Comparison of Comfort Properties of Jersey and Interlock Knits in Polyester, Cotton/Spandex, and Polyester/Rayon/Spandex

Shuvo Kumar Kundu[#1], Usha Chowdhary[*2]

*[#]Graduate student& *Professor, Fashion, Interior Design & Merchandising*
Central Michigan University, USA

Abstract

This study evaluated the effects of two independent variables thickness and weight on the five dependable variables air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance. Total 5 hypotheses were developed to test the relationship among jersey and interlock knits with different fiber content. Mean (M), standard deviation (SD), t-test (t) and probability (p) were calculated to compare intra group fabric based of dependable variables. Analysis of Variance (ANOVA), Pearson Correlation and Regression Analysis were performed to determine the relation of independent variables to all dependable variables. Differences were found in jersey and interlock knits of different thickness and weight for air permeability, evaporative resistance, bursting strength, and horizontal wicking. Both positive and negative correlations were found between dependent and independent variables.

Keywords -*Thermal Comfort, Fabric Thickness, Fabric Weight, Air Permeability, Bursting Strength, Thermal Insulation, Evaporative Resistance, Horizontal Wicking.*

I. INTRODUCTION

The expectation from our clothes has changed over time with changed living standards [1].Researchers asserted the importance of thermal comfort, called clothes as a second skin and identified comfort as the key factor in clothes [2-4]. Therefore, testing comfort properties of fabrics deemed important before making garments out of it.

Knitting is the fabric construction method that uses an intermeshing technique. The knitted stitch is the primary unit of intermeshing. At least three or more intermeshed needle loops make a knitted stitch. The center loop is drawn through the head of the loop underneath it and is, on the other hand, intermeshed through its head by the loop above it [5].

Plain jersey looks different by technical face and technical back. The technical face is smooth, with the side stem of the needle loops, which look likes the columns of V's (also called wales). Wales are used as primary units when producing knits with different colored yarns. Technical back, on the other hand, is not as smooth as the technical face. The bottom of the sinker loops and heads of the needle loops the form the semi-circles of interlocking loops. This appearance is sometimes important for the knitting of alternate courses in different colored yarns [5].

Interlock knit exhibits identical faces on both sides, and they look same as technical face of plain knit. The surface of interlock knit is smooth. It cannot be stretched out to see the reverse meshed loop wales because the wales on alternate sides are locked together and directly opposite to each other. Interlock is a balanced, smooth, stable structure that lies flat without curl. It does not open from the end knitted first. It is thicker, heavier and narrower than rib of similar gauge. Interlock needs fine, better, and more expensive yarn. Interlock knits have four-way stretch and are appropriate for exercise apparel as well as tight fitting dresses including leggings. Thick structure of interlock knit provides both warmth and comfort [5].

Knitted fabrics have become very popular over the last few decades. Some of the reasons for their popularity include easy production technique, less expense, a wide range of products, and high level of clothing comfort. Additionally, knitting technology copes with the fast-changing demand of fashion and usage better than the woven fabrics. Knit fabrics render comfort properties like elasticity, high stretch, snugness for fitting, soft handle, freshness and help transfer vapor from our body effectively [6]. For the aforementioned reasons, the knitted fabric is widely used for sportswear, casual wear and underwear [6-8]. Researchers are working on making the knitted fabric more comfortable by integrating different fibers, changing yarn parameters like twist, bulk, count and finishing treatment, and knitting factors like loop length, Course Per Inch (CPI), Wales Per Inch (WPI) and fabric weight and adopting new or different finishes [6]. Study reported that fiber content and fabric count impacted stretch and recovery of jersey and interlock knits [9]. Therefore, to achieve an optimum level of comfort, end use of garments must be considered. Researchers suggested using interlock fabrics for colder weather due to their high thermal insulation value. Single jersey fabrics for active sportswear/summer garments because of their better moisture management properties than interlock knits [7].

The concept of comfort was introduced by researchers many decades ago from different aspects [10-13]. Comfort is the absence of displeasure or discomfort or a balance between the environment and a human being [11-16].Researchers stated physiological comfort as an association of thermal and non-thermal elements and its relation to the stability of temperature and in each environment [10].It is hard to maintain comfort for us as our body is responsive to all weather parameters such as temperature, moisture, humidity etc. [11-13, 16]. In addition, our clothes can contribute toward body comfort/discomfort [17].

The ability of fabrics to bring equilibrium of skin temperature with weather and transfer of perspiration produced from the body is considered as thermal comfort [18]. Although researchers find it very complex to define, clothing comfort is a key attribute for customers' satisfaction that can be impacted by their textile choice[17,19-21]. Moreover, inappropriate fabric choices can cause both psychological and physiological discomfort [13]. Researchers found that thermal comfort in apparel depends on various parameters of textile materials. Textile materials offer a different level of comfort depending on their physical, mechanical, and aesthetic properties. Physical properties include knit structure, thickness, heaviness, fiber content, flexibility, handle and drape. Examples of the mechanical properties include heat and moisture transfer, air permeability, bursting strength, and moisture absorbency. The aesthetic properties are luster, color, fashion, fit and style. Comfort can also vary from individual to individual and from culture to culture [17].

The amount of air passing through the fabric in a certain time is defined as Air permeability [22]. The evaporative resistance is the rate at which water vapor passed through a complex system and system includes not the fabric as well as air layers which contribute a much larger portion of the total resistance [23]. Both air permeability and water vapor permeability are important factors for clothing comfort [22, 24]. The flow of air between our environment and the human body is affected by air permeability. Higher air flow impacts both heat and moisture transfer. The transfer process can take place in both water and vapor phases [22]. Heat transfer is the process of the energy change of a system. There are three main methods of heat transfer: conduction, convection, and radiation. Practically, heat transfer always happens if a temperature difference exists between a material and the environment [25].The water vapor transport of clothing system is of critical importance in deciding thermal comfort during hot environments and/or heavy workday. The higher rate of water vapor permeability of the clothing systems helps the moisture transfer from the human skin into the environment throughfabric layers than the lower rate of water permeability [26].

The bursting strength of the knitted fabric is a measure of the resistance to rupture when subjected to stretching [27]. Many researchers explored the relationships of breaking strength and other fabric properties such as stitch length, fabric count, elongation, extension, and ultraviolet protection [20, 28-33]. Reported study examined the relation between bursting strength and comfort.

Wicking is the spontaneous flow of a liquid in a porous substance, driven by capillary forces [34]. Scholars found sweat transportation and drying rate of fabrics are two crucial factors affecting the physiological comfort of our outfit [35-37]. Therefore, it is important to evaporate the perspiration from the skin surface and to transfer the moisture to the atmosphere [38]. Because of our physical activity, the wearer perspires, and the fabric gets wet. Wet fabrics lower the body heat and as a result, the wearer becomes exhausted. Therefore, clothing next to the skin should be able to absorb moisture and then release to the atmosphere [39].

Clothing can provide thermal comfort by allowing moisture management of sweat in summer and offering thermal comfort through layered clothing or textured fabrics in winters. If a wearer sweats a lot, it is not expected that the garments would stick with his/her skin by high absorption of liquid. Rather it is expected that the garments would absorb and transfer moisture promptly thus the wearer skin remain dry and there are no uncomfortable feelings. If a wearer is in a clothing system which has very poor breathability, heart rate and rectal temperature will increase more rapidly than more breathable fabrics. Therefore, a wearer with breathable clothing can feel more comfortable than one without it [40]. Because of high absorbency and moisture transfer abilities of the cellulosic fibers, their use has increased in the recent years [41].

As evidenced by the preceding information, literature provides sufficient evidence of research on thermal comfort. Previous work focused on handful blends and recommended testing on other types of blends. Modern equipment to measure thermal comfort has changed and previous studies examined the different factors that influence thermal comfort than proposed in the reported study. Studies also discussed how the comfort characteristics change with fiber ratio changes. No published work explored and compared comfort properties of jersey and interlock knits in polyester, cotton/spandex blend, and polyester/rayon/spandex blend based on fabric weight and fabric thickness for thermal resistance, evaporative resistance, bursting strength and air permeability. Therefore, the purpose of this study was to investigate the correlations among polyester, cotton/spandex, and polyester/rayon/spandex blend fabrics for their comfort properties such as thermal resistance, evaporative resistance, bursting strength and air permeability. This study will help textile engineers and designers to select the right fabric for their production or design respectively. Five hypotheses were developed for this study.

II. LITERATURE REVIEW

Clothing comfort is one of the most important factors or customers' decisions to purchase clothing. This is not only for sportswear but also all kind of textile apparel. In recent years, several studies examined ways to eliminate discomfort and enhance comfort in apparel. The reported study focused to compare comfort properties of jersey and interlock knits of 100% polyester Cotton/Spandex, and Polyester/Rayon/Spandex blend of different fabric weights and thicknesses. To capture the crux of previous work on the topic, the literature review was conducted. This section is divided into weight and thickness, air permeability, thermal and evaporative resistance, and horizontal wicking.

Fabric thickness and weight are important and represent the structural attribute of knit fabrics. These two attributes determine many properties of clothing textile. Structural attributes like fabric count, fabric thickness, and fabric weight to determine their impact on the selected performance attributes [42].The author also reported that due to shrinkage, the fabric counts and weight increase. In winter, lightweight and thicker fabric will be more comfortable than the lightweight and thinner fabrics ofsame weight [43]. Researchers stated that fabric density is the function of fabric weight and fabric thickness, which impacts comfort [30]. Other researchers reported that the thickness of cotton fabric influences comfort [43].Study found that with the increase in thickness, porosity and air permeability decrease [44].Fabric's physical properties like fabric thickness, fiber type, and fabric thickness also affect thermal properties of the textile [45]. Investigators found that thickness enhanced warmth [46].

Overall, previous research demonstrated that thickness and weight influence both air permeability and warmth to enhance comfort. However, they did not compare different knit types.

Air permeability is one of the most important determining in evaluating knitted fabrics and apparel. Air permeability helps with transporting dampness from the skin to the outside environment [47].These physical parameters help with determining the intended end usage [48]. In the recent years, numerous studies have been conducted to anticipate the porosity and air permeability based on their structural parameters. These studies include both knitted and woven fabric. The fabric with the less yarn number and course count exhibits the higher air permeability values the fabrics with high yarn number and course count. Again, longer loop length produces a looser fabric and increased air permeability in knits. They also found a positive linear relationship between air permeability and porosity, it means the fabric with high porosity possesses higher air permeability [47, 49]. The knitted fabric made with the cotton hosiery yarn exhibit constant decrement of air permeability as stretch gradually increase and relaxation progress.Therefore, the air permeability of knitted structures is inversely proportional to stretch and relaxation [50].Researcher asserted that the pique structure exhibits the highest air permeability followed by the single jersey and the interlock structures [51].

The study investigated that under relaxed conditions, fabrics with lower weight/m^2, higher air permeability and thickness enhanced thermal comfort. In contrast, fabrics with higher air permeability, vertical wicking height and moisture regain will provide better moisture management properties than lower values [52]. Air permeability is related to the thickness, porosity and tightness factor of the knitted fabrics and due to the higher air permeability, preferred single jersey fabrics for warmer climate sportswear [53]. Overall, previous research demonstrated that thickness and count affect air permeability and comfort for jersey and pique knits. Both air permeability. However, they did not test interlock knits.

The thermal resistance (RCT) is a measure of the resistance to heat transfer from the sweating guarded hotplate to the ambient environment. Whereas, the evaporative resistance (RET) is a measure of the resistance to water vapor transfer from the sweating guarded hotplate through a fabric to the ambient environment. The capability of textile to transport heat and moisture vapor from our skin to the environment is an important factor of clothing comfort, especially in a situation where heavy sweating is involved [54]. Vapor transport and thermal transfer properties are important predictors of thermal comfort [55].

Researcher reported that thicker materials have higher thermal insulation, less flexibility, more bulk, and poorer drape than the thinner materials [20]. Thermal comfort parameters like air permeability, thermal resistance, and water vapor permeability are significantly affected by the presence of bamboo fibers. The thermal resistance of knitted fabric decreases with an increase of bamboo fibers content [56, 57]. In contrast, the water vapor permeability and air permeability increase consistently with an increase in the bamboo percentage in the fabric[4,58].In comparison with cotton fabric, modal microfiber blended fabric exhibited lower thickness, bursting strength, and higher air permeability. In the case of thermal comfort properties, modal microfiber blended fabrics displayed lowest thermal resistance and the highest absorptivity [45].

The fabrics knitted from the mix of man-made bamboo yarns and synthetic threads show lower thermal conductivity than the fabrics knitted from the mix of cotton and identical synthetic threads. The fabrics with combined knitted patterns show higher thermal conductivity and thermal resistance than the plain knitted pattern [46]. Statistical analyses showed that the fabrics containing at least 25% of rabbit fiber exhibited a significant difference in thermal comfort properties. As the ratio of Angora fiber increased, yarn hairiness, fabric thickness, and thermal resistance increased, whereas thermal conductivity thermal absorptivity and relative water vapor permeability decreased [59].

A research on Viloft/cotton and Viloft/polyester blended fabric found that thermal conductivity, thermal absorptivity, and thermal resistance value increase with the increase of Viloft fiber proportion in single jersey knitted fabric. Whereas, thermal diffusivity, air permeability decreases and there is no effect on water vapor permeability with the increase of Viloft fiber [60].

Some researchers also focused on the physical attributes of fabrics like stitch length and fabric structure. Thermal resistance and thermal conductivity decrease as yarn gets finer and the water vapor permeability, and air permeability increase consistently as the linear density and stitch length increase [6]. Researchers also found that with the increase in stitch length, fabric weight and fabric bursting strength decrease but air permeability increases. Researcher found that an increase in the stitch length decreases thermal conductivity and thermal absorptivity [45].Study reported that thermal conductivity coefficient increases with the increase in loop length [46].

Due to structural uniqueness, single jersey fabrics show significantly lower thermal resistance and thermal conductivity but higher water-vapor permeability than rib and interlock fabrics. It also gives warm feeling at the first touch due to low thermal absorptivity [7, 60]. On the contrary, interlock knit shows higher thermal insulation and lower water vapor permeability rib knits [61].

Knitted fabric with combed yarn displays higher thermal conductivity, thermal absorptivity, and water vapor permeability [61]. The thermal absorptivity does not get affected by carded or combed yarns. The fabrics knitted from ring spun yarn exhibit more thermal insulation and feel warmer than open-ended (OE) yarn. However, they have less water vapor permeability than that of fabrics knitted from OE yarns. This resulted from different yarn surface hairiness. Research suggested of at least 25% of Angora fiber blend for warm clothes and very low percentage of Angora fiber for active garments [59]. Overall, previous research demonstrated extensive work in this area. However, they did not focus on the variables of the reported study collectively. Additionally, very limited information was found on interlock knits.

Researchers defined the movement of liquids in fabrics by capillary pressure as wicking [62]. The researcher also compared the two different wicking behavior of fabrics, namely, the vertical and horizontal wicking of water on a strip of textile material. To provide comfort to the wearer, moisture transportation in a fabric is an important factor. Clothes act as the interface between body and environment. Therefore, structural characteristics of the textiles influence body heat and moisture loss to the ambient environment. For active and sportswear, moisture management is critically important. Investigator found the wicking rate of textiles can form a pleasant microclimate next to the skin [42].

Researchers concluded that textiles fabrics contain imperfect capillaries and there is no property that represents their wicking behavior universally [62]. Therefore, the wicking rate of each fabric must be determined individually. Wicking is generally impacted by the spaces between the fibers and these spaces again are affected by the type of fiber and the way they are organized [63]. The fiber's structural properties like length, width, shape, and arrangement have a great impact on the capillary channels. Garment's attributes such as absorbency, wicking and environmental parameters such as temperature, humidity are important are determining the factor for comfort [54]. The reported study is designed to fill the gap in the previous literature.

Bursting strength is a measure of resistance to rupture, in another word pressure at which fabric tears/bursts. Bursting strength depends on extensibility and tensile strength of the fabric. The researcher suggested the wool fiber blended with Kevlar possesses higher bursting strength than that of Kevlar only, and the average tear strength of Kevlar/wool fabric increases by approximately 38.7% compared to Kevlar fabric [64].Bursting strength increases as the yarn becomes coarser, reduction occurs with enzyme treatment and an increase results with water-repellent finish [65].Researchers found that bursting strength decreases with the increase of stitch length [28].

Researchers examined mechanical properties such as heat and moisture transfer, air permeability, bursting strength, and moisture wicking [17]. Study reported the inverse relationship between elongation and breaking strength [66]. Investigators found that bursting strength can be impacted by knit structures [67]. A study revealed that filament yarns have the lower extension and higher strength than staple fibers [32]. Overall, previous research demonstrated the impact of mechanical properties on comfort. However, they did not compare jersey and interlock knits with controlled structural attributes.Based on the reviewed literature, the following five hypotheses were developed.

Hypothesis 1: Jersey knit (96% cotton, 4% spandex) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

Hypothesis 2: Jersey knit (70% polyester, 26% rayon, and 4% spandex) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, evaporative resistance.

Hypothesis 3: Interlock knit (100% polyester) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, evaporative resistance.

Hypothesis 4: Two interlock knits (polyester/rayon and spandex blend) with two significantly different thicknesses will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

Hypothesis 5: No relationship will exist between fabric weight and fabric thickness for air permeability, bursting strength, horizontal wicking, thermal insulation, and Evaporative Resistance.

III. METHODOLOGY

The purpose of this study was to evaluate the effects of fabric thickness and fabric weight on the fabric comfort properties air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance. Eight fabrics were purchased from the local fabric store and grouped into four groups based on thickness and weight and two groups based on the knit structure. The research design, sample description, experimental methods applied to achieve the research objectives are described in this chapter, followed by an overview of the data analysis. A quantitative design was used for this investigation. Knit structures (jersey and interlock), fabric thickness and weight served as the independent variable. The dependent variables were air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

Sample Description

Jersey and interlock fabrics were selected for this research. Eight fabrics were divided into 4 groups (Table 1). Group 1 fabrics were jersey knits with 96% cotton, 4% spandex. They had the same fiber content but differed for thickness and weight. Group 2 had jersey knits with 70% polyester, 26% rayon, and 4% spandex. Both group 3 and 4 had interlock knits with 100% polyester and polyester/rayon/spandex blend respectively. The same dataset was used for both thickness and weight, a separate hypothesis was developed to find a correlation between these two variables for all the dependent variables.To separate two different samples in the same group they are labeled with “A” and “B”. The Significance of the same groups for thickness and weight was determined by t-test analysis. Findings revealed that two fabrics for each group differed significantly for both thickness and weight (Tables 1 & 2). All samples within the group are statistically significant based on thickness. Table 1 shows $p < .05$ for all four pairs of samples. Based on the mean value of thickness, samples are called “Thicker” or “Thinner” within the group. From the weight details of samples, it can be predicted that except group 4 all samples within the group are statistically significant based on weight. Table 2 displays p < .05 for group 1 to 3 whereas p= .082 hence not significant. Based on the mean of weight value, samples are called "Heavier" or "Lighter" within the group.

Sample Preparation

All test specimens were conditioned using ASTM D 1776-2016 for 12 hours before being tested in a controlled chamber of 23 ± 0.5°C and 50 ± 5% RH prior the thermal insulation test and of 35 ± 0.5°C and 40 ± 5% RH prior Evaporative Resistance test respectively. The mean surface temperature of the hot plate was maintained at 35± 0.2°C and 35± 0.5°C during a 30 minutes' test for thermal insulation and evaporative resistance test respectively. All specimens were preconditioned under 21± 1°C and 65± 2% RH for determining air permeability, thickness, weight, bursting strength and horizontal wicking. 125 Pa (12.7 mm or 0.5 in. of water) water pressure differential was maintained for air permeability test.

Test Procedure

Fabric Thickness (ASTM D1777-2011) [68]

The test followed the test standard ASTM-D1777. Prior to beginning data collection, the researcher ensured that the thickness gauge was dust free, set in the mm mode, and had 0 as the initial reading. No specimens were required. Measurements were taken from different sections of the fabric to allow for optimum representation of the fabric. AMES Digital Thickness Tester (model: BG1110-1-04) were used for the test.

To start the test, (step 1) lift the lever, (step 2) place specimen under the thickness gauge. It was made sure specimen was evenly spread and there was no crease/wrinkle. (Step 3) the pressure foot was lowered until it sits on the specimen relaxingly. (Step 4) the thickness was recorded in mm. The steps 1 to step 4 were repeated 5 times. Finally, mean (M), standard deviation (SD), t-test (t) and probability (p) were calculated using SPSS software.

Fabric Weight (D3776/D3776M-09a)[69]

According to ASTM D3776/D3776M standards, a specimen should have a minimum of 20 square inch area. Researcher suggested testing specimen of 5X 5 in^2, since it covers same distance for courses and wales. [66] Therefore, five specimens of 5X 5 in^2 fabric specimens were weighed in gm by the Mettler Toledo weighing scale and converted into Oz/yd^2 and then converted into g/m^2 by following formula:

Oz/yd^2: 45.72*G/L*W

g/m^2: 33.906* Oz/yd^2

Where:

G: Weight of the specimen in gm.

L: Length of the specimen in inch.

W: Width of the specimen in inch.

Air Permeability (ASTM D737-04)[70]

The TEXTEST Air Permeability Tester (model: FX 3300 LabAir IV) was used to measure the air permeability. No swatches were required for the Air Permeability (ASTM D737-04) test. The fourth generation TEXTEST instrument is user-friendly, simple, ignore a source of error, and better predictability of the test results.

TABLE I.
Thickness Data of the Knit Fabrics

List of samples					Thickness (mm)			
Group	**Sample**	**Color**	**Knit Structure**	**Fiber Content**	**M**	**SD**	**t**	**p**
Group 1	A	Black	Jersey	96% Cotton, 4% Spandex	0.820	0.020	7.960	0.000
	B	Black	Jersey	96% Cotton, 4% Spandex	0.710	0.023		
Group 2	A	C. Grey	Jersey	70% Polyester, 26% Rayon, 4% Spandex	0.660	0.017	4.540	0.001
	B	H. Grey	Jersey	70% Polyester, 26% Rayon, 4% Spandex	0.620	0.017		
Group 3	A	Yellow	Interlock	100% Polyester	0.530	0.011	39.192	0.000
	B	Purple	Interlock	100% Polyester	0.720	0.000		
Group 4	A	Black	Interlock	86% Polyester, 11% Rayon, 3% Spandex	0.780	0.017	2.140	0.032
	B	Ivory	Interlock	76% Polyester, 20% Rayon, 4% Spandex	0.760	0.000		

TABLE II
Weight Data of the Knit Fabrics

List of samples					Fabric Weight (GSM)			
Group	**Sample**	**Color**	**Knit Structure**	**Fiber Content**	**M**	**SD**	**t**	**p**
Group 1	A	Black	Jersey	96% Cotton, 4% Spandex	197.481	0.925	53.040	< .00001
	B	Black	Jersey	96% Cotton, 4% Spandex	155.738	1.497		
Group 2	A	C. Grey	Jersey	70% Polyester, 26% Rayon, 4% Spandex	189.445	4.146	17.500	< .00001
	B	H. Grey	Jersey	70% Polyester, 26% Rayon, 4% Spandex	147.639	3.366		
Group 3	A	Yellow	Interlock	100% Polyester	121.137	2.320	76.930	< .00001
	B	Purple	Interlock	100% Polyester	225.905	1.972		
Group 4	A	Black	Interlock	86% Polyester, 11% Rayon, 3% Spandex	241.667	3.757	1.530	0.082
	B	Ivory	Interlock	76% Polyester, 20% Rayon, 4% Spandex	244.867	2.778		

Before starting the test, it was confirmed that the machine is calibrated, and the head is mounted correctly. The rubber plate was placed under the test head to determine the air loss and the air loss was less than 1%. To start the test, the specimen was placed under the test head and it was confirmed that there is no crease/wrinkle. The clamping arm was lowered and pressed down. The test result was read after the display had established. Total 10 readings were recorded from ten different places of the specimen.

Bursting strength (ASTM D 6797-15)[71]

The Instron Constant Rate of Extension (CRE) machine (model:5544) was used to determine the bursting strength. The five 5 * 5 in^2 specimen required for the Bursting strength (ASTM D 6797-15). The CRE machine contains a ball-burst attachment and the clamping mechanism. To start the test, the specimen was securely clamped between the plates. Once the machine started, the ball-burst travels at a constant rate of 12 inches/min. The machine stopped automatically once it burst the specimen and data were recorded by the system. The data were collected as computer printout in a form of table and graph.

Horizontal Wicking (AATCC 198-2013)[72]

Horizontal Wicking (AATCC 198-2013) test required 8 * 8 in^2 specimens. The specimens were then tightly placed in the embroidery hoop. It was confirmed that the specimen was neither under tension nor loose but relaxed. A burette was filled with 10 ml of distilled water. Then the burette was placed in the middle and 1 cm above the surface of the specimen. One ml of distilled water was slowly dispensed and let it sit for five minutes. After 5 minutes, the length and width of spread were measured in mm with a scale. Five readings were recorded, and the horizontal wicking rate was calculated with the following formula:

W= r*1/4*d1*d2/t

Where,

W: Wicking rate (mm^2/sec).
d1: Wicking distance lengthwise (mm)
d2: Wicking distance widthwise (mm)
t: Wicking time (sec)

Thermal Resistance (ASTM F1868-17)[73]

Before starting the thermal resistance test with hotplate, a bare test (with no fabric) had been completed prior each time the system was started. Fabric specimens were tested once the bare test was done. Bare plate thermal resistance (R_{cbp}) was measured in the same way thermal resistance (R_{ct}) was done. The only exception was the plate did not cover during the bare test.

Five 12*12 $inch^2$ specimens were prepared and conditioned for thermal resistance (ASTM F1868 – 17) test. To test total thermal resistance (R_{ct}), the specimen was placed on the test plate. It was confirmed that the test plate touched the same fabric side that human skin touches. Unexpected bubbles and wrinkles were eliminated to avoid air gap. The air gap can affect the actual insulation of fabric than worn on the human body. Once the specimen was set up, the height of the airflow sensor was adjusted. To run the test, appropriate test standard was selected in ThermaDac software, clicked “start test” and saved the file to an assigned folder.

This test generated one reading per minute, the result recorded for 30 min of the steady period once the fabric arrives steady-state condition. The total thermal resistance (R_{ct}) was calculated by the following formula.

$$R_{ct} = (T_s - T_a) A/H_c$$

Where:

R_{ct} = total resistance to dry heat transfer provided by fabric and air layer (K*m^2/W),
A = area of the plate test section (m^2),
T_s = surface temperature of the plate (^{o}C),
T_a = air temperature of the plate (^{o}C), and
H_c = power input (W).

Five specimens were tested, and the results were averaged to determine the total thermal resistance.

Evaporative Resistance (ASTM F1868-17)[73]

Before starting the bare test for evaporative resistance, water was supplied to the test plate and guard. Both test plate and guard sections were covered by a liquid barrier which prevented fabric specimen from getting wet. It was made sure that there were no air bubbles or wrinkles in between the test plate and liquid barrier. Bare plate evaporative resistance ($R_{ebp)}$ was measured in the same way evaporative resistance (R_{et}) was done. The only exception was the plate didn't cover during the bare test.

Five 12*12 inch^2 specimens were prepared and conditioned for evaporative resistance (ASTM F1868 – 17) test. To test total evaporative resistance (R_{et}), the specimen was placed on the test plate. It was confirmed that the test plate touched the same fabric side that human skin touches. Specimens were spread flat on test plate and made sure there was no ripple, swell or curl. Bubbles and wrinkles were eliminated to avoid air gap. The actual insulation of fabric can be affected by the air gap than worn on the human body. Once the specimen was set up, the height of the airflow sensor was adjusted. To run the test, appropriate test standard was selected in ThermaDac software, clicked "start test" and saved the file to an assigned folder.

This test generated one reading per minute, the result recorded for 30 min of the steady period once the fabric arrives steady-state condition. The total evaporative resistance (R_{et}) was calculated by the following formula.

$$R_{et} = (P_s - P_a) A/H_E$$

Where:

R_{et} = total resistance to evaporative heat transfer provided by fabric and air layer (kPa*m^2/W),
A = area of the plate test section (m^2),
P_s = water vapor pressure at the plate surface (kPa),
P_a = water vapor pressure in the air (kPa), and
H_E = power input (W).

Five specimens were tested, and the results were averaged to determine the total evaporative resistance. All tests and specimen details are shown in Table 3.

Table III.
Details of Test Methods

Sl. No.	Test	Method	Specimen size
1	Thickness	ASTM D1777	N/A
2	Weight	D3776/D3776 M-09a	5"X5"
3	Air permeability	ASTM D737-04	N/A
4	Thermal insulation	ASTM F1868-17	12"X12"
5	Evaporative resistance	ASTM F1868-17	12"X12"
6	Bursting strength	ASTM D6797-15	5"X5"
7	Horizontal wicking	AATCC 198-2013	8"X8"

Data Analysis

Inferential statistics used for the study was t-test analysis, correlation coefficient, and regression analysis. Hypotheses 1-4 used t-test and hypothesis 5 was tested by regression analysis and correlation coefficient. The Statistical Package for the Social Science (SPSS) and Microsoft Excel were used to perform statistical calculation. Mean (M), standard deviation (SD), probability (p) and t-test (T) were performed to test five hypotheses. The confidence level of 95% was used to accept or reject the hypotheses.

IV. RESULTS AND DISCUSSION

As described earlier, eight specimens divided in the groups were chosen for this study. The groups were based on fiber content, fabric weight, and fabric thickness. Eight groups have two different knit structures; jersey and interlock and their different fiber blend; cotton/spandex, polyester/rayon/spandex, and 100% polyester. Although the polyester/rayon/spandex blend ratio varies between groups. The purpose of this study was to compare the comfort properties of jersey and interlock knits of the stated blend for three different fabric weights and fabric thicknesses.

Results from the inferential testing are tabulated in table 4 that will be used to accept or reject the hypotheses.

Hypothesis 1

Jersey knit (96% cotton, 4% spandex) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

Results from t-test analysis (Table 4) revealed that two groups differed significantly for air permeability ($t8 = 16.83$, $p<0.00$), horizontal wicking ($t8 = 5.58$, $p<0.01$), and evaporative resistance ($t8 = 3.26$, $p<0.05$). However, differences were not significant for bursting strength and thermal insulation. Hypothesis 1 was accepted. Thinner/lightweight fabrics had higher air permeability, lower horizontal wicking, and lower evaporative resistance than thicker heavyweight fabrics. Comparison with literature review indicated that findings from this study were consistent for air permeability [22, 40]. Thinner fabrics demonstrated higher air permeability and wicking but lower water vapor permeability than ticker fabrics.

Hypothesis 2

Jersey knit (70% polyester, 26% rayon, and 4% spandex) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

T-test analysis from Table 4 reports that air permeability ($t8 = 33.85$, $p<0.00$), and evaporative resistance ($t8 = 14.86$, $p<0.00$) differed significantly for two groups. However, horizontal wicking, bursting strength, and thermal insulation were not significantly different. Hypotheses 2 was accepted. Thinner/lightweight fabrics had higher air permeability, and lower evaporative resistance than thicker/heavyweight fabrics. For jersey knits, thinner fabrics had higher air permeability but lower Evaporative Resistance than thicker fabrics. Comparison with literature revealed that findings from this study were inconsistent for thermal resistance. Since the thickness of fabric had no significant effect of warmth [46].

TABLE IV
Means, Standard Deviation, T-Test Analysis, and Probability of Evaluations

Group		Parameter	Air Permeability ($ft^3/ft^2/min$)	Bursting Strength (psi)	Horizontal Wicking (mm^2/sec)	Thermal Insulation ($K*m^2/W$)	Water Vapor Resistance ($kPa*m^2/W$)
Group 1	A	M	59.88	5453.03	0.89	0.03	4.34
		SD	4.72	1001.76	0.14	0.00	0.10
	B	M	134.90	5271.61	0.43	0.03	4.16
		SD	11.61	1139.59	0.18	0.00	0.09
	t		16.83	0.27	5.58	0.11	3.26
	p		0.00	0.40	0.01	0.92	0.03
Group 2	A	M	228.80	7405.97	0.00	0.03	4.10
		SD	12.59	471.55	0.00	0.00	0.09
	B	M	405.40	7830.81	0.00	0.03	3.34
		SD	11.76	323.85	0.00	0.00	0.17
	t		33.85	1.66	1.00	0.54	14.86
	p		0.00	0.07	0.37	0.62	0.00
Group 3	A	M	373.30	12189.66	3.22	0.02	1.77
		SD	19.28	2113.48	1.82	0.01	0.07
	B	M	270.10	21474.48	1.09	0.01	2.67
		SD	3.48	3472.67	0.24	0.00	0.12
	t		17.22	5.11	2.61	1.36	18.16
	p		0.00	0.00	0.06	0.25	0.00
Group 4	A	M	169.60	19069.55	0.06	0.03	4.37

		SD	6.33	19069.55	0.08	0.00	0.16
	B	M	158.50	17527.49	19.30	0.03	4.18
		SD	8.76	17527.49	1.72	0.00	0.22
	t		3.74	1.55	25.97	0.02	1.10
	p		0.01	0.08	0.00	0.99	0.34

Notes: M= Mean, SD= Standard Deviation, t= t-test, and p= Probability .

Hypothesis 3

Interlock knit (100% polyester) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

Results from t-test analysis revealed that air permeability (t8 = 17.22, p<0.00), bursting strength (t8 = 5.11, p<0.00), and evaporative resistance (t8 = 18.16, p<0.00) were significantly different. However, differences were not significant for horizontal wicking, and thermal insulation. Hypothesis 3 was accepted. Thinner/lightweight fabrics had higher air permeability, lower bursting strength, and lower evaporative resistance than thicker/heavyweight fabrics. Limited published study focused on the variables collectively of the reported study. Moreover, a very limited number of literatures found on interlock knits.

Hypothesis 4

Two interlock knits (polyester/rayon and spandex blend) with two significantly different thicknesses will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

T-test analysis from Table 4 revealed that two groups differed significantly for air permeability (t8 = 3.74, p<0.05), and horizontal wicking (t8 = 25.97, p<0.00). However, no significant differences found for bursting strength, thermal insulation, and evaporative resistance. Hypothesis 4 was accepted. Thinner/lightweight fabrics had higher horizontal wicking and lower air permeability than thicker/heavyweight fabrics. This study reveals inconsistency result in comparison to the previous study. Researchers investigated that fabrics with lower weight/m^2, higher thickness, and air permeability will be more heat comfortable [52]. But this study found no significant difference for thermal resistance between thicker/lighter fabric with higher air permeability and thinner/heavier fabric with lower air permeability.

TABLEV

Pearson Correlation Table by Thickness and Weight on Thermal Resistance, Evaporative Resistance, Air Permeability, Bursting Strength and Horizontal Wicking

		Air Permeability	Thermal Resistance	Water Vapor Resistance	Bursting Strength	Horizontal Wicking
Weight	Pearson Correlation	-0.54**	0.03	0.52**	0.28	0.4*
	Sig. (2-tailed)	0	0.86	0.00	0.08	0.01
	Sum of Squares and Cross-products	-102855.55	0.46	804.99	212.69	4295.43
	Covariance	-2637.32	0.01	20.64	5.45	110.14
	N	40	40	40	40	40
Thickness	Pearson Correlation	-0.86**	0.26	0.76**	0.55**	0.17
	Sig. (2-tailed)	0	0.11	0	0	0.3
	Sum of Squares and Cross-products	-343.01	0.01	2.44	0.86	3.74
	Covariance	-8.8	0	0.06	0.02	0.1
	N	40	40	40	40	40
** Correlation is significant at the 0.01 level (2-tailed).						
* Correlation is significant at the 0.05 level (2-tailed).						

Hypothesis 5

No relationship will exist between fabric weight and fabric thickness for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.

Table 5 reveals that the relationship of weight is significantly correlated with air permeability, Evaporative Resistance and horizontal wicking but not with thermal insulation and bursting strength. Thickness is not correlated to horizontal wicking and thermal insulation. However, it is strongly related to air permeability, water permeability, and bursting strength. From the table, it can be observed that thickness is correlated with bursting strength, but the weight is not. In contrast, weight is related significantly to horizontal wicking, but the thickness is not. Both weight and thickness are related air permeability and evaporative resistance. Thermal resistance is not correlated with either weight or thickness. Therefore, hypothesis 5 was rejected.

Weight and Thickness Vs Air Permeability

Table 6 presents that the result of regression ANOVA comparing air permeability based on weight and thickness of the knit sample and shows the significant result (F (2,37) = 66.69, $p<0.05$; p =0.00). It indicates that the weight and thickness reliably predict the air permeability. Again, Pearson correlation table (Table 5) indicates that air permeability has a strong negative correlation with both weight (r = -0.54) and thickness (r = -0.86).

Table VI
Regression ANOVA Table by Thickness and Weight on Air Permeability.

ANOVA[a]					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Regression	391384.71	2	195692.35	66.69	0.00[b]
Residual	108569.18	37	2934.30		
Total	499953.88	39			
a. Dependent Variable: Air Permeability					
b. Predictors: (Constant), Thickness, Weight					

Weight and Thickness Vs Thermal Resistance

Comparison of thermal resistance (R_{ct}) with weight and thickness of knit fabric revealed the non-significant result (F (2, 37) = 3.13, p = 0.06) according to the result of ANOVA in table 7. It means the weight and thickness are unable to predict the thermal resistance. Pearson correlation table (Table 5) also indicates weak positive correlation of weight (r = 0.03) and thickness (r = 0.26) with thermal resistance.

TABLE VII
Regression ANOVA Table by Thickness and Weight on Thermal Resistance.

ANOVA[a]					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Regression	0.00	2	0.00	3.13	0.06[b]
Residual	0.00	37	0.00		
Total	0.00	39			
a. Dependent Variable: Thermal Resistance					
b. Predictors: (Constant), Thickness, Weight					

Weight and Thickness vs Evaporative Resistance

The result from table 8 shows that weight and thickness are strong predictors of evaporative resistance. It exhibits that the result of regression ANOVA is significant (F (2, 37) = 27.04, $p < 0.05$; p = 0.00) for evaporative resistance with weight and thickness. Again, Pearson correlation table (Table 5) exhibits that evaporative resistance is in strong positive relation with both weight (r = 0.52) and thickness (r = 0.76) at .01 level.

TABLE VIII
Regression ANOVA Table by Thickness and Weight on Evaporative Resistance.

ANOVA[a]					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Regression	19.1	2	9.55	27.04	0.00[b]
Residual	13.07	37	0.35		
Total	32.16	39			
a. Dependent Variable: Evaporative Resistance					
b. Predictors: (Constant), Thickness, Weight					

Weight and Thickness Vs Bursting strength

As the regression ANOVA table (Table 9) shows the significant result ($F(2, 37) = 9.97$, $p < 0.05$; $p = 0.00$), it can be agreed that weight and thickness can reliably predict bursting strength. Pearson correlation table (Table 5) shows that bursting strength has a weak positive correlation with weight ($r = 0.28$) but a strong positive correlation with thickness ($r = 0.55$).

TABLE IX
Regression ANOVA Table by the Thickness and Weight on Bursting Strength.

ANOVA[a]					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Regression	2.74	2	1.37	9.97	0.00[b]
Residual	5.08	37	0.14		
Total	7.82	39			
a. Dependent Variable: Bursting Strength					
b. Predictors: (Constant), Thickness, Weight					

Weight and Thickness Vs horizontal wicking

The result of regression ANOVA from Table 10 presenting horizontal wicking based on weight and thickness. It shows the significant result ($F(2, 37) = 5.00$, $p < 0.05$; $p = 0.01$) which indicates that the weight and thickness are unable to anticipate the horizontal wicking reliably. Additionally, Pearson correlation table (Table 5) also point out that air permeability has the moderate positive correlation with weight ($r = 0.4$) and weak positive correlation with thickness ($r = 0.17$).

TABLE X
Regression ANOVA table by thickness and weight on Horizontal Wicking.

ANOVA					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Regression	330.63	2	165.31	5.00	0.01[b]
Residual	1228.93	37	33.21		
Total	1559.56	39			
a. Dependent Variable: Horizontal Wicking					
b. Predictors: (Constant), Thickness, Weight					

The reported study found the consistent result with previous studies as researchers found air permeability decreases with thickness increases[42, 44].The reported study found a strong negative correlation between thickness and air permeability (Table-5).

TABLE XI
Summarized Results of Hypothesis Testing.

No. of Hypothesis	Hypothesis	Result
1	Jersey knit (96% cotton, 4% spandex) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.	Accepted
2	Jersey knit (70% polyester, 26% rayon, and 4% spandex) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.	Accepted
3	Interlock knit (100% polyester) with two significantly different thicknesses and weights will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.	Accepted
4	Two interlock knits (polyester/rayon and spandex blend) with two significantly different thicknesses will differ for air permeability, bursting strength, horizontal wicking, thermal insulation, and evaporative resistance.	Accepted
5	No relationship will exist between fabric weight and fabric thickness for air permeability, bursting strength, horizontal wicking, thermal insulation, and Evaporative Resistance	Rejected

V. SUMMARY AND CONCLUSION

This research mainly focused on the comfort properties of jersey and interlock knits in polyester, cotton/spandex, and polyester/rayon/spandex with different variables such as air permeability, bursting strength, thermal resistance, evaporative resistance and horizontal wicking for different weights and thicknesses. To design the study and perform the tests, AATCC and ASTM methods and standards were used. Results showed both consistencies and inconsistencies with the previous research in the field. Key findings of the study follow.

Jersey knit (96% cotton, 4% spandex) with two different thickness and weight were significantly different for air permeability, evaporative resistance, and horizontal wicking but they did not differ for bursting strength and thermal insulation. Thinner and lighter jersey knit showed higher air permeability but lower horizontal wicking and evaporative resistance than thicker and heavier fabric. Thinner and lighter jersey knit (70% polyester, 26% rayon, and 4% spandex) showed higher air permeability but lower evaporative resistance than thicker and heavier fabric. Whereas, specimens were not significantly different for thermal resistance, bursting strength and horizontal wicking. Differences were found for interlock knits (100% polyester) of two different weights and thickness for air permeability, evaporative resistance and bursting strength but the results for thermal resistance and horizontal wicking were not significant. Thicker and heavier interlock exhibited higher bursting strength and evaporative resistance but lower air permeability than thinner and lighter fabrics. On the other hand, two interlock knits of polyester/rayon/spandex blend with different weight and thickness showed different results for air permeability and horizontal wicking but not for bursting strength, thermal insulation, and evaporative resistance. In this case, thinner and heavier fabric showed lower air permeability and higher horizontal wicking than thicker and lighter fabric.

The reported study also revealed that air permeability had a negative correlation with both weight and thickness, whereas evaporative resistance had a positive correlation with both predictors. Bursting strength has a positive correlation only with thickness but not with weight and vice-versa for horizontal wicking. The reported study revealed that thermal resistance has no correlation with either of the predictors.

To conclude, weight and thickness reliably predict air permeability and the reported study revealed thinner and lighter fabrics possess higher air permeability than thicker and heavier fabrics. Weight and thickness could not predict thermal resistance and horizontal wicking but were strong predictors for evaporative resistance and bursting strength. Thicker and heavier fabric showed higher bursting strength and evaporative resistance.

VI. LIMITATION

The physical attributes of the specimens were hard to control since all specimens were sourced from the local market. Treatment on fabric specimens did not evaluate, which can influence the result of the study. Cutting swatches, specimen preparation, and data record (for weight, thickness, and horizontal wicking) were done manually, therefore human error can present. The literature review revealed that physical and mechanical terms were used interchangeably. Therefore, it was hard to keep them clearly defined. Similar confusion was created with the use of water vapor resistance and evaporative resistance.

VII. FUTURE IMPLICATION

The strengths of this research include extending previous work and contributing to the field by comparing comfort properties with weight and thickness. The outcome from the reported study suggests some future implications. Different Fabric constructions knitted (pique, rib) and woven (plain, twill, satin), and garments for various end uses, and different fiber contents similar or additional structural and performance attributes could be studied for comprehensive understanding. Study with controlled specimens can produce more accurate results. Specimens with more variety in weight and thickness can expand the understanding further. Same variables can also be tested with different testing (heat camera) method of heat comfort. The results from the reported study can be used to develop prediction models and enhance the efficiency of the product development process. Due to the confusing use of the terms it will be helpful if researchers define their technical terms clearly.

The study was restricted to laboratory testing. Wear or service testing can provide better consumer perspective than possible by lab testing alone. Additionally, seeking consumer input through the survey or focus groups to identify their specific needs prior to lab testing will enrich the reservoir of knowledge base further. The study reinforced that AATCC and ASTM test methods could be continually used in textile testing for effective quality control [20].

VIII. ACKNOWLEDGMENT

The authors extend their gratitude to Md RashedulIslam for his help with the SSRG formatting.

REFERENCES

[1] Guanxiong, Q., Yuan, Z., Zhongwei, W., Jianli, L., Min, L., &Jie, Z. (1991). Comfort in knitted fabrics. International Man-Made Fibres Congress Proceed-ing, 112.

[2] Horn, M. J., &Gurel, L. M. (1981). The Second Skin: An Inter-disciplinary Study of Clothing.

[3] Troynikov, O., &Wardiningsih. (2011). Moisture management properties of wool/polyester and wool/bamboo knitted fabrics for the sportswear base layer. Textile Research Journal, 81(6), 621-631

[4] Prakash, C., & Ramakrishnan, G. (2013). Effect of blend pro-portion on thermal behaviour of bamboo knitted fabrics. The Journal of The Textile Institute, 114(9), 907-913.

[5] Spencer, D. J. (1983). Knitting Technology. Cam-bridge: Woodhead Publishing Limited

[6] Prakash, C., Govindan, R., & Koushik, C. V. (2013). A study of the thermal properties of bamboo knitted fabrics. Journal of Thermal Analysis and Calorime-try, 111, 101-105

[7] Oğlakcioğlu, N., &Marmarali, A. (2007). Thermal Comfort Properties of Some Knitted Structures. Fi-bers & Textiles in Eastern Europe, 15(5-6), 67-65

[8] Bakkevig, M. K., and Nielsen, R., The Impact of Activity Level on Sweat Accumulation and Thermal Comfort Using Different Underwear, Ergonomics, 38(5), 926–939 (1995).

[9] Chowdhary, U. (2018). Stretch and recovery of jersey and inter-lock knits. International Journal of Textile Science and engi-neering, 2018 -1, 1-9. DOI: 1029011/IJTSE – 112/100012.

[10] Fourt, L. E., & Hollies, N. R. (1970). Clothing; com-fort and function. New York: Marcel Decker Inc.

[11] Cabanac, M. (1971). Physiological Role of Pleasure. Science, 173(4002), 1103-1107.

[12] Slater, K. (1985). Human comfort. Springfield, Illi-nois, USA: Charles C. Thomas Publisher

[13] Smith, J. E. (1986). The comfort of clothing. Textiles, 23-27.

[14] Milenkovic, L., Skundric, P., Sokolovic, R., & Nikol-ic, T. (1999). Comfort properties of defence protec-tive clothing. The Scientific Journal Facta Universita-tis, 101-106

[15] Hensel, H. (1982, February 26). Thermoreception and tempera-ture regulation. Science, 215(4536).

[16] Nakamura, M., Yoda, T., Crawshaw, L. I., Kasuga, M., Uchida, Y., Tokizawa, K., . . . Kanosue, K. (2013, January). Relative importance of different surface regions for thermal comfort in humans. European Journal of Applied Physiology, 113(1), 63-76.

[17] Ravandi, S. A., &Valizadeh, M. (2011). Properties of fibers and fabrics that contribute to human comfort-2. In Improving com-fort in clothing (pp. 61-78). Elsevier Ltd.

[18] Dias, T., &Delkumburewatte, G. B. (2007). The in-fluence of moisture content on the thermal conduc-tivity of a knitted struc-ture. Measurement Science and Technology, 1304-1314.

[19] Choudhury, A. K., Majumdar, P. K., & Datta, C. (2011). Factors affecting comfort: human physiology and the role of clothing. Elsevier Ltd.

[20] Chowdhary, U. (2009). Textile analysis, quality con-trol and innovative uses. Deer Park, NY, USA.

[21] Kaplan, S., &Ayse, O. (2008). The Meaning and Importance of Clothing Comfort: A Case Study for Turkey. Journal of Sensory Studies, 23(5), 688-706.

[22] Chen, T.-H., Chen, W.-P., & Wang, M.-J. J. (2014, June). The Effect of Air Permeability and Water Vapor Permeability of Cleanroom Clothing on Physi-ological Responses and Wear Comfort. Journal of Occupational and Environmental Hygiene, 366–376.

[23] Fourt, L., &Harrist, M. (1947, May). Diffusion of Water Vapor Through Textiles. Textile Research Journal, 256-263.

[24] Dai, X.-Q., Imamura, R., & Liu, G.-L. (2008). Effect of mois-ture transport on microclimate under T-shirts. Eur J Appl Phy-siol, 337-340.

[25] Sun, Z., & Pan, N. (2014). Thermal conduction and moisture diffusion in fibrous materials. In N. Pan, & P. Gibson, Thermal and Moisture Transport in Fibr-ous Materials (p. 225). Wood-head Publishing Series in Textiles.

[26] Huang, J., & Qian, X. (2008). Comparison of Test Methods for Measuring Water Vapor. Textile Re-search Journal, 78(4), 342-352.

[27] Ertugrul, S., &Ucar, N. (2000). Predicting bursting strength of cotton plain knitted fabric using intelligent techniques. Textile Research Journal, 70, 845-851.

[28] Uyanik, S., Degirmenci, Z., Topalbekiroglu, M., &Geyik, F. (2016). Examining the Relation Between the Number and Loca-tion of Tuck Stitches and Burst-ing Strength in Circular Knitted Fabrics. Fibres& Textiles in Eastern Europe, 1(115), 114-119.

[29] Yesmin, S., Hasan, M., Miah, M. S., Momotaz, F., Idrish, M. A., & Hasan, M. R. (2014). Effect of stitch length and fabric constructions on dimensional and mechanical properties of knit-ted fabrics. World Ap-plied Sciences Journal, 32(9), 1991-1995.

[30] Collier, B. J., & Epps, H. H. (1999). Textile analysis and test-ing. Upper Saddle River, New Jersey, USA: Prentice Hall.

[31] Kadolph, S. J. (1998). Quality assurance for textiles and appa-rel. Fairchild, New York, USA.

[32] Chowdhary, U., Adnan, M. M., & Cheng, C.-I. (2018). Bursting Strength and Extension for Jersey, Interlock and Pique Knits. Trends in Textile Engineer-ing & Fashion Technology, 1(2), 1-9.

[33] Kan, C. W. (2015). Relationship between bursting strength and ultraviolet protection property of 100% cotton-knitted fabrics. The Journal of The Textile Institute, 106(9), 978-985.

[34] Fangueiro, R., Filgueiras, A., &Soutinho, F. (2010). Wicking Behavior and Drying Capability of Func-tional Knitted Fabrics. Textile Research Journal, 80(18), 1522-1530.

[35] Laughlin, R. D., & Davies, J. E. (1961). Some As-pects of Ca-pillary Absorption in Fibrous Textile Wicking. Textile Research Journal, 31(10), 904-910.

[36] Hollies, N. R., Kaessinger, M. M., Watson, B. S., &Bogaty, H. (1957). Water Transport Mechanisms in Textile Material. Tex-tile Research Journa, 27(1), 8-13.

[37] Zhang, Y., Wang, H., Zhang, C., & Chen, Y. (2007). Modeling of Capillary Flow in Shaped Polymer Fiber Bundles. Journal of Materials Science, 42(19), 8035-8039.

[38] Ramachandran, T., &Kesavaraja, N. (1997). A Study on In-fluencing Factors for Wetting and Wicking Behavior. Fabrics. J. Text. Inst., 80(15), 252.

[39] Morent, R., Geyter, N. D., Leys, C., Vansteenkiste, E., Bock, J. D., & Philips, a. W. (2006). Measuring the wicking behavior of textiles by the combination of a horizontal wicking experiment and image processing. Review of Scientific Instruments

[40] Bartels, V. T. (2005). Physiological comfort of sportswear. In R. Shishoo, Textile in sport (pp. 177-202). Cambridge: Woodland Publishing Limited.

[41] Bartels, V. T. (2005). Physiological comfort of sportswear. In R. Shishoo, Textile in sport (pp. 177-202). Cambridge: Woodland Publishing Limited.

[42] Chowdhary, U., (2017). Comparing three brands of cotton t-shirts. AATCC Journal of Research, Re-search, 4(3), 22-33.

[43] Ulson de Souza, A. A., Cherem, L. F., & Souza, S. M. (2009). Prediction of Dimensional Changes in Circu-lar Knitted Cotton. Textile Research Journal Fabrics, 236-252.

[44] Marsha, S.S. (2018). Comparison of Selected Struc-tural and Performance Attributes of Cotton and Cot-ton/Polyester Blend T-Shirts (unpublished master's thesis). Central Michigan Uni-versity, Mount Pleasant, Michigan.

[45] Gun, A. D. (2011). Dimensional, Physical and Ther-mal Proper-ties of Plain Knitted Fabrics Made from 50/50 Blend of Modal Viscose Fiber in Microfiber Form with Cotton Fiber. Fibers and Polymers, 12(8), 1083-1090.

[46] Bivainyte, A., Mikucioniene, D., &Kerpauskas, P. (2012). In-vestigation on Thermal Properties of Double-Layered Weft Knitted Fabrics. Materials Science-Medziagotyra, 18(2), 167-171.

[47] Ogulata, R. T., &Mavruz, S. (2010). Investigation of Porosity and Air Permeability Values of Plain Knitted Fabrics. FIBRES & TEXTILES in Eastern Europe, 18(5 (82)), 71-75.

[48] Puszkarz, A. K., &Krucińska, I. (2018). Modeling of Air Per-meability of Knitted Fabric Using the Compu-tational Fluid Dynamics. AUTEX Research Journal, 1-13.

[49] Oinuma, R. (1990). Effect of stitch length on some properties of cotton 1×1 rib knitted fabrics. Journal of the Textile Machinery Society of Japan, 36, 91-95.

[50] Kumar, V., Sampath, V. R., & Prakash, C. (2016). Investigation of stretch on air permeability of knitted fabrics part II: effect of fabric structure. The Journal of The Textile Institute, 107(10), 1213-1222.

[51] Miraftab, M. (2012). Comparison of air permeability and mois-ture management properties of jersey, inter-lock and pique knit-ted fabrics. The Journal of The Textile Institute, 2, 1-5.

[52] Chen, Y. S., Li, J., & Zhang, W. Y. (2008). Analysis and predic-tion of the dynamic heat-moisture comfort property of fabric. Fibres and Textiles in Eastern Europe, 16, 51-55.

[53] Bhattacharya, S. S., &Ajmeri, J. R. (2013). Factors affecting air permeability of viscose & excel single jersey fabric. Interna-tional Journal of Engineering Research and Development, 5, 48-54.

[54] Prahsarn, C., Barker, R. L., & Gupta, B. S. (2005). Moisture Vapor Transport Behavior of Polyester Knit Fabrics. Textile Research Journal, 75(4), 346-351.

[55] Lee, H., & An, S. K. (2018). A Comparative Analysis of Ther-mal Comfort Properties for Nurse Scrub Jack-ets. AATCC Journal of Research, 5(2), 35-39. doi:10.14504/ajr.5.2.4

[56] Majumdar, A., Mukhopadhyay, S., & Yadav, R. (2010). Ther-mal properties of knitted fabrics made from cotton and regene-rated bamboo cellulosic fibres. International Journal of Thermal Sciences, 49(10), 2042-2048.

[57] Karthikeyan, G., Nalankilli, G., Shanmugasundaram, O. L., & Prakash, C. (2016). Thermal comfort proper-ties of bamboo tencel knitted fabrics. International Journal of Clothing Science and Technology, 28(4), 420-428.
[58] Ramakrishnan, G., Umapathy, P., & Prakash, C. (2015). Comfort properties of bamboo/cotton blended knitted fabrics produced from rotor spun yarns. The Journal of The Textile Institute, 106(12), 1371-1376.
[59] Oglakcioglu, N., Celik, P., Ute, T. B., Marmarali, A., &Kadoglu, H. (2009). Thermal Comfort Properties of Angora Rabbit/Cotton Fiber Blended Knitted Fabrics. Textile Research Journal, 79(10), 888-894.
[60] Demiryurek, O., &Uysalturk, D. (2013). Thermal comfort properties of Viloft/cotton and Vi-loft/polyester blended knitted fabrics. Textile Re-search Journal, 83(16), 1740-1753.
[61] Özdil, N., Marmaralı, A., & Kretzschmar, S. D. (2007). Effect of yarn properties on thermal comfort of knitted fabrics. International Journal of Thermal Sciences, 46, 1318-1322.
[62] Crow, R., & Dewar, M. M. (1993, January). The Vertical and Horizontal Wicking of Water in Fabrics. Defence Research Establishment Ottawa, 1-12.
[63] Hepburn, C.D. (1998). The Wicking of Water Through Multi-Layer Fabric Assemblies (published doctoral thesis). The University of Leeds, Leeds.
[64] Mahbub, R. F., Wang, L., Arnold, L., Kaneslingam, S., &Padhye, R. (2014). Thermal comfort properties of Kevlar and Kevlar/wool fabrics. Textile Research Journal, 84(19), 2094-2102.
[65] Ibrahim, N. A., Khalifa, T. F., El-Hossamy, M. B., & Tawfik, T. M. (2011). Factors Affecting the Func-tional- and Comfort-related Properties of Reactive Dyed Cotton Knits. Journal of Industrial Textiles, 41(1), 41-56. doi: 10.1177/1528083710390966
[66] Chowdhary, U. (2007). Textile Analysis: Laboratory Manual. Deer Park, New York, USA: LINUS.
[67] Emirhanova, N., &Kavusturan, Y. (2008). Effect of knit structure on the dimensional and physical proper-ties of winter outerwear knitted fabrics. Fibres& Textiles in Eastern Europe, 6(2), 69-74.
[68] ASTM D1777-96, ASTM International, West Con-shohocken, PA, 2015, www.astm.org.
[69] ASTM D3776 / D3776M-09a, ASTM Interna-tional, West Conshohocken, PA, 2017, www.astm.org.
[70] ASTM D737-04, ASTM International, West Con-shohocken, PA, 2018, www.astm.org.
[71] ASTM D6797-15, ASTM International, West Consho-hocken, PA, 2015, www.astm.org.
[72] AATCC 198-2013, American Association of Textile Chemists and Colorists, Durham, NC, 2013, www.aatcc.org.
[73] ASTM F1868-17, ASTM International, West Consho-hocken, PA, 2017, www.astm.org.