivity and thermal absorptivity are influenced by fabric properties like structure, density, humidity, material type and properties of fibers, type of weave, surface treatment, finish and compressibility, air permeability, surrounding temperature and the like. Thermal comfort properties of textile fabrics are actually influenced by the gamut of fiber, yarn and fabric properties. Fiber type, spinning technology, yarn linear density, yarn twist, yarn hairiness, fabric thickness, fabric cover factor, fabric porosity and finish are major factors that determine the comfort properties of fabrics. [20]

Thermal measurement in fabrics can be divided into two groups in general. One of them is transient-state thermal properties and the other is steady-state thermal properties. In the most general way, thermal conductivity and thermal resistance properties of the fabric that provide information about the thermal properties. Transient heat transfer occurs when contact between skin and surface occurs. Transient measurements measure the thermal diffusivity and thermal absorptivity of the fabric. [42]

- **Thermal conductivity:**

  Thermal conductivity is a property that varies from material to material. Heat conduction takes place from high temperature to low temperature in the principle of heat conduction with condensation. Because the energies of the molecules with high temperatures are high and they want to transfer this energy to the molecules at low energy level. Conceptually, the thermal conductivity can be thought of as the container for the medium-dependent properties which relate the rate of heat loss per unit area to the rate of change of temperature. [43]

Thermal conductivity is defined as the quantity of heat (Q) transmitted through a unit thickness (L) in a direction normal to a surface of unit area (A) due to a unit temperature gradient (ΔT) under steady state conditions and when the heat transfer is dependent only on the temperature gradient. In equation 3.6 form it can be expressed as:

Thermal Conductivity = heat × distance / (area × temperature gradient)

$$\lambda = Q \times L / (A \times \Delta T) \qquad (3.6)$$

For textile materials, still air in the fabric structure is the most important factor for conductivity value, as still air has the lowest thermal conductivity value compared to all fibres ($\lambda_{air} = 0.025$). Therefore, as the amount of entrapped air in the fabric structure increases, the fabric provides lower thermal conductivity and higher thermal insulation.

The effect of blend proportion was investigated by Prakash & Ramakrishnan and they found that the thermal conductivity of knitted fabrics is reduced as the proportion of bamboo fiber increases in the yarn. [44]

- **Thermal resistance:**

Thermal resistance is defined as the ratio of the temperature difference between the two faces of a material to the rate of heat flow per unit area. Thermal resistance determines the heat insulation property of a textile material. The higher the thermal resistance, the lower is the heat loss. The thermal resistance, R, is connected with the thermal conductivity, λ, and the fabric thickness, h, as follows (Equation 3.7) : [42]

$$R = h / \lambda \qquad (3.7)$$

According to de equation the thermal resistance is inversely proportional to its thermal conductivity. The resistance that a fabric offers to the movement of heat through it is of critical importance to its thermal comfort. In studying the thermal insulation properties of garments during wear, it is clear that thermal resistance to transfer of heat from the body to the surrounding air is the sum of three parameters:

(i) The thermal resistance to transfer heat from the surface of the material,

(ii) The thermal resistance of the clothing material, and

(iii) The thermal resistance of the air interlayer. [45]

- **Thermal Absorptivity :**

Thermal absorptivity determines the contact temperature of two materials and indicates the warm-cool feeling of fabrics. [46]

Thermal absorptivity is the heat flow between the skin and the textile material in contact. Human skin is considered to have infinite thermal capacity and temperature and is a semi-finite body when the thermal contact time between the skin and the contacting fabric is also considered to be very short. This affects the 'warm-cold feeling' at the moment of touch. It is effective on the fabric handle. [47]

When a person touches a material at a temperature different from his or her skin temperature, heat exchange occurs between the material he touches and the skin. If the thermal absorbability of the material to be touched is high, it gives the contact person a cold feeling at the first contact. [48]

The thermal conductivity can be expressed in equation 3.8 as:

$$B = (\lambda \rho c)^{1/2} \qquad (3.8)$$

Where λ is the thermal conductivity, ρ is the fabric density and c is the specific heat of fabric. ,

- **Water Vapour Permability:**

Water Vapour Permability of a fabric is also known as 'breathability'. This ability of the fabric is the transfer of the water vapour from the skin to the outer environment through the fabric.

Water Vapor permeability of fabrics used in sportswear is important. The human body has its own cooling and heating mechanism. It can self-cool with sensitive sweating and / or sensitive sweating to balance the heat produced in the body in line with daily activities. A constant body temperature is thus obtained. If the sweat evaporated by body temperature cannot be transmitted to the outside environment, the relative humidity in the garment will increase. This causes wet feel and naturally causes uncomfortable feeling. [41]

Su et al. [49] pointed out that if the amount of cotton fiber in the cotton/PET blend increases, the water absorption of the structure also increases but the drying rate of the yarn decreases.

- **Air permability:**

Air permeability is the volume of air passing through the unit fabric surface due to the pressure difference between the two sides of the fabric. According to British standarts (BS3424-16-1995) air permeability is defined as velocity of an air flow passing perpendicularly through a test specimen under specified conditions of test area, pressure drop and time. [50]

The fabric structural parameters have an impact on air permeability by causing a in the length of airflow paths through a fabric. Density (porosity), eg. The shape and sizes of pores, and finishing processes also influence air permeability. [51]

Air permeability occurs through the pores of the fabric. The porous structure of the fabric is effective on air permeability. Air permeability plays an important role in determining the comfort of a fabric. Because it provides the transfer of moisture vapor to the external environment. [19]

Chidambaram et al.[52] investigated the thermal properties of single jersey fabrics knitted with 20 Ne, 25 Ne and 30 Ne 100% bamboo yarns with different loop lengths. They found that the increase in linear density and loop length in the fabric affected the thermal comfort properties. When the yarn gets finer the thermal resistance and thermal conductivity decrease. The water vapor permeability and air permeability increases as the linear density and loop length increases.

Milenkovic et al. [15] reviewed that fabric thickness, enclosed still air, and external air movement are the major factors that affect the heat transfer through fabric.

Greyson [53] and Havenith [54] noted that heat and water-vapor resistance increases with the increment of material thickness and air entrapped in the fabric.

Dhinakaran et al. [55] noted that the comfort characteristics of fabrics mainly depend the structure, types of raw materials used, mass, moisture absorption, heat transmission, and skin perception.

Li et al. [56] showed that the heat transfer process, which is influenced by fabric and porosity, significantly impacts moisture transport processes.

- **Wetting and Wicking**

The behavior of a textile material as a result of contact with liquid is one of the comfort properties. In textile materials, the space between the fibers is in the form of capillaries which can be filled by the liquid. Therefore, it is important that the material can be wetted and able to conduct liquid. In the textile material, both wetting and wicking are observed during finishing processes, processing of the material and use of the material. The wetting and wicking behavior of the fibers is therefore important. [57]

In porous structures, the spontaneous transport of water by capillary forces is called wicking. Wicking is caused by spontaneous wetting of a porous system. [58]

Wetting must take place before it can become wicking. The fibers must be wettable in order to penetrate the fabric. Wettability and wicking properties is generally a feature that affects the performance of many textile products such as sportswear, disposable hygienic materials and medical articles. Consequently, wetting during the garment is also important for the comfort of the garment. [57]

Wetting: The term "wetting" is usually used to describe the displacement of a solid-air interface with a solid-liquid interface. When a small liquid droplet is put in contact with a flat solid surface, two distinct equilibrium regimes may be found: partial wetting with a finite contact angle 0, or complete wetting with a zero contact angle as shown in Fig. 3.6. [59]

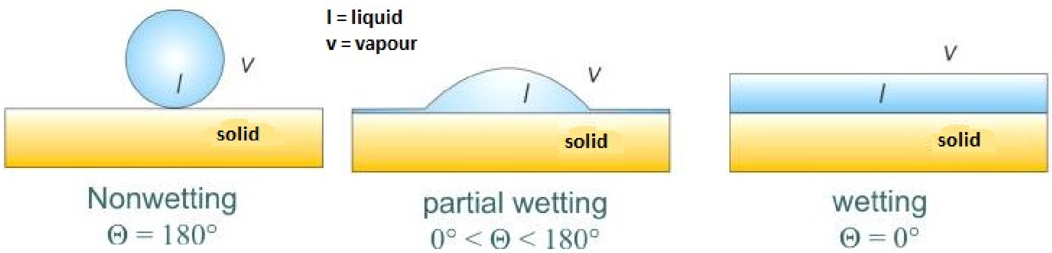


Figure 3.6 A small liquid droplet in equilibrium over a horizontal surface

The forces in equilibrium at a solid-liquid boundary are commonly described by the Young's equation 3.9 :

$$\gamma_{sv} - \gamma_{sl} - \gamma_{lv} \cos\Theta = 0 \qquad (3.9)$$

where γ_{sv} γ_{sl} and γ_{lv} denotes interfacial tensions between solid/vapor, solid/liquid and liquid/vapor, respectively, and 0is the equilibrium contact angle.[57]

Wicking: Wicking is the self-transport of liquid applied to a porous material. Wicking is self-wetting in a system. Capillary forces occur as a result of wetting, and wicking is the result of spontaneous wetting of a capillary system. [58]

In fibrous structures, water transport behavior is called wicking and this feature is used to determine the comfort properties of fabrics. The formation of wicking is observed by the effect of external forces, in particular the forces to be rendered. This formation occurred by moving in a three-dimensional fabric structure. It is a spontaneous displacement between the solid-air interface and the solid-liquid interface. [57]

In the simplest case of wicking in a single capillary tube, as shown in Fig 3.7. a meniscus is formed. The surface tension of the liquid causes a pressure difference across the curved liquid/vapor interface. This is the case when the interfacial energy of the fiber surface in contact with vapor (air) γ_{sv} exceeds the interfacial energy between the liquid and the fiber surface γ_{sl} ;

$$W_P = \gamma_{sv} - \gamma_{sl} \tag{3.10}$$

The work of penetration W_P is a measure of the energy required for capillary penetration (Equation 3.10). Since γ_{sv} and γ_{sl} are exceedingly difficult to measure independently, workers have attempted to estimate the surface energy indirectly by interaction with liquids.

According to Young-Laplace equation 3.11:

$$\Delta P = 2\gamma_{lv} / R, \tag{3.11}$$

where $R = r / \cos \Theta$ and r is the capillary radius.

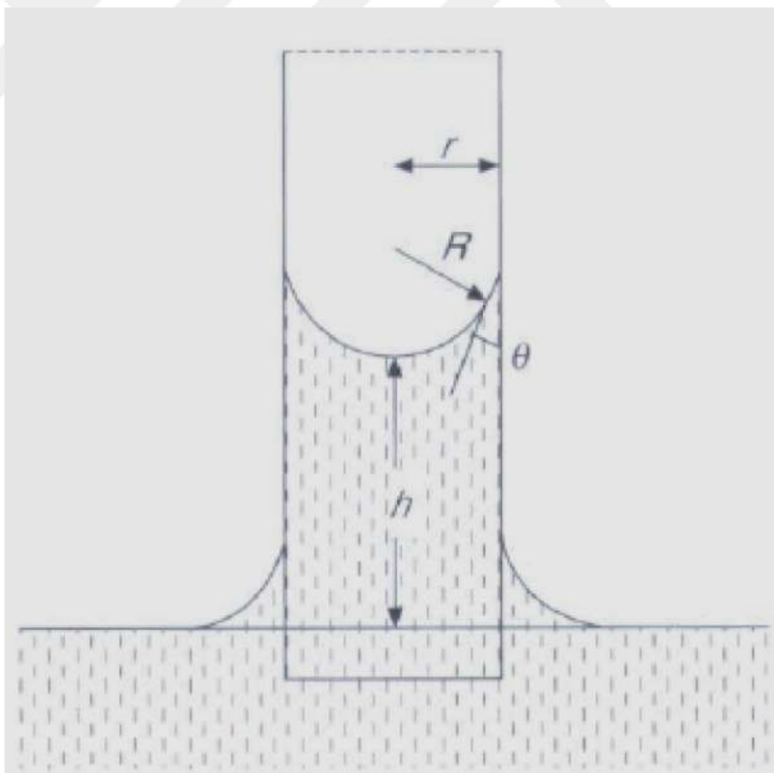


Figure 3.7 Wicking in a Capillary **[59]**

When the capillary wall is completely wettable by the liquid, then $\cos \Theta = 1$. For a positive capillary pressure, the values of Θ have to be between 0° and 90°. Capillary pressure is inversely related to the capillary radius.

The driving force for such surface wicking depends on the geometry of the grooves, surface tension of the liquid, and free energies of the solid gas and solid-liquid interfaces. The wicking rate is not solely governed by interfacial tensions and the wettability of the fibers, The wicking rate depends on the capillary dimensions of the substrate and the viscosity of the liquid.[60]

3.5. Some literature surveys

Oglakcioglu and Marmarali [61] studied the thermal properties of cotton and polyester basic knitted structures and found that each knitted structure tends to show quite different thermal comfort properties. They compared the comfort properties of plain, rib and interlock knitted fabrics made from cotton and polyester yarns. Mercerized fabrics provide higher thermal absorptivity and give cooler feeling at first contact. Fabrics knitted either double plied yarns have higher thermal conductivity values than knitted with single yarns.

Ratna and Gowthami studied bi-layer fabric sportswear which is blends bamboo-PP. They found that bamboo layer keeps the body cool soft and makes to breathe easy. It passes the airquickly to the outer layer. The polypropylene layers have good wick ability, thermal conductivity and light weight. [62]

Park (2016), has prepared double-face knitted fabric with polypropylene, dyeable polypropylene, polyester and Coolmax yarns. And study on thermal insulation, moisture permeability index of the fabrics that examined the properties of moisture and steam permeability on fabric thermal comfort was emphasized. It is reported that the fabric structure prepared from dyeable PP / Coolmax yarn mixture gives the best capillity, highest thermal insulation and moisture permeability index.[63]

Sakthi et al. (2016), the thermal comfort properties of double-face ribana knitted fabrics, which were produced as 100% polypropylene and tencel yarns, were produced as PP on the inside and tencel on the outside, were measured but no structural variations were made. It was evaluated that the fabric structure proposed for the study was suitable for sports garment. In this study, low moisture absorption, excellent water vapor permeability and capillary properties of PP fiber were emphasized. [64]

Jhanji et al. (2014), prepared double-sided flat knitted fabric samples which are produced with cotton, polyester, polypropylene and polyamide yarns. In the study of thermal properties of the fabrics were measured and polypropylene fiber has good moisture management property and exhibits high thermal insulation even when wet, because it is more olephilic than polyester to absorb body oils better emphasis has been made. Regardless of fiber type, fabric thermal resistance, thermal conductivity and thermal absorbtivity values increased as the yarn thickened; air permeability value decreased. This was associated with the high statistical effect of fiber type (fiber thermal conductivity) and yarn fineness.[65]

Geraldes et al. (2008), Thermal comfort properties of double-sided knitted fabrics, which are prepared polypropylene and cotton yarns, examined and evaluated that increasing in the percentage of polypropylene fiber thermal absorbance and thermal resistance values of the fabric increased linear character. Fabrics knit report has effect too. These two data show that the percentage of polypropylene is critical in sports garment fabrics. [66]

Bajzik et al. (2016), Used 12 different knitted fabric for sportswear and they made measurements with Alambeta and Permetest devices fort he dry and the wet conditions of these fabrics. They obtained WCI (Wet Comfort Index) value from the mesurements. According to this value, It is accepted that the higher the value between 0 and 1, the higher the perception of thermophysiological comfort when wet. The highest WCI values were observed in the knitted fabric sample containing polypropylene.[67]

Saravanan et al. (2016), the main features expected from sportswear fabrics are to keep the user dry during the activation period and help to establish thermal balance with the external environment. Therefore, the garments should exhibit sufficient heat, air and moisture transfer properties. This garment group should be low in weight but with shape retention. It should show adequate thermal insulation and dimensional stability when wet. In this study, it is emphasized that polypropylene fiber can be preferred in sportswear production due to its low moisture absorbency but excellent water vapor permeability and capillary, high thermal insulation even when wet and keeping the user cool in hot and cold weather. [68]

Suganthi et al. (2017), prepared jersey, tuck knit and double face rib knit fabrics which are made with the same yarn count of modal, polypropylene and micro polyester yarns. In the study, air permability, water vapor permability, thermal conductivity and liquid water condition properties of the fabric were mesured. Polypropylene - modal yarns used in the double - sided ribana fabrics are considered to be the most suitable structure for sportswear. [69]

Gülsevin (2005) has investigated the comfort properties of different thread types, fabric constructions and different loop density. As a result of statistically evaluation, the parameters that affect the water vapor permeability and thermal resistance were determined. According to the study, yarn count increasing, the PET and PP fiber including were made the water vapor permeability higher. Besides the using elastane threads decreased the water vapor permeability. For the fabric construction, it is stated that the use of the supreme type of fabrics which have high porosity, is an advantageous for water vapor permeability. As the porosity increases, the areas in which the steam can move increase and more water vapor passes.When the thermal resistance values are examined, it is seen that thinning of the yarn number and use of PP fiber decrease the thermal resistance.It has been found that the fabrics made with the fabric such as interlock have more thermal resistance. Thermal resistance results are explained by the amount of stagnant air retained in the material. Air flow paths through a fabric affect the thermal resistance. [70]

In the study of Güneşoğlu et al (2005), 4 different knitted fabrics were selected with various ground and loop yarn combinations. The fabrics were tested in Alambeta and Permetest devices and the hot-cold feeling of the fabrics was examined and the use of these fabrics for the outdoor environment was investigated. According to the results obtained; 100% cotton fabric on the ground and the loop, gave the maximum thermal absorbency value. Therefore, it is stated that it gives a feeling of coolness when touched. It was found that the presence of PET fiber increased the heat absorption ability. It is emphasized that the effect of the fiber type on the warm-cold feeling is the first factor. It is stated that it will give comfort and comfort to the user by absorbing the sweat and quickly evaporating the sweat in contact with the sweaty body. [47]

Ute et al. (2008) in their work, blended natural cotton fiber and Angora fibers in different proportions and double-sided knitted fabrics were produced from these yarns. Thermal comfort properties of the fabrics were measured. The effects of using different faces as inner or outer layers and the effect of different Angora ratio were investigated. The measurements showed that the thermal absorption value of the face with Angora blended yarn in fabrics was lower and therefore gave a warmer feeling at the time of the first contact. Increasing the Angora fiber ratio in the fabric causes decreasing the thermal absorbtion of the fabric, increasing the thermal resistance and decrease the water vapor permability accordingly. [71]

Majumdar et al. (2010) investigated the thermal properties of different knitted fabric structures produced from cotton, regenerated bamboo and cotton / bamboo blend yarns. For this study, three blends of fibres (100% cotton, 50:50 cotton: bamboo and 100% bamboo) were used to produce three yarn counts (30 tex, 24 tex and 20 tex). Each type of yarn is knitted in 3 types of knitted fabric (flat-rib-interlock). The results show that the increase of bamboo fiber ratio reduces the thermal conductivity of knitted fabrics. For the same fiber blend proportion, the thermal conductivity was lower for fabrics made from finer yarns. The thermal conductivity and thermal resistance values of interlock fabric was the maximum followed by the rib and plain fabrics. The thermal conductivity of the fabrics produced from finer yarns for the same fiber blends is lower. The highest thermal resistance value was obtained in interlock knitted fabrics. As the bamboo fiber ratio increased, the water vapor and air permeability of the fabric increased. The highest water vapor and air permeability values were obtained in flat knitted structures. [72]

Hes (2002) developed functional knitted structure to control moisture and heat transfer. The improved double layer knit structure has a hydrophobic PP fiber of first layer to touch the skinand the second layer of cotton fiber with hydrophilic character to absorb the humidity. [73]

Bertaux et al. (2010) investigated the effect of textile properties, physiological and sensory parameters on comfort properties of socks. The comfort parameters of sports socks were evaluated in two different sports exercises. The sensory cirteria as defined the sensation of foot temperature and pain. Foot temperature and humidity were measured with sensors during sport exercise. The friction between the sock fabric and the mechanical leather model was investigated. As a result of subjective tests, socks with high friction coefficient were found to be less comfortable. It is stated that the fiber content primarily affects comfort. Cotton socks are less comfortable than synthetic (PET / Pa, PET / Ptfe / Pa, Pp) socks are emphasized. However, the users still prefer cotton socks, and it is stated that the reason why users love cotton sense. In addition, it was stated that the socks produced from synthetic fibers with low friction coefficients will keep the feet dry and at a suitable temperature. [74]

CHAPTER IV

MATERIALS AND METHODS

To achieve the objective the study, the following methodology has been adopted:

4.1. Sample Selection :

According to the market research, commercial fabrics were carried out to find the physical and structural properties of the fabric. According to recent trends and commercial base layer of sports clothing, knitted fabric construction was selected.

Knitted fabric is the most common fabric structure for the base layer because of its stretch an recovery property. It provides movement freedom, shape retention and well fit. Knitted fabrics also have relatively uneven surfaces, which make them feel more comfortable than smooth-surface woven fabric of similar fiber compositions. This effect results from the fact that the fabric whichever surfaces has less direct contact with the skin. [18]

The proposed list of the samples that has been produced is given below in Table 4.1. Ring spun 100% Cotton (Ne 20/1, Ne30/1 and Ne40/1), 100% PET (Ne 20/1, Ne 30/1, Ne 40/1) staple ring spun and 100% PP CF (140/72 Denier, 180/72 Denier, 280/72 Denier) fabrics were eployed to produce plain knit (single jersey), cross miss and double-faced and stitch transferred fabrics.

In this study, the samples have been knitted in industrial environment (Uniteks / İzmir, the industrial partner of the TUBITAK 1505 project) and PP (CF), PET and cotton (staple) yarns have been used for knitting. The samples differ in structure, yarn blend, yarn count and fiber type. Practically, single jersey fabric samples were prepared on 32 gauge / 22 Fein, cross miss fabrics 34 gauge/18 fein and the stitch transferred fabrics (3 different reports) on 34 gauge/16 Fein knitted machines.

The stitch diagrams of the fabrics and structure details given in Figure 4.1.

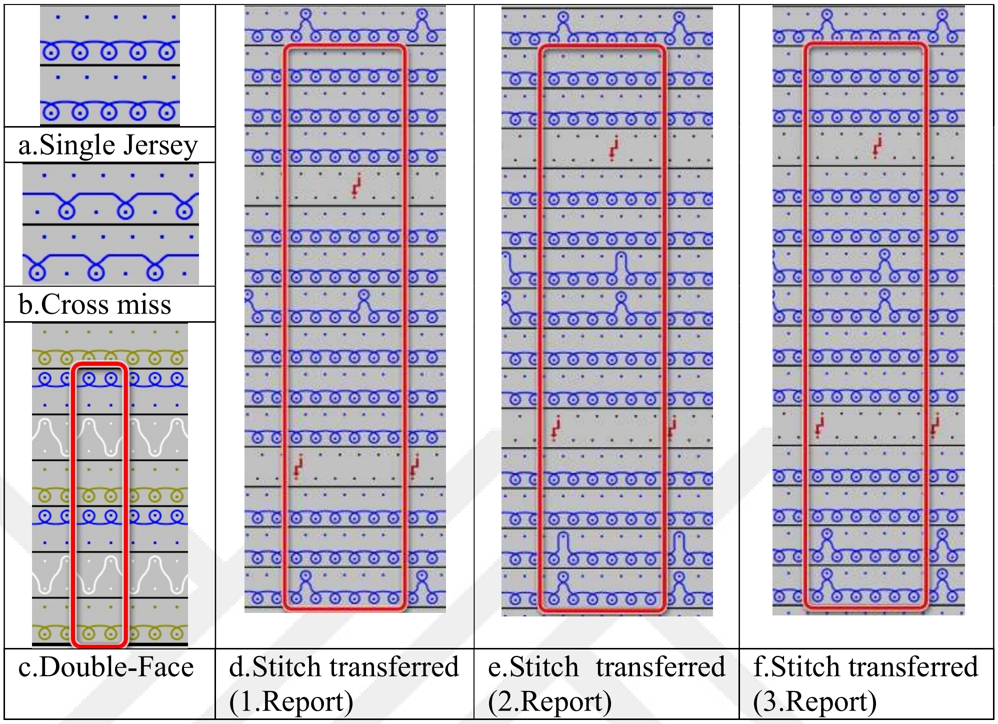


Figure 4.1 Stitch diagram of the samples

Experimental sample fabrics were produced as Supreme (Single Jersey), cross miss, Double-Face and 3 different stitch transferred fabrics as given in Table 4.1.

Table 4.1 List of Samples

Trial No	Knitting Structure	Technical Face			Technical Back		
		Blend Ratio	Fiber Type	Thread No	Blend Ratio	Fiber Type	Thread No
1	Single Jersey	100%	PP	20		-	
2	Single Jersey	100%	PET	20		-	
3	Single Jersey	100%	CO	20		-	
4	Single Jersey	100%	PP	30		-	
5	Single Jersey	100%	PET	30		-	

Table 4.1 (continued): List of Samples

6	Single Jersey	100%	CO	30	-		
7	Single Jersey	100%	PP	40	-		
8	Single Jersey	100%	PET	40	-		
9	Single Jersey	100%	CO	40	-		
10	Single Jersey	25/75%	PP/CO	30/30			
11	Single Jersey	50/50%	PP/CO	30/30			
12	Single Jersey	75/25%	PP/CO	30/30			
13	Single Jersey	25/75%	PET/CO	30/30			
14	Single Jersey	50/50%	PET/CO	30/30			
15	Single Jersey	75/25%	PET/CO	30/30			
16	Cross Miss	100%	PP	30	100%	PP	30
17	Cross Miss	100%	PP	30	100%	CO	30
18	Cross Miss	100%	PP	30	50/50%	PP/CO	30/30
19	Cross Miss	100%	CO	30	100%	PP	30
20	Cross Miss	100%	CO	30	100%	CO	30
21	Cross Miss	100%	CO	30	50/50%	PP/CO	30/30
22	Cross Miss	50/50%	PP/CO	30/30	100%	PP	30
23	Cross Miss	50/50%	PP/CO	30/30	100%	CO	30
24	Cross Miss	50/50%	PP/CO	30/30	50/50%	PP/CO	30/30
25	Cross Miss	100%	PET	30	100%	PET	30
26	Cross Miss	100%	PET	30	100%	CO	30
27	Cross Miss	100%	PET	30	50/50%	PET/CO	30/30
28	Cross Miss	100%	CO	30	100%	PET	30

Table 4.1 (continued) : List of Samples

29	Cross Miss	100%	CO	30	100%	CO	30
30	Cross Miss	100%	CO	30	50/50%	PET/CO	30/30
31	Cross Miss	50/50%	PET/CO	30/30	100%	PET	30
32	Cross Miss	50/50%	PET/CO	30/30	100%	CO	30
33	Cross Miss	50/50%	PET/CO	30/30	50/50%	PET/CO	30/30
34	Double Face	100%	PP	30	100%	PP	30
35	Double Face	100%	PP	30	50/50%	PP/CO	30/30
36	Double Face	100%	CO	30	100%	PP	30
37	Double Face	100%	CO	30	100%	CO	30
38	Double Face	50/50%	PP/CO	30/30	100%	CO	30
39	Double Face	50/50%	PP/CO	30/30	50/50%	PP/CO	30/30
40	Double Face	100%	PET	30	100%	PET	30
41	Double Face	100%	PET	30	50/50%	PET/CO	30/30
42	Double Face	100%	CO	30	100%	PET	30
43	Double Face	100%	CO	30	100%	CO	30
44	Double Face	50/50%	PET/CO	30/30	100%	CO	30
45	Double Face	50/50%	PET/CO	30/30	50/50%	PET/CO	30/30
46	Stitch Transferred 1.Report	100%	PP	30	-		
47	Stitch Transferred 1.Report	100%	PET	30	-		
48	Stitch Transferred 1.Report	100%	CO	30	-		
49	Stitch Transferred 2.Report	100%	PP	30	-		
50	Stitch Transferred 2.Report	100%	PET	30	-		
51	Stitch Transferred 2.Report	100%	CO	30	-		

Table 4.1 (continued) : List of Samples

52	Stitch Transferred 3.Report	100%	PP	30	-
53	Stitch Transferred 3.Report	100%	PET	30	-
54	Stitch Transferred 3.Report	100%	CO	30	-

4.2. Scouring and Preparing of Experimental Sample Fabrics:

Experimental sample fabrics were scoured to remove dirt and oil from the production process and were prepared for testing according to below finishing diagram as Figure 4.2. The fabrics were scoured to remove dirt and make the yarn relax. The samples scoured at 90^{0}C for 30 minutes using wetting agent, wax remover and soda. After this process, rinse at 80^{0}C for 15 minutes. Then the temperature has been decreased to 55^{0}C. At this temperature fabric has been treated with acetic acid for 10 minutes. Then the samples were dried.

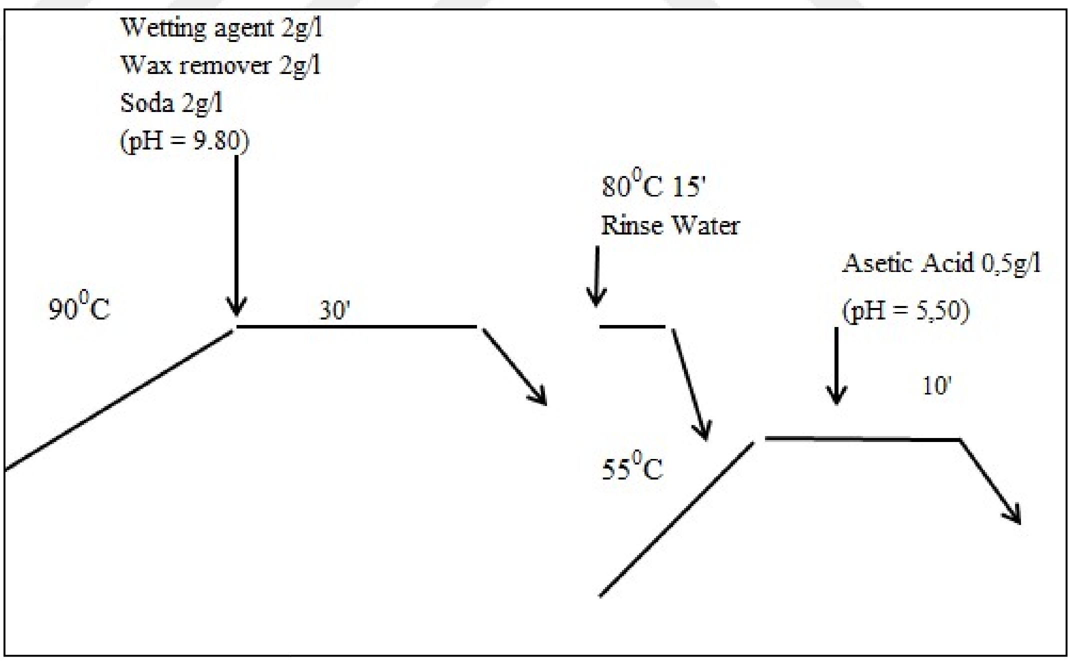


Figure 4.2 Pre-Finishing Diagram of the Sample Fabrics

4.3. Testing Fabrics:

The samples have been evaluated according to the measurements below in Table 4.2. The physical and structural properties; weight, thickness, spirality, bursting strength, abrasion and pilling resistance were evaluated in Uniteks/ İzmir. Crease recovery and %Elongation were tested in Gaziantep University. The comfort properties selected for testing were air permeability that has been tested in Gaziantep University. Water Vapour Permeability Tests have been evaluated in Kayseri Erciyes University. Wicking of the fabrics has been evaluated in Kahramanmaraş USTİM. Thermal conductivity, thermal resistance and absorptivity tests were tested with ALAMBETA test device in Gaziantep University, Textile Engineering laboratory.

Table 4.2 The List of the tests

Property	Test method	Device	Test center
Thermal comfort	Air permeability	SDL Atlas	Gaziantep University
	Water vapour permeability	Permetest	Erciyes University
	Wicking	MMT	USTİM
	Thermal conductivity, resistance and asborbtivity	Alambeta	Gaziantep University
Mechanical comfort	Bursting strength	James Heal Tester	Uniteks
	Weight / Thickness	--	Uniteks
	Spirality		Uniteks
	Abrasion and pilling resistance	ICI Pilling Box	Uniteks
	Wrinkle recovery	SDL	Gaziantep University
	Fabric Growth (% Elongation)	--	Gaziantep University

4.4. Methods:

Four commercial sample fabric constructions were selected for this study (see at Table 4.1). This selection was based on the current commercial base layer sportswear market.

Circular knitting machine was used for knitting of the fabric. For single jersey (20/1 thread) and cross miss fabrics adjustment of the machine gauges and dia are the same which are 32 inches dia / 22 gauge. 32 inches dia and 28 gauge machine is used for single jersey (30/1 and 40/1 thread) fabric manufacturing. Manufacturing the double face fabric is made with 34 inches dia / 18 gauge machines. For the stitch transferred fabrics 34 inches dia and 16 gauge machines are used. The blending was during knitting by the yarn feeding.

4.4.1. Wrinkle Recovery Test:

Wrinkles are three-dimensional versions of creases, and form the fabrics are forces to developed high levels of double curvature, which result in some degree of permanent in-plane and out-of-plane deformations. Most fabrics will generate some wrinkles after laundering, dressing, and folding. These wrinkles seriously compromise the cloth's acceptability. [50]

The method used in the laboratory to evaluate the wrinkle recovery of fabric is AATCC test method 128, 'Wrinkle recovery of fabrics: appearance method'. The principle of this method is to induce wrinkles in the fabric under standard atmospheric conditions in a standard wrinkle device (see. Figure 4.3) under a predetermined load for a certain period of time. Then the specimen is rated by comparing it with AATCC wrinkle replicas (see Figure 4.4).

Figure 4.3 Wrinkle Testing Device

According to the AATCC 128 test standards, three 15x28 cm size samples were prepared for every fabric. All fabric specimens were conditioned in an environment of 21 ± 1^0 C and 65 ± 2% RH for at least 24 hours. All test steps were performed in

21 ± 1^{0} C and 65 ± 2% RH environments. Wrinkle tester device was used for testing. The specimen was wound on the steel plate in the lengthwise direction, with the front side facing outward, and the specimen was fixed steel springs and clamp rings. The other end of the specimen was wound around the steel plate in the lengthwise direction, and the specimen was fixed with a steel spring and clamp ring. When the locking pin removed the lower plate went down and 3500 g weight placed on it. After 20 minutes, weight has been removed and spring and clamp has also been removed. After lifted up steel plate, specimen has been removed gently. The specimen was hanged on a rack. After 24 hours of suspension in the standard environment, samples were removed for rating. [75]

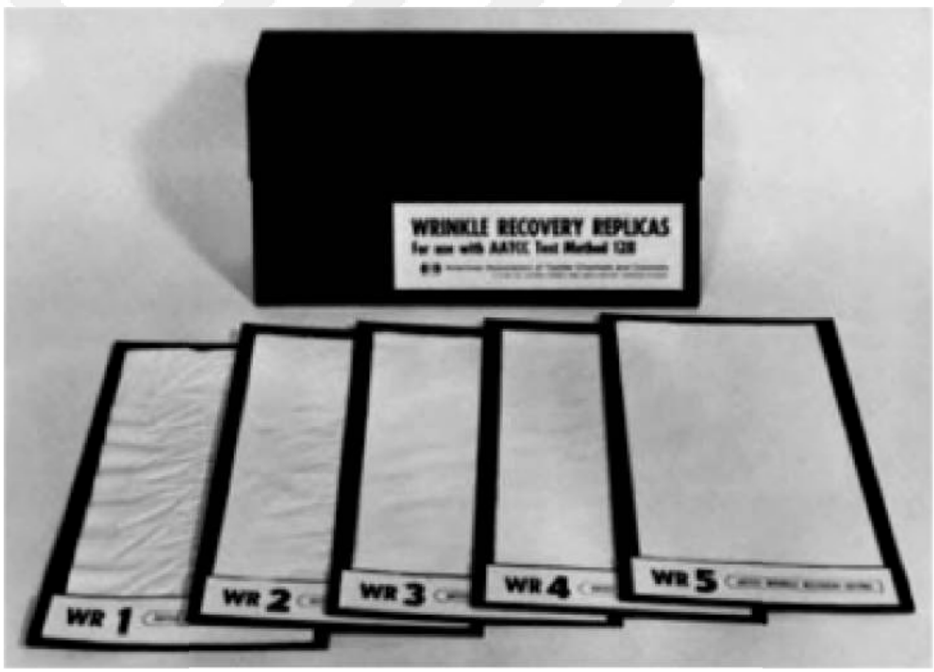


Figure 4.4 Wrinkle replicas for grading

Rating of the samples have made by three different educated graders with an observation board, under the fluorescent light source in light box. All samples compared with replikas and rated accordingly. All test results given below in Table 4.3. According to the replikas, wrinkling grade 1, which represents a deep wrinkle appearance or the highest degree of wrinkling; grade 5 which refers an almost absolutely flat surface or the slightest.

Table 4.3 Test Results of Crease Recovery Test

Trial No	Wrinkle Grade	Trial No	Wrinkle Grade	Trial No	Wrinkle Grade
	Mean		Mean		Mean
1	3,00	19	2,33	37	2,78
2	3,44	20	1,67	38	2,89
3	2,44	21	2,11	39	3,22
4	2,11	22	2,67	40	4,11
5	3,22	23	2,89	41	4,11
6	2,11	24	2,44	42	3,11
7	3,22	25	3,44	43	3,89
8	3,89	26	3,44	44	3,89
9	2,78	27	3,78	45	3,44
10	2,22	28	2,89	46	3,56
11	2,78	29	2,22	47	3,78
12	3,22	30	2,89	48	2,89
13	2,67	31	3,56	49	3,00
14	3,33	32	3,22	50	3,44
15	3,56	33	3,67	51	3,78
16	2,56	34	3,22	52	3,00
17	2,00	35	3,67	53	3,22
18	2,44	36	3,44	54	3,67

4.4.2 Fabric Growth (% Elongation) Test:

Comfort is an important parameter for textile products. Body movement comfort is one of the most important part of the comfort properties. Consumers' expectations during wearing are basically; easy movement, not to prevent body movement, easy stretching and recovering and fitting the body shape. As a consequence, the fabric growth is an important parameter that defines the ability of fabric to recover to its original size and shape after the physical movements of the user, such as sitting, bending or flexing of knees and elbows. Fabric growth of the specimens have tested accordance with ASTM 2594 test standard.

According to the ASTM Standard; *"fabric growth" is the difference between the original length of a specimen and its length after the application of a specified tension for a prescribed time and the subsequent removal of the tension. Fabric growth usually is expressed as a percentage of the length of the specimen prior to application of the tension*.[76]

For testing the sample a test device has been manufactured according to other commercial test devices. (See Figure 4.5.) Test device has 24 upper and 24 lower frames and extension screw apparatus.

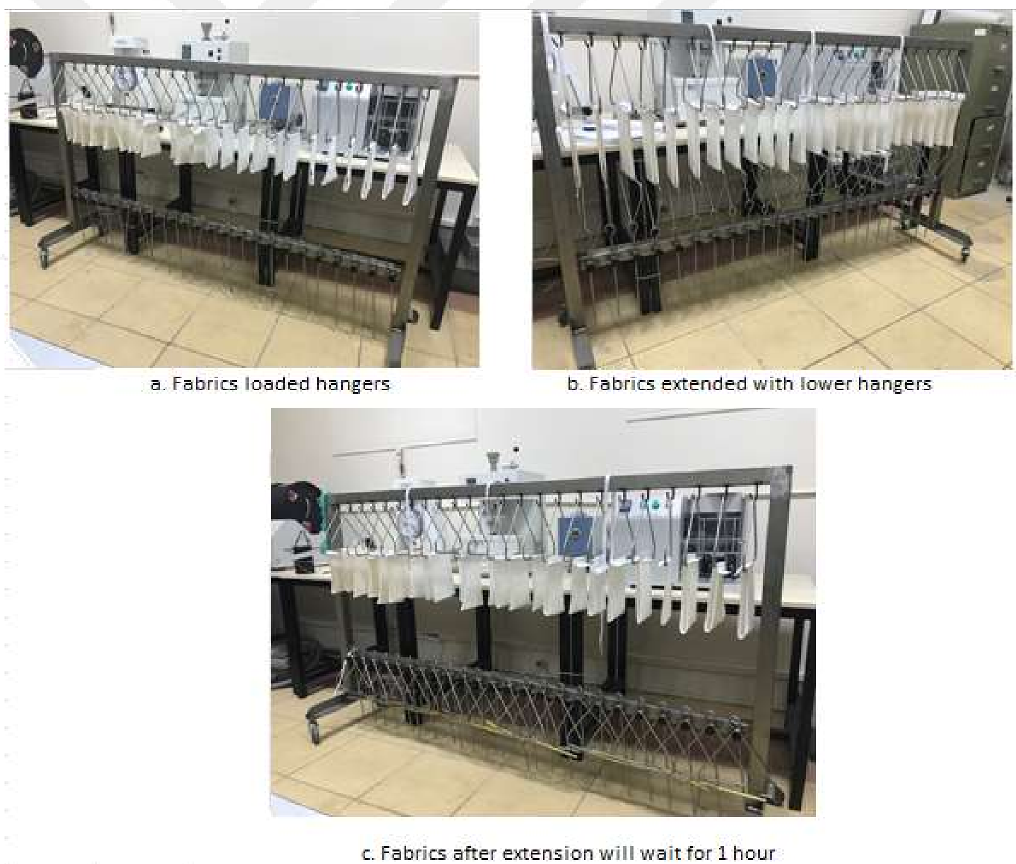


Figure 4.5 Fabric Growth Test Device

According to the ASTM 2594 test standards, five wale-wise (lengthwise) and five course-wise (widthwise) 127 ± 3 mm x 398 ± 8 mm size samples prepared for every fabric specimen. All fabric specimens were conditioned in an environment of 21 ± 1^0 C and 65 ± 2% RH for at least 24 hours. All test steps were performed in 21 ± 1^0 C and 65 ± 2% RH environments. Each specimen has been sewn into a loop and benchmarks are made in 130 mm apart on one side. The loops are held by a hanger at each end and the appropriate extension according to the standard has held for 2 hour. After this time the samples were released and the growth measured at 60 seconds and 1 hour after by a rule which is attached to the specimen.

Calculation of the fabric growth and fabric stretch properties of individual specimens to the nearest 1 % using Eq 4.1-2 , as applicable.

$$\text{Fabric Growth}_{60s}, \% = 100 \times (B–A) / A \tag{4.1}$$

$$\text{Fabric Growth}_{1h}, \% = 100 \times (C–A) / A \tag{4.2}$$

where:

A = *original distance between bench marks prior to tension force, mm ,*
B = *distance between bench marks, mm measured after release of the tension, force following 60 seconds recovery,*
C = *distance between bench marks, mm measured after release of the tension, force following 1 hour recovery*

Calculated fabric growth results of specimens are given in Table 4.4.

Table 4.4 Fabric Growth Test Results

Trial No	**Fabric Growth60s, % (Wale)**	**Fabric Growth60s, % (Course)**	**Fabric Growth1h, % (Wale)**	**Fabric Growth1h, %(Course)**
1	8,46	3,59	4,4	2,05
2	3,59	3,59	1,8	1,03
3	12,56	6,41	10,3	4,62
4	8,97	5,38	2,8	2,05
5	4,87	2,56	1,3	1,28

Table 4.4 (continued) : Fabric Growth Test Results

6	11,28	4,10	8,5	2,82
7	5,38	3,59	2,8	1,28
8	2,31	1,54	1,0	0,77
9	9,49	5,13	4,9	1,54
10	10,77	5,38	8,5	3,33
11	10,26	3,85	7,2	1,54
12	8,46	4,87	3,8	2,05
13	8,97	3,85	6,9	2,05
14	5,13	3,08	3,6	1,28
15	2,31	1,28	0,8	0,0
16	10,26	3,08	5,1	1,0
17	9,49	4,36	3,8	1,8
18	8,97	3,08	4,4	0,8
19	8,72	3,59	7,9	2,8
20	13,85	4,87	10,8	2,6
21	12,56	4,62	7,9	3,6
22	7,95	5,13	4,4	3,3
23	13,85	4,87	9,5	3,3
24	12,05	3,85	7,7	1,8
25	3,59	1,03	3,1	1,0
26	6,41	1,54	4,4	0,3
27	4,36	1,03	2,6	0,5
28	8,46	3,59	6,9	2,8
29	12,31	4,62	9,2	3,1
30	10,77	5,13	7,9	3,8
31	6,92	2,82	5,1	2,1
32	8,46	3,08	7,2	1,8
33	5,38	1,28	3,8	1,0
34	7,18	3,08	4,1	2,3
35	11,79	5,13	6,4	2,56
36	11,03	2,31	5,6	0,77
37	12,05	5,90	7,7	3,33
38	14,36	4,36	7,4	2,31
39	8,72	3,85	5,1	2,31
40	3,85	0,26	2,3	0,00
41	3,33	1,03	2,1	0,77
42	6,15	3,08	4,9	2,05
43	6,92	3,85	4,9	3,33
44	3,85	2,56	3,1	2,31

Table 4.4 (continued) Fabric Growth Test Results

45	3,33	1,79	0,8	0,26
46	17,95	7,69	5,9	3,08
47	2,82	1,79	1,5	0,51
48	8,21	4,87	4,9	2,56
49	17,95	5,90	8,2	1,54
50	5,13	2,05	3,1	1,03
51	11,28	3,85	8,5	2,05
52	19,23	6,15	8,2	3,08
53	4,36	4,62	1,8	2,82
54	9,23	5,13	6,7	3,85

4.4.3. Fabric Thickness:

Fabric thickness is the distance between the upper and the lower surface of the fabric. The thickness of a fabric is one of its basic properties giving information on its warmth, heaviness or stiffness in use [77]. The thickness of fabric samples was measured as the distance between the reference and parallel presser foot. [78]

Table 4.5 Fabric Thickness Test Results

Trial No	Thickness (mm)		Trial No	Thickness (mm)		Trial No	Thickness (mm)
1	0,650		**19**	0,800		**37**	1,096
2	0,544		**20**	0,768		**38**	1,066
3	0,648		**21**	0,768		**39**	1,188
4	0,518		**22**	0,782		**40**	0,990
5	0,472		**23**	0,796		**41**	0,996
6	0,510		**24**	0,796		**42**	1,158
7	0,524		**25**	0,668		**43**	1,064
8	0,388		**26**	0,716		**44**	1,034
9	0,486		**27**	0,718		**45**	1,096
10	0,532		**28**	0,668		**46**	0,564
11	0,538		**29**	0,764		**47**	0,854
12	0,536		**30**	0,708		**48**	0,852
13	0,510		**31**	0,746		**49**	0,638
14	0,466		**32**	0,718		**50**	0,892
15	0,478		**33**	0,712		**51**	0,946
16	0,790		**34**	1,218		**52**	0,656
17	0,712		**35**	1,226		**53**	0,786
18	0,798		**36**	1,118		**54**	0,878

Test specimens were conditioned and tested in the standard atmosphere. Five specimens were selected from each fabric sample. The thickness tester was prepared and the presser foot was lifted, the fabric sample was positioned on the thickness tester reference plate, and then the presser foot was gently lowered to apply pressure to the fabric sample. Test results of specimens are given in Table 4.5.

4.4.4. Fabric Weight:

Fabric weight is mass per unit area. It is an important fabric property that is often used in determining the fabric cost and quality. [7] Weight of the fabrics have been evaluated according to TS EN 12127 test standards. In this method GSM cutter, cutting pad and electric balance were used. The tests of the samples were carried out after conditioning at 27 °C ± 2 °C & 65% RH. Five specimens selected from each fabric sample. After sample preparation, every test samples have been cut with GSM cutter as seen on Figure 4.6. (GSM means grams per square meter). Cut pieces of fabric have been weighted with electric balance [79]. Results are reported in grams per square meter (g/m^2) and given in Table 4.6.

$$m_{ua} = \frac{m}{a} \tag{4.3}$$

m_{ua} = mass per unit area, in g/m^2

$a = specimen\ area, in\ m^2$

$m = mass\ of\ specimen, in\ g$rams

Figure 4.6 GSM cutter

Table 4.6 Fabric Weight Test Results

Trial No	Weight (g/m2)	Trial No	Weight (g/m2)	Trial No	Weight (g/m2)
1	241,40	**19**	181,40	**37**	280,80
2	186,00	**20**	173,80	**38**	312,00
3	181,80	**21**	182,60	**39**	327,60
4	191,00	**22**	212,40	**40**	279,60
5	146,80	**23**	204,60	**41**	278,80
6	141,00	**24**	207,40	**42**	284,00
7	153,20	**25**	183,80	**43**	269,40
8	102,00	**26**	176,80	**44**	272,20
9	113,60	**27**	177,80	**45**	270,40
10	149,20	**28**	171,00	**46**	127,40
11	155,20	**29**	168,80	**47**	196,60
12	169,60	**30**	173,60	**48**	189,60
13	144,40	**31**	179,60	**49**	122,60
14	148,20	**32**	178,20	**50**	194,60
15	148,20	**33**	175,60	**51**	198,40
16	242,20	**34**	395,60	**52**	125,00
17	230,60	**35**	368,80	**53**	206,00
18	233,60	**36**	335,40	**54**	194,60

The fabric weight and thickness determined the packing density and porosity of the fabric structure.

4.4.5. Burst Strength Test:

Burst Strength testing is the application of a perpendicular force to a fabric until it ruptures. A pneumatic pressure method was selected for determination of bursting strength of fabrics. According to ISO 13938-2 test standard the bursting strength has evaluated by James Heal TruBurst3 testing device as seen on Figure 4.7.

Figure 4.7 James Heal TurBurst3 Testing Device

As the standard mentioned " *A test specimen is clamped over an expansive diaphragm by means of a circular clamping ring. Increasing compressed air pressure is applied to the underside of the diaphragm, causing distension of the diaphragm and the fabric. The pressure is increased smoothly until the test specimen bursts. The bursting strength and bursting distension are determined."* [80]

All test results are given on below Table 4.7:

Table 4.7 Bursting Strength Test Results

Trial No	Bursting Strength		Trial No	Bursting Strength	
	Strength (kPa)	Distance(mm)		Strength (kPa)	Distance(mm)
	mean	mean		mean	mean
1	604,20	52,68	**28**	188,68	36,14
2	478,12	37,36	**29**	189,62	35,76
3	241,76	40,28	**30**	191,08	37,00
4	475,80	44,22	**31**	206,34	35,86
5	275,50	32,50	**32**	211,94	35,50

Table 4.7 (continued) Bursting Strength Test Results

6	191,30	38,86	**33**	213,10	36,36
7	377,80	51,88	**34**	596,48	49,16
8	249,42	41,02	**35**	453,94	45,98
9	171,38	41,40	**36**	422,66	37,88
10	201,66	30,38	**37**	241,54	38,10
11	207,94	39,28	**38**	213,20	29,76
12	241,60	33,80	**39**	274,28	39,18
13	213,40	31,32	**40**	463,84	39,52
14	214,52	30,50	**41**	355,74	40,12
15	224,60	37,88	**42**	324,78	33,24
16	593,66	48,84	**43**	233,42	36,56
17	600,44	45,02	**44**	317,24	36,50
18	601,92	52,44	**45**	237,88	33,02
19	205,58	38,64	**46**	328,88	49,06
20	188,66	31,94	**47**	419,00	43,02
21	206,46	29,72	**48**	206,20	39,46
22	224,08	37,20	**49**	347,00	46,06
23	215,34	35,76	**50**	387,94	41,40
24	206,40	36,24	**51**	191,14	33,12
25	362,86	39,04	**52**	327,92	37,78
26	367,08	32,76	**53**	476,52	35,16
27	360,40	33,30	**54**	181,94	38,14

4.4.6. PillingTest:

Pilling is a phenomenon of fiber movement or slipping out of yarns, which is usually happening on the fabric surface during abrasion and wear. The development of pilling could be divided into four stages: fuzz formation, entanglement, growth, and wear-off. The formation of fuzz and pills suspended on the fabric surface could affect the fabric aesthetic and its ultimate acceptance by customers.[50]

The most popular abrasion machine to simulate wear condition in the market is the ICI pilling box tester. (see Figure 4.8).

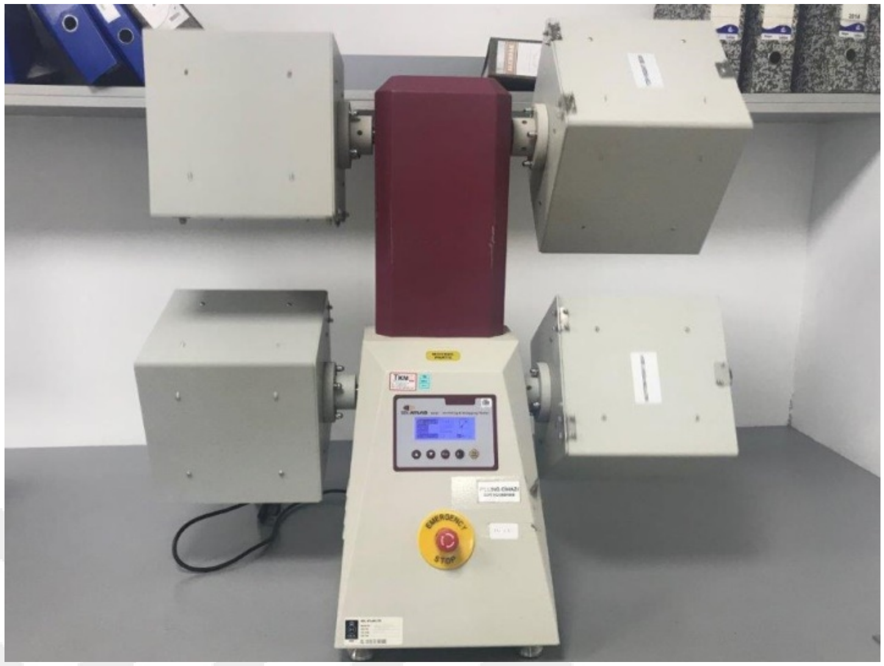


Figure 4.8 SDL Atlas ICI Pilling Box Tester

The test specimens were conditioned to a temperature 20 ^{0}C (±5 ^{0}C) and relative humidity %65 ± 2% for at least 6 hours. Specimens are mounted on the polyurethane tubes and tumbled randomly in a cork-lined box for a certain time. Pilling test was evaluated according to ISO 12945-1 test standard [81] and all test results are given below in Table 4.8.

Table 4.8 Pilling Test Results

Trial No	Pilling
1	4-5
2	1-2
3	3-4
4	4-5
5	1-2
6	3
7	4-5
8	2
9	2
10	4

Trial No	Pilling
19	4
20	3
21	4
22	4
23	4
24	4-5
25	2
26	2
27	1-2
28	3-4

Trial No	Pilling
37	2-3
38	2-3
39	2
40	4-5
41	2
42	4-5
43	2
44	2
45	2
46	4-5

Table4.8 (continued) Pilling Test Results

11	4	**29**	4	**47**	2-3
12	4	**30**	4	**48**	3-4
13	2-3	**31**	2	**49**	4-5
14	2	**32**	2-3	**50**	4
15	2	**33**	2-3	**51**	4-5
16	4-5	**34**	4-5	**52**	4-5
17	4-5	**35**	2	**53**	2
18	4-5	**36**	2-3	**54**	4

4.4.7. Dimensional Stability and Spirality Test:

Dimensional stability refers to a fabric’s ability to resist a change in its dimensions. A fabric or garment may exhibit shrinkage in some dimensions or growth in other dimensions under conditions of washing, drying, steaming and pressing.

Spirality is defined as angular displacement of filling yarns or knitted courses from a line perpendicular to edge or side of fabric or garment.

ISO 6330 standard testing method has been used for determining the dimensional stability and spirality. For testing, James Heal Wascator FOM71CLS used. (see Figure 4.9).

Figure 4.9 James Heal Wascator FOM71CLS test device

The basic procedure for testing fabric for dimensional change is measurement of length and width benchmarks before and after a selected refurbishing process. The benchmarks drawn with indelible ink are placed 25 cm or 50 cm apart for better precision, in each direction. After a standard laundering or dry cleaning method is applied, the marks are re-measured and dimensional change (DC) is calculated from:

$$DC\ (\%) = \frac{100\ (B-A)}{A} \tag{4.4}$$

Where A is the original dimension and B is the dimension after treatment. Length and width changes are calculated separately. Shrinkage is reported as a negative number, while growth is reported as a positive percentage. [82] All test results are given in Table 4.9.

Table 4.9 Dimensional Change and Spirality test results:

Trial No	Dimensional Change		
	Width (%)	Length (%)	Spirality (%)
1	-0.2	+0.2	0
2	+0.6	-0.8	0
3	+4.1	-6.7	0
4	+0.6	-0.6	0
5	+1.8	+1	0
6	+6.2	-12.2	0
7	+1	-0.9	0
8	0	-1.9	0
9	+3	-4	0
10	+2.3	-7.3	5,1
11	+2.8	-5.7	0
12	+0.4	-3.1	0
13	+11.7	-8.5	0
14	+2.1	-6	0
15	-0.6	-3	0
16	0	-0.2	0
17	-0.3	-1.5	0
18	+0.6	-0.9	0

Trial No	Dimensional Change		
	Width (%)	Length (%)	Spirality (%)
28	+8.8	-10.3	0
29	+6.5	-13.7	0
30	+4.9	-10.2	0
31	+2.5	-5.2	0
32	+2.4	-7.7	0
33	+3.6	-5.3	0
34	+0.7	-0.9	0
35	+2.1	-2.1	0
36	+2	-7.1	0
37	+7.8	-15.1	0
38	+3.6	-9.8	0
39	+3.2	-5.8	0
40	-0.9	-1.3	0
41	+1.5	-1.3	0
42	+2.7	-4.8	0
43	+3.6	-11	0
44	+0.7	-6.2	0
45	+1.7	-8.6	0

Table 4.9 (continued) Dimensional Change and Spirality test results:

19	+1.7	-10.1	3,2	**46**	+1.9	-2.1	0
20	+6.9	-12.7	0	**47**	-1.1	-2.6	0
21	+4.8	-10.7	0	**48**	+7.3	-14.6	7,6
22	+2.2	-3.8	0	**49**	-0.9	-2.7	0
23	+2.3	-5.9	0	**50**	-0.8	-2.1	0
24	+1.4	-5.3	0	**51**	+9.3	-12.4	3,4
25	+0.5	-0.4	0	**52**	+1.6	-1.7	0
26	+1.3	-1.3	0	**53**	+1.7	-1.5	0
27	-0.4	-0.9	0	**54**	+9.1	-16.6	0

4.4.8. Air Permeability Test:

The air permeability of fabric is a measure of how well it allows the passing of air through it. Air permeability is defined as the volume of air in milliliters which is passed through in one second 100s mm^2 of the fabric at a pressure difference of 10 mm head of water.

According to ASTM D737 test standard, SDL Atlas test device has been used for testing. The rate of air flow passing perpendicularly through a specified area of fabric is adjusted to obtain a prescribed air pressure differential between the two fabric surfaces. From this rate of air flow, the air permeability of the fabric is determined.[83] Test results are given in Table 4.10.

Table 4.10 Air Permeability Test Results

Trial No	Air Permeability (l/m2/s)	Trial No	Air Permeability (l/m2/s)	Trial No	Air Permeability (l/m2/s)
1	421,8	**19**	322	**37**	616
2	1106	**20**	402,4	**38**	970,6
3	383	**21**	369	**39**	537,4
4	507	**22**	271,2	**40**	1042,4
5	1374	**23**	376,8	**41**	968,2
6	356,2	**24**	361,4	**42**	712,6
7	961,4	**25**	1021,2	**43**	859,4
8	2042	**26**	864,4	**44**	1048
9	941,2	**27**	1016,2	**45**	927,8

Table 4.10 (continued) Air Permeability Test Results

10	668,4	**28**	591,4	**46**	1972
11	611	**29**	387,4	**47**	2167,6
12	620	**30**	456,8	**48**	891
13	583	**31**	664,6	**49**	2298
14	821,8	**32**	639,6	**50**	2094
15	1136	**33**	701,8	**51**	895,6
16	222,4	**34**	339	**52**	2212
17	331,8	**35**	372,4	**53**	2087,5
18	267,6	**36**	483,6	**54**	864,2

4.4.9. Moisture Management Test:

The Moisture Management Tester instrument was used to test the liquid solution transfer and distribution in knitted fabric samples. The principle utilized by the MMT is based on the fact that when moisture travels through a fabric, the contact of electrical resistance of the fabric will change. The fabric is in contact with the sensor rings, which determine the liquid content and the liquid moisture transfer behaviour on the top and bottom surfaces of the fabric. On the basis of the measured voltage charges, the variation of water content with time on the fabric's top and bottom can be quantitatively measured.[84]

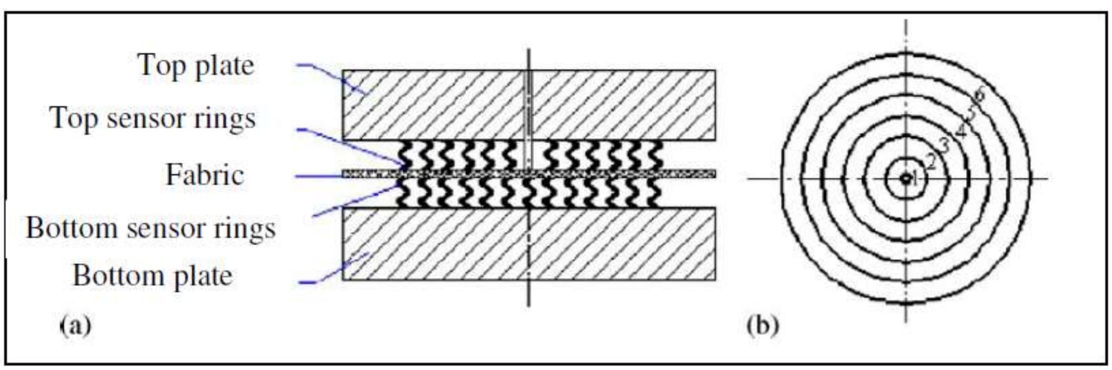


Figure 4. 10 Sketch of MMT sensors: a) sensor structure; b) measuring rings [84]

During testing, each fabric specimen, the size of 80 x 80 mm, was placed flat between the top and bottom sensors (see Figure 4.10) and a predetermined quantity (0.15 g) of the testing solution was pumped onto the upper surface of the fabric to simulate a drop of liquid sweat. The signal for electrical resistance of the fabric samples was processed by the MMT software. All fabrics were tested under the same laboratory conditions. The upper surface of the fabric is considered the surface closest to the skin of the human body and the bottom surface of the fabric is the closest to the neighbouring environment. The parameters (indices) measured were:

> *Wetting Time*, *WTt* (top surface) and *WTb* (bottom surface), is the time in which top and bottom surfaces of the fabric just start to get wet respectively after the test commences.
>
> *Absorption Rate*, *ARt* (top surface) and *ARb* (bottom surface), is the average moisture absorption ability of the fabric's top and bottom surface during the rise of water content,respectively.
>
> *Maximum Wetted Radius, MWRt* (top surface) and *MWRb* (bottom surface), is defined as maximum wetted ring radius at the top and bottom surfaces.
>
> *Spreading Speed, SSt* (top surface) and SSb (bottom surface), is the accumulative spreading speed from the centre of the fabric sample to the maximum wetted radius.
>
> *Accumulative One-Way Transport Index, (AOTI)* represents the difference of the accumulative moisture content between the two surfaces of the fabric and determines to a large extend whether the fabric has good moisture management properties. In terms of comfort, it means that the higher the one-way transport capacity, the quicker and easier the liquid sweat can be transferred from next to the skin to the outer surface of the fabric, thus keeping the skin dry.
>
> *Overall Moisture Management Capability, (OMMC)* indicates the overall capability of the fabric to manage the transport of liquid moisture. The larger the OMMC is, the higher the overall moisture management capability of the fabric. [4,85]

Test results are given in Table 4.11.

Table 4.11 MMT test results

Trial No	MMT OMMC Front	MMT OMMC Back	Trial No	MMT OMMC Front	MMT OMMC Back
1	0,5790	0,0000	**28**	0,6057	0,5158
2	0,4630	0,5568	**29**	0,5804	0,3020
3	0,2684	0,3781	**30**	0,3876	0,4552
4	0,6344	0,0000	**31**	0,3063	0,3666
5	0,4725	0,6785	**32**	0,7784	0,3285
6	0,6392	0,7579	**33**	0,2034	0,3469
7	0,2681	0,7824	**34**	0,1517	0,6947
8	0,4003	0,7461	**35**	0,7455	0,4862
9	0,2949	0,8686	**36**	0,7558	0,0506
10	0,4202	0,6980	**37**	0,5695	0,3195
11	0,6235	0,6900	**38**	0,1891	0,3552
12	0,6445	0,7712	**39**	0,7081	0,3112
13	0,4566	0,7388	**40**	0,7559	0,4088
14	0,6251	0,6413	**41**	0,6742	0,2846
15	0,8692	0,6275	**42**	0,6907	0,3774
16	0,3101	0,6263	**43**	0,6686	0,4758
17	0,4936	0,6547	**44**	0,7732	0,4078
18	0,3171	0,5249	**45**	0,7098	0,3165
19	0,4395	0,6003	**46**	0,6741	0,7015
20	0,8146	0,3751	**47**	0,7582	0,5633
21	0,2402	0,6175	**48**	0,7500	0,2424
22	0,4514	0,8522	**49**	0,2897	0,6136
23	0,5911	0,8656	**50**	0,6708	0,6150
24	0,4978	0,7854	**51**	0,6175	0,3504
25	0,4716	0,6912	**52**	0,0456	0,7334
26	0,6002	0,5623	**53**	0,7756	0,5199
27	0,7075	0,4221	**54**	0,8341	0,2973

4.4.10. Permetest:

The Permetest (Fig. 4.11) was used to test the fabrics for three comfort-related properties, namely water vapour permeability, water vapour resistance and thermal resistance. Samples were conditioned for 24 hours in laboratory with a temperature of 21◦C (±2◦C) and 65% (±2%) humidity before testing. Three measurements were taken per fabric.

Figure 4.11 Permetest Test Device

The Permetest is a semi-automated computer controlled device, developed by Hes (2009), and manufactured by the Sensora company in the Czech Republic, providing results similar to those described in ISO 11092. The measuring head of the Permetest is covered with a semipermeable foil. A sample is mounted on the measuring head, where sensors distinguish small changes in the amount of water absorbed by the fabric during unsteady state of diffusion, which are then recorded by the computer. Tests on the Permetest are conducted under isothermal conditions, and the temperature of the measuring head is maintained at room temperature. When water flows into the measuring head, some heat is lost due to evaporation, and the device measures the evaporation when the measuring head is covered with a sample, as well as when uncovered. [86,87,88]

To calculate the water vapor permeability (P), the ratio of heat loss from the measuring head, with fabric (q_s) to that without fabric (q_0) is used [87]:

$$P(\%) = 100 \cdot q_s/q_0 \tag{4.5}$$

Water vapor resistance (Rt), expressed in m2Pa/W, is determined as following equation 4.6 (Hes 2009):

$$R_t(m^2\,Pa/W) = (P_{wsat} - P_{wo})(1/q_s - 1/q_o) = k(100 - \varphi)(1/q_s - 1/q_o) \tag{4.6}$$

where P_{wsat} and P_{wo} are the saturated water vapor partial pressure, in Pascal, valid for the temperature (t_0) of the air in the laboratory, and the partial water vapor pressure in the air, respectively. The relative humidity, φ, is kept between 45% and 60%, and the constant, K, is determined by the calibration procedure.

Thermal resistance R_{ct}, expressed in m^2K/W, is determined while keeping the measuring head dry, using the following equation 4.7 [87]:

$$R_{ct} = K(t_H - t_0)(1/U_1 - 1/U_0) \tag{4.7}$$

Test results are given in Table 4.12.

Table 4.12 Permetest Test Results

Trial No	PERMETEST			Trial No	PERMETEST	
	Relative W.V. Perm. (%)	Absolute W.V.Perm. (Pa.m2W-1)			Relative W.V. Perm. (%)	Absolute W.V.Perm. (Pa.m2W-1)
	Mean	Mean			Mean	Mean
1	54,90	4,32		**28**	66,14	5,97
2	57,29	3,87		**29**	68,86	5,33
3	53,44	4,41		**30**	68,34	5,47
4	55,07	4,49		**31**	70,23	5,17
5	54,45	4,76		**32**	64,02	7,08
6	65,79	2,70		**33**	67,71	5,68
7	74,88	3,89		**34**	53,77	10,35
8	74,57	3,96		**35**	54,03	10,77
9	67,10	5,27		**36**	54,63	10,10
10	66,21	5,55		**37**	53,16	11,19
11	61,30	6,83		**38**	53,75	10,65
12	62,11	7,34		**39**	53,23	11,06
13	65,70	5,94		**40**	56,66	9,45
14	63,58	6,81		**41**	56,58	9,70
15	65,49	6,67		**42**	53,65	10,36
16	58,78	8,54		**43**	57,37	9,44
17	58,16	8,93		**44**	54,20	10,25

Table 4.12 (continued) Permetest Test Results

18	60,69	8,64	**45**	55,96	10,00
19	59,86	8,49	**46**	68,78	5,78
20	62,43	7,63	**47**	62,21	8,01
21	63,36	7,27	**48**	57,14	9,45
22	59,02	8,59	**49**	67,96	6,18
23	59,30	9,11	**50**	60,18	8,45
24	58,70	9,01	**51**	58,03	9,29
25	62,51	7,74	**52**	69,38	5,79
26	59,24	8,63	**53**	60,73	8,29
27	61,52	7,98	**54**	58,06	9,20

4.4.11. Alambeta:

The thermal comfort properties (thermal conductivity, thermal resistance) of the fabrics were also evaluated and the Alambeta (Fig. 4.12) instrument was used to measure thermal conductivity, fabric thickness and thermal resistance. All measurements were performed under the standard atmospheric conditions and they were repeated five times.

Figure 4.12 Alambeta

Alambeta measuring device was developed by Prof. Hes in Czeck Republic to measure the thermal absorbtion of the materal. When er look the device in general we see a measuring head and a measuring plate on the rights side and a monitorized display and the main machine on the left. Measuring head has heat flow sensors. (Figure 4.13). Fabric measurement can be performed after calibrating the temperature measurement sonsor by placing the standard fabric on the sample measuring plate. When the measurement starts, the head with the heat flow sendor comes down and touches the fabric on the measuring plate. In this case, the surface temperature of the sample is suddenly changed by the device and thus the heat flow values of the sample are analaysed and recorded by the Alambeta device.

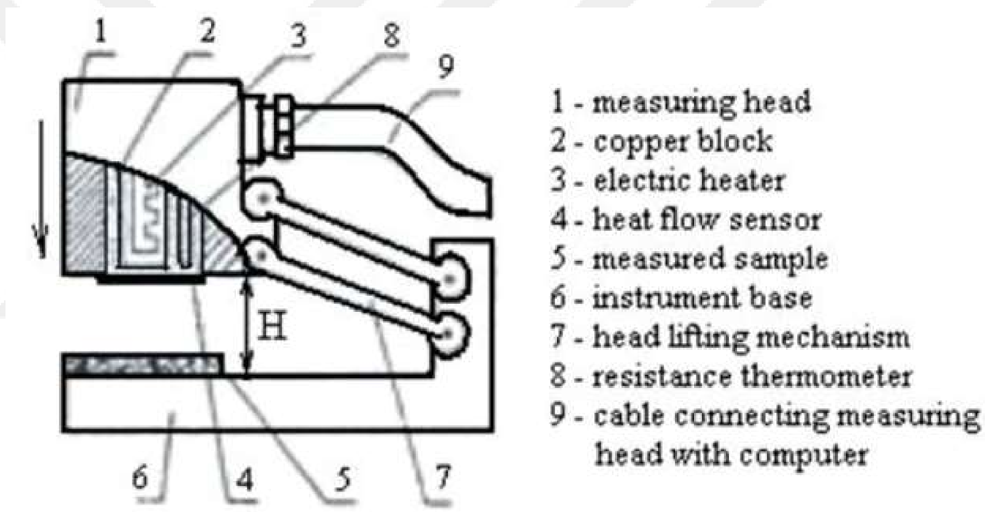


Figure 4.13 Functional scheme of the computer controlled Alambeta instrument. [90]

Alambeta device measures six parameters: thermal conductivity, thermal diffusion (a), thermal absorption (b), thermal resistance(r), the ratio of maximal to stationary heat flow density (q_{max}/q_s), and stationary heat flow density (q_s) at the contact point. The instrument also determines the fabric thickness.

Test results are given below Table 4.3.

Table 4.13 Alambeta Test Results

Trial No	ALAMBETA					
	Technical Fabric Back Side			Technical Fabric Front Side		
	la (mW/m.K)	a (mm2/s)	b (W.$s^{0.5}$ m^2K)	la (mW/m.K)	a (mm2/s)	b (W.$s^{0.5}$ m^2K)
1	32,360	0,041	160,240	32,180	0,036	170,000
2	29,120	0,077	105,140	29,560	0,071	111,000
3	32,480	0,082	113,480	32,760	0,081	115,500
4	29,660	0,044	141,120	29,600	0,042	145,060
5	28,280	0,084	97,720	28,160	0,084	97,560
6	28,160	0,063	112,760	27,920	0,085	96,740
7	29,240	0,058	122,200	29,820	0,064	117,720
8	24,160	0,209	94,700	22,520	0,064	88,900
9	29,400	0,100	93,060	26,260	0,087	89,600
10	24,520	0,035	131,340	25,120	0,039	127,540
11	25,100	0,033	138,320	25,320	0,037	131,200
12	26,120	0,035	138,940	26,280	0,033	145,680
13	23,500	0,032	130,960	23,640	0,036	124,700
14	22,800	0,034	123,280	23,120	0,036	122,600
15	22,480	0,032	124,740	22,100	0,033	121,500
16	32,900	0,062	132,300	33,260	0,041	164,640
17	33,140	0,060	135,140	33,300	0,039	169,440
18	34,480	0,063	138,620	33,980	0,044	162,480
19	30,980	0,073	115,020	31,360	0,055	133,660
20	31,580	0,074	116,080	31,620	0,055	135,120
21	31,340	0,069	120,080	29,940	0,052	132,600
22	32,980	0,057	138,340	32,220	0,048	146,600
23	33,420	0,073	124,300	33,360	0,057	139,780
24	36,880	0,114	109,220	37,660	0,073	139,620
25	31,860	0,083	110,400	32,160	0,077	116,300
26	33,400	0,094	108,940	34,280	0,088	115,000
27	28,140	0,071	105,500	28,420	0,061	115,200
28	27,760	0,054	119,860	28,240	0,043	136,400

Table 4.13 (continued) Alambeta Test Results

29	36,680	0,095	119,160	37,260	0,077	134,440
30	34,920	0,090	117,000	35,560	0,077	128,400
31	35,360	0,108	107,940	34,640	0,085	118,660
32	30,700	0,077	110,560	31,260	0,070	118,520
33	35,020	0,099	111,620	35,040	0,077	126,560
34	53,340	0,116	156,420	52,860	0,092	174,560
35	46,820	0,085	160,720	46,300	0,083	160,360
36	48,740	0,107	148,860	49,860	0,119	144,600
37	48,500	0,107	148,320	47,920	0,114	142,280
38	44,240	0,085	152,180	44,280	0,086	150,540
39	44,940	0,092	148,580	45,480	0,090	151,740
40	38,420	0,092	126,380	38,540	0,098	123,300
41	38,800	0,109	117,980	38,180	0,091	126,460
42	39,380	0,110	118,900	38,680	0,095	125,700
43	39,920	0,104	124,380	39,480	0,097	127,420
44	38,320	0,111	115,380	39,540	0,105	122,380
45	40,700	0,088	137,600	40,540	0,082	142,040
46	29,500	0,073	109,460	28,020	0,061	113,600
47	34,940	0,099	111,180	34,460	0,095	112,140
48	39,060	0,097	125,900	39,060	0,092	128,980
49	27,800	0,060	113,840	27,900	0,053	120,720
50	35,200	0,107	107,700	34,980	0,109	106,240
51	27,560	0,053	119,600	28,620	0,049	128,860
52	29,020	0,073	107,580	29,480	0,065	116,160
53	34,880	0,106	107,600	34,780	0,092	114,720
54	37,540	0,102	117,540	37,720	0,091	124,880

CHAPTER V

DISCUSSION

Primarily mechanical and thermal comfort components have been measured. According to literature; garment fabrics' mechanical comfort have been described as the result of sensation due to the touch of skin and fabric. Also including the feeling of fabric softness, flexibility, itching and irritating due to this touch. Most of the fabric mechanical properties are associated with these factors, therefore variation of measurement results are used for mechanical comfort evaluations. Fabric strength due to mechanical force is also considered as one of the components of mechanical comfort. With the guidance of these evaluations, following measurements for mechanical comfort properties have been performed within the scope of our project; weight (TS EN 12127),thickness (ISO EN 5084) and with the formation of these two ; fabric density, as an indicator of vertical and horizontal elasticity of elongation % due to the free swing that fabric will provide to body (ASTM D 2594), crumpling recovery (AATCC 128), spirality as a resistance property against mechanical force (ISO 16322-2), bursting resistance (ISO 13938-2), peeling resistance (ISO 12945-1) and dimensional stability after washing (ISO 6330).

Regarding the thermal comfort, properties following measurements have been performed; characteristics of mass (air, water, vapour) and heat transition of the fabrics have been evaluated therefore air permeability (ASTM D737), liquid permeability (AATCC 195), water vapour permeability (Permetest Sensora device standard which is derived from ISO 11092) thermal permeability, thermal resistance, thermal capacity and thermal absorptivity (Alambeta Sensora device standard).

Measurements have been performed at Gaziantep University Textile Engineering Departments' and ÜNİTEKSs' laboratories with controlled standard conditions.

Using the average values of measurement results, multi-dimensional graphics have been done and graphic areas have been used for comfort evaluation. Fabrics' mechanical and thermal comfort properties have been determined one by one.

Below fundamentals have been considered for the evaluation of mechanical comfort properties:

1. The fabrics with higher wrinkle recovery and higher elongation % provide higher mechanical comfort.

2. Fabrics with lower density provide higher mechanical comfort.

3. Whereas bursting resistance, diaphragm height and pilling increases; spirality and dimensional stability after washing decreases, fabric provides higher mechanical comfort.

4. Where as the multi-dimensional graphics area increases, total mechanical comfort also increases, considering this when describing the dimension values of the measurement results, revisions have been made to increase the graphic area. For instance, with the aim of evaluating positive effect of lower density to comfort feeling we have considered the reverse values of density parameters, which contributes in a more useful data for graphic area. Similiar approach also has been applied for spirality and dimensional stability after washing values.

5. Due to having different scales for measurement results, revisions have been made to ensure the dimension values in same scale and visually to be easier to distinguish and also to have higher correlation when the order of the dimension values change. The test results were at different scales so some of them were converted to the same scale (between *0.1 – 10*) by using different coefficients prior using as axis value to make them have similar contributions on graph areas: Bursting strength results were divided by 100, bursting distension by 10. The pilling and wrinkle recovery rating scores were used as axis value; if the score was an intermediate value like 2-3, it was used as number with a half, like 2,5.

The reciprocal of the fabric density values were used as axis value. This not only led to convert the value to the mentioned scale but also to associate the low fabric density with better comfort since the reciprocal of lower fabric density gave higher value and that increased the calculated graph area which was used in comfort value calculation. Similarly, the spirality and the dimensional change testing results were converted to axis value by using following Equation (5.1):

$$\text{Axis value for spirality and dimensional change} : \frac{\mathbf{1}}{[|\ \boldsymbol{Test\ result}|\ \mathbf{+0{,}1}]} \qquad (5.1)$$

so that *0* as test result was converted to *10* which is the maximum in selected scale; and the lower test results were converted to higher axis values. Then, unitless multi-axial graph area was calculated by Equation (5.2):

$$\text{Graph area} = {}^{1}/_{2} * \left(\sum_{1}^{n} Axis\ value\ (n-1) * Axis\ value\ n\right) * \sin((360/n*\pi)/180) \qquad (5.2)$$

In accordance with these evaluations, multi-dimensional graphics for mechanical comfort of the jersey fabrics manufactured within the scope of the Project can be seen in Figure 5.1 – 5.4; graphic areas in Table 5.1.

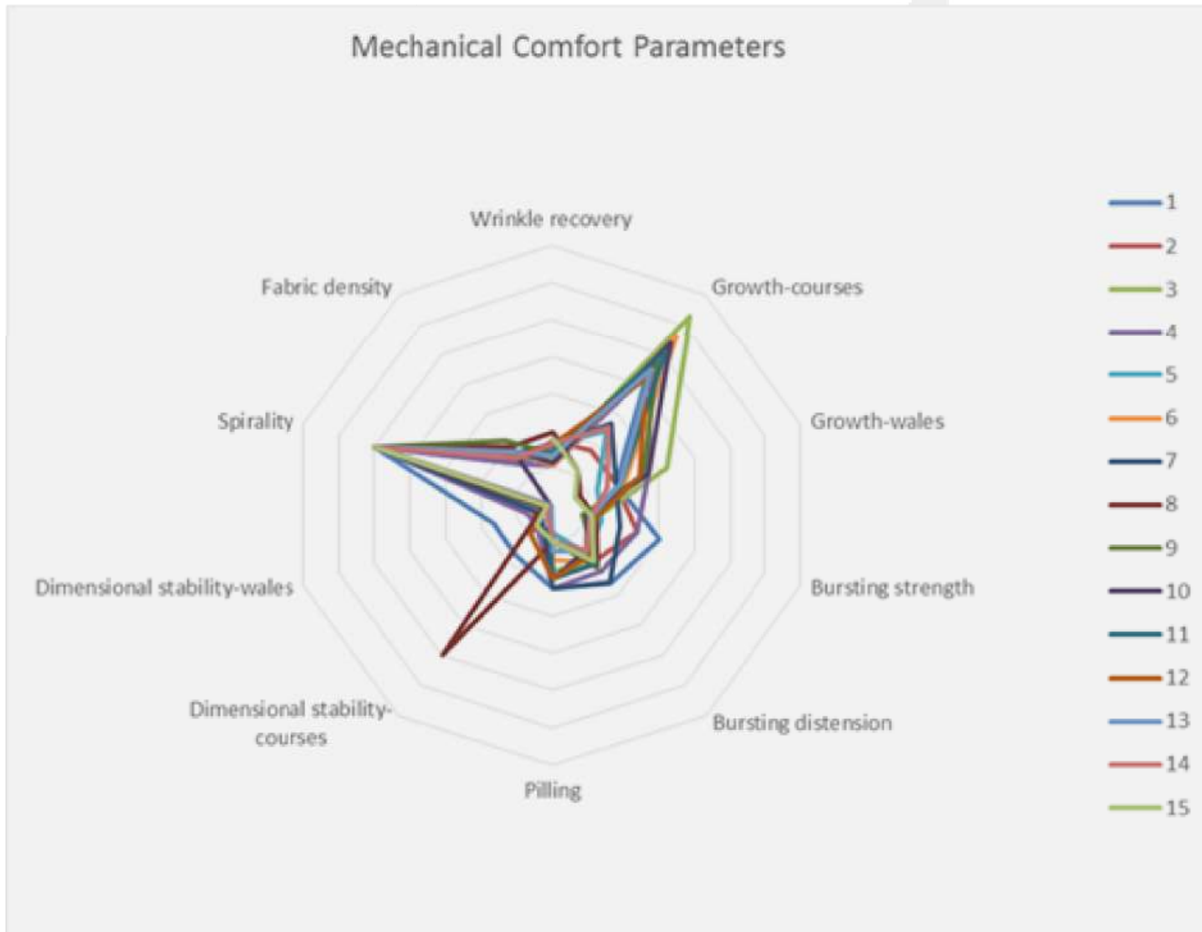


Figure 5.1 Graphics for Mechanical Comfort Components of Single jersey fabrics

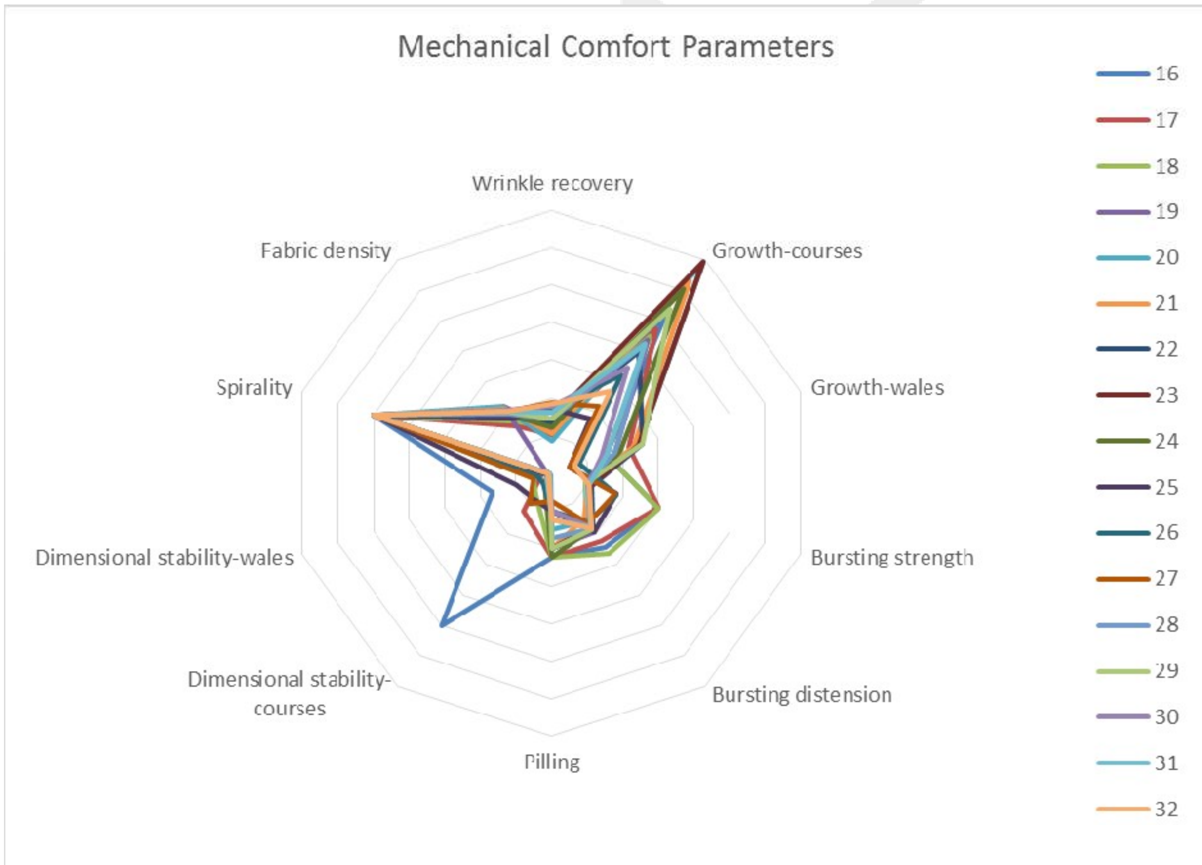
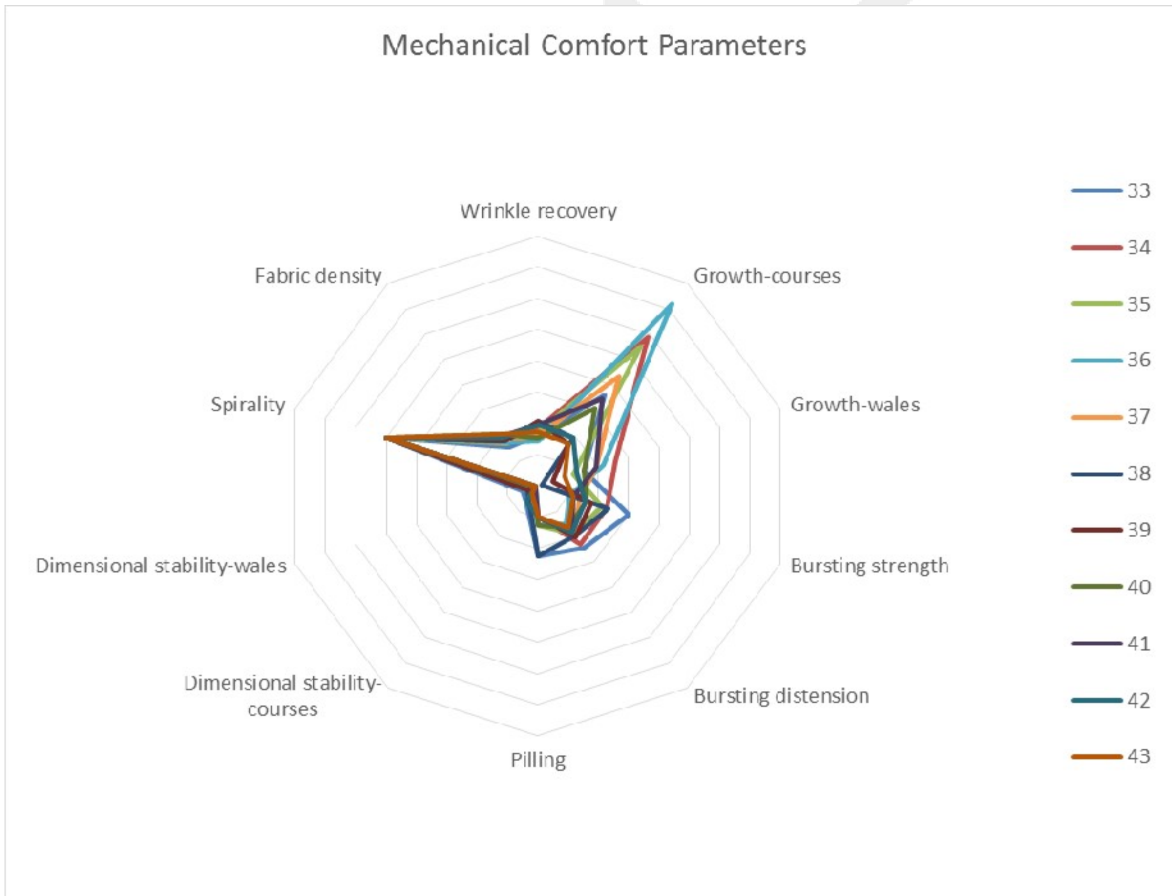


Figure 5.2 Graphics for Mechanical Comfort Components of cross miss fabrics



Figüre 5.3 Graphics for Mechanical Comfort Components of double – face fabrics

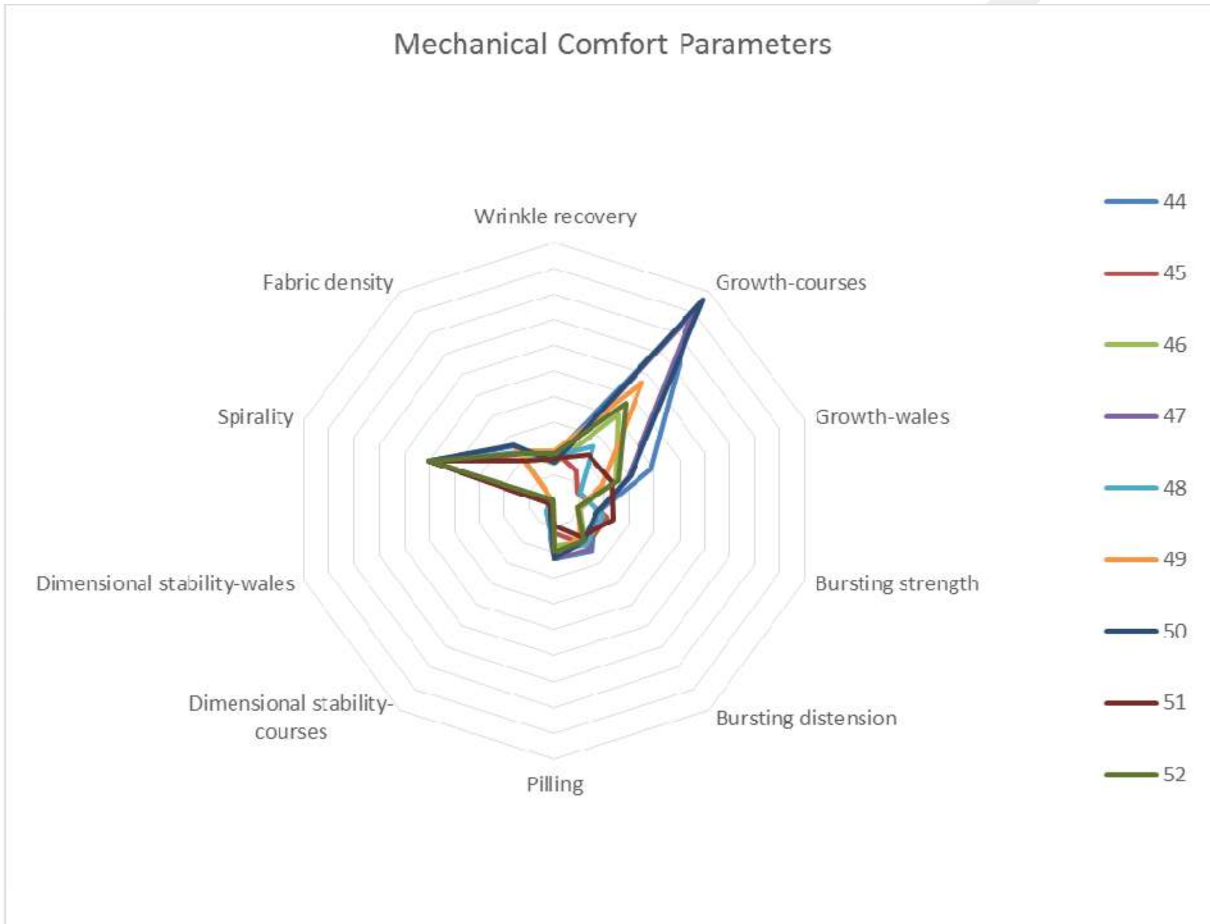


Figure 5.4 Graphics for Mechanical Comfort Components of stitch transferred fabrics

Table 5.1 Mechanical Comfort Components Graphic Areas

Knit Structure	Sample No	GraphicArea (Unit)
Single Jersey	**1**	**66,84**
	2	35,28
	3	57,98
	4	55,67
	5	29,96
	6	41,78
	7	45,09
	8	34,57
	9	46,14
	10	35,68
	11	43,28
	12	45,69
	13	37,41
	14	28,41
	15	23,63
Cross miss	**16**	**82,18**
	17	55,81
	18	53,96
	19	28,32
	20	49,41
	21	48,42
	22	43,41
	23	56,87
	24	47,1
	25	34,47
	26	35,18
	27	32,99
	28	39,02
	29	50,15
	30	50,66
	31	36,32
	32	38,74
	33	30,63

Knit Structure	Sample No	GraphicArea (Unit)
Double-face	34	50,73
	35	**61,18**
	36	42,94
	37	55,36
	38	50,81
	39	41,45
	40	34,22
	41	30,07
	42	36,34
	43	39,59
	44	32
	45	27,34
Stitch Transferred	**46**	**97,7**
	47	34,67
	48	32,25
	49	86,1
	50	41,11
	51	39,52
	52	88,86
	53	40,59
	54	51,55

Results in Table 5.1 shows that, in all knitting types fabrics with polypropylene (PP) compositions, performs the highest mechanical comfort properties. Statistical analysis performed with single jersey fabric sample's data, shows that composition difference makes a reasonable effect on mechanical comfort property.100% polyester (PET) fabrics have the lowest mechanical comfort and where yarn count increases fabric performs even lower mechanical comfort. According to measurement results, PP/cotton blend single jersey fabrics have higher mechanical comfort comparing to PP/PET composition fabrics. Similiar result also evaluated for cross miss fabrics. Highest mechanical comfort measured for 100% PP fabrics and lowest mechanical comfort measured for 100% PET fabrics. Fabrics with back side (the side touches to skin) cotton composition and front side PP composition performs higher mechanical comfort property comparing to PET/cotton fabrics. For double-face and stitch transferred fabric construction samples highest and lowest mechanical comfort have been reviewed in 100% PP and 100%PET fabrics. For double-face construction samples cotton/PP blend fabrics performed higher mechanical comfort comparing to cotton/PET ones.

Below fundamentals have been considered for the evaluation of thermal comfort properties:

1. Fabrics which have higher air permeability, water vapour permeability, moisture management capability, provide higher thermal comfort.
2. Fabrics with higher thermal conductivity and higher thermal absorptivity (the cold feeling when touched) perform higher thermal comfort.
3. When preparing multi-dimensional thermal comfort graphics following values have been considered; conditional water vapor permeability (%) of the fabric samples, air permeability, total average moisture management capability of front and back sides of the fabric (OMMC), thermal conductivity and thermal absorptivity values of back side of the fabrics.
4. Due to having different scales for measurement results, revisions have been made to ensure the dimension values in same scale and visually to make easier to distinguish and also to have higher correlation when the order of the dimension values change.
5. The test results were at different scales so some of them were converted to the same scale (between *0.1 – 10*) by using different coefficients prior using

as axis value to make them have similar contributions on graph areas:, air permeability by 200, relative water vapor permeability by 10, thermal conductivity by 10, thermal absorbtivity by 20 and overall moisture management capability values were multiplied by 10.

Then, unitless multi-axial graph area was calculated by Equation (5.2) as mentioned before.

Where the value of multi-dimensional graphic area increases, total thermal comfort of the fabric also increases.

In accordance with these evaluations, multidimentional graphics for thermal comfort of the fabrics manufactured within the scope of the Project, can be seen in Figure 5.5 – 5.8 ; graphic areas in Table 5.2.

Results in Table 5.2 shows that, stitch transferred fabrics perform the highest thermal comfort properties. For single jersey fabrics where thread is finer, thermal comfort values increases. For PP/cotton and PET/cotton blend fabrics where synthetic fiber composition percentage increase thermal comfort value also increases. This condition is associated with water vapor permeability and capillarity performance. On the other hand, PET/cotton blend single jersey fabrics perform higher thermal comfort comparing to PP/cotton ones. Correlatively, PET/cotton blend cross miss fabrics perform higher thermal comfort comparing to PP/cotton blend cross miss ones. For double-face fabrics, back side (the side touches the skin) with cotton fiber has higher thermal comfort values.

Various researches on comfort studies, shows the effect of thermal and mechanical comfort on Total Comfort as in Equality (5.3) [66] :

$$C_{total} = {}^{1}/_{3}\, C_{physica} + {}^{2}/_{3}\, C_{Thermal} \qquad (5.3)$$

C_{total}= *Total Comfort*

$C_{physical=}$ *Physical (Mechanical) Comfort*

$C_{thermal}$= *Thermal Comfort*

Using Equality 5.3 and values for fabric samples in Table 5.5 and Table 5.6, total comfort values have been calculated and results are as shown in Table 5.3.

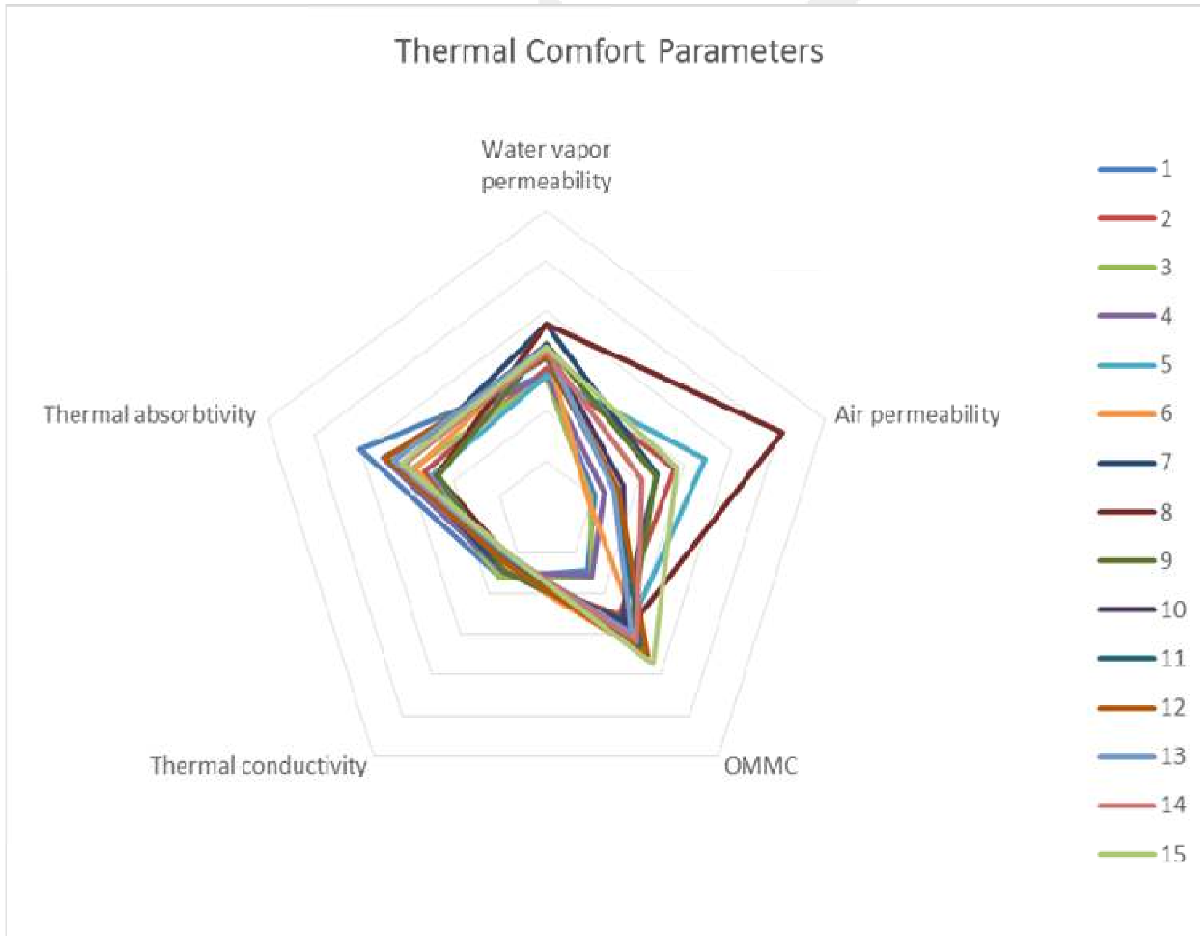


Figure 5.5 Graphics for Thermal Comfort Components of single jersey fabrics

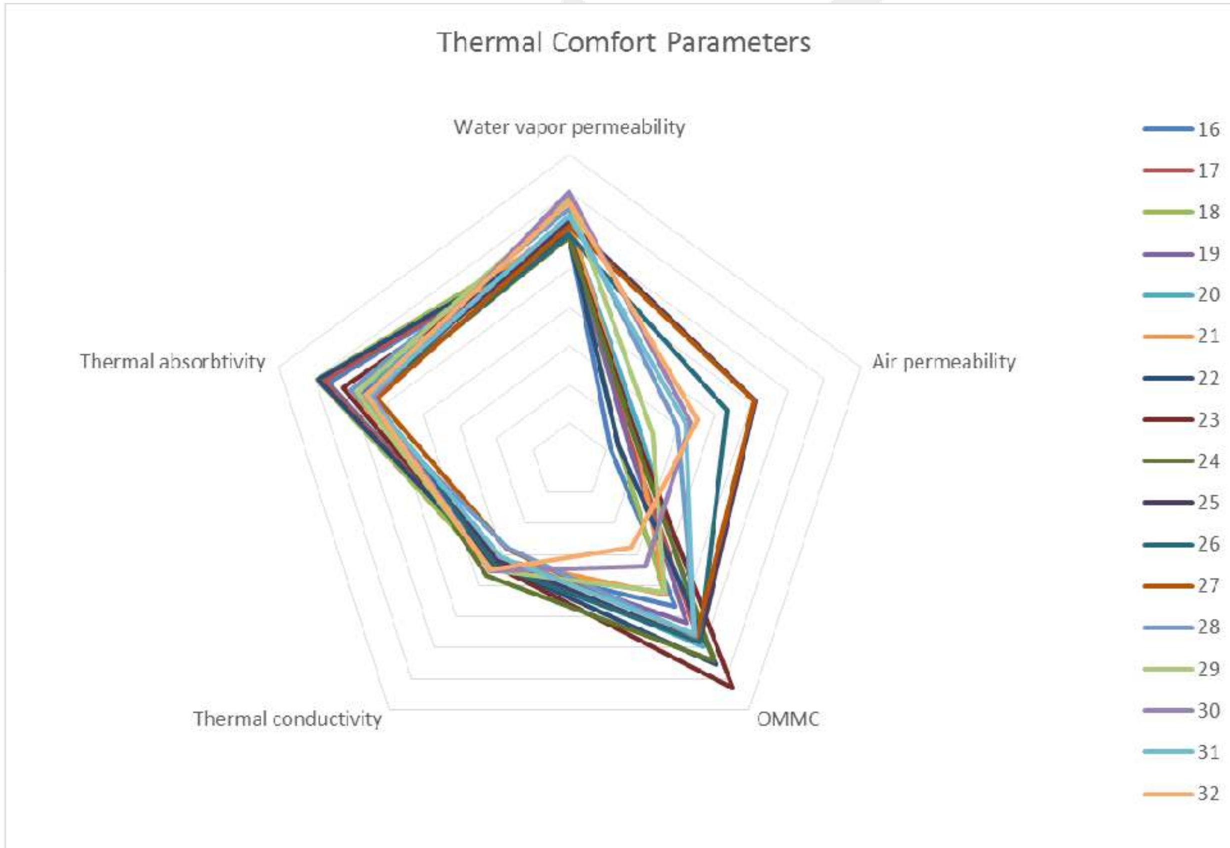


Figure 5.6 Graphics for Thermal Comfort Components of cross miss fabrics

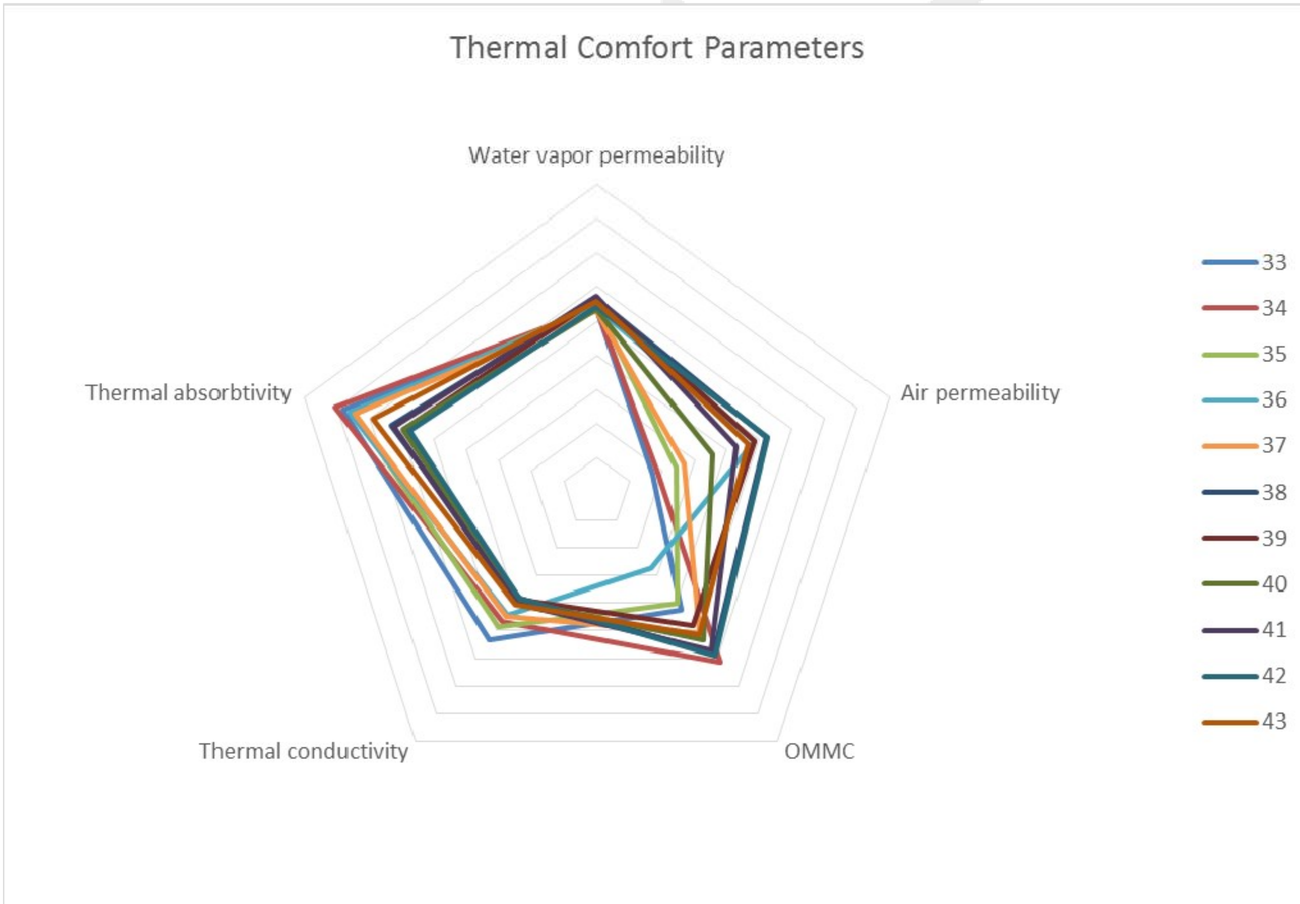


Figure 5.7 Graphics for Thermal Comfort Components of doube-face fabrics

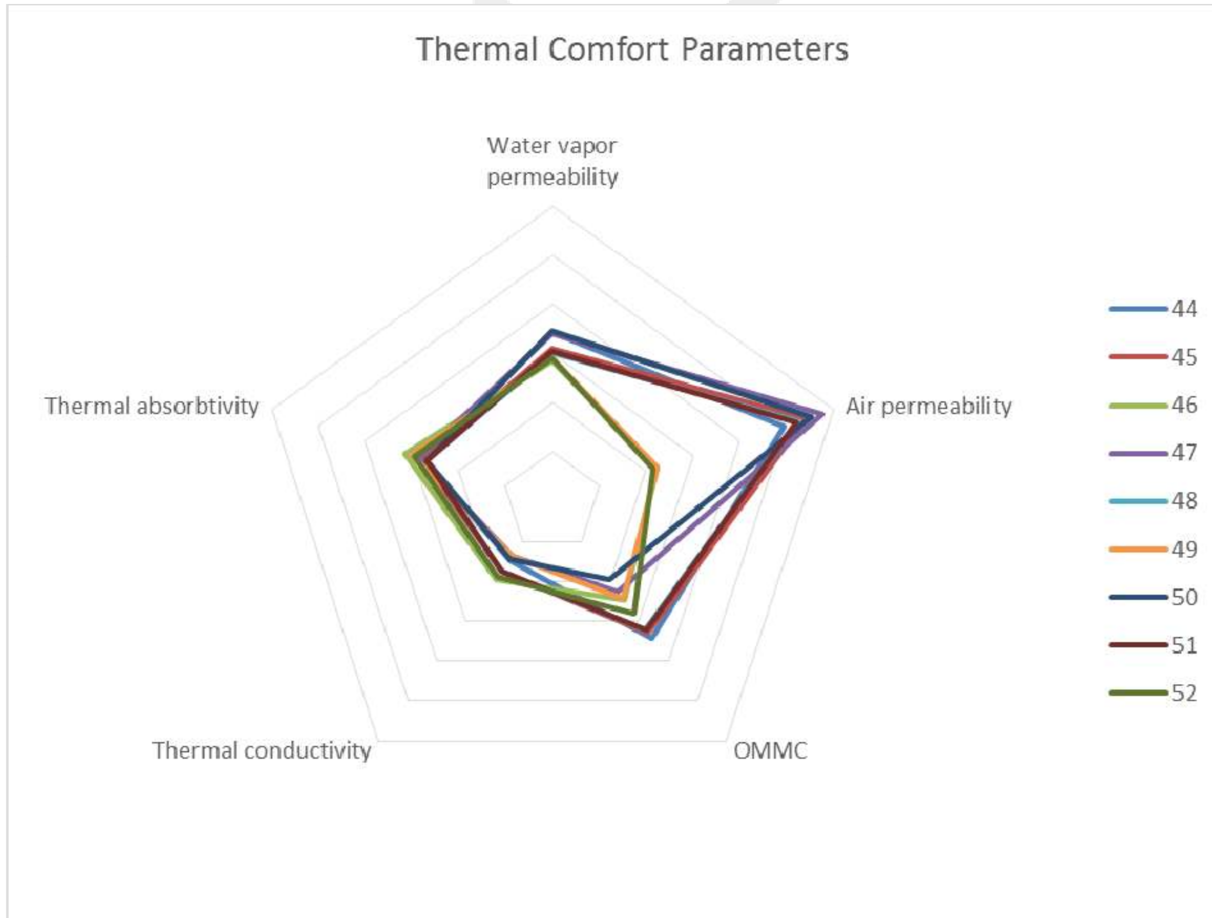


Figure 5.7 Thermal Comfort Components of stitch transferred fabrics

Table 5.2 Thermal Comfort Components Graphic Areas.

Knitting Structure	Sample Code	Graphic Area (unit)
Single Jersey	1	46,11
	2	57,14
	3	35,99
	4	43,37
	5	63,55
	6	46,03
	7	66,68
	8	**92,85**
	9	57,52
	10	54,26
	11	54,7
	12	57,53
	13	51,85
	14	56,98
	15	71,99
Cross miss	16	41,75
	17	47,5
	18	44,81
	19	41,07
	20	46,55
	21	42,75
	22	48,49
	23	50,82
	24	46,63
	25	**62,88**
	26	57,35
	27	58,56
	28	51,35
	29	48
	30	47,72
	31	49,17
	32	51,13
	33	47,74

Knitting Structure	Sample Code	Graphic Area (unit)
Double-face	34	58,32
	35	62,49
	36	56,85
	37	60,4
	38	59,86
	39	58,89
	40	**67,68**
	41	59,66
	42	54,44
	43	63,05
	44	64,36
	45	65,22
Stitch Transferred	46	99,72
	47	**102,77**
	48	60,63
	49	93,7
	50	97,16
	51	27,73
	52	48,81
	53	31,22
	54	41,73

Table 5.3 Total Comfort Value

Knitting Structure	Sample No	Value (unit)
Single jersey	1	53,02
	2	49,85
	3	43,32
	4	47,47
	5	52,35
	6	44,61
	7	59,48
	8	**73,42**
	9	53,73
	10	48,07
	11	50,89
	12	53,58
	13	47,03
	14	47,46
	15	55,87
Cross miss	**16**	**55,23**
	17	50,27
	18	47,86
	19	36,82
	20	47,5
	21	44,64
	22	46,8
	23	52,83
	24	46,79
	25	53,41
	26	49,96
	27	50,04
	28	47,24
	29	48,72
	30	48,7
	31	44,89
	32	47
	33	42,03

Knitting Structure	Sample No	Value (unit)
Double-face	34	55,79
	35	**62,05**
	36	52,21
	37	58,72
	38	56,85
	39	53,07
	40	56,53
	41	49,8
	42	48,4
	43	55,23
	44	53,57
	45	52,59
Stitch Transferred	**46**	**99,05**
	47	80,07
	48	51,17
	49	91,17
	50	78,47
	51	48,74
	52	87,96
	53	78,53
	54	57,43

Values in Table 5.3 shows that the samples with the highest comfort value are 46,49 and 52 which are 100% PP composition, stitch transferred jersey fabrics. For stitch transferred fabrics lowest total comfort values are measured for 48,51 and 54 numbered fabric samples which are 100% Cotton composition ones. For fabrics with single jersey, cross miss and double face constructions and with same yarns as in stitch transferred fabrics, 100% PET and 100% PP ones perform higher total comfort values comparing to same construction 100% Cotton ones. For the blended composition single jersey fabrics where PP and PET percentages increase, total comfort values also increase.

For double-face fabrics with 100% PP on back side (the side that touches to skin) of the fabric performs higher total comfort value comparing to back side 100% PET, 100% Cotton, PP/Cotton blend and Cotton/PET blend ones. We can also remark that for the ones with front side 100% Cotton, back side 100% PP ones perform higher thermal and total comfort values comparing to back side 100% PET ones. On the other hand, for the ones with blend compositions both for front and back sides, PET blend ones perform higher thermal and total comfort values comparing to PP blend ones.

CHAPTER VI

STATISTICAL ANALYSIS

Multivariate analysis of variance (ANOVA) was used for statistical analysis of the results. Statistical analysis was performed separately for all fabric sample types. The severity level of the effects of variance sources (fiber type, blend, yarn count) on the measurement results were evaluated according to F-statistical values. As the effect severity level of the variance source increases, the F-statistical value increases. SNK test was used to determine whether there was a significant difference between variance sources. When the average measurement results of variance sources were marked with the same letter in SNK test, it was evaluated that there was no significant difference between them.

The F-statistical values and SNK test results found in the statistical analysis performed by selecting fiber type and yarn count as the source of variance of single jersey fabric samples numbered 1 to 9 are shown in Tables 6.1 and 6.2.

Table 6.1 F –Statistical values of ANOVA analysis of single jersey fabric samples numbered 1 to 9

Mechanical / Thermal parameters	**Fiber Type**	**Yarn Count**
Wrinkle Recovery	22,856	12,657
% Elongation	59,136	9,269
Strength	2682,825	1109,028
Water Vapour Permability	86,657	0,085
Air Permability	6044,670	2633,028
Thermal conductivity	141,018	116,696
Thermal absorbtivity	530,638	151,442

The results in Table 6.1 show that fiber type is more effective on mechanical and thermal parameters in single jersey fabrics than yarn count. The change in fiber type is particularly effective on strength and air permeability. According to SNK evaluations, wrinkle recovery, strength and air permeability values of the fabrics that produced with polyester fiber were significantly higher in single jersey fabrics. Cotton fiber, % elongation and water vapor permeability gave the best performance. The moisture vapour transmission was higher for finer fabrics than for fabrics made of coarser filaments Besides, polypropylene fiber gave the best performance in thermal absorbency and thermal conductivity values. PP fibers have the lowest thermal conductivity of all fiber types. The high thermal conductivity seen in PP samples was associated with high fabric density. SNK results show that fabrics produced using finer yarns yield higher water vapor and air permeability values; thicker yarns give higher strength and thermal conductivity.

Table 6.2 SNK analysis of single jersey fabric samples numbered 1 to 9

Mechanical / Thermal parameters	**Fiber Type**	**Yarn Count**
Wrinkle Recovery	PET a PP b Cotton b	Ne40 a Ne20 a Ne30 b
% Elongation	Cotton a PP b PET c	Ne30 a Ne20 a Ne40 b
Strength	PP a PET b Cotton c	Ne20 a Ne30 b Ne40 c
Water Vapour Permability	Cotton a PET a PP a	Ne40 a Ne30 b Ne20 c
Air Permability	PET a Cotton b PP c	Ne40 a Ne30 b Ne20 c
Thermal conductivity	PP a Cotton a PET b	Ne20 a Ne30 b Ne40 c
Thermal absorbtivity	PP a Cotton b PET c	Ne20 a Ne30 b Ne40 c

In statistical analysis made by taking the source of variance of PP / Cotton and PET / Cotton blended jersey fabrics (Sample 10-15 and sample 6 for comparison) blend type and blend ratio (100/0 - 25/75 - 50/50 - 75/25 - 0/100). According to these analysis, the presence of PP or PET in the fabric structure showed that there was no statistically significant effect on the water vapor permeability of all mechanical and thermal parameters examined. SNK table 6.4 shows that higher % elongation, strength and thermal conductivity values can be obtained if polypropylene fiber is preferred instead of polyester in single jersey fabrics. We can associate this with the high strength of the polypropylene fiber. As the percentage of cotton fiber in the fabric structure increases, wrinkle recovery, strength and air permeability performances decrease and % elongation and water vapor permeability values improve. According to the literature, as the rate of hydrophilic materials in textile materials increases, water vapor permeability also increases. We can explain the increasing of the water vapor permability performances with the hydrophilic property of cotton fiber. There was no significant difference between synthetic / cotton blending ratios in thermal parameters.

Table 6.3 F-Statistics values of ANOVA analysis of the Blended Single Jersey fabrics

Mechanical / Thermal parameters	**Blend type**	**Blend Ratio**
Wrinkle Recovery	11,733	13,869
% Elongation	23,840	64,344
Strength	859,245	314,390
Water Vapour Permability	15,263	0,744
Air Permability	1219,077	2583,102
Thermal conductivity	350,322	185,836
Thermal absorbtivity	124,534	461,557

Table 6.4 SNK analysis of blended single jersey fabrics

Mechanical / Thermal parameters	**Blend Ratio**	**Blend Type**
Wrinkle Recovery	75/25 a 50/50 ab 100/0 bc 25/75 cd 0 /100 d	PET/Cotton a PP/Cotton b
% Elongation	0/100 a 25/75 a 50/50 b 100/0 b 75/25 c	PP/Cotton a PET/Cotton b
Strength	100/0 a 75/25 b 50/50 c 25/75 d 0/100 e	PP/Cotton a PET/Cotton b
Water Vapour Perm.	25/75 a 0/100 a 75/25 a 50/50 a 100/0 b	PET/Cotton a PP/Cotton a
Air Perm.	100/0 a 75/25 b 50/50 c 25/75 d 0/100 e	PET/Cotton a PP/Cotton b
Thermal conductivity	100/0 a 0/100 b 75/25 c 25/75 c 50/50 c	PP/Cotton a PET/Cotton b
Thermal absorbtivity	75/25 a 25/75 a 50/50 a 100/0 b 0/100 c	PP/Cotton a PET/Cotton b

According to the statistical analysis, the fiber type is the source of variance of cross miss knitted fabrics (Sample no: 16 – 20 – 25) produced using single fiber type on the front and back side did not show a significant effect on fiber type to water vapor permeability. The fiber type was highly effective on the strength and air permeability of the fabric. It has been seen that the preference of polypropylene fiber on both sides of cross miss knitted fabrics offers higher values in terms of % elongation and thermal conductivity properties than those used in polyester fiber (Tables 6.5 – 6.6). PP has high strength and lowest thermal conductivity.

Table 6.5 F-statistics values of ANOVA Analysis of %100 PP, %100 PET and %100 Cotton cross miss knitted fabrics

Mechanical / Thermal parameters	**Fiber Type**
Wrinkle Recovery	11,247
% Elongation	42,014
Strength	3035,385
Water Vapour Permability	3,698
Air Permability	2973,675
Thermal conductivity	11,809
Thermal absorbtivity	57,884

Table 6.6 SNK Analysis of %100 PP, %100 PET ve %100 Cotton cross miss knitted fabrics

Mechanical / Thermal parameters	**Blend Ratio**
Wrinkle Recovery	PET a PP ab Cotton b
% Elongation	Cotton a PP b PET c
Strength	PP a PET b Cotton c
Water Vapour Permability	PET a Cotton a PP a
Air Permability	PET a Cotton b PP c
Thermal conductivity	PP a PET b Cotton b
Thermal absorbtivity	PP a Cotton b PET b

In the cross miss lining knitted fabrics, which are frequently used in sports garment products, the statistical evaluation of polypropylene / cotton blended fabrics, which is considered to be an alternative to the frequently preferred polyester / cotton blend, was made separately for different compositions. In this context, statistical analysis results and evaluations of samples having identical composition where polypropylene and polyester yarns are produced on the front or back sides are shown in Table 6.7 – 6.10.

Table 6.7 F-statistic values of ANOVA analysis of the samples of cross miss lining fabric samples between 16-18 and 25-27

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	2,753	77,313
% Elongation	2,861	105,331
Strength	1,167	2482,847
Water Vapour Permability	2,469	3,994
Air Permability	7,412	6628,541
Thermal conductivity	91,000	303,340
Thermal absorbtivity	0,152	736,256

Table 6.8 SNK analysis of 2 thread lining fabric samples between 16-18 and 25-27

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	100/50-50 a 100/100 a 100/Cotton a	PET a PP b
% Elongation	100/Cotton a 100/100 a 100/50-50 a	PP a PET b
Strength	100/Cotton a 100/50-50 a 100/100 a	PP a PET b
Water Vapour Permability	100/50-50 a 100/100 a 100/Cotton a	PET a PP a
Air Permability	100/50-50 a 100/100 ab 100/Cotton b	PET a PP b
Thermal conductivity	100/Cotton a 100/100 b 100/50-50 c	PP a PET b
Thermal absorbtivity	100/Cototn a 100/50-50 a 100/100 a	PP a PET b

The results in Tables 6.7 and 6.8 are for PP and PET fabrics with 100% synthetic or cotton or 50-50 cotton blend cross miss lining on the backside, and the presence of cotton yarn on the backside results has an increase in all thermal and mechanical parameters. If PP is preferred in this fabric structure, it is understood that higher strength, % elongation and thermal conductivity will be obtained and PET fiber gives higher water vapor and air permeability values. The better thermal conductivity property is due to the low thermal conductivity of PP fiber. In addition, thinner fabrics give better results for better air permeability.

Table 6.9 F-statistic values of Anova Analysis of cross miss lining fabric samples 22 -24, and 31-33

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	0,036	17,350
% Elongation	19,990	81,218
Strength	0,634	1,954
Water Vapour Permability	2,648	62,360
Air Permability	126,438	8344,161
Thermal conductivity	374,273	46,222
Thermal absorbtivity	36,691	134,788

Table 6.10 SNK Analysis of cross miss lining fabric samples 22 -24, and 31-33

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	50-50/100 a 50-50/50-50 a 50-50/Cotton a	PET a PP b
% Elongation	50-50/Cotton a 50-50/50-50 b 50-50/100 b	PP a PET b
Strength	50-50/100 a 50-50/Cotton a 50-50/50-50 a	PP a PET a
Water Vapour Permability	50-50/100 a 50-50/50-50 a 50-50/Cotton a	PET a PP b
Air Permability	50-50/50-50 a 50-50/Cotton b 50-50/100 c	PET a PP b
Thermal conductivity	50-50/50-50 a 50-50/100 b 50-50/Cotton c	PP a PET b
Thermal absorbtivity	50-50/100 a 50-50/Cotton b 50-50/50-50 c	PP a PET b

According to the statistical evaluation shown in Table 6.9 and 6.10, the use of PP or PET yarn in production has an effect on all thermal and mechanical parameters except the strength of the yarns. It can be said that the preference of PP yarn in this structure causes a significant increase in thermal conductivity and % elongation values. The effect of high strength and low thermal conductivity properties of PP fiber is also evident here. Variations in the composition did not have a distinctive effect on mechanical and thermal comfort parameters.

Table 6.11 F-statistic values of ANOVA analysis of cross miss lining fabric samples 19,21,28,30

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	0,667	24,733
% Elongation	7,646	0,831
Strength	0,729	17,440
Water Vapour Permability	4,242	16,606
Air Permability	57,070	1259,064
Thermal conductivity	322,882	3,577
Thermal absorbtivity	0,002	1,375

Table 6.12 SNK analysis of cross miss lining fabric samples 19,21,28,30

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	Cotton/100 a Cotton/50-50 a	PET a PP b
% Elongation	Cotton/50-50 a Cotton/100 b	PP a PET a
Strength	Cotton/50-50 a Cotton/100 b	PP a PET b
Water Vapour Permability	Cotton/50-50 a Cotton/100 a	PET a PP b
Air Permability	Cotton/100 a Cotton/50-50 b	PET a PP b
Thermal conductivity	Cotton/50-50 a Cotton/100 b	PET a PP a
Thermal absorbtivity	Cotton/50-50 a Cotton/100 b	PET a PP a

According to the results in Table 6.11 and 6.12, the use of cotton yarn on the back side of cross miss lined fabrics, which are 100% cotton on the front side, leads to higher mechanical performance. The use of PP or PET yarn in this fabric structure has a significant effect on the crease recovery, water vapor permeability, air permeability and strength values of the fabric. PP and PET fibers have better wrinkle resistance and strength than cotton fibers and their thermal properties are better than cotton fiber. When the measurement results of all cross miss lined knitted fabrics are evaluated together, it is seen that higher % elongation, strength, thermal conductivity and thermal absorbency values (colder contact feeling) can be obtained if PP is preferred instead of PET in the fabric structure.

Statistical evaluation of double plate interlock (double face) knitted fabrics ,which are produced with the same yarn on both plates of the machine in all feeding systems, (100% PET, 100% Cotton or 100% PP), polyester / cotton blend and polypropylene / cotton blend ,which is considered to be an alternative, made separately. Statistical analysis results and evaluations of 100% cotton, polypropylene and polyester double-sided fabrics are shown in Tables 6.13 and 6.14.

Table 6.13 F-statistical values of ANOVA analysis of 100% PP, 100% PET and 100% Cotton double face knitted fabric samples

Mechanical / Thermal parameters	**Fiber Type**
Wrinkle Recovery	12,465
% Elongation	11,632
Strength	505,560
Water Vapour Permability	5,331
Air Permability	794,410
Thermal conductivity	1886,783
Thermak absorbtivity	218,003

Table 6.14 SNK analysis of 100% PP, 100% PET and 100% Cotton double face knitted fabric samples

Mechanical / Thermal parameters	Blend Ratio
Wrinkle Recovery	PET a PP b Cotton c
% Elongation	Cotton a PP b PET b
Strength	PP a PET b Cotton c
Water Vapour Permability	PET a Cotton b PP c
Air Permability	PET a Cotton b PP c
Thermal conductivity	PP a Cotton b PET c
Thermal absorbtivity	PP a Cotton b PET c

According to the statistical analysis, fiber type had a significant effect on all mechanical and thermal parameters of double sided fabrics (34 - 37 - 40) which were produced using single fiber type on the front and back side. The weakest effect among thermal comfort parameters was observed in water vapor permeability measurements as in other fabric types. It has been seen that the preference of polypropylene fiber on both sides of double-sided fabrics offers higher values in terms of % elongation, strength and thermal conductivity than polyester fiber fabrics.

Table 6.15 F-statistical values of ANOVA analysis of double faced fabric samples 35, 36, 38, 39, 41, 42, 44 ve 45

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	3,344	4,699
% Elongation	5,560	162,683
Strength	1776,202	348,221
Water Vapour Permability	0,921	0,642
Air Permability	671,098	2206,400
Thermal conductivity	104,697	4567,948
Thermal absorbtivity	34,269	1539,990

Statistical analysis results and evaluations of samples with identical composition where polypropylene and polyester yarns are produced on the front or back sides are shown in Tables 6.15 – 6.16.

Table 6.16 SNK analysis of double faced fabric samples 35, 36, 38, 39, 41, 42, 44 ve 45

Mechanical / Thermal parameters	**Blend**	**Fiber Type**
Wrinkle Recovery	100/50 Cotton a 50-Cotton/Cotton a 50-Cotton/50-Cotton a Cotton / 100 a	PETa PP b
% Elongation	50-Cotton/Cotton a Cotton /100 a 100/50-Cotton ab 50-Cotton/50-Cotton b	PPa PET b
Strength	100/50-Cotton a Cotton/100 c 50-Cotton/Cotton b 50-Cotton/50-Cotton d	PP a PET b
Water Vapour Permability	100/50-Cotton a 50-Cotton/50-Cotton a Cotton/100 a 50-Cotton/Cotton a	PET a PP b
Air Permability	50-Cotton/Cotton a 50-Cotton/50-Cotton b 100/50-Cotton c Cotton/100 d	PET a PP b
Thermal conductivity	Cotton/100 a 50-C otton/50-Cotton b 100/50-Cotton b 50-Cotton/Cotton c	PP a PET b
Thermak absorbtivity	50-Cotton/50-Cotton a Cotton/100 b Cotton/100 c 50-Cotton/Cotton c	PP a PET b

According to the results in Table 6.15 and 6.16, polyester / polypropylene exchange has the greatest effect on thermal conductivity and thermal absorbency in identical double-faced fabrics and preferring PP fiber in the fabric structure leads to higher % elongation, strength and thermal conductivity values.

The statistical analysis of the measurement results of the stitch transferred fabrics is shown as in Tables 6.15 and 6.16. In the analysis of these fabrics, it should be understood that the number of stitches between two consecutive stitches transferred increases as the report notations (1 to 3) increase. This means that the longer air duct is formed by stitch transferring.

Table 6.17 F-statistical values of ANOVA analysis of the stitch transferred knitted fabrics

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	3,333	2,109
% Elongation	2,972	182,740
Strength	12,361	1857,798
Water Vapour Permability	2,306	505,880
Air Permability	9,835	2031,975
Thermal conductivity	437,777	917,743
Thermal absorbtivity	12,291	111,916

Table 6.18 SNK analysis of stitch transferred knitted fabrics

Mechanical / Thermal parameters	Blend	Fiber Type
Wrinkle Recovery	Report2 a Report1 a Report3 a	PET a PP a Cotton a
% Elongation	Report2 a Report3 a Report1 a	PP a Cotton b PET c
Strength	Report3 a Report1 b Report2 c	PET a PP b Cotton c
Water Vapour Permability	Report3 a Report1 a Report2 a	PP a PET b Cotton c
Air Permability	Report2 a Report3 a Report1 b	PP a PET b Cotton c
Thermal conductivity	Report1 a Report3 b Report2 c	Cotton a PP b PET c
Thermal absorbtivity	Report1 a Report2 a Report3 b	Cotton a PP b PET c

The results in Tables 6.17 and 6.18 show that the change in the physical condition of the air ducts in the knitted fabric structure has no significant effect on wrinkle recovery, % elongation and water vapor permeability values; it shows that fabrics with shorter air ducts give higher thermal conductivity and lower air permeability values. On the other hand, if PP fiber is preferred in the fabric structure, the highest water vapor and air permeability values can be obtained and PP fabrics give higher elongation and thermal conductivity values than PET. This can be explained by the lowest thermal conductivity and high strength property that PP has.

CHAPTER VII

WEAR TRIALS

Before the application of wear trials on participants, Ethics Committee Permission was obtained for Non-Interventional Clinical Trial from the Gaziantep University Clinical Research Ethics Committee.

7.1. Fabric Selection:

During the previous periods of the project, samples of jersey, 2-yarn, double-sided and stitch transferred knitted fabric samples were prepared, samples were pretreated and mechanical / thermal comfort parameters of the samples were completed. As a result of the interpretation of the measurement results, the fiber and knitting types of the garments to be used in wear trials were determined as follows:

1. 100% PP single jersey fabric (Sample No.7 / Sample has high total and thermal comfort)

2. 100% PET single jersey fabric (Sample No.8 / Sample has high total and thermal comfort)

3. 100% Cotton single jersey fabric (Sample No.9 / Comparative sample)

(The use of Ne 40 yarn as in samples 7 and 8 yielded high water vapor permeability, air permeability and low % elongation values in fabric samples)

4. Report 1 100% PP fabric (Sample No.46 / Sample has high total and thermal comfort)

5. Report 1 100% PET fabric (Sample No.47 / High total and thermal comfort sample)

6. Report 1 100% Cotton fabric (Sample No.48 / Comparative sample)

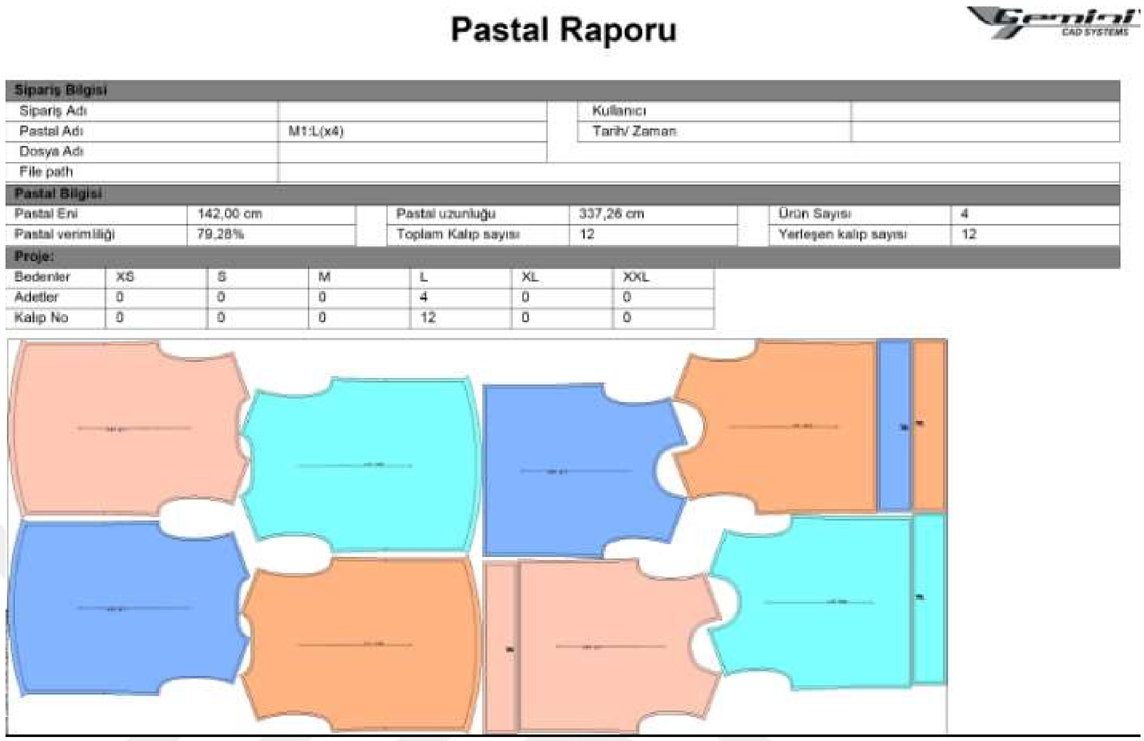
(Fabrics with report 1 using shorter air tunnels in the fabric gave high thermal conductivity, thermal absorptivity, and air permeability and low % elongation values)

7.2. Garment Sample Preparation:

Garment samples for wear trials have been sewed by Üniteks / İzmir. The style of the samples prepared according to the style demands of the customer brands of the Üniteks which are the international sportswear brands. Garments for men have round (crew) neckline, insert on both sides, top sports stitching (100% PET sewing thread) ;and the women's styles with raglan short sleeves, for men's styles, shoulder shape aligned, raglan sleeveless T-shirt was determined (Figure 29). T-shirt samples did not have any patter / coloring. The micro-pastal and measurement tables used by Üniteks for the production of garment samples are shown in Figure 7.2 , 7.3, 7.4 and 7.5 .

	
a. Style for men	b. Style for women

Figure 7.1 Used Garment Samples for Wear Trials



Pastal Raporu

Sipariş Bilgisi			
Sipariş Adı		Kullanıcı	
Pastal Adı	M1:L(x4)	Tarih/ Zaman	
Dosya Adı			
File path			

Pastal Bilgisi					
Pastal Eni	142,00 cm	Pastal uzunluğu	337,26 cm	Ürün Sayısı	4
Pastal verimliliği	79,28%	Toplam Kalıp sayısı	12	Yerleşen kalıp sayısı	12

Proje:						
Bedenler	XS	S	M	L	XL	XXL
Adetler	0	0	0	4	0	0
Kalıp No	0	0	0	12	0	0

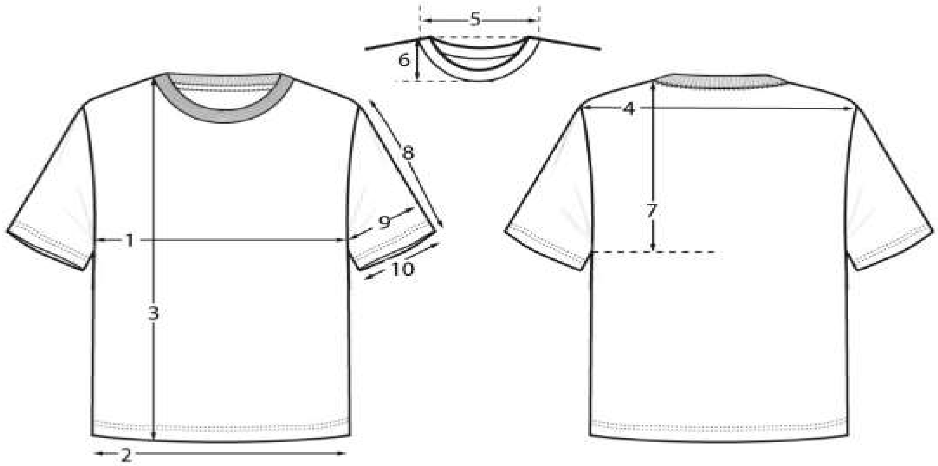
Figure 7.2 Micro Pastal for Men

Sipariş Bilgisi			
Sipariş Adı		Kullanıcı	
Pastal Adı	M1:M(x2);L(x2)	Tarih/ Zaman	
Dosya Adı			
File path			

Pastal Bilgisi					
Pastal Eni	142,00 cm	Pastal uzunluğu	277,18 cm	Ürün Sayısı	4
Pastal verimliliği	82,61%	Toplam Kalıp sayısı	32	Yerleşen kalıp sayısı	32

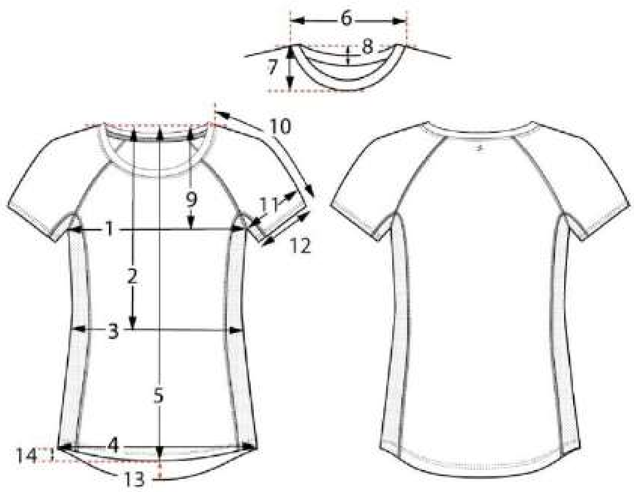
Proje:							
Bedenler	XS	S	M	L	XL	2XL	3XL
Adetler	0	0	2	2	0	0	0
Kalıp No	0	0	16	16	0	0	0

Figure 7.3 Micro Pastal for Women



		XS	S	M	L	XL	XXL
1	½ CHEST	47	51	55	59	63	67
2	½ BOTTOM	46	50	54	58	62	66
3	FRONT LENGTH fr. inner shoulder	71	72.5	74	75.5	77	78.5
4	SHOULDER TO SHOULDER	44	46	48	50	52	54
5	NECK WIDTH	17.9	18.7	19.5	20.3	21.1	21.9
6	NECK DROP FRONT	10.5	11	11.5	12	12.5	13
7	SCYE DEPTH fr. inner shoulder	27	28	29	30	31	32
8	SLEEVE LENGTH short	21.5	22.25	23	23.75	24.5	25.25
9	½ BICEPS	19.75	21	22.25	23.5	24.75	26
10	½ BOTTOM SLEEVE short	16	17	18	19	20	21
11	½ MINIMUM EXTENDED NECKLINE	30	30	30	30	30	30

Figure 7.4 Measurement Table for Men



		XS	S	M	L	XL	2XL	3XL
1	½ CHEST other grading than nest	38.5	42.5	46.5	50.5	56.8	62.8	68.8
2	LENGTH TO WAIST	41.4	42	42.6	43.2	43.8	44.4	45
3	½ WAIST	36	40	44	48	54	60	66
4	½ BOTTOM straight	42	46	50	54	59	63.7	68.7
5	CF LENGTH FR. INNER SHOULDER FOLD other grading than nest	63.5	65	66.5	68.5	71	73.5	76
6	NECK WIDTH	17	17.8	18.6	19.4	20.2	21	21.8
7	NECK DROP CF	11.1	11.5	11.9	12.3	12.7	13.6	14.5
8	NECK DROP CB	2.8	3	3.2	3.4	3.6	3.8	4
9	SCYE DEPTH, APPROX (flat pattern 23cm, dart not closed)	20.9	22	23.1	24.2	25.3	26.4	28
10	SLEEVE LENGTH	20.3	22.3	24.3	25.9	28.1	30.5	32.9
11	½ BICEPS	16	17	18	19.5	21.3	22.3	23.6
12	½ BOTTOM SLEEVE	14.7	15.5	16.3	17.5	18.9	19.9	21.2
13	DIFF CF & CB LENGTH	4	4	4	4	4	4	4
14	DIFF CF & SIDE LENGTH	1	1	1	1	1	1	1

Figure 7.5 Measurement Table for Women

7.3. Trial:

Male and female volunteers whose birth dates ranged from 1992 to 2001 were used for wear trials. The mean age of male volunteers was 19.60, average height was 174.20 cm, weight average was 66.00 kg and body mass index (BMI) average was 21.75. The mean age of female volunteers was 21.33, average height was 162.17 cm, weight average was 57.17 kg and BMI average was 21.63. The volunteers were informed about the project work before the clothing trials and the Informed Consent Form was read, explained and signed. See the form in Figure 7.6 and 7.7.

INFORMED CONSENT FOR

This study is a scientific research and the name of the research is "A New Approach with the Use of Polypropylene Fiber in the Production of Sports Garment Knitted Fabrics". The aim of this research, supported by TUBITAK, is to investigate the comfort characteristics of daily and sports garments developed from polypropylene knitted fabrics. In this study, you will be dressed with sportswear samples produced from the types determined by the evaluation of mechanical and thermal comfort parameter measurements taken from 56 knitted fabric samples and a questionnaire will be applied to collect your comfort perception assessments after use. The duration of the study is 1 (one) month and the number of volunteers will be 20 (twenty).

With regard to this investigation, it is your responsibility to use the samples of clothing provided to you for the period and conditions to be requested. In this research, no risk or discomfort is foreseen since it is not intended to go beyond your clothing and activity patterns.

The results of this research will be used for scientific purposes only and your identity will be kept confidential at all times. You will not be charged any money for participating in this research. You will not be paid in the same way.

You do not have to participate in the research, and when you agree to participate, you have the right to leave at any time. However, if you inform us of this decision in advance, you will not prevent the investigation from being corrupted.

PARTICIPANT'S STATEMENT

I have informed within the scope of the research that titled "A New Approach with the Use of Polypropylene Fiber in the Production of Sports Garment Knitted Fabrics" and clothing trials were given to me. Adequate explanation was made about the purpose of the research, the way of application, the method and the questionnaire forms will not be used for commercial purposes and the confidentiality of user information will be ensured. For all my questions about this research, I could contact Prof. Dr. Cem GÜNEŞOĞLU (0 342 317 27 05/0 533 640 49 06) and Lect. Dr Sinem GÜNEŞOĞLU (0 342 317 27 15). I was informed that I know I can withdraw from research at any time. It was stated that my participation in the research was entirely voluntary, and that I would not be affected by my participation or when I withdrew from the research. I would participate in this research with my own approval.

Voluntary.

Participant:

Name-Surname	*Date of Birth*	*Adress/Tel*	*Signature*

Responsible researcher:

Name-Surname: *Signature:*

Figure 7.6 Informed Consent Form for Volenteers

Survey for Test & Analysis Proceedings of Sports Garment Sample Developments

Volenteer's Age: **Gender:** **Height:** **Weight:**

Education Status:

From you,

- You should wear the samples of the delivered clothes in routine activities for at least 5 hours a day for at least 1 week and at least once during 30 minutes of walking.

- After each wearing stage, you should fill Table 2 by avaluating according to the scales that are given in Table 1.

Table 1. Subjective Clothing Comfort Rating Scale

Skin Wetness		Softness		Warm/Cool Contact Feeling		Itching /Sink		General Comfort Feeling	
1	Dry	1	Very Tough	1	Very Cool	1	No irritation	1	Very Uncomfortable
2	Moist	2	Tough	2	Cool	2	Rarely	2	Uncomfortable
3	Semi-wet	3	Neutral	3	Neutral	3	Neutral	3	Neutral
4	Wet	4	Soft	4	Warm	4	Irrtitate	4	Comfortable
5	Very Wet	5	Very Tough	5	Very Cool	5	Very irritate	5	Very Comfortable

Please write your evaluation on Table 2.

Table 2. Clothing Comfort Rating

Skin Wetness		Softness		Warm/Cool Contact Feeling		Itching /Sink	
Routine	**Paced**	**Routine**	**Paced**	**Routine**	**Paced**	**Routine**	**Paced**

Thank you for your participation.

Prof. Dr. Cem GÜNEŞOĞLU

Lect. Dr. Sinem GÜNEŞOĞLU

Figure 7.7 Survey For Test & Analysis Proceedings of Sports Garment Sample Developments

Volunteers were asked to wear their samples of clothing for 1 week for 3 hours in routine activities and once in a closed - air conditioned environment with 30 minutes of tempo exercise time and to complete the scoring table in Table 7.1 using the evaluation scale shown in Table 7.2. Male volunteers should not wear underwear during their clothing trials; female volunteers were asked to wear a bra only. Wear trials were repeated twice. Subjective evaluation scores of volunteers at the end of clothing trials are shown in Table 7.3. In Table 7.3, the numbers in parentheses show the% CV of the measurement means.

Table 7.1 Subjective Garment Comfort Evaluation Scale

Skin Wetness		**Softness**		**Warm/Cool Contact Feeling**	
1	Dry	1	Very Tough	1	Very Cool
2	Moist	2	Tough	2	Cool
3	Semi-wet	3	Neutral	3	Neutral
4	Wet	4	Soft	4	Warm
5	Very Wet	5	Very Soft	5	Very Warm
Itching / Sink		**General Comfort Feeling**			
1	No irritation	1	Very Uncomfortable		
2	Rarely	2	Uncomfortable		
3	Neutral	3	Neutral		
4	Irrtitate	4	Comfortable		
5	Very irritate	5	Very Comfortable		

Table 7.2: Clothing Comfort Evaluation Table *

Skin Wetness			**Softness**			**Warm/Cool Contact**		
B	**R**	**P**	**B**	**R**	**P**	**B**	**R**	**P**
İtching / Sink			**General Comfort**					
B	**R**	**P**	**B**	**R**	**P**			

*B:Before Trial, R:Routine,P:Paced

Table 7.3 Subjective Evaluation Scores After Wear Trials

Garment Sample	Skin Wetness			Softness			Warm/Cool Contact Feeling		
	B	R	P	B	R	P	B	R	P
1	1,94 -43%	1,92 -44%	2,64 (%28)	3,69 -23%	3,67 -25%	3,42 -22%	2,92 -29%	2,86 -29%	2,75 -26%
2	1,42 -38%	1,25 -34%	2,14 -24%	4,5 -15%	4,53 -14%	4,17 -14%	3 -40%	2,92 -40%	2,97 -30%
3	1,47 -41%	1,47 -41%	2,69 -36%	4,31 -11%	4,25 -11%	3,92 -16%	2,89 -36%	2,81 -40%	2,69 -29%
4	1,36 -44%	1,36 -44%	1,67 -39%	3,56 -25%	3,53 -26%	3,64 -17%	2,64 -48%	2,64 -40%	2,58 -29%
5	1,25 -35%	1,25 -34%	1,72 -37%	4,14 -19%	4,14 -19%	3,97 -19%	2,42 -42%	2,42 -42%	2,53 -34%
6	1,47 -45%	1,47 -44%	2,36 -25%	2,81 -36%	2,81 -36%	2,58 -36%	2,75 -35%	2,75 -35%	2,67 -26%

Garment Sample	Itching / Sink			General Comfort Feeling		
	B	R	P	B	R	P
1	1,47 -50%	1,56 -56%	1,47 -41%	3,56 -28%	3,61 -28%	3,44 -24%
2	1,39 -49%	1,39 -49%	1,47 -56%	4,39 -12%	4,39 -12%	3,97 -15%
3	1,14 -50%	1,17 -50%	1,22 -13%	4,11 -13%	4,11 -13%	3,72 -22%
4	1,39 -48%	1,33 -43%	1,31 -48%	3,42 -29%	3,42 -29%	3,44 -28%
5	1,31 -49%	1,31 -49%	1,53 -46%	3,69 -20%	3,69 -20%	3,44 -18%
6	2,03 -56%	2,03 -54%	2,03 -55%	2,61 -38%	2,61 -38%	2,22 -32%

According to the results in Table 7.3 , we can reach the following evaluations:

1. % CV values of all parameters determined in subjective comfort evaluations were high (between 12 - 56%). This result shows that the reliability of subjective assessment methods in clothing comfort studies is lower than objective methods, as frequently emphasized in the literature. Although it is expected that increasing the number of participants (volunteers) or using

larger measurement scales will increase the reliability, it does not seem possible to achieve reliable results without the absolute control of outdoor conditions in wear trials. Even the PMV (predicted average feeling), which was developed by Fanger to define the natural thermal comfort zone in different combinations of clothing and activity levels and which is the basis of BS EN ISO 7730 (1995) standard, did not give reliable results in some studies where subjective perception of comfort was evaluated [90].

2. There was no significant difference between pre-trial and routine activities (low-paced), whereas in general post-paced exercise, perceptions of comfort were altered. This result also shows numerically that activity level has an effect on comfort perception.

3. The greatest increase in the sensation of wetness in the skin was observed in 3 (83%) and 6 (61%) samples, which were 100% cotton after paced exercise; the lowest increase was observed in 1 (36%) and 4 (23%) samples with 100% PP. The garment samples produced in the hanger-reported fabrics showed a lower increase in the wetness sensation assessment of all three fiber types than jersey samples.

4. Sample 1, which is 100% PP in single jersey samples, had the lowest degree of softness. This is associated with the high weight value of example 1.

5. In general, the subjects stated that after the paced exercise, the softness of the garment decreased and they felt cooler contact. These results may be related to the effect of changing body temperature and increased skin wetness on comfort assessment after the activity level [91, 92].The fact that the greatest change in softness and warm / cold contact sensation after paced exercise was observed in 100% cotton garment samples, which indicated the greatest increase in wetness sensation evaluation, reinforces the interpretation. The R^2 value between the warm-cold contact sensation of the subjects and the thermal absorbency measurement results of the fabric samples was 0.07 (no correlation) for single jersey types; 0,65 (medium-strong relationship) was found for the types of suspension reports. The R^2 values between the softness assessment of the garment samples of the subjects and the% permanent

elongation and wrinkle strength values of the fabric samples were 0.16 and 0.11 (weak correlation) for single jersey types, 0.50 (medium-strong relationship) and 0,96 for suspending type types, respectively (strong relationship).

6. It was observed that fiber type, knitting type and activity level did not affect the itching / stinging sensation in the samples used in clothing trials.
7. In the overall comfort perception assessment, 100% polyester samples obtained the highest evaluation score for both knitting types, while it was stated that the comfort perception decreased in all garment samples after high activity level. The lowest decrease in overall comfort perception after brisk exercise was reported in 100% PP samples. The general comfort perception scores of garment samples and the total comfort perception values calculated for the fabrics used in the production of these samples were calculated as 0.29 (weak relation) for single jersey types; 0,64 (medium-strong relationship) was found for the types with suspension reports.

Analysis studies carried out within the scope of the project showed that polypropylene (PP) blended fabrics perform the highest mechanical comfort feature in all knitting types; According to the measurement results, PP / cotton blend single jersey fabrics offer higher mechanical comfort than PET / cotton fabrics. Among the fabric types, the fabrics with suspend reports perform the highest thermal comfort values, while the PET / cotton blend jersey and cross miss fabrics perform higher thermal comfort than the PP / cotton ones. On the other hand, the samples with the highest total comfort value were found as 100% PP stitch transferred knitted fabrics. Among the fabrics with stitch transferred, the samples with 100% cotton gave the lowest total comfort values. In single jersey, cross miss and double-sided fabrics obtained by using the yarns used in the production of fabric samples with stitch transferred, 100% PP and PET fabrics gave higher total comfort values than 100% cottons.

According to these general results, it has been evaluated that the use of synthetic fibers in the production of sports garment knitted fabrics has a positive effect on the perception of mechanical, thermal and general comfort and that PP fiber can be an alternative to PET fiber consumed intensively in the sector. Wear trials have shown that 100% PP and PET samples, especially those with stitch transferred, are considered to have ‘ higher comfort’ in their evaluations of softness, wetness of the skin itching / stinging sensation and overall comfort perception compared to 100% cotton ones. 100% PP jersey and stitch transferred garment samples showed the lowest percentages of changes in skin wetness and itching / stinging assessment, softness and general comfort perception regression values, which strengthened the perception of discomfort after paced exercise. These evaluations have shown that apparel trials support the conclusion that PP fiber can be used as an alternative to PET fiber in sports garment knitted fabrics. Another result of clothing trials was that stronger correlations could be obtained between subjective evaluations and objective measurement results in the types of suspend reports using controlled fabric samples.

CHAPTER VIII

RESULTS AND FUTURE STUDIES

Within the scope of the project, thermal and mechanical comfort properties of cotton, polyester, polypropylene and their blends were developed and fabrics of different knitting constructions were developed. Cotton and polyester fibers are the most commonly used fiber types in knitted sportswear products. As a result of the experiments, the comparison of the fabrics produced from polypropylene fibers with the fabrics produced from these fibers has been made. The results of the project showed that Polypropylene yarns have the potential to be used in sportswear products where the comfort of clothing is a priority. It has been seen that sportswear products designed with different yarn counts and fabrics developed in different constructions provide good thermal and mechanical comfort, convenient use and easy maintenance properties as an alternative to the polyester fiber consumed intensively in the clothing market. At the same time, all products developed within the scope of the project have been tested in accordance with the quality standards of the customers and approved to comply with these standards.

According to literature; garment fabrics' mechanical comforts have been described as the result of sensation due to the touch of skin and fabric. Also including the feeling of fabric softness, flexibility, itching and irritating due to this touch. Most of the fabric mechanical properties are associated with these factors, therefore variation of measurement results are used for mechanical comfort evaluations.

Fabric strength due to mechanical force is also considered as one of the components of mechanical comfort. With the guidance of these evaluations, following measurements for mechanical comfort properties have been performed within the scope of our project; weight (TS EN 12127),thickness (ISO EN 5084) and with the formation of these two ; fabric density, as an indicator of vertical and horizontal elasticity of elongation % due to the free swing that fabric will provide to body (ASTM D 2594), wrinkle recovery (AATCC 128), spirality as a resistance property against mechanical force (ISO 16322-2), bursting resistance (ISO 13938-2), peeling resistance (ISO 12945-1) and dimensional stability after washing (ISO 6330).

Regarding the thermal comfort, properties following measurements have been performed; characteristics of mass (air, water, moisture) and heat transition of the fabrics have been evaluated therefore air permeability (ASTM D737), liquid permeability (AATCC 195), water vapour permeability (Permetest Sensora device standard which is derived from ISO 11092) thermal permeability, thermal resistance, thermal capacity and thermal absorptivity (Alambeta Sensora device standard).

Below fundamentals have been considered for the evaluation of mechanical comfort properties:

1. The fabrics with higher wrinkle recovery and higher elongation % provide higher mechanical comfort.

2. Fabrics with lower density provide higher mechanical comfort.

3. Whereas bursting resistance, diaphragm height and pilling increases; spirality and dimensional stability after washing decreases, fabric provides higher mechanical comfort.

4. Where as the multi-dimensional graphics area increases, total mechanical comfort also increases, considering this when describing the dimension values of the measurement results, revisions have been made to increase the graphic area. For instance, with the aim of evaluating positive effect of lower density to comfort feeling we have considered the reverse values of density parameters, which contributes in a more useful data for graphic area. Similiar approach also has been applied for spirality and dimensional stability after washing values.

5. Due to having different scales for measurement results, revisions have been made to ensure the dimension values in same scale and visually to be easier to distinguish and also to have higher correlation when the order of the dimension values change

Below fundamentals have been considered for the evaluation of thermal comfort properties:

1. Fabrics which have higher air permeability, water vapur permeability, moisture management capability, provide higher thermal comfort.
2. Fabrics with higher thermal conductivity and higher thermal absorptivity (the cold feeling when touched) perform higher thermal comfort.
3. When preparing multi-dimensional thermal comfort graphics following values have been considered; conditional water vapor permeability (%) of the fabric samples, air permeability, total average moisture management capability of front and back sides of the fabric (OMMC), thermal conductivity and thermal absorptivity values of back side of the fabrics.
4. Due to having different scales for measurement results, revisions have been made to ensure the dimension values in same scale and visually to make easier to distinguish and also to have higher correlation when the order of the dimension values change

Where the value of multi-dimensional graphic area increases, total thermal comfort of the fabric also increases.

The test results were at different scales so some of them were converted to the same scale (between *0.1 – 10*) by using different coefficients prior using as axis value to make them have similar contributions on graph areas: Bursting strength results were divided by 100, bursting distension by 10, air permeability by 200, relative water vapor permeability by 10, thermal conductivity by 10, thermal absorbtivity by 20 and overall moisture management capability values were multiplied by 10.

The pilling and wrinkle recovery rating scores were used as axis value; if the score was an intermediate value like 2-3, it was used as number with a half, like 2,5.

The reciprocal of the fabric density values were used as axis value. This not only led to convert the value to the mentioned scale but also to associate the low fabric density with better comfort since the reciprocal of lower fabric density gave higher value and that increased the calculated graph area which was used in comfort value calculation. Similarly, the spirality and the dimensional change testing results were converted to axis value by using following Equation (8.1):

$$\text{Axis value for spirality and dimensional change} : \frac{\mathbf{1}}{[|\ \boldsymbol{Test\ result}|\ +\mathbf{0,1}]} \tag{8.1}$$

so that *0* as test result was converted to *10* which is the maximum in selected scale; and the lower test results were converted to higher axis values. Then, unitless multi-axial graph area was calculated by Equation (8.2):

$$\text{Graph area} = {}^{1}/_{2} * \left(\sum_{1}^{n} Axis\ value\ (n-1) * Axis\ value\ n\right) * \sin\left((360/n*\pi)/180\right) \tag{8.2}$$

and Total Comfort Value (TCV) was calculated by Equation (8.3) as offered before [67]:

$$\text{TCV} = {}^{\mathbf{1}}/_{\mathbf{3}}\, \boldsymbol{C_{mechanical}} + {}^{\mathbf{2}}/_{\mathbf{3}}\, \boldsymbol{C_{thermal}} \tag{8.3}$$

where, $C_{mechanical}$ is the area of multi-axial graphic of mechanical properties (mechanical comfort) and $C_{thermal}$ is the area of multi-axial graphic of heat/mass transfer properties (thermal comfort).

From the method used we had the following statements:

1. It is known that synthetic fibers are widely preferred in sportswear market it is contributed to better comfort sensations. The study showed that the TCV value of 100% polyester (PET) and polypropylene (PP) fabrics were higher than that of 100% cotton samples in all knit type in accordance with the sportswear market choice. Within the samples, high TCV values were obtained by PP and PET fabrics with tuck-stitches which also fit well with the latest recent sportswear trends on mesh-structured synthetic fabrics. As observed in single jersey fabrics, TCV value increased as the synthetic fiber portion in the fabric increases and that is induced greatly by thermal properties. Also as the yarn fineness increased, single jersey fabrics gave better heat/mass transfer (thermal comfort) property but worse mechanical performance (mechanical comfort) which also aggress with the literature [93, 94].

As a result of the studies carried out within the scope of the project and their analysis, it has been observed that PP fabrics exhibit the highest mechanical comfort properties in all knitting types.

We see that the effects of the high strength property of PP fiber provide high mechanical comfort properties for each fabric type in total mechanical comfort. The average values of fabric thickness and density, burst strength, fabric elongation, crease strength, dimensional stability and pilling properties were used to find the total mechanical comfort value. In addition to these parameters, parameters such as fabric construction and yarn count also affect both mechanical and thermal comfort. Because fabric comdtruction is effective on fabric density due to thickness and weight. In addition, we must say that the fabric construction has aesthetic value for the end user. [27,29].

In single jersey fabrics, PP / Cotton blended fabrics gave better mechanical comfort results than PET / cotton fabrics.

2. For cross miss and double-sided fabrics, the samples with the synthetic face side, which in touch with human skin had higher TCV for cotton face. Also, fabrics with polypropylene face introduced better TCV for polyester face and polypropylene / cotton blends had higher TCV than polyester / cotton blends among double-face knitted samples As the transferred stitch length increases for tuck-stitch, (form 2-tuck stitches to 4-tuck) an important change at TCV was not observed.

When the fabric reports are taken into consideration, stitch transferred fabrics exhibited high thermal comfort properties. Single jersey and cross miss fabrics with PET/Cotton blends showed higher thermal comfort properties than PP/Cotton blends.

The samples with the highest total comfort value are stitch-transferred fabrics with 100% PP.

We have stated the effect of fabric thickness and accordingly fabric density on comfort values. We see that these properties affect air and water vapour permeability and thermal insulation from thermal comfort properties. The lower the fabric density, the higher the air and heat permeability. For this reason, 100% PP fabric number 46 among stitch transferred fabrics has the highest total comfort value. Air permeability was affected by the presence of air channels in the fabric structure. These channels in the fabric structure affect heat and moisture transfer and thus thermal comfort. This allows us to understand that the presence of air channels in the fabric construction is an important parameter in sportswear. Since the pores in the fabric make it easier to transfer heat and moisture, sportswear designers may prefer to use mesh fabrics in products that need better ventilation. [27]

3. Among the results, it was also stated that polyester, as a widely used fiber type in sportswear may be replaced with polypropylene fiber with highly acceptable comfort performance. In general, the use of synthetic fibers in sportswear fabrics has a positive effect on the perception of mechanical comfort, thermal comfort and total comfort.

If we examine the graphic area table of the total comfort values, we see that the fabrics with the highest total comfort values are the fabrics with 100% PP stitch transfer. Here, too, we see the effect of fabric porosity and thus fabric density. Again, the values closest to these values belong to the Single jersey fabric structure. Here we can see that it is due to fabric density and porosity. Fabric construction is important in heat and moisture transfer and affects air and moisture permeability and thermal insulation. [27]

It has been determined that PP fiber can be used as an alternative to PET fiber.

The project results showed that Polypropylene yarns have the potential to be used in sportswear products where wearing comfort is a priority.

4. The findings was also revealed with wear trials where 12 male and 12 female volunteers with similar BMI (Body Mass ındex) have worn t-shirts produced by %100 polypropylene, polyester and cotton single-jersey and 2-tuck stitches fabrics. The volunteers were asked to complete a survey for comfort assessment rating the comfort level between 1 – 5 (5 is the most comfortable) after low and high level physical activity. The tuck-stitch shirts were rated as “more comfortable” especially after high activity level. It was also noted that the differences between TCV values of synthetic and cotton tuck-stitch samples was higher than single jersey fabrics which is concluded that the wearer’s subjective perception on separating the comfort level of synthetic and cotton would be easier for tuck-stitch fabrics. Wear trials also pointed the same result with higher comfort level rating differences among tuck-stitch shirts (lower for cotton).

Analysis of wear trials carried out within the scope of the project showed that polypropylene (PP) blended fabrics perform the highest mechanical comfort feature in all knitting types. According to the measurement results, PP / cotton blend single jersey fabrics offer higher mechanical comfort than PET / cotton fabrics. Among the fabric types, the fabrics with suspend reports perform the highest thermal comfort values, while the PET / cotton blend jersey and cross miss fabrics perform higher thermal comfort than the PP / cotton ones. On the other hand, the samples with the highest total comfort value were found as 100% PP stitch transferred knitted fabrics. Among the fabrics with stitch transferred, the samples with 100% cotton gave the lowest total comfort values. In single jersey, cross miss and double-sided fabrics obtained by using the yarns used in the production of fabric samples with stitch transferred, 100% PP and PET fabrics gave higher total comfort values than 100% cottons.

According to these general results, it has been evaluated that the use of synthetic fibers in the production of sports garment knitted fabrics has a positive effect on the perception of mechanical, thermal and general comfort and that PP fiber can be an alternative to PET fiber consumed intensively in the sector. Wear trials have shown that 100% PP and PET samples, especially those with stitch transferred, are considered to have ‘higher comfort’ in their evaluations of softness, wetness of the skin itching / stinging sensation and overall comfort perception compared to 100% cotton ones. 100% PP jersey and stitch transferred garment samples showed the lowest percentages of changes in skin wetness and itching / stinging assessment, softness and general comfort perception regression values, which strengthened the perception of discomfort after paced exercise. These evaluations have shown that apparel trials support the conclusion that PP fiber can be used as an alternative to PET fiber in sports garment knitted fabrics. Another result of clothing trials was that stronger correlations could be obtained between subjective evaluations and objective measurement results in the types of suspend reports using controlled fabric samples.

Statistical analysis of the measurement results was performed with multifactor analysis of variance (ANOVA) at 5% confidence interval. Statistical analysis was applied for fabric types separately; The severity of the effects of the sources of variance (fiber type, composition, yarn count) on the measurement results were evaluated according to the F-statistics values. As the effect intensity of the variance source increases, the F-statistic value grows. Whether there was a significant difference between the sources of variance was evaluated with the SNK test. In the SNK test, when the mean measurement results of the sources of variance were marked with the same letter, it was evaluated that there was no significant difference between them.

As a result of the project, it has been demonstrated that polypropylene fibers can be used as an alternative in knitted garment products and parameters for developing sports clothes with polypropylene fibers have been determined. With this project, a study on polypropylene fibers was carried out for the first time at ÜNİTEKS company and it was confirmed that this fiber type was suitable for the production of the company. In addition, a wide range of polypropylene fabrics were developed and evaluated in terms of comfort parameters.

As a result of the project, UNITEKS will develop from polypropylene fibers through daily and sports garments. For the new product platform it aims to use in production, yarn, fabric and garment parameters know-how.

Furthermore, knitted fabric samples were produced for the first time by the customer organization from 100% non-centered polypropylene yarns, and the experience related to the machine types and settings required for this type of product group was formed.

The project is one of the rare studies in the literature where objective and subjective assessments on clothing comfort are made together. For the first time, a multi-graphic method was used in a clothing comfort study, which provides a combination of measurement results of multiple mechanical and thermal comfort components of different fabric types. The results were supported by clothing trials.

With the project activities, four different knitting type cotton, PP and PET fabric samples were produced for sports garment production. The mechanical and thermal comfort components of the samples were measured and a new method (multi-axis graphical method) was used to evaluate objective general comfort. Within the scope of the project, which made subjective comfort evaluation with clothing trials, physiological (mechanical), and thermophysiological (thermal) and psychological comfort concepts were measured together. The objective of the project is to evaluate objective and subjective comfort assessment in literature; from another perspective, physiological, thermophysiological and psychological comfort (three components of clothing comfort) is one of the few studies in which measurements are made together.

At the end of the project activities, the projected / targeted sample production plan, tests and analyzes, results and evaluations were completed; the proposal of the project (the suitability of polypropylene fiber for the production of sports garment knitted fabric and its use as an alternative to polyester fiber) can be verified.

8.1. Future Trends:

In the completed project, mechanical and thermal comfort components of 54 different fabric samples produced by using cotton, PP and PET yarns in the basic knitting structures were measured and a new method was used for the evaluation of the measurement results (objective evaluation). Supporting these method outputs with clothing trials (subjective assessment) is the most important experience gained with the project. Undoubtedly, the parameters related to the construction take an important place on the mechanical and thermal comfort properties of knitted fabrics for sportswear. Knitting and needle reports of fabrics, stitch length, density values, the number of contact points with the human body, the use of elastane yarn, dyestuff / pigment type and so on. Examining the effect of parameters on comfort properties is another project subject. The main aspects of the project will be to evaluate the effect of the mentioned parameters of knitted fabrics using PP yarns on comfort perception and to determine the knitting report (s) and product details that will exhibit the highest mechanical / comfort characteristics. In this project, it will be necessary to use the research method followed in the current project. Knitting reports and production details to be determined by the project will also be the subject of patents.

The most important difficulty to be experienced in the production of the outputs from the project is the delays in PP CF yarn supply and pricing problems due to producer costs. In addition, it will be necessary to cooperate with a few manufacturers who can produce PP CF yarn at the fineness used in the project in order to ensure quality continuity. These problems can be solved by stocking with different suppliers. The production of staple PP yarn at high order volumes will contribute positively to the comfort perception of fabrics and garments.

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Education

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High School	Science Math	Vefa Anatolian High School	2001

Publications

Güneşoğlu S.,Babalık E.,Güneşoğlu C. (2020). Polipropilen Lifinin Spor Giyimde Kullanımına Uygunluğunun Objektif Metotla Değerlendirilmesi. *İTÜ Ulusal Tekstil Kongresi II. AR-GE Günü*, İstanbul (Summary Text /Oral Presentation)

Babalık E.,Çetmeli A.,Utebay B.,Güneşoğlu S.,Güneşoğlu C. (2019). A new approach for assessment of polypropylene fiber usage in sportswear. *AUTEX 2019*, Belgium (Full Paper Text/Oral Presentation)

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Çütcü, İ., Babalik, E. (2016). Yenilikçi tekstil ürünlerinin ihracat potansiyeli: Türkiye uygulaması. In *International Congress of Management Economy and Policy* (pp. 230-244).

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Experiences

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