ABSTRACT

CLARK, MATTHEW L. Integrated Measures of Comfort for Athletic Performance Apparel Using A Sweating Manikin and Other Advanced Systems. (Under the direction of Dr. Roger Barker and Dr. Nancy Cassill.)

Comfort in athletic apparel has gotten increased attention from the apparel market. The tagline of ‘performance’ has taken on a more ubiquitous status within the athletic apparel market as an alternative term to comfort. Comfort must be defined properly for this product and measured in order to properly assess the products in this category. This research seeks to determine what is considered comfortable in athletic performance apparel, and to utilize the most appropriate and most advanced methods available to measure comfort in a way which includes human input alongside test results.

The first step toward testing the comfort in this category was to determine what aspects of comfort to test for as well as which test methods to use in the testing phase. This began with a consumer market survey which asked the opinion on comfort issues in athletic t-shirts of over 38,000 consumers in and outside of the United States. Four comfort aspects were identified for measurement; in increasing order of consumer-identified importance they were: Moisture Management, Cooling, and (Soft Hand and Breathable). Fit was identified as the most important aspect by a wide margin; however the measurement of fit is not included in the scope of this research.

The primary measurement emphasis for this research on the garment level was the NCSU Sweating Thermal Manikin (Coppelius). Additional test methods used on the fabric level were the Kawabata Evaluation System for the measurement of fabric hand (KES), the

Kawabata thermal sweating hot plate (Thermolabo), and the Gravimetric Absorbency Testing System (GATS) with a coupled fabric drying test. These test measures were used to compare fabric level results to garment level results as well as to provide information as to how the fabric performed in the identified comfort aspect without regard to garment construction.

The garments used in this research were all performance athletic apparel short sleeved t-shirts for the purpose of running, with the exception of a 100% cotton t-shirt. This exception was included for comparison from cotton to polyester shirts in this category. The shirts were from various sources; specialty retailers, mass retailers, with varying price ranges. The final sample set included seven shirts from seven different manufacturers, made in seven different countries.

The results of this study provided information on target consumer groups within the consumer survey based on purchase history data. The comfort preferences for these groups were tracked and used in order to identify which samples from the sample set performed to the highest level in the testing phase in light of the comfort preferences of these groups. Moisture management was identified as a comfort aspect which was extremely important in the review of literature to the overall comfort complex, however was quite undervalued by the consumers, which points to a possible need for an increase in marketing emphasis on this point. The manikin results had few correlations stronger than .7500, which is due to garment construction, namely the presence of air in the manikin test which is not a factor in fabric testing.

The primary recommendation for future research is to include a human wear trial to confirm both the preferences of the consumers from the survey as well as the results from the testing phase.

Integrated Measures of Comfort for Athletic Performance Apparel Using a Sweating Manikin and Other Advanced Systems

by
Matthew L. Clark

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APPROVED BY:

Dr. Barker, Chair of Advisory Committee	Dr. Nancy Cassill, Co-Chair of Advisory Committee
Dr. Bhupender Gupta, Committee Member	Dr. Henry Boyter, Committee Member

BIOGRAPHY

The author, Matthew L. Clark, was born in Pittsboro, North Carolina on December 16, 1982. His parents are Danny and Linda Clark and he has a younger brother named Aaron. Matt grew up in Pittsboro, North Carolina and attended Northwood High School where he graduated in the spring of 2001. He enjoys playing most sports, particularly basketball, as well as attempts at playing the guitar and mandolin.

In the fall of 2001 he moved to Raleigh, North Carolina to attend North Carolina State University where he graduated with dual degrees in Textile Technology and Textile Apparel Management in the spring of 2006. Collegiate extra curricular activities included becoming Vice-President and later President of Delta Kappa Phi Professional Textile fraternity, as well as active membership in Sigma Tau Sigma Textile Honor Fraternity and Kappa Tau Beta Textile Leadership fraternity where he was the representative to the Tompkins Textile Student Council. Matt also served for two years as the student co-chair for the weekly meeting committee for Campus Crusade for Christ at NC State, and enjoys attending NCSU athletic events.

In the fall of 2006, Matt began pursuit of a master of science in Textile Technology and Management within the Institute of Textile Technology, located at North Carolina State University. Matt is now working on the transition from school to full time employment with Glen Raven Inc. and looks forward to an interesting and productive career in the textile industry.

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Finally I am particularly thankful to my family members who have been there for me through every step and who I can trust to continue to do so; for their unconditional love and support as well as their patience with my absence throughout this time. I am also particularly grateful for the love and support from my companion and best friend Kate Strader; for her prayers, encouragement, motivation, and for giving me at least an hour every day where the stresses of the process could be forgotten.

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CHAPTER I

INTRODUCTION

Comfort is the key factor in many of the purchases people make in the area of apparel, especially in athletic apparel. In athletic apparel comfort and performance are synonymous in many ways. A big challenge is discovering exactly what it is that goes into the equation of comfort, in the mind and body of the active athlete. The measurement of comfort is done in two areas. One area is through market and consumer research whereby the consumer reveals what is important in the comfort of athletic performance garments. The other area is through objective comfort testing with several types of quantitative comfort tests available; also the human wear trial is an extremely important tool to augment the measurement of comfort.

Comfort may not have changed in terms of importance over time in the athletic field, however, the emphasis that apparel companies have placed on comfort has improved greatly under the tagline of ‘performance’ in a time where the average person can consider themselves an athlete. Whether a professional athlete, a member of a local recreational sports team, or simply one who engages in running or weight training, active consumers are trying to find apparel that will either improve their performance in athletic endeavors or apparel that will simply make their athletic endeavors a more pleasant experience. Apparel companies have taken notice of the growing performance trend within the athletic apparel market and they are all competing for the same growing market by offering an ever expanding product field of performance athletic apparel.

A trip to the local sporting goods store today when compared to a trip to the same store merely 10 years ago will give evidence to this market growth. Cotton has long been the standard bearer for athletic activity but since the performance wave has gone through the athletic apparel market, cotton has been made ‘the enemy’ as one marketing tagline for performance apparel maker Under Armour® suggests. Cotton has been steadily slipping out of the performance athletic apparel market.

This shift in focus within the athletic community has also caused a shift in the mentality of how to market athletic apparel. It used to be that the large athletic apparel companies were there by virtue of their success in selling athletic shoes. Companies such as Nike®, Reebok®, and Adidas® were strong in the athletic apparel market because they had long been the leaders in the athletic footwear market. These companies were generating athletic apparel sales by virtue of the strong brands they had made for themselves in other areas. This all changed as the focus shifted to performance not only in shoes but also in clothing. Now there is an opening for the consumer to consider not only brand but performance; this opening creates the ability for a lesser known company to thrive.

The most well known and probably the greatest benefactor of this shift has been Under Armour®. They began by selling performance apparel, and were so successful that they have created a strong brand presence in a very short amount of time. So while companies used to creating clothing sales based on their brand strength, now there is a company that has created tremendous brand strength from their strong performance athletic apparel sales. Under Armour® now has begun a successful shoe campaign to compliment their apparel. While Under Armour® has come to the point of leading the market, Nike® has held its own and is the second largest performance apparel athletic wear company with its popular Dri-Fit® line (Gale Research Inc, 2006). Adidas® and New Balance® also hold a strong third and fourth place, respectively, in a market which has many more companies (Gale Research Inc, 2006).

With this greater focus on performance has also come an emphasis on creating the optimal athletic garment. The ingredients that go into athletic performance and comfort must be identified and quantified. Once this has been achieved it is possible to determine the best way to meet these comfort needs. This began by identifying the comfort claims made in the marketing material for several performance athletic apparel companies. A common theme in the performance claims were built around moisture management with claims of garments keeping the athlete dry and wicking sweat away from their skin, and reducing cling. Other claims worked around the theme of having good breathability and ventilation. Still other claims worked around the soft feel whether they claims was that flat seams prevented chaffing or that the fabric had a cotton-like feel.

The challenge with these claims was to take them as the definition of performance by the apparel companies and to determine whether these claims agree with the ideas consumers have about performance. It is important to assess comfort on a technical level by quantitatively testing the comfort aspects in lab testing, it is also important to determine whether comfort claims in the market are valid to describe comfort. Another determination which must be made is whether the market actually understands and demands the attributes of comfort which the marketing efforts on behalf of the apparel companies suggest. These performance claims were taken to the consumers in the form of a consumer survey in order to determine their feelings on performance.

Purpose of this Study

The purpose of this study is to utilize the technological advances of the Coppelius Advanced Sweating Manikin at NCSU in cooperation with more traditional objective comfort measurement methods to evaluate the comfort of performance athletic apparel and to utilize market research to determine the most important comfort descriptors to the athletic apparel consumer, as well as determine the significance of the overall athletic apparel market. Figure 1.1 shows a representation of how the objectives of this project work together toward a common goal. The objectives of this study are to:

1. Collect and review information on the elements of comfort, and their role as a part of the larger comfort perception.
2. Collect and review information on measures commonly used in the quantitative evaluation of comfort.
3. Perform a market survey to collect information on the qualitative comfort descriptors most important to athletic apparel consumers, and to quantify the significance of the athletic apparel market.
    a. Identify the core consumer groups most likely to use the product via purchase history data.
    b. Look at purchase decision factor for apparel purchases.
    c. Evaluate the importance placed on comfort parameters of an athletic performance t-shirt.
        i. Analyze decision parameter and comfort parameter responses by comparing for each one:
            1. US Market v/s International Market

2. Age Differences
3. Gender Differences
4. Income Differences *(data available in US group only)*

4. Select candidate garments for use in fabric level comfort testing as well as garment level comfort testing.
5. Select quantitative comfort measures to test in order to match the most important consumer identified qualitative comfort descriptors.
6. Identify test methods most ideally suited to quantitatively measure the desired comfort parameters.
7. Perform fabric level comfort testing on candidate materials, using selected fabric level testing methods, in order to determine fabric level performance of the material.
8. Perform garment level comfort testing, utilizing the Coppelius Advanced Sweating Thermal Manikin, to determine the garment level performance characteristics of the candidate materials.
9. Evaluate the performance of the candidate fabrics and their respective garments, as a function of the results of the fabric and garment level tests.
10. Provide performance assessments of the candidate garments as defined by comfort testing results when the market survey results are taken into consideration.

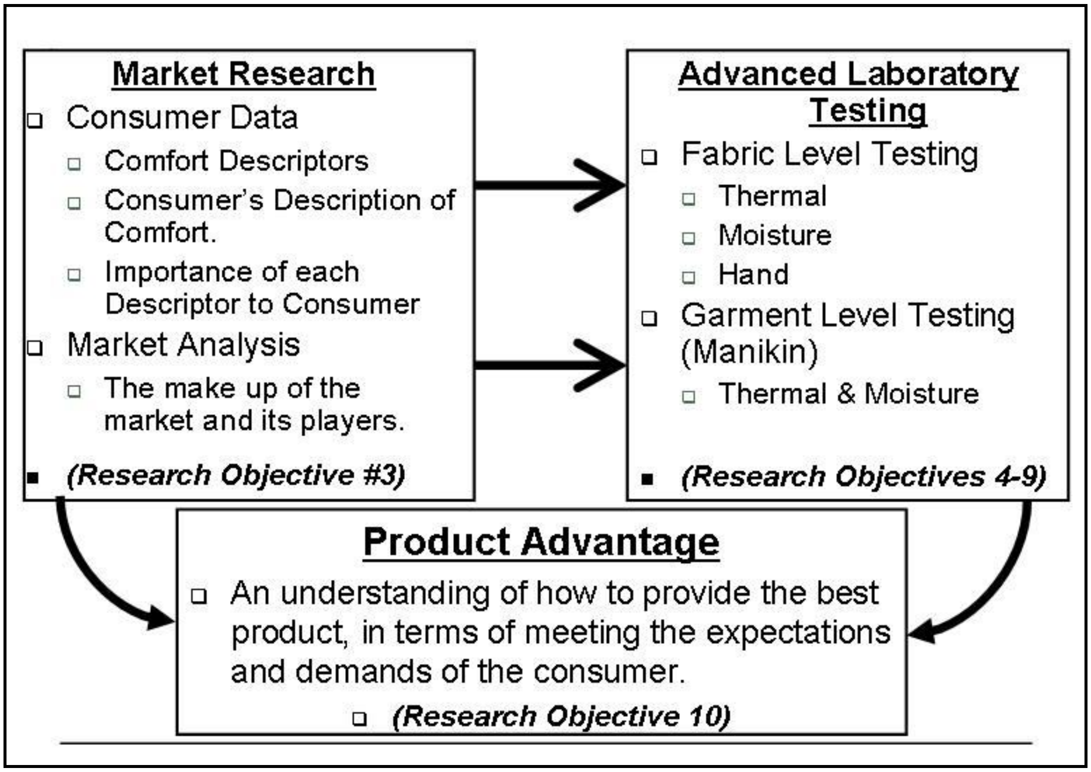

Figure 1.1 – Purpose of the Comfort Study

Significance of this Study

This study is significant for three reasons:

1. The result of this study should provide a greater understanding of the values consumers place on comfort, as well as an understanding of how the current offerings in the market perform in these areas.
2. To provide the ability to test the comfort claims made by the market and to determine how well they target the most important comfort aspects as identified by the consumer survey.
3. To provide the ability to cross reference the market research half with the fabric testing side of the project, allowing for an understanding of whether apparel are

meeting the needs of the consumers in the marketplace, as well as an understanding of what they must do to in order to better market to consumers and meet consumer needs.

Limitations of this Study

There are a few significant limitations on this study, most of which are related to time constraints. While all related to time constraints, the limitations fall into three categories: Technical limitations, Sample Set limitations, and Market Limitations. These limitations were procedural in nature and did not have any negative impact upon the original intent of the scope of this research.

Technical (Research Scope) Limitations

1. The most crucial limitation is the inability to include a human wear trial in this study. Ideally the consumer information from the consumer survey would be coupled with the test results, then confirmed or refuted with a round of human wear trials on live subjects, who could provide real time input on the comfort qualities of the garments in this study.
2. The nature of this project has one foot in the technical testing side of comfort study and the other foot in the market research side of the study of comfort. This study set-up is a significant benefit in that the issue is looked at in academic and practical terms together. The downside is that the nature of this project is to cover two very different, but related focuses. This does not allow all questions on each side can be carried out to an end within the scope of this project.

Sample Set Limitations

1. The sample set in this study only contains seven garments, one of which is not for the purpose of running, and is not considered 'performance apparel'. The remaining six shirts represent a relatively small sample set from the performance apparel population and do not provide any definitive statement about all performance athletic apparel.
2. All shirts used in this study were men's shirts, meaning that this study does not necessarily speak to the female market in terms of ideal performance, even though more than half of the consumer survey was responded to by female consumers.
3. The t-shirt is only one of many different garments that figure into the total comfort of an athlete; other studies would need to be done in order to address other garment types.
4. The samples selected for testing were selected in order to be a representative sample of the garments in the marketplace, rather than selected to all have the same physical characteristics or controlled differences in physical characteristics. This diversity of traits in the samples is meant to compare the performance of garments based on varying price-points and retail channels, rather than on more technical information such as fiber cross-section.
    a. The benefit to this type of sample selection is that the samples tested in this research are representatives of the actual market, and are real garments that are out on the current athletic performance apparel market, rather than garments that have been engineered here at the college of textile to compare individual chemical, yarn, fabric, and garment traits.

b. The limitation of this type of sample selection is that garment characteristics are not individually controlled for complete technical comparison and cannot be individually analyzed to determine the effect of each garment, fabric and yarn characteristic.

Market Limitations

1. Due to the fact that the Market Survey was conducted by an outside party, there was not 100% control on this side of the study, as there was in the testing phase. The extremely positive side of this is that NPD produced a survey infinitely more significant than could have been produced if the survey had been done by the researcher alone, with over 38,000 respondents.
2. The down side of this is a lack of control; certain information is unknown such as which countries are represented in the International side of the survey, the exact wording of the questions to the consumer is unknown, the presence or nature of any lead-in given to the consumer to educate them on the meaning of any terms such as 'moisture management' is also unknown.

Acronyms Used in Research

TPACC	=	Textile Protection and Comfort Center
GATS	=	Gravimetric Absorbency Testing System
KES	=	Kawabata Hand Evaluation System
RN #	=	Registered Identification Number
A	=	Represents Garment A or fabric from Garment A in the testing phase.
B	=	Represents Garment B or fabric from Garment B in the testing phase.
C	=	Represents Garment C or fabric from Garment C in the testing phase.
D	=	Represents Garment D or fabric from Garment D in the testing phase.
E	=	Represents Garment E or fabric from Garment E in the testing phase.
F	=	Represents Garment F or fabric from Garment F in the testing phase.
G	=	Represents Garment G or fabric from Garment G in the testing phase.

Glossary of Terms

Comfort – A function of the physical properties of materials and clothing as interpreted by human physiological and psychological response. Also altered by human expectations which filter the perception based on past experiences. (R.L. Barker, 2002).

Human Wear Trial – Statistically significant subjective human subject garment comfort study. Conducted in a controlled environment within an environmental chamber, and designed to replicate certain wear conditions appropriate to the garment type being tested (R. L. Barker, Scruggs, & Shalev, Spring 2000).

Moisture Management – The ability of a clothing material to transport moisture away from sweat wetted skin. This is very important to the comfort perception. (R.L. Barker, 2002).

Hand – The feel or handle of a material. Associated with sensations related to stiffness, hardness, rigidity, density, thickness, bending, compression, and extensibility (R.L. Barker, 2002).

Breathability – The capacity of a material to allow the passage of heat and moisture vapor through the surface of the material into the surrounding environment. (R.L. Barker, 2002).

Clo – An arbitrary unit of measure describing the amount of thermal insulation said to represent the common men's business suit.

CHAPTER II

LITERATURE REVIEW

A solid background knowledge of the field of comfort, as it relates to the athletic apparel market and its consumers, will assist in ensuring that the best research direction is chosen in order to move forward with solid primary research that will specifically target and address the issue at hand; the issue of subjectively evaluating the comfort of athletic performance apparel through the use of an advanced sweating thermal manikin and other table top fabric level methods. The two areas most pertinent to research are those of comfort and the performance apparel market.

The field of clothing comfort has been the subject of much existing research (R.L. Barker, 2002) (Pontrelli, 1990). The goal in reviewing material from this research is two fold. On one side the field of comfort and comfort measurement will be studied to gain an understanding of the mechanics behind comfort. On the other side the market for performance apparel will be evaluated in order to understand what characteristics of performance apparel are most crucial to the decision making customer, as well as to gain an understanding of the significance of the performance apparel market. With these two branches of study reviewed, it will be possible to give unique significance to the methods as well as the eventual findings of the research to come. This will allow the coupling of how fabrics perform with how they are expected to perform in order to satisfy market demands. It will be helpful to initially review these two fields and their related issues independently. The most opportune point at which to couple the information from these two fields will be when the results of the research are completed and ready for analysis.

The boundaries for review in these fields will be such that the information covered is related to moisture management, heat management, and fabric hand in the comfort field; the focus for the marketing field will be targeted toward the size and significance of the athletic apparel market, as well as some companies and products involved. The fields of comfort and performance apparel certainly reach far beyond these boundaries, however the topics contained within these boundaries will best serve this project in order to maintain a focus on the objective measurement of comfort in athletic performance apparel.

Evaluation of Comfort

The challenge in the field of comfort is based in the reckoning that must take place between the qualitative phenomena that makes up the experience of comfort and the quantitative means that must be utilized to express them. An important trait of comfort is that it is a mixture of physiological and psychological parts. Each part is affected by the impact of the other (R. L. Barker, 2002). This theme is covered in greater detail in the idea of ‘Comfort’s Gestalt’.

Comfort’s Gestalt

The nature of comfort has three main factors according to G.J. Pontrelli (1990). Pontrelli discusses this in his idea of “Comfort’s Gestalt”. This idea is based on the concept that the desired properties of the fabric are determined by the use intended for the product. Once these comfort properties are identified, they can be designed into the product with the use of the correct manmade fibers and fabrics and garments (Pontrelli, 1990). In his work Pontrelli identified three main types of factors that affect the perception of comfort. The areas he outlined were: Physical Variables, Psycho-Physiological Parameters, and Stored Modifiers. The meaning of Gestalt in this instance is that comfort or discomfort responses are part of a configuration of physiological and psychological stimuli as well as stored modifiers. The assertion is that these parts are so thoroughly integrated as to constitute a functional unit with properties not derivable simply from the summation of its parts (Pontrelli, 1990). While the three 'parts' of the Comfort Gestalt are not individually significant enough to help predict or determine comfort, it is important to take a closer look a them individually so as to be able to gain an understanding of the variables of comfort Pontrelli has identified in his work.

'Physical Variables' is the branch of the Comfort Gestalt that is most easily associated with the ability to adjust and control the level of comfort. This is because these variables are tangible and can be adjusted. Environment is one of the physical variables that have a great impact upon comfort (Pontrelli, 1990). The temperature and humidity of the environment in which the athletic activity takes place have a great impact upon the comfort that will be perceived by the athlete wearing the garment. If the athlete is indoors with relatively stagnant air, controlled temperature, and no direct sunlight, the environmental impact on comfort will be much different than if the athlete were outdoors where an infinitely varying amount of sunlight, temperatures, air velocities and humidity levels can be experienced. Another Physical Variable is the Level of Activity that the athlete is engaged in; a higher level of activity will result in a higher amount of sweating, and heat generation in the athlete's body. This will affect the perception of comfort greatly. The last Physical Variable that Pontrelli discussed was Fiber, Fabric, and Garment Properties. This is where the textile industry sees its opportunity to adjust and try to prepare for all of the other physical comfort factors which it cannot control. The ability of the garment to manage sweat and heat effectively is the variable of comfort that the textile industry is most concerned with, because the properties of fiber, fabric and garment can be manipulated most easily by the manufacturer whereas the environment and the level of activity are all controlled by the consumer.

'Psycho-Physiological Parameters' constitute another branch of The Comfort Gestalt. While this branch has both aspects that can and cannot be controlled by the textile manufacturer, it is on the whole more complicated than the Physical Variables Branch. These variables are less tangible than the ingredients of the Physical Variables branch of the Gestalt. There are several variables Pontrelli discussed that are a part of the Psycho-Physiological branch of the Gestalt. One variable is the State of Being of the wearer. A highly anxious state of being would result in a much lower perception of comfort, whereas a state of being that was more relaxed and pleasant would result in a higher perception of comfort by the wearer. This is often an important aspect of human wear trials, to provide an aspect of mental stress in order to simulate a higher level of anxiety during a comfort trial. Another of the Psycho-Physiological variables is End Use and occasion of wear. The reasoning here is that one would not feel comfortable if wearing athletic apparel that was not suited for their particular activity. A garment considered comfortable for one purpose may be considered very unacceptable for another purpose, in terms of comfort (Pontrelli, 1990). For instance a long distance runner would feel extremely uncomfortable if they were wearing the long and constricting pants that are seen in the attire of a baseball player.

'State of Being' and 'End Use' are both variables that cannot be controlled by the textile manufacturer, while the last two variables in the Psycho-Physiological branch of the gestalt are more easily manipulated. These variables are 'Tactile and Visual Aesthetics', and 'Fit'. The tactile and visual aesthetics, expressed in textile terms, can be changed via the manipulation of the design and hand characteristics of the fabric used in the final athletic apparel garment. Fit is a variable that, in most cases, can be adjusted with less difficulty than would be involved in adjusting visual and tactile aesthetics. Fit is a function of the cut and sew operation as well as a function of the degree of personalization a company focuses its efforts on, while visual and tactile properties require adjustments to be made at the fabric, yarn, and even fiber level.

The third and final branch of the Comfort Gestalt is the Stored Modifier. This branch was referred to as a filter by Pontrelli, as the variables contained in this branch do 'modify' the consumer's perception of the garment. The primary variable in this branch is a mixture of the individual consumer's own past fantasies, experiences, and expectations. Essentially this branch of the Gestalt accounts for the presuppositions that are held by the consumer. This branch is virtually impossible for the manufacturer to manipulate. The experiences of one customer may lead them to call a garment very uncomfortable, when the previous customer has called it very comfortable. Figure 2.1 shows a depiction of how these three areas function together and are interdependent. Figure 2.2 details the aspects of Comfort's Gestalt

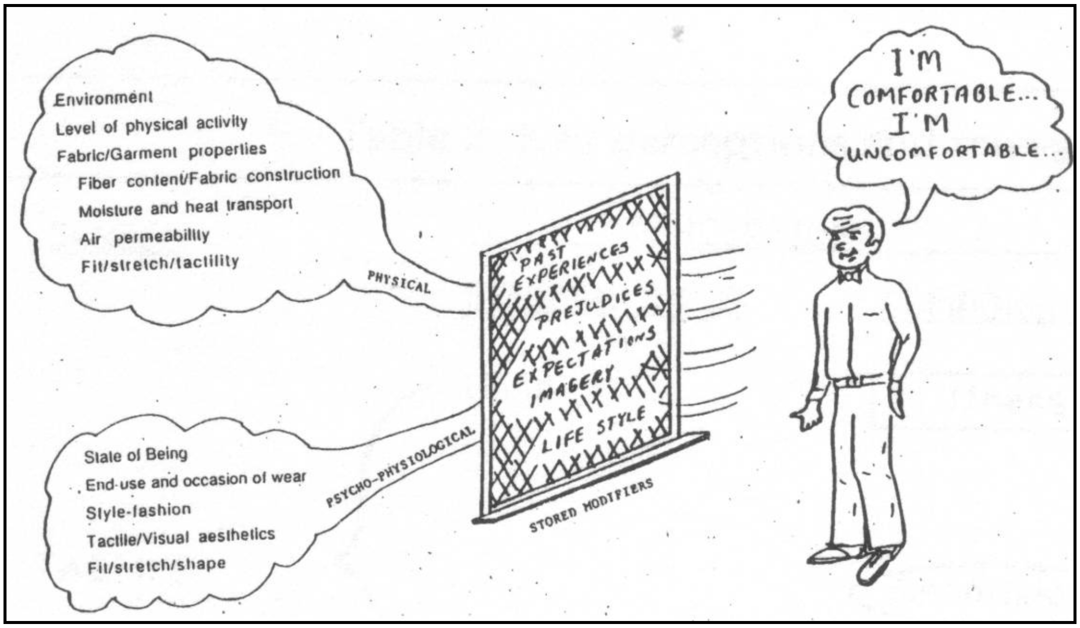

Figure 2.1 - Comfort's Gestalt

Source: Pontrelli, G.J. (1990), "Comfort by design", *Textile Asia,* Vol. 21 No.1, pp.52–61

Physical Stimuli	Psycho-Physiological Factors
Level of physical activity Fabric/ garment properties - Fiber content/ fabric constructions - Moisture and heat transport - Air permeability - Fit/ stretch/ tactility Environmental Factors - Air temperature, humidity, etc.	State of being End-use and occasion of wear Style-fashion Fit, familiarity <u>Stored Modifiers</u> Past experiences Bias Expectations Life style

Figure 2.2 - Aspects of Comfort's Gestalt

Source: Barker, R. L. "From fabric hand to thermal comfort: The evolving role of objective measurements in explaining human comfort response to textiles". *International Journal of Clothing Science and Technology*. (14), 181.

With the Stored Modifier branch of the Gestalt taken into consideration, the conclusion Pontrelli draws is that the physical garment is only a part of the overall comfort response, and that asking one person what they find comfortable may not provide any real value as a response. With this in mind Pontrelli states that no fiber, yarn, fabric, or garment is inherently comfortable. Despite this conclusion, Pontrelli does state that it is possible to gain a positive comfort response, for a given purpose and occasion of wear when:

- The garment is properly tailored
- The fabric satisfies the garment requirements
- The appropriate fiber(s) are selected
- The environment does not cause undue stress
- The subject has a positive emotional state (Pontrelli, 1990).

Physical Comfort

While it has been determined that comfort exists on two levels, physical and psychological, (Pontrelli, 1990) the physical aspect of comfort is important enough to warrant its own discussion. It is the physical attributes of comfort which are the most important to the textile manufacturer because these are the aspects of comfort to which the product can be tailored and manipulated, in order to best meet the demand of the customer. This is where an advantage stands to be gained, in the pleasing of the customer, and since the customer's psychological needs are something that the manufacturing community currently has no way of predicting, the importance of ensuring the correct physical comfort characteristics is amplified. There are two levels of comfort on the physical side. These levels are Thermophysiological Comfort and Sensorial Comfort (R. L. Barker, 2002) (Pontrelli, 1990).

Thermophysiological Comfort

In Thermophysiological Comfort there are two phases (Yoo & Barker, July 2005b). These phases can exist independently in a wearer's experience or they can both be involved in the wear experience. The two phases are the Steady State phase and the Transient Wear phase.

Steady state occurs to regulate body temperature in normal wear conditions. The clothing becomes part of the skin system to regulate temperature. Perspiration is insensible during steady state heat and moisture fluxes. These fluxes are gradually dissipated to maintain thermoregulation and a feeling of thermal comfort. In Steady State, clothing becomes part of the thermoregulatory system. Steady State properties can be measured with the Sweating Guarded Hot Plate; usually at 21ºC and 65% Relative Humidity (Yoo & Barker, July 2005b). An image of the sweating guarded hotplate is in figure 2.3.

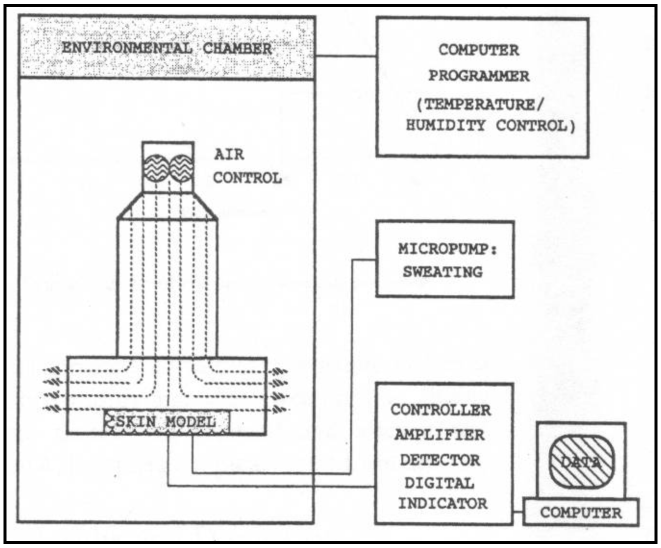

Figure 2.3 - Sweating Guarded Hot Plate

Source: Prahsarn, C., Barker, R. L., & Gupta, B. S. (2005). Moisture vapor transport behavior of polyester knit fabrics. *Textile Research Journal, 75*, 346-351.

Transient Wear occurs with the presence of surges in activity which results in surging amounts of sweat production. In these cases the clothing must effectively manage the increased sweat presence. This is the area with which this study is mostly concerned; the ability of the test samples to handle the surges in sweat production. Sensorial comfort is determined more by the ability of a fabric to transport moisture and by the extent to which the fabrics can buffer the moisture vapor. The pulsed vapor and heat transmission associated with the Transient Wear phase can be measured with the Dynamic Sweating Hot Plate at NCSU. An important aspect of the fabric that can be measured with the Dynamic Sweating Hot Plate is the Buffering Response (B_d). A higher Buffering Response indicates an advantage in the moisture vapor modulating capabilities of a fabric in Transient Wear sweating conditions. Below are listed the parameters and the equation for determining the Buffering Response of a fabric based on the parameters measured by the Dynamic Sweating

Hot Plate (Yoo & Barker, July 2005b). As the equation below shows, the less the % RH increases during simulated sweating, and the faster it returns to a normal state once simulated sweating ceases, the higher the Buffering Response of a fabric (Yoo & Barker, July 2005b).

Buffering Response (B_d):

- $B_{d\,=}$ (D)/(S10 * ΔRH_{max} * T_d)

Where:

- S_{10} = Rate of %RH increase in microclimate during 10 minutes after sweat pulse begins
- ΔRH_{max} = maximum increase in microclimate %RH during test.
- T_d = time for microclimate %RH to return to steady state after test (sweat pulse) terminates.
- D = constant (1000) to give desired range.

Another important measure that can be calculated from data gathered by using the sweating guarded hot plate is the Comfort Limits or comfort range. The hotplate can measure both heat transfer and moisture vapor transfer simultaneously for both the steady state and transient wear conditions. These comfort limits are calculated from such measures as thermal insulation (I) and Permeability Index (i_m), both of which can be calculated from the data generated by the guarded sweating hotplate or Thermolabo device. The comfort limits are derived based on the assumption that the comfort zone is extendable by the inclusion of evaporation with normal (dry) heat transfer (R. L. Barker, 2002)

Sensorial Comfort

There are a few properties that are included in the measurement of Sensorial Comfort. Sensorial comfort can be objectively measured by the Dynamic Sweating Hot Plate (R. L. Barker, 2002). Some of the main factors in comfort are fabric structure, as well as moisture transport and buffering. The related descriptive aspects of comfort are associated with skin contact and the sensations perceived from this contact. This is important because each fabric descriptor such as prickly, soft, smooth, damp, etc. is able to be correlated with objective measurements of fabric properties. Such descriptors include clamminess, softness, smoothness, clinginess, prickliness, etc. The properties related to these aspects can be: fiber characteristics, yarn and fabric construction, as well as fabric finish.

Fabric Hand is another key property which is included in sensorial comfort; this issue will be discussed in further detail in subsequent sections. Another important aspect of Sensorial Comfort within the greater comfort complex is Liquid Moisture Management, which will also have its own subsequent section. An interesting test to note, which is related to the effect of Moisture Management on Sensorial Comfort, is the Hohenstein Test which measures the force of a fabric that is sticking to moist skin (Yoo & Barker, July 2005b) (R.L. Barker, 2002).

Fabric Hand

Pontrelli's (1990) Comfort Gestalt included 'tactile aesthetics', which is another way to title this key physical property of a garment being evaluated on the basis of comfort. The way a fabric feels against the skin of the wearer is very important, because when being worn, any garment is in contact with the skin; this is especially true with athletic apparel that is often in contact with a larger portion of the body than is clothing more suited as outerwear.

The physical properties of the fabric which are involved in the hand perception of the resultant garment are more readily identified than the physical properties which are responsible for comfort itself. The totality of comfort is a more complicated measure. F.T. Pierce, in his work on fabric hand, has identified some specific fabric properties that affect the overall fabric, and thus the garment's hand. The properties he identified were:

- Bending Length (C)
- Flexural Rigidity (G)
- Thickness, Density (d)
- Hardness (H)
- Bending Modulus (q)
- Compression Modulus (h)
- Extensibility (q).

These fabric properties are easily quantifiable and therefore are able to be adjusted to reach the desired hand for a garment in terms of its intended use (R. L. Barker, 2002).

Kawabata Hand Evaluation System (KES)

The Kawabata Evaluation System (KES) for the objective measurement of fabric hand is the most widely accepted existing method for the objective measurement of fabric hand. Kawabata began his theory of fabric hand measurement based on the assumption that fabric hand is the accumulation of fabric properties such as stiffness, softness, and roughness. Kawabata's second theory is that the final determination of fabric hand is biased depending upon the end use intended for the fabric (R. L. Barker, 2002). The Kawabata System's biggest advantage is the ability that the machines in the system have to measure very small strain values with a high degree of sensitivity and accuracy. This capability allows very specific properties, (such as shear, tensile, compression, bending, and surface) of fabric hand to be separately and accurately measured. This advantage makes the Kawabata system the most advanced measurement tool for the objective measurement of fabric hand (R. L. Barker, 2002).

Studies have been conducted at NC State University that have compared qualitative human tactile observation with objective hand measurements from the Kawabata system. Certain fabric types were used in these studies, such as sheeting, men's suiting, and single knits (R.L. Barker, 2002). For these fabrics human perception was able to be predicted accurately by using a combination of surface properties measured by the KES as well as (sometimes as little as one) fabric bulk properties (tensile, bending, or compression) to make this prediction.

Moisture Management

The ability of a fabric to manage the moisture of the microenvironment between the fabric and skin is very important to the perception of comfort. If moisture is stagnant in the microenvironment, then it is not being used to cool the body, as is the natural purpose and result of the body's sweating mechanism. In addition to cooling issues, often as little as a 3% to 5% increase in the level of moisture present in the skin to fabric layer will result in an increase in discomfort sensations. A study by Scheurell et. al. discovered a direct connection, stating that instantaneous moisture level changes within the layer of fabric adjacent to the skin surface resulted in sensations of discomfort by the subjects in a human wear trial, which was conducted under sweating conditions (Scheurell D., Spivak S., & Hollies N.., 1985). The moisture transport ability of a garment is very important in the comfort perception of the garment, most especially in conditions where sweating will occur (Prahsarn et al., 2005). This is true because sweating causes the humidity in the microenvironment between the skin and the fabric to rise dramatically. A rise in humidity decreases the effectiveness of the evaporation process to contribute to the cooling of the active individual. When humidity breaches 75% this decrease in cooling efficiency of sweat evaporation begins to take place (Kaufmann, 2007). A garment with good moisture management properties will be required not only to move the moisture away from the skin and into the fabric, but it must also continuously take that moisture and move it from the fabric into the surrounding environment; effectively 'clearing the way' for the moisture that the body is continuously producing in the act of sweating. This is important because sweating is the most efficient means by which the human body can be cooled (Kaufmann, 2007). A garment must also be able to handle the amount of sweat being produced by the body and continuously move the moisture away from the skin in order to allow the body to continue its natural cooling action through sweating. This is important because while the typical human loses half a liter of water through their skin in a day (Performance apparel markets, 2007), they are capable of sweating at rates upward of 2 or even 3 liters per hour, under more extreme work levels and conditions (Kaufmann, 2007).

One of the most prevalent, if not the most prevalent, terms used in the marketing of performance athletic apparel is "Wicking". Wicking occurs when a fabric takes up liquid, even though the driving pressure gradient is zero or negative. The phenomenon is called wicking when one edge of the material is dipped in the liquid, and the movement of moisture is primarily in the plane of the fabric. When the liquid front enters through the face of a fabric, it is not customary to call it wicking, although the basic mechanism is the same. This effect is called ‘Demand Wettability’ (Yoo & Barker, 2004).

Wicking is dependant upon the wettability of the fiber used to construct the fabric and subsequent garment. One method of determining if a fiber will result in a wicking garment is to perform a test, determining the contact angle between a drop of water placed on this material and the plane of the material. If the contact angle is small this reveals a material that will more readily wick water, while a large contact angle suggests a material that will resist wicking (Ramachandran & Kesavaraja, 2004). Wicking is defined by Ramachandran as the transport of liquid, by the fiber’s surface by means of capillary action. Capillary action is the ability to draw up a liquid against the force of gravity (Performance apparel markets, 2007). Wicking increases with an increase in the viscosity of the liquid, and increases with a decrease in the contact angle of the liquid (Ramachandran & Kesavaraja, 2004). The contact angle is dependant upon the surface energy of the fiber. Hydrophilic fibers have a high surface energy and result in a low contact angle and strong wicking properties while hydrophobic fibers have a low surface energy and result in a high contact angle and poor wicking properties (Performance apparel markets, 2007). Figure 2.4 shows the contact angle of a non wicking drop test (left) with a large contact angle, and a wicking drop test (right) with a smaller contact angle.

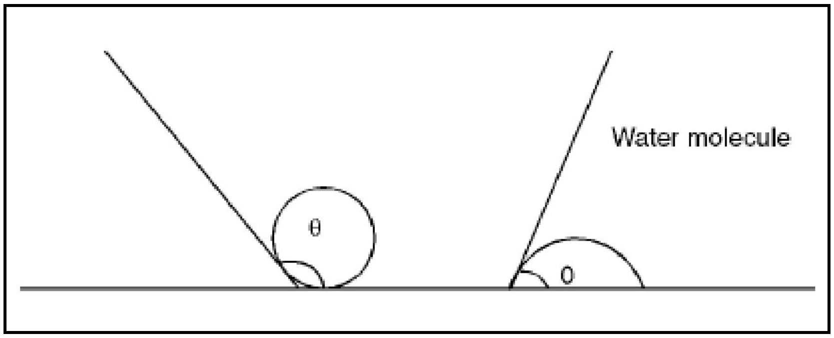

Figure 2.4 - Contact Angles between Surface and Water Involved in Wetting

Source: Ramachandran, T., & Kesavaraja, N. (2004). A study on influencing factors for wetting and wicking behaviour. *Journal of the Institution of Engineers (India): Textile Engineering Division, 84,* 37-41.

There are two types of wicking (Ramachandran & Kesavaraja, 2004); longitudinal wicking and transverse wicking both take place in a sweating environment. Transverse wicking is the most important as it is responsible for removing moisture from the skin during activity. The thickness of the material has a lot to do with the amount of transverse wicking ability a fabric displays. Pore size within a fabric is also important as smaller pore sizes improve moisture transport due to high pressure. This leads to less retention of water and increased water transport (Ramachandran & Kesavaraja, 2004).

Yoo and Barker (2004) studied the moisture properties of heat-resistant work wear and dealt with the fabric property of Demand Wettability. Together they utilized several useful equations for understanding the moisture (or sweat) management of a fabric. One of these equations, the Washburn Equation, is shown below:

- $dV/dt = ([2\gamma \cos\theta / R_c] - hg\,\delta)\ \pi R_c^4/8\eta L)$ (Washburn Equation)
- Where:
  - η = fluid viscosity
  - L = wetted length of the tube
  - R_c = pore size of the fabric system
  - γ = liquid surface tension
  - θ = contact angle at the tube wall
  - h = height of elevation
  - δ = liquid density
  - g = acceleration due to gravity (Yoo & Barker, 2004).

The Washburn Equation shows that: three liquid properties (surface tension (γ), density (δ), and viscosity (η)), one 'solid phase' property (effective pore size $R_{c)}$, and one interaction factor (contact angle θ) affect liquid uptake. For sweat, the density (δ), and viscosity (η) will be a constant value. This leaves effective pore size (R_c), contact angle (θ), and surface tension (γ) as the adjustable parameters within the equations. From these equations it is clear that the larger the pore size the faster the rate of absorption by a fabric. A higher ($\cos\theta$) yields a better liquid uptake, and is affected by the surface tension. These two factors together are often called the 'Wettability Function" ($\gamma \cos\theta$) (Yoo & Barker, 2004).

Liquid moisture management can be objectively measured via the Gravimetric Absorbency Testing System (GATS). This machine is used at North Carolina State University's College of Textiles to measure the ability of fabric to transport moisture away from the skin. The mechanism of this machine is to measure how much liquid moisture (by weight) is taken away from a simulated skin surface in a given amount of time (R. L. Barker, 2002). This machine performs a demand wettability test, and allows fabric to simulate being on a constantly sweating skin surface, thus the term demand wettability. Many tests exist to determine the moisture wicking properties of a fabric when exposed to a finite and static amount of moisture, however the GATS (seen in figure 2.5) measures the ability of a fabric to move a continuously replenished moisture supply over a period of time.

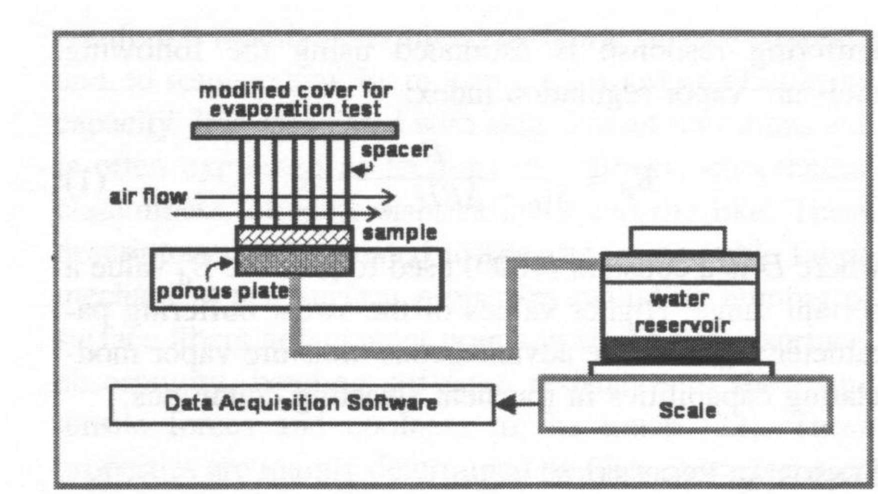

Figure 2.5 - Gravimetric Absorbency Testing System (GATS)

Source: Yoo, S., & Barker, R. L. (July 2005b). Comfort properties of heat-resistant protective workwear in varying conditions of physical activity and environment. part I: Thermophysical and sensorial properties of fabrics. . *Textile Research Journal, 75*, 523-530.

Yoo and Barker (2005) performed a study utilizing the GATS test in the prediction of human wear trial comfort for protective Workwear. In this study they tested six fabrics on the GATS and conducted human wear trials with these same fabrics. They were able to correlate the results of the GATS test with the human trials and found that the demand wettability test on the GATS was a solid predictor of a ‘clamminess’ comfort descriptor used in the wear trials (Yoo & Barker, July 2005a).

Hatch et al. (1990) performed a study where the four mechanisms, by which water (in liquid or vapor form) can pass through a textile layer, were used as an experimental basis. This was done in order to test three different fabrics in their abilities to allow this moisture transport. The four methods used were outlined by Mecheels and are: “penetration through the space between fibers according to the laws of diffusion, absorption by the fiber material as a result of transfer within fibers and desorption, transfer of liquid water through capillary interstices in yarns, and migration of water on fiber surfaces.” (Hatch K. L. et al., 1990). The first two methods of passage through the fabric pertain to diffusion of water vapor through the fabric while the second two methods pertain to liquid water transport (Hatch K. L. et al., 1990). The testing for this portion of the study was performed on the Kawabata Thermolabo sweating hot plate, with a dry condition test to simulate a cooler less active environment, as well as a ‘wet-skin’ condition test to simulate an active state or a tropical climate.

The results of this study were that the three fabrics under review, (1.5 denier filament polyester, 3.5 denier filament polyester, and 24/1 combed cotton), all behaved similarly in terms of comfort when the tests were conducted to simulate a relatively cool and dry setting. The wet skin or tropical climate tests however showed some differentiation between the fabrics’ performance in terms of comfort. The cotton fabric dissipated less energy through the fabric in the wet test than did its polyester counterparts. This would mean a less comfortable wear experience as a hot or humid environment requires a fabric to diffuse more vapor in order to maintain a cooling effect. Compounding the discomfort, the decrease in cooling is accompanied by the increase in skin wetting which could lead to fabric clinging to the skin, creating a sensation of discomfort fed by the feeling of wetness and thermal discomfort (Hatch K. L. et al., 1990).

Prahsarn, Barker, and Gupta (2005) studied 14 polyester knits with varying fiber and fabric structures to determine the construction effect on moisture management properties. Evaporative Thermal Resistance is the relationship used by Prahsarn, Barker, and Gupta. They discovered that a fabric which matches this description of having good moisture management properties will display a low evaporative thermal resistance. That is, the fabric will provide a minimal amount of hindrance to the natural evaporation process which would take place were it not being worn at all. Any fabric will display some level of resistance to this evaporation of the moisture from the skin into surrounding environment, simply due to its presence on the skin. The equation and parameters used in the study for evaporative thermal resistance are shown below.

- $R_e = L/D_a\beta$, *Where:*
    - R_e = evaporative thermal resistance
    - L = fabric thickness
    - D_a = water vapor diffusivity of air
    - β = optical porosity (Prahsarn et al., 2005).

Heat Management

The Moisture Management properties of a fabric work in tandem with the ability of a fabric to allow the skin surface to cool. Fabrics must allow heat generated by the body to escape through the fabric into the surrounding atmosphere. If this does not occur the core body temperature will climb dangerously high and could pose serious health risks. When in a neutral climate the human body typically regulates its core temperature at 37ºC, while due to a phenomenon called the circadian rhythm the body temperature is actually closer to 36.7ºC upon waking in the morning, and climbs throughout the day to reach around a 0.8ºC increase and returning to 36.7ºC as we sleep (Havenith, 2002). Hard work or exercise can cause the body's core temperature to increase to around 39ºC for moderate levels of activity and around 40ºC for heavy activity. The cause of this rise in body temperature, during increased activity, is a result of the function of the body to feed the muscles the necessary nutrients to continue working. The muscles burn these nutrients which creates heat within the muscle thereby increasing the body's core temperature (Havenith, 2002). If the body had no means of cooling then someone performing a moderate activity level would experience an increase in body temperature of approximately 1ºC for every 10 minutes (Havenith, 2002). This seemingly small increase could prove deadly. The point at which a health risk is posed is when the core body temperature eclipses 41.1ºC (106ºF) (Kaufmann, 2007). Sources of heat generation between the skin and the fabric of the garment are metabolic output, radiant heating, and convective heating. Metabolic output increases as work increases, thus making the ability of a fabric to evacuate heat extremely important for athletic apparel, due to the high amount of work that takes place during athletic activities. Figure 2.6 shows the forces of body heat exchange. This graphic was developed by Havenith.

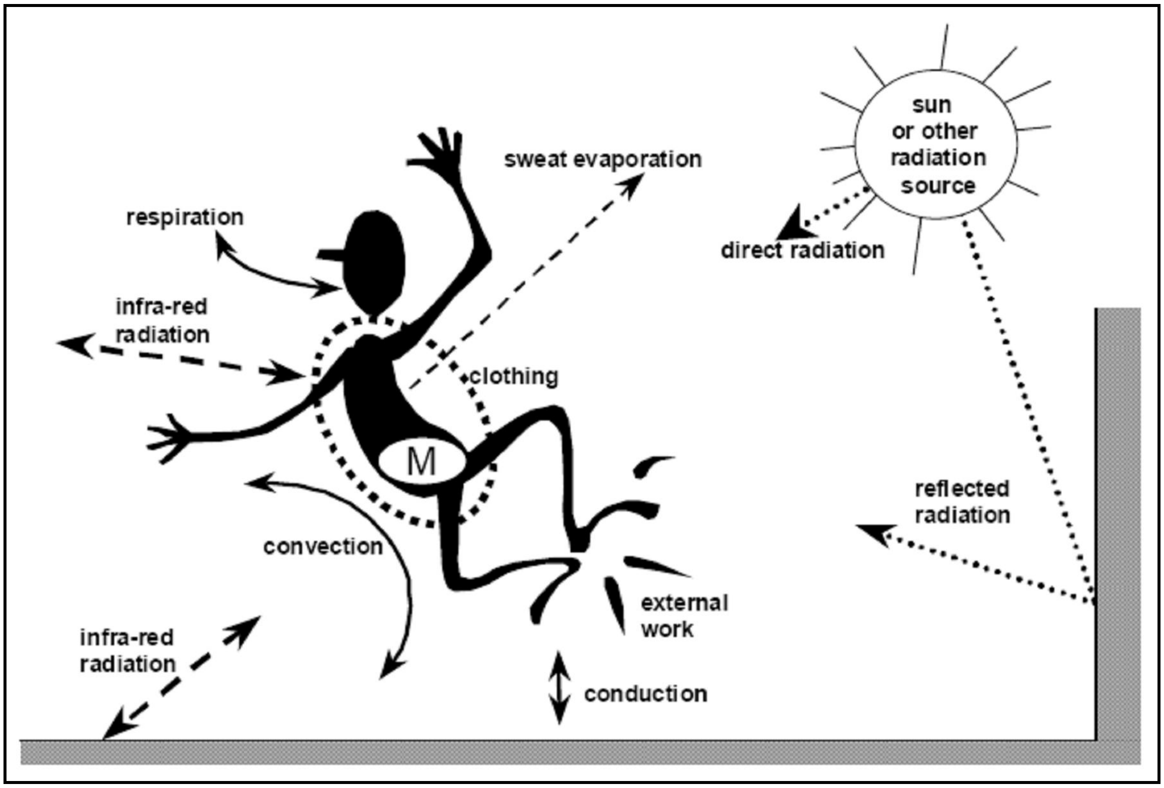

Figure 2.6 - Schematic Representation of the Pathways for Heat Loss From the Body.

Source: Havenith, G. (2002). The interaction of clothing and thermoregulation. *Exogenous Dermatology, 1*(5), 221.

While this study is not concerned with cold conditions or sedentary wear conditions it is important to note the converse effects of the body in the cold environment. The body's natural reaction to a drop in core body temperature is the act of shivering, which is muscle activity with zero efficiency, meaning that all of the heat generated by this muscle activity is kept within the body (Havenith, 2002). Li et. al. (2005) performed a human wear trial study with female subjects in a cold controlled environment within an environmental chamber. This study states that cold is perceived in a continuum from indifferent to cool to cold, and that clothing has a great effect on controlling the ability of the wearer to maintain control of their perceived level of coolness in a cold environment (Li J, Wang Y, Zhang W, & Barker

RL, 2005). The objective of this study was to discover how different parts of the body react to cold exposure. Skin temperature was monitored through the placement of sensors on the subjects' bodies and the test subjects reported being comfortable at a skin temperature of 33ºC. The study included garments that had removable patches in order to expose certain body segments to the cold environment. After the participants had been given a resting period for their body temperature to moderate in the garments, a patch was removed for 30 minutes, and then replaced for 20 minutes with skin temperature monitored throughout. This study concluded that the body parts closest to the core were more sensitive to cold exposure; the torso reacts most sensitively to the cold exposure while the upper limbs, calves and thighs reacted with less sensitivity (Li J et al., 2005).

A study performed by Pan and Xing (2007) was interested in the interaction between skin and fabric. In this study they state that there are four mechanisms of heat exchange between the human body and its surrounding environment (Pan & Xing, 2007). The four mechanisms listed are radiation, conduction, convection, and evaporation of perspiration. Another mechanism of heat exchange given by Havenith is respiration whereby the heated and moisturized air is expelled from the body and cooler air is inhaled to replace it. Respiration can account for up to 10% of the body's heat production (Havenith, 2002). Figure 2.6 from Havenith (2002) demonstrates this exchange. The authors note that only one of the four heat exchange mechanisms is independent of the outside environment, in terms of the direction of heat exchange; this independent mechanism was evaporation of perspiration. This means that when it is cold in the environment, radiation, conduction, and convection are all in the outward direction leaving the human body and entering the atmosphere, but if the outside environment is hotter than the human body core, these three all are in the inward direction moving from the atmosphere into the human body. In the outward phase it is stated that radiation accounts for 80% of heat loss (Pan & Xing, 2007). Radiation typically occurs when the skin temperature and the temperature of the environment are different; at this point heat will exchange by means of radiation (Havenith, 2002). When the heat transfer is in the inward direction for a hot environment, the responsibility falls solely on the evaporating perspiration to counteract the effects of radiation, conduction, and convection. Evaporation of sweat is also the only mechanism of the four that does not work against the comfort needs of the body in both cold and hot exterior climates (Pan & Xing, 2007). Radiation, conduction, and convection all remove needed heat from the body in cold temperatures, but in hot temperatures they actually increase the heat on the body which needs to be removed in order to gain a comfortable and healthy state (Pan & Xing, 2007). This highlights the importance of moisture management as being a primary function of heat management, so that while they are separate topics, they become heavily interrelated in a hot atmosphere.

A study by McCullough et. al. (2004) was done to compare several standards, methods, and apparatuses for the measurement of thermal insulation value. Five different dry hot plate standards and four different wet hot plate standards were used in the comparison that this study completed. Three different fabric configurations were tested as well; two configurations had three layers of fabric, and the other was a one layer fabric configuration. The study concluded that the guarded sweating hot plate which is used in this study was a valuable instrument for the measurement of thermal resistance as well as evaporative resistance (McCullough, Huang, & Kim, 2004). These measures are also able to calculate such indices as permeability index and total heat loss which will be discussed further in the methodology section for the guarded sweating hotplate (Thermolabo) device.

Warm/Cool Feeling

The ability of a fabric to allow heat to penetrate outwardly from the body is called 'transient heat flux'. This is also called maximum heat flow (q_{max}). Maximum heat flux can be measured by the Kawabata guarded hot plate (Thermolabo). The machine tests how well the fabric allows heat to penetrate outward (transient heat flux). This measure has been correlated with the warm/cool feeling by various studies (R.L. Barker, 2002). Correlations between warm/cool feeling and Thermolabo 'q_{max}' values have also been found at NCSU (R. L. Barker, 2002). The actual measurement is gathered by applying fabric to the surface of a heated hot plate, meant to simulate skin temperature. The higher area of contact, as found on a smooth fabric, increases the amount of transient heat flux.

Objective Measurement of Full Garment Clothing Comfort

The measurement tools outlined thus far are some of the leading current objective measures of fabric comfort variables available. While these tests are all advanced and very useful to the study of comfort, they are designed to test for comfort variables at the fabric level. This has its value, but does not take full piece garments construction into account. One measurement tool that has been developed to address this gap is the Sweating Manikin. At NCSU the Advanced Sweating Manikin (Coppelius) is used to measure objectively the properties involved in clothing comfort.

Coppelius is able to control the amount (and rate) of sweat supplied during long term testing, which is a unique ability within the longer history of sweating and thermal manikins; the original Coppelius was the first of its kind. The NCSU sweating manikin was built at NCSU, and was developed using the model of 'Coppelius' the Finnish sweating thermal manikin at the Technical Research Centre of Finland (VTT) (K. A. Ross, 2005). The original Coppelius was developed in the 1980's in Scandinavia, where it was modeled after a dry Swedish thermal manikin called Tore; the sweating functionality was added in order to make Coppelius a sweating Thermal Manikin (Meinander, 1997).

The water originates in a weight measured reservoir on the ceiling. It then travels through 187 different sweat gland sites which are controlled individually. The manikin hangs from a balance allowing the weight change on the manikin from moisture (absorbed in 'skin' and in clothing) to also be measured (Deaton, Barker, & Thompson, 2002). Figure 2.7 shows Coppelius from the front and rear views. In the rear view, Coppelius's back panel has been removed to reveal the inner workings.

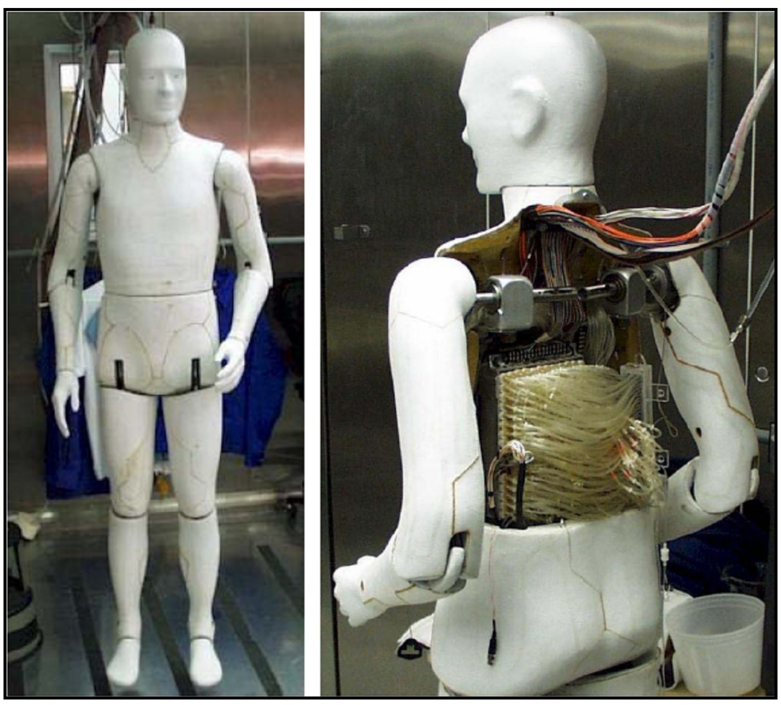

Figure 2.7 - Coppelius NCSU Advanced Sweating Manikin.

Source: Ross, K. A. (2005). *Evaluation of an instrumented sweating manikin for predicting heat stress in firefighters' turnout ensembles* from http://www.lib.ncsu.edu/theses/available/etd-02022006-113326/unrestricted/etd.pdf

A study by Deaton et. al. (2002) was conducted to utilize this manikin to determine heat stress with protective clothing. From the measurements taken with the Coppelius NCSU Sweating Manikin in a dry state, the thermal resistance (an insulation value) as well as the clo value, a multiple of thermal resistance, were able to be calculated in order to gain an understanding of the ability of the garments to hold or release heat in a dry state (Deaton et al., 2002). When the manikin was tested in sweating, or in a wet condition, several other measures were able to be gathered including evaporative resistance, and permeability index (Deaton et al., 2002). These measures will be discussed in further detail in the sweating manikin section of chapter three. In this study the manikin was able to reliably produce expected values of thermal insulation and breathability that correlated logically with a diverse set of clothing which were chosen to provide a range of protection from warm weather to cold weather garments (Deaton et al., 2002).

Subjective Human Comfort Evaluation

While the mechanisms of objectively measuring comfort variables are quite advanced, the numbers they generate have no meaning if not compared to the subjective human perception (R.L. Barker, 2002). If quantitative research states that a certain range of values for any given test produce results that yield a comfortable garment, yet human test subjects in a wear trial find the garment to be uncomfortable, then the values of that test are irrelevant. It is necessary to utilize human subjective trials, such as wear trials and hand trials, in order to gauge comfort perception. The wear trials are often done in a way that takes the wearer through the normal range of sweating amounts for the product under investigation. This often occurs in cycles with recurring resting periods (R. L. Barker, 2002). Figure 2.8 shows the cycle used in a human wear trial for the evaluation of hospital gowns.

Rating Period	Time (minutes)	Activity	Temperature °C (°F)	Relative Humidity (%)
1	10	rest	21 (70)	65
2	15	aerobics/ exercise*	21 (70)	65
3	15	rest	27 (80.6)	65
4	5	mental dexterity activity**	27 (80.6)	65
5	5	rest	21 (70)	65

Figure 2.8 - Wear Trial Test Protocol

Source: Barker, R. L., Scruggs, B. J., & Shalev, I. (Spring 2000). “Evaluating operating room gowns: Comparing comfort of nonwoven and woven materials”. *International Nonwovens Journal, 9*(1)

In the evaluation of human comfort perception, it is necessary for the purpose of reporting and comparison to quantify the qualitative sensations the human participants are experiencing. Comfort descriptors, with associated numerical values, are often given to the participants to use in their reporting of the sensations they are experiencing. Barker, Scruggs, and Shalev (2000) performed a study to measure the perceived comfort of nonwoven versus woven operating room gowns. In this study they chose to use negative comfort descriptors as the avenue by which the participants were to express themselves. This decision was made because it has been shown that negative comfort descriptors are more readily identified by human evaluators to report their sensation than are positive comfort descriptors (R. L. Barker et al., Spring 2000).

Research by Hollies et. al. (1979) suggests that human wear trials can have differing response rates dependant upon the circumstances of the trial, regardless of the garment type being tested (Hollies N. R. S., 1979). This study indicates that when conditions are near normal, meaning that there is no perspiration or stress, and humidity is normal, that the differences detected by human subjects from one garment to another are minimal. A few exceptions to this are the most detectable tactile characteristics such as slick, smooth, cold, clammy, rough, and scratchy where differences can be noted even in normal conditions. The study also notes that when there is mild to heavy sweating, especially when combined with a cold or warm temperature or a change in activity, that this test situation is conducive to subjects giving an uncomfortable rating to most commercial garments (Hollies N. R. S., 1979). This sweating can be caused in three ways; thermal heat such as a summer day, metabolic heat such as that caused by rigorous activity, and emotional stress such as being under pressure to perform (Hollies N. R. S., 1979).

Another important factor in the use of human comfort perception trials falls into the psychological arena. Participants should not be allowed to discuss the test garments amongst themselves because the opinions (pre-existing or not) of one participant can influence the other participants to have a certain bias toward a garment before the experiment begins (R. L. Barker et al., Spring 2000). Such a bias would invalidate any results generated from the study because the participants may or may not be reporting their sensations based solely on their perceptions. They likely would be reporting sensations that would have been reported differently had they not formed an opinion of the garments before the trial began. (R. L. Barker et al., Spring 2000). Garments also should be assigned in a randomized fashion to the evaluators. This prevents any influence on the behalf of the study's administrators. If the administrator were to order (or rank in order of appearance) the garments based on their opinion of any physical trait of the fabric, they might lead the participants to form an opinion of the subsequent garment based on a trend that may have been perceived up to that point. Presenting the garments in a truly random order provides a solution to this potential problem (R. L. Barker et al., Spring 2000).

An opportunity that exists with human comfort perception testing is to compare the human reported results against purely quantitative fabric property measurements. If the measures gathered by the human participants can be compared against test results from laboratory equipment, then a correlation can be performed between certain physicals parameters of fabric that can be used to predict how those parameters will affect the comfort perception a human will experience. While this is an excellent opportunity and the two types of tests are highly beneficial when performed together, no amount of predictive ability will fully replace the need for using humans in wear trials. This is due largely to the non-physiological aspects of comfort and the inability of lab equipment to measure or predict this aspect, as well as the propensity these aspects have to change over time as well as from one person to the next.

Materials in Athletic Performance Apparel

Today's performance apparel market is populated mostly by fabrics made of synthetic fibers, such as polyester and nylon, many of which have been given moisture wicking treatments (Ozer, Salenda, Stockton, & Ware, 2007). The reason for this is that the majority of synthetic fibers are to some degree hydrophobic and therefore they do not absorb or wick moisture, which is desirable for use in athletic apparel. Other means of improving the moisture management properties of synthetics have been a variety of fiber cross-sectional shapes, differing yarn constructions, and differing fabric knit constructions (Ozer et al., 2007). For a long time the standard was for more natural fibers to be used in athletic wear due to their ability to absorb moisture. Cotton for example absorbs moisture readily, and has a naturally soft hand as well as good breathability traits. Cotton is also less expensive than many materials and is universally available. The question then arises as to why the modern performance athletic apparel industry consists almost exclusively of synthetic materials which require additional treatment steps in order to reach the desired characteristics of athletic apparel material. The reason is that while cotton does have good absorption properties, it also has very low wicking properties, meaning nearly all absorbed moisture is held within the fabric causing it to become heavy and to stick to the skin of the athlete. In addition to this, cotton also has a slower drying rate than many other optional materials (Ozer et al., 2007).

Knitted wool fabric has also been used in the past due to its ability to transport moisture vapor from the body, as well as its ability to absorb odors, and to regulate body heat. Wool also is highly durable, which is a positive for a material that is to be used for such rigorous activity. This raises the same question for wool as to why it is not more popular in today's athletic apparel market. Wool's drawbacks include a poor ability to wick liquid moisture away from the skin, which compounds its already rough texture on skin, as well as its high cost and tendency to shrink or felt when washed.

Improvements have been made for both cotton and wool in making them more useful for athletic purposes. Cotton has been blended with synthetic fibers as well as treated to not absorb water in order to improve its wicking characteristics. Wool has been treated to make it washable in order to avoid shrinkage and felting, which leaves it with no water absorption or wicking characteristics. To answer this need Ozer et. al. (2007) with Nano-Tex Inc. have developed a moisture wicking treatment for washable wool that does not decrease the fabric's burst strength and is durable under multiple washings (Ozer et al., 2007). Despite these advances for cotton and wool, however, synthetic fibers remain the dominant material in the performance athletic apparel market due to the high degree of control and ability to engineer desired characteristics into these materials. Polyester is the most commonly used fiber in the moisture management market. Polyester is commonly treated either by a hydrophilic coating or by changing its surface characteristics through a chemical means in order to improve its otherwise poor ability to allow moisture transport (Performance apparel markets, 2007).

The choice of material for athletic purposes is important given the extremely urgent need for body heat release in athletic activities. This heat is built up by the nature of the athletic activity, so the garment chosen for this activity must be appropriate in that it allows this heat to escape the body in order to keep the athlete safe, cool, and comfortable. Clothing serves to resist both heat and moisture exchanges between the human body and the surrounding environment (Havenith, 2002). The optimal athletic clothing will minimize these effects. The barrier to heat and vapor exchange is actually comprised of both the garment itself and of the air enclosed by the garment. For dry heat exchange the means are mostly conduction and radiation, and while fibers influence the amount of radiated heat transfer, fiber type is less important than the thickness of the material itself. Thickness is the most important aspect of insulation. For normal and permeable materials, thickness determines a great deal of vapor resistance as well (Havenith, 2002). Figure 2.9 illustrates the effect thickness has on vapor resistance.

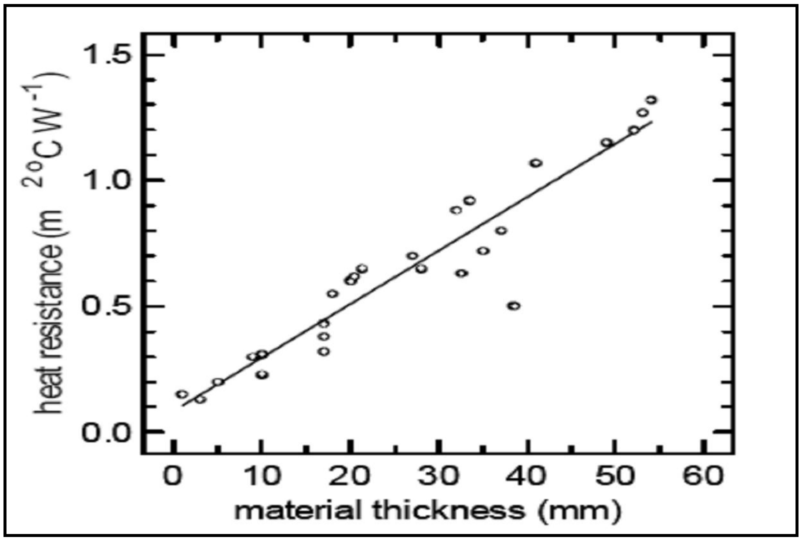

Figure 2.9 - Vapor Resistance vs. Material Thickness

Source: Havenith, G. (2002). The interaction of clothing and thermoregulation. *Exogenous Dermatology, 1*(5), 221.

Clothing also has an impact on the moisture related aspect of comfort, therefore it is important for clothing to have proper moisture management properties. Clothing can amplify the wetness sensation that comes from the body's sweating mechanism. While sweating is intended to cool the body it also is related to increased discomfort sensations. Sweat wets the skin and causes the clothing to become sticky which increases the friction of the skin to clothing interface. This is a strong tactile sensation that is generally interpreted as uncomfortable. Clothing that can transport this moisture away from the skin will both allow the body to cool at the same time as avoiding this additional discomfort reaction (Havenith, 2002). The two methods by which moisture is moved from the skin into the atmosphere are diffusion and wicking. Fiber type and fabric construction dictate the ability of a fabric to perform these actions (Ramachandran & Kesavaraja, 2004).

The Performance Apparel Market

The market for athletic wear is ruled by synthetic fabrics with moisture wicking treatments to overcome their hydrophobicity (Ozer et al., 2007). Nearly 90% of the athletic wear market consists of sportswear products with moisture management properties (Ozer et al., 2007). As performance increases for these products, the competition to become the best is increasingly crowded, in order to capture the growing market which is accustomed to features in addition to function.

The best way to look at the landscape of this market is to have a look at the money being spent on this product in the United States. Tables 2.1 and 2.2 give information on the spending of Americans for active sportswear. The size of the US market for this product category will give some indication as to how much of an impact this product category has on the apparel and textile markets in general. The source of this information is the book *Household Spending* (2005) which is a reference source that provides information on the amount of money the average American consumer is spending on all types of products. They include a textile section in the book, and within this section there is data for "active sportswear" (New Strategist Publications, Inc, 2005).

The data presented from the *Household Spending* book is from 2003, and is divided along lines of age and before tax income. In the spending data broken down by age there are seven groupings of age beginning with under 25 and as high as 75 and up. The spending numbers for the full population are also given. The numbers shown in the charts below are the annual per person spending figures in US dollars. The numbers reported in the *Household Spending* book are reported as annual spending in US dollars per 'consumer unit'. The *Household Spending* book also gives the number of people per consumer unit. This number was multiplied by the figures for spending per consumer unit in order to obtain the per person spending figures which are represented in the tables below.

One thing that is obvious by looking at the numbers for the total population is that the money being spent on female active sportswear is greater than the money being spent on male active sportswear. One thing the numbers do not tell is whether this is the case due to higher prices of female sportswear garments, or if it indicates that females on average are buying more activewear than are their male counterparts. In one age group, Age 35 to 44, more money was spent on male activewear than on female activewear. The rest of the groups reflected the same picture as the total population being that more money was spent on female rather than male activewear.

Looking at the age data it is clear to see that the highest purchasers are those who are old enough to hold a career level job yet are young enough that they are likely to exercise regularly. Ages 25-54 are the top purchasers of these garments. This may be to some degree that these groups are buying higher end versions of these products rather than a higher quantity of these products. The lowest spending age group are those age 75 and above. This is likely attributable to the fact that those in this age category are exercising less. It may also be attributable to the fact that persons from this generation still consider cotton t-shirts to be the standard bearer for athletic apparel. All spending data as arranged by age is show in Table 2.1.

Table 2.1 – Household Spending on Active Sportswear by Age (2003)
(annual average per person in US $)

Category	**Under 25**	**25 to 34**	**35 to 44**	**45 to 54**	**55 to 64**	**65 to 74**	**75+**	**Average**
Men's Active Sportswear	$28.40	$34.54	$80.93	$68.30	$29.78	$30.61	$6.27	$44.93
Women's Active Sportswear	$49.87	$98.46	$74.72	$70.49	$41.24	$59.49	$26.51	$65.10
Total	**$78.27**	**$133.00**	**$155.65**	**$138.79**	**$71.02**	**$90.10**	**$32.78**	**$110.03**

Source: New Strategist Publications, Inc. (2005). *Household Spending : Who spends how much on what.* (10th ed.). Ithaca, N.Y.: New Strategist Publications.

More money per person is being spent on female activewear as compared to male activewear. Again, being that this is raw data no insight is given as to the reason for the disparity in money spent on female active sportswear as contrasted to the amount being spent on male active sportswear. All of the income groups in the annual household income table reflected this trend of greater expenditure on female active sportswear with the exception of one. The top earning income group, those earning $100,000 per year and above, spent more money on male active sportswear than on female active sportswear. As would be expected the spending on active sportswear increases with increased income. Conventional wisdom says that with more spending power comes more spending. There was one group that was 'out of order' for this trend; the income range of $40,000 to $49,000 actually spent slightly less money, at an average of $82.63 per person, than the group of those who earned $20,000 to $39,000 annually, who spent an average of $98.95 per person. All data for household spending as delineated by income is represented in Table 2.2.

Table 2.2 - Household Spending on Active Sportswear by Income (2003)
(annual average per person in US $)

Category	Under $20,000	$20,000 to $39,999	$40,000 to $49,999	$50,000 to $69,999	$70,000 to $79,999	$80,000 to $99,999	$100,000 and above	Average
Men's Active Sportswear	$15.03	$26.47	$19.06	$52.86	$91.11	$79.89	$216.78	$49.20
Women's Active Sportswear	$34.27	$72.48	$63.57	$75.18	$80.13	$116.88	$157.07	$71.85
Total	**$49.30**	**$98.95**	**$82.63**	**$128.04**	**$171.24**	**$196.77**	**$373.85**	**$121.05**

Source: New Strategist Publications, Inc. (2005). *Household Spending : Who spends how much on what.* (10th ed.). Ithaca, N.Y.: New Strategist Publications.

Another means of gauging the strength of the athletic performance apparel market, is to look at markets outside the United States for this textile market category. Work done by Subhash Anand (2003) analyzes the European market for activewear and sportswear. Anand states that the market is very broad with an extremely wide range of applications for various sports as well as a wide range of levels of sophistication, noting that products exist for everyone from the professional athlete who has customized performance wear to the average customer who may only wear the apparel for its fashion appeal (Anand, 2003). Anand also attributes this as a catalyst to much of the growth within this market.

Anand learns from Peirre Duffar, DuPont's European sportswear manager that sportswear sales in the European (EU15) market were worth $21.1 Billion at the time of the report, and that $18 Billion of that was representative of sports apparel sales, with the rest being footwear. A Key Note survey was also profiled by Anand which reports that in 2002, sales in the United Kingdom alone were £4.05 Billion ($7.3 Billion) and £2.9 Billion ($4.73 Billion) of that was spent on the sportswear apparel portion of that market. The Key Note study continues to say that the £4.05 Billion figure represents 10.3% of the entire UK apparel and footwear market.

It is also important to gain a global perspective and dig deeper within the broad sportswear market to the performance apparel sector within the sportswear category. This is the precise category with which this study is concerned. A report released by *just-style.com* states that the performance apparel segment is responsible for 10% of the overall global sportswear market. *Just-Style.com* has a Global Market Review states that this segment is still in its growth phase and is 'coming of age' (*Global market review of performance apparel - forecast to 2012 - 2006 edition,* 2006), suggesting significant room for growth.

One factor pointing to the 'coming of age' of the performance sector of sportswear is, as *Just-Style.com* reports it, is that consumers are beginning to move away from being impressed by performance in their activewear and are moving toward developing an expectation of these performance characteristics when they go to purchase athletic apparel (*Global market review of performance apparel - forecast to 2012 - 2006 edition,* 2006). This fact alone points to the growth of the segment, as any product seeks to one day achieve ubiquitous status in the mind of the consumer. Finally *Just-Style* makes a market forecast for the performance apparel market in the United States, predicting that the performance apparel segment of the sportswear market category will be worth $4.29 Billion by the year 2012 (*Global market review of performance apparel - forecast to 2012 - 2006 edition,* 2006). This report was published in 2006, and makes predictions for the year 2012 based on growth and market trends.

One final thought on the growth of athletic performance apparel markets around the world is provided by Anand, as he notes that there is an increased importance placed on athletic performance apparel for fashion purposes. Anand notes that of the sportswear purchased only 25% of it was actually used for active or athletic purposes (Anand, 2003).

Companies and Their Products – Past and Present

The first quarter 2007 edition (volume 20) of *Textiles Intelligence* was focused on performance apparel markets. Within this issue was an excellent source of information on the history of the performance textile market as well as a wealth of information on the current offerings from companies within the performance textile market. This information was specifically related to the manufacture of fibers for performance textile, but is not limited to fiber producing companies.

The first company to produce a moisture management fabric was called Damart. They made a product called Thermolactyl in 1953 which garnered the nickname 'magical fiber'. In the 1970's polypropylene became popular in the market of high performance and in 1986 DuPont came out with CoolMax®. DuPont® has since divested and sold their textile segment which today is known as Invista™. Today Invista™ is the dominant player in the performance apparel sector with their moisture management line of fabrics which include such brands as CoolMax®, Tactel®, Aquator®, ThermaStat®, Thermax®, and Thermolite® (Performance apparel markets, 2007).

While Invista's strength has been noticeable in the market, the growth of the market itself has fueled the entry of many other companies into the performance fabric market. Such companies include: American Fibers and Yarn®, Comfort Technologies®, Hind®, Honeywell®, Intera®, Lenzing®, Marmot®, Milliken®, Mitsui®, Nano-Tex®, Nike®, Patagonia®, Pearl Izumi®, Polartec®, Reebok®, Rhovyl®, Schoeller®, Tomen®, USA-Pro® and Wellman® (Performance apparel markets, 2007).

This section will look at some of the more interesting product offerings shown in the 2007 issue of *Textiles Intelligence*, in order to show the variety of materials and processes that are being used in the performance apparel market today. As consumers begin to expect more from their athletic wear, more companies are refocusing their effort from volume to performance in order to stay in step with the changing marketplace. These companies primarily use moisture management and other performance claims as unique ways to market their products; the following are several companies' latest offerings to the fields of moisture management and wicking, odor resistance, and environmental awareness (Performance apparel markets, 2007).

Moisture Management / Wicking Products

- American Fibers and Yarn Company® has a product called Innova™ which is made from a byproduct gleaned from post-industrial waste. These yarns are 40% lighter than polyester and 25% lighter than polyamides. They transfer moisture in the vapor phase to the fabric's exterior (Performance apparel markets, 2007).

- Comfort Technologies® has two products, Akwatek™ and Akwadyne™ which are polyester and polyamide fibers respectively. These yarns transport moisture in an innovative way known as 'electrochemical transport' which is done by chemically and permanently modifying these fibers surfaces. These two fabrics are unique because they do not use capillary action in order to transport moisture to the exterior of the garment. The result of this is that the garment does not need to be worn close to the skin in order to achieve effective moisture management (Performance apparel markets, 2007).

- Hind® is an athletic fabric company that produces a product called Drylete™. This is a yarn made from a combination of hydrophobic polyester, hydro polyamide (hydrophilic) and Lycra. This material works on the 'push-pull' mechanism of moisture transport (Performance apparel markets, 2007).

- Invista® has long held the advantage in the industry with its well marketed CoolMax® product, which was first used in the 1984 Olympic Games by top athletes in Los Angeles, and now is used for a broad range of products. This product is simple in theory as it is a polyester yarn. The unique thing about CoolMax® is that is has a cross-section that optimizes the surface area of the fibers. Each fiber has either four or six channels on its surface depending on the product in use. The six channel fiber for example has three channels on each side of the fiber taking the surface area far beyond what most fibers have to offer. CoolMax® holds solid claims to be the fastest drying, best wicking, and most highly breathable product on the market (Performance apparel markets, 2007).

- Tencel™ is a product made by Lenzing®, and is their brand for lyocell, a wood pulp cellulose product. Tencel™ is 50% more absorbent than cotton and has much greater durability, likened to the durability to synthetic fibers. The increased absorbency is due to nanofibrils in the fiber (Performance apparel markets, 2007).

- Milliken® and Company produces Dryline™ which is a bi-component with polyester facing the skin and polyamide on the exterior. This product is also based on the 'push-pull' mechanism whereby the interior polyester layer moves moisture to the exterior hydrophilic polyamide where it is evaporated (Performance apparel markets, 2007).

- Nano-Tex® has introduced Nano-Dry™ which utilizes nanotechnology in order to change the product at the molecular level in order to facilitate wicking (Performance apparel markets, 2007).

- Dri-Fit™ by Nike® works on the basis of the 'push-pull' technique, and is made from microfiber polyester (Performance apparel markets, 2007).

Odor Resistant Product

- Intera™ is a product created by a company of the same name which is made from treated polyester. Hydrophilic molecules are bound to hydrophobic polyester in order to draw up moisture for evaporation. An additional benefit is that the inherent hydrophobicity of the polyester prevents the growth of odor causing bacteria, which relies on moisture for growth (Performance apparel markets, 2007).

Environmentally Conscious Product

- Finally on the ‘green’, or ‘sustainability’ front, there is EcoSpun™ by Wellman® which is a polyester fiber with breathability and wicking traits. The unique aspect with this product is that it is made entirely from recycled plastic bottles (Performance apparel markets, 2007).

CHAPTER III

RESEARCH METHODOLOGY

Purpose

The purpose of this study is to utilize the technological advances of the Coppelius Advanced Sweating Manikin at NCSU in cooperation with more traditional objective comfort measurement methods to evaluate the comfort of performance athletic apparel and to utilize market research to determine the most important comfort descriptors to the athletic apparel consumer, as well as determine the significance of the overall athletic apparel market. Objectives 3 through 10 have yet to be addressed and will be met in the results section in chapter four. The objectives of this study are to:

1. Collect and review information on the elements of comfort, and their role as a part of the larger comfort perception. This objective was met in the chapter two review of literature.
2. Collect and review information on measures commonly used in the quantitative evaluation of comfort. This objective was also met in the review of literature in chapter two.
3. Perform a market survey to collect information on the qualitative comfort descriptors most important to athletic apparel consumers, and to quantify the significance of the athletic apparel market. This involved three steps:
    a. Identify the core consumer groups most likely to use the product via purchase history data.

b. Look at purchase decision factor for apparel purchases.

c. Evaluate the importance placed on comfort parameters of an athletic performance t-shirt.

   i. Analyze decision parameter and comfort parameter responses by comparing for each one:

      1. US Market v/s International Market

      2. Age Differences

      3. Gender Differences

      4. Income Differences *(data available in US group only)*

4. Select candidate garments for use in fabric level comfort testing as well as garment level comfort testing.

5. Select quantitative comfort measures to test in order to match the most important consumer identified qualitative comfort descriptors.

6. Identify test methods most ideally suited to quantitatively measure the desired comfort parameters.

7. Perform fabric level comfort testing on candidate materials, using selected fabric level testing methods, in order to determine fabric level performance of the material.

8. Perform garment level comfort testing, utilizing the Coppelius Advanced Sweating Thermal Manikin, to determine the garment level performance characteristics of the candidate materials.

9. Evaluate the performance of the candidate fabrics and their respective garments, as a function of the results of the fabric and garment level tests.

10. Provide performance assessments of the candidate garments as defined by comfort testing results when the market survey results are taken into consideration.

Research Design

This study includes the collection of both primary and secondary data. In Part I of the study, secondary data was used in order to gain an understanding of the background of comfort research, as well as to gather a concept of the financial significance, the size and growth, of the athletic apparel market. Part II consisted of the gathering of primary data, both on the market side and on the technical side. The first step of Part II was to perform a Market Survey in order to help identify the qualitative comfort descriptors that are most important to the athletic apparel consumer, as well as gain a clear picture of the market for this product. This information gathered in the market survey was paired with the testing data generated by quantitative comfort testing. The analysis of the primary data was be used to make recommendations as to the candidate fabrics and garments which best fit the consumer desired qualitative comfort descriptors, as well as those that best performed in the traditional comfort testing. Table 3.1 shows how each of the Research Objectives were met and where they are discussed in this document. Table 3.1 also pairs each research objective with the part of the study in which that research objective was met; either Part I with secondary research or Part II with primary research.

Table 3.1 – Research Objectives and Where They are Met.

Research Objective:	Objective Covered in Chapter:	Objective met in Research Part:
Research Objective 1	Chapter Two	Part I – Secondary Research
Research Objective 2	Chapter Two	Part I – Secondary Research
Research Objective 3	Chapters Three and Four	Part II – Primary Research
Research Objective 4	Chapter Three	Part II – Primary Research
Research Objective 5	Chapter Four	Part II – Primary Research
Research Objective 6	Chapter Three	Part II – Primary Research
Research Objective 7	Chapters Three and Four	Part II – Primary Research
Research Objective 8	Chapters Three and Four	Part II – Primary Research
Research Objective 9	Chapter Four	Part II – Primary Research
Research Objective 10	Chapter Four	Part II – Primary Research

Part I - Secondary Research

Part I of this research will involved gathering secondary data from the fields of comfort study. This aids in obtaining an understanding of the concepts of comfort, as well as helps to build a set of parameters within which to develop the methods to be used in Part II (the primary research) of the study. The information in Part I of the research can be found in Chapter two, as literature on a variety of comfort topics is reviewed. The market research done in this phase is used to develop a picture of the market for performance athletic apparel; identifying how large the athletic apparel market is, and how its growth is trending.

Part II – Primary Research

Part II of this research is the primary research stage where a market survey will be performed as well as selection, testing and evaluation of the candidate garments and their fabrics. The information from Part I will be used in aiding the decisions on the selection of garments for the testing in Part II. The results of the market survey will help determine which tests to perform and which tests are most important to the consumer. Quantitative measurements of selected comfort parameters will be taken with the standardized testing of the candidate garments and their fabrics. After the candidate fabrics and garments have been chosen, the fabric level tests to be run will be chosen based on the appropriate comfort parameters to be measured. Again, the selection of these tests is aided by the qualitative comfort descriptors that are discovered in the market survey. The results from these tests, in addition to the results gathered from testing with the Coppelius advanced sweating Manikin will be used to determine which fabrics and garments are best suited to meet the needs of the customers in terms of matching the customer's comfort demands and expectations.

Market Survey

The market survey is an integral portion of this study. It aids in the selection of tests to perform on the garments selected as well as gives a portrait of the consumer market in terms of their views on the various aspects of comfort as it relates to t-shirts. This descriptive research will give added significance to the values gathered in the testing phase. Rather than simply reporting on the performance of the candidate garments in the various tests, it will be possible to report on their performance and follow that with a report on how much importance is placed on the comfort ingredient that is associated with each test. In the end this will allow for an assessment of the candidate garments in terms of how well they meet the consumer desired aspects of comfort.

Survey Development and Implementation

The market survey was originally developed in the spring of 2007. The first step of developing this survey was a meeting in the Textile Protection and Comfort Center (TPACC), at the North Carolina State University College of Textiles, with Dr. Roger Barker. This meeting allowed for an understanding of the testing capability of the labs at TPACC as well as an understanding of some of the basic elements of traditional comfort study. Also an understanding was gained as to which characteristics of comfort (ex. soft hand, breathable, etc.) could be qualitatively tested at the TPACC labs. This allowed the development of a list of questions about the various comfort descriptors or characteristics that would need to be asked to the public. The comfort descriptors were identified with an understanding of the testing capabilities at the TPACC labs as combined with the marketing claims on performance products as seen in the marketplace. A meeting with Dr. Nancy Cassill was held to determine the best market research methodology which would allow for the collection of the highest level of data possible from the consumers in the marketplace. In meeting with Dr. Cassill a list of questions was developed which would give the best picture of the public's view on each of the identified comfort descriptors.

With the survey's questionnaire assembled, Marshal Cohen, Chief Industry Analyst for NPD, was contacted and agreed to help to administer this survey. Mr. Cohen is the Chief Industry Analyst who is responsible for the apparel industry research branch of NPD. The NPD Group, (formerly National Panel Diary) founded in 1967, is the leading global provider of consumer and retail market research information for a wide range of industries. NPD provides critical consumer behavior and point-of-sale (POS) information as well as expertise across more industries than any other market research company. Through their consumer panel, retail sales tracking services, special reports, and custom research, NPD helps their clients understand and profit from consumer and retail trends (NPD website.2007). NPD's website is http://www.npd.com.

The large Consumer Panel which NPD has collected is what was needed to get this questionnaire out to the purchasing public. The full size of NPD's consumer panel is over 3 Million people which helps them to provide information about consumer behaviors and attitudes in many different industries (NPD website.2007). Mr. Cohen agreed to take the questionnaire and help to revise it to best fit the format with which their panel is accustomed. He then submitted the questionnaire to part of the NPD consumer panel. After NPD took the questionnaire and made a few adjustments to the questions in order to fit their format, the questionnaire was sent out in late August of 2007. The answers to the survey questions were returned by Mr. Cohen in late September of 2007; a few additional questions for NPD internal interest were included, but will not be reported on in this study.

Instrument Development

When the time came to formulate the survey instrument, the most important task was to ask the right questions. The survey needed to address the specific comfort parameters that were able to be measured by modern scientific methods. The parameters chosen to be included in the survey were: Moisture Management, Cooling, Soft Hand, Fit, and Breathability. There are quantitative methods in the NCSU TPACC lab to measure all of these comfort factors except for fit which was included to get an idea of its importance relative to the importance of the other comfort parameters. Questions were developed in three categories to uncover three different types of information. Table 3.2 shows each question and gives information about which type of data the question was developed to generate, as well as the parameters the question was addressing.

The questionnaire consisted of eleven questions, nine of which were used in this research, and two of which were included by NPD for their own internal use. The questionnaire can be found at the end of section A.1 of the Appendix. Two questions addressed purchase history, and were asked in a ‘yes/no’ format. These questions were used to identify target consumers who had most purchased performance athletic apparel in the past; they were also used to identify the proportion of consumers who consider comfort when making apparel purchases. One other question addressed the consumers’ feeling towards parameters that affect the decision to purchase apparel in general, such as price or style/color. Finally, six questions addressed the consumers’ feelings about specific elements of comfort. Five of these questions were each devoted to one comfort element, which was asked in order to gain an understanding of the importance placed on each individual comfort parameter by the consumers; these questions were on a likert scale of ‘very important’, ‘important’, and ‘not important’, whereby one option was chosen. These five questions were used in the determination of how important each comfort characteristic was; this was done by using the percentage of consumers who chose ‘very important’ for each comfort aspect. Each question is listed in Table 3.2, where detailed information is given about each question.

Table 3.2 – Instrument Element Details

Question	Data Scale	Parameters Addressed
Have you ever purchased apparel with comfort in mind? [yes/no]	Dichotomous Scale	**Purchase History**
Have you ever purchased a t-shirt for sports/athletic use? [yes/no]	Dichotomous Scale	**Purchase History**
Which of the following factors are important to you when purchasing apparel? [Select all that apply]	Nominal Scale 6 options	**Purchase Decision:** Importance of: • Price • Fit • Comfort • Moisture Management • Style/Color • Other
Which of the following factors do you consider to be the most important in a t-shirt? [Select all that apply]	Nominal Scale 6 options	**Purchase Decision:** Importance of: • Moisture Management • Cooling • Soft Hand • Fit • Breathability • Other
How important are the following features in t-shirts? : **Moisture Management** (Very Important, Important, Not Important) ; [Select One]	Likert Scale 3 Levels	**Comfort Feature:** Importance of Moisture Management
How important are the following features in t-shirts? : **Cooling** (Very Important, Important, Not Important) ; [Select One]	Likert Scale 3 Levels	**Comfort Feature:** Importance of Cooling
How important are the following features in t-shirts? : **Soft Material (Hand)** (Very Important, Important, Not Important) ; [Select One]	Likert Scale 3 Levels	**Comfort Feature:** Importance of Soft Hand
How important are the following features in t-shirts? : **Good Fit and Mobility** (Very Important, Important, Not Important) ; [Select One]	Likert Scale 3 Levels	**Comfort Feature:** Importance of Fit
How important are the following features in t-shirts? : **Breathable** (Very Important, Important, Not Important) ; [Select One]	Likert Scale 3 Levels	**Comfort Feature:** Importance of Breathability

Survey Purpose

When the survey was returned at the end of September 2007 it was then evaluated to uncover what the results said about the consumers and their answers to the questions posed. The first step was organizing the data, which was returned in excel files, into an organized table format. These tables are arranged such that they give the responses to each question by age and gender. There were six age categories with responses for males and females in each category. There was also separate data for consumers in the United States and from those who were International consumers. Within the data for the United States there was also an iteration of the data that was reported by Income Level. There were 12 categories of income levels and this allowed for comparison based on household income of the respondents from the United States.

The analysis of the data gathered by NPD is included in chapter four and will have two purposes. One purpose will be to gain an understanding as to how important comfort factors are to the consumer. This will aid in emphasizing test results of highly desirable comfort parameters over those which are identified as less desirable by the consumers in the survey. The other purpose of the survey is to gain an understanding of the market for performance athletic apparel. With the purchase history data generated by this survey it is possible to pick out a demographic from the full survey population and to declare them as a core market. Then it will be possible to know exactly to which demographic the marketing efforts for such products should be aimed.

The ultimate goal of determining which comfort characteristics are the most important to the consumer is to have the ability to assess the candidate garments and their fabrics, as a function of their performance in light of the survey results. It will be possible to quantify the importance placed on each comfort characteristic with the data the NPD survey generated. This will allow each measured comfort parameter to be viewed in light of the demands of the consumer. If each comfort parameter is viewed in this way, it then becomes possible to compare one garment to another in terms of how well it meets the desires of the consumer. The possibility then opens up to compare the garments based on the views of the entire survey, or to compare them as based on the views of an identified core demographic group within the survey. Of course the option is also still open to compare the test results with no regard to consumer preferences.

Materials Selection

The first step in the testing phase of this research is to collect a good set of sample garments to test. The set of shirts tested should meet a very specific set of requirements. These requirements will dictate what samples are to be tested in this research. There are two overall categories of requirements used in the selection of the samples. The first type of requirement the sample set must meet was physical requirements. These must be met in order to ensure that the quantitative comfort measurements will yield data that can be assured to carry a high level of significance. This ensures that some traits of the sample shirts remain the same across the sample set in order to give no unfair advantage to any one garment; other traits, however, build in differences to compare the performance of samples which differ in selected ways.

The other category of requirements is that which is defined by market considerations. These ensure that the sample set will represent the performance athletic t-shirt market as much as possible. While it is not possible to fully satisfy this requirement, due to time and financial constraints, as much market variation as possible was built into the sample set in order to allow for comparison across a variety segments within the market for this product.

Physical Requirements

In the interest of uniformity and preventing extra variables, the garment construction to be used with Coppelius will be uniform; a traditional t-shirt cut was chosen as the standard. Small variations in construction will be allowed, such as a side or back panel rather than a simple side seam. The shirts selected for testing in this study are for the purpose of running or other high energy cardiovascular exercises. The sample t-shirts are best selected from a range of shirts that are designed specifically to be used in enhancing the performance of a runner. This is done in order to prevent a running shirt from being compared with a soccer or tennis shirt.

The body of Coppelius is designed after that of a man who would wear a size 40 shirt, meaning that Coppelius has a 40 inch chest circumference. With this in mind the set of tests samples will be selected from men's performance running shirts. Most shirts in this category will not be sized by number but rather by sizes such as small, medium, large and so forth. A strong effort will be made to choose samples that fit Coppelius, but not in such a manner that the shirts will be tight fitting. If the shirt is too tight, it would behave more like a 'compression shirt', which is a different category of performance athletic apparel. The best size to accomplish a good fit with room for a runner's mobility will not be uniform across all manufacturers; for instance not all of the shirts will necessarily be "medium" size shirts. In order to ensure a good fit for Coppelius, an individual with a matching 40 inch chest circumference was used to try on all shirts before purchase.

The attributes discussed thus far are mainly requirements which represent the characteristics that should be uniform across all of the samples. The remaining sample attributes are all variables that will be used in order to compare the performance of garments, and their fabrics, which do differ in these categories. The samples may display differing degrees of variation, depending on the attribute. These attributes are: fiber content, fabric construction, finish applied to the fabric, price (original retail, as well as retail markdown), national brand versus private label, and retail store versus specialty retail store (ex: Wal-Mart® versus Dick's Sporting Goods®). Another attribute that will be considered in the comparison of samples within the sample set is the performance claims that are included on the garment's labeling. Finally, any finish information that is available will also be considered. A control shirt has also been added that is composed of 100% cotton; this was done to compare all materials in the study to the traditional cotton t-shirt.

Market Considerations in Sample Selection

The performance athletic apparel market is relatively young and has grown rapidly since it began growing in the late 1990's. This leaves plenty of options from which to choose when developing the sample set. In order to choose a limited number of samples, while at the same time gaining a sufficient representation of the marketplace, there are a few considerations to be made. The decision was made to focus on three areas of differentiation when trying to develop a market-representative sample set. The first area was that of *Market Share*. It was important to ensure that some of the samples included in the sample set represented the largest players in this market. The 2006 edition of Market Share Reporter (Gale Research Inc, 2006) reveals that the two largest companies in this market in 2005 were

Under Armour® with a 46.18% share and Nike® with a 28.06% share (Gale Research Inc, 2006). Another area of consideration was *Retail Channel*. Samples were needed from both specialty and mass merchant retailers in order to capture a representative of these two retail channels. Specialty retailers such as REI® were sought while mass merchants such as Target® were also looked to for purchasing samples. The final market consideration used was *Branding Strategy*. Brands were sought from several areas; national brands such as Under Armour® and Nike® were one area to represent, while private label brands were also important to include. Private label brands were used from both specialty and mass merchants. An exclusive brand was also included in sample C, which sells only at one chain of retail stores, but is made by a national brand.

The Sample Set

The samples for this research were chosen to best satisfy the physical and market requirements given above. There are seven garments in this study and they are similar in many aspects and unique in others. Tables 3.3 through 3.5 have the information for the sample set, in alphabetical order, in tabular format for quick comparison. The garments will be detailed in alphabetical order according to the acronyms which are used to represent them in the testing phase of this study.

- ***100% Cotton Tee (Garment A)***

  This shirt was purchased to be a control for the testing in this research. It is a 100% cotton short sleeve t-shirt with no additional side or back panels. The A shirt and its fabric is abbreviated "A" in the testing phase. The garment selected to fit the manikin was a size ‘large’. The fabric is a single jersey knit, with a basis weight of 5.633 oz/yd^2. No special marketing claims are made for this garment since it is not a performance piece of apparel. This garment was purchased for $19.99 from a specialty retailer.

- ***Garment B***

In the testing phase Garment B or fabric from Garment B is abbreviated “B”. The garment selected to fit the manikin was a size ‘small’, where the rest of the samples in the set were size ‘large’; this indicates a scaled up sizing system for this garment compared to most brands. The garment is a 100% polyester double knit short sleeve t-shirt with no additional side or back panels. The fabric in this garment has a basis weight of 3.978 oz/yd^2. This garment was priced at $7.68 from a mass retailer. The marketing claims made for this garment are that it wicks moisture and keeps you cool and dry.

- ***Garment C***

In the testing phase Garment C and its fabric are abbreviated “C”. The shirt purchased to fit the manikin was a size ‘large’. This shirt is 100% polyester and the fabric construction is a warp knit mesh fabric, with a basis weight of 3.179 oz/yd^2. The garment construction is a short sleeve t-shirt with side panels of a warp knit mesh knit construction. The marketing claims made for this garment are that it wicks moisture and keeps you cool and dry. This garment was purchased for a $14.99 retail price and is a private brand for a mass retailer and is made by a national brand.

- ***Garment D***

Garment D and its fabric are abbreviated “D” in the testing phase of the research. The garment purchased for the manikin was a size ‘large’. The marketing claims made for this garment are that it wicks moisture and keeps you cool and dry; the claim is also made that the garment has antimicrobial performance. This garment is a 100% polyester short sleeve t-shirt with a fabric basis weight of 4.620 oz/yd^2 and a double knit cellular fabric construction. This garment also has side panels of single jersey knit construction. This shirt was purchased at a specialty retailer for a retail price of $24.99.

- **Garment E**

Garment E is an international brand that is independent of any private label affiliation with any specific retail entities. In the testing phase Garment E and its fabric are abbreviated “E”. The garment selected to fit the manikin was a size ‘large’. The garment is a 100% polyester single jersey knit short sleeve t-shirt with side panels of a single jersey mesh knit construction. The fabric basis weight is 4.131 oz/yd^2. The marketing claims made for this garment are that it wicks perspiration and keeps you dry and comfortable. This garment was also found at a specialty retailer for a price of $35.00, but was purchased at a markdown price of $24.99.

- ***Garment F***

In the testing phase Garment F and its fabric are labeled “F”. The garment selected to fit the manikin was a size ‘large’. The marketing claims made for this garment are that it wicks moisture, dries fast, and is stretchy for ease of movement. The fabric in this garment has a basis weight of 5.156 oz/yd^2. The garment is a 100% polyester single jersey knit short sleeve t-shirt with no additional side or rear panels. This garment was purchased at a specialty retailer for a retail price of $22.00.

- ***Garment G***

This shirt is a 100% polyester short sleeve t-shirt of rib knit construction on the front, and double knit mesh fabric construction on the back. Garment G has a rear panel large enough that it warrants testing of its own. The abbreviation for this rear panel, in the testing phase, is “Gb” or “G_b” when possible. The rear panel has a fabric basis weight of 3.268 oz /yd^2. The abbreviation for the front of the shirt is “Gf” or “G_f” when possible. The front of the shirt has a fabric basis weight of 4.081 oz/yd^2. The garment selected to fit the manikin was a size ‘large’. The marketing claims made for this garment are that it wicks moisture from the skin and keeps you dry with a consistent body temperature. Garment G is an independent international brand with no specific ties to any retail stores. This shirt was purchased from a specialty retail store at the retail price of $39.99.

Tables 3.3 and 3.4 give the information for the shirts used in this study in a concise format. Table 3.5 gives the weight and basis weight for the shirts. The basis weight was taken by weighing four 5” X 5” samples and taking their average. This figure allows for the calculation of basis weight. Also the garment weight was taken for the shirts that were purchased to fit the manikin. All samples wee weighed with the Mettler PM460 scale, and all measurements are taken in grams.

Table 3.3 - Information for Candidate Garments in Testing Sample Set.

	Garment A	**Garment B**	**Garment C**	**Garment D**
Abbreviation	"A"	"B"	"C"	"D"
Main Fabric Structure	Single Jersey Knit	Double Knit	Warp Knit Mesh	Double Knit Cellular
Fiber Content	100% cotton	100% polyester	100% polyester	100% polyester
Performance Claims	N/A	Wicking, Cool, Dry	Wicking, Cool, Dry	Wicking, Cool, Dry, Antimicrobial
Cost	$19.99 (retail)	$7.68 (retail)	$14.99 (retail)	$24.99 (retail)
Brand or Private Label	N/A	Private Label	Exclusive Brand	Private Label
Retail or Specialty	Specialty	Retail	Retail	Specialty

Table 3.4 - Information for Candidate Garments in Testing Sample Set Continued

	Garment E	**Garment F**	**Garment G**
Abbreviation	"E"	"F"	"G", "G_f", and "G_b"
Main Fabric Structure	Single Jersey Knit	Single Jersey Knit	Front – Rib Knit Back – Double Knit Mesh
Fiber Content	100% polyester	100% polyester	100% polyester
Performance Claims	Wicking, Dry, Comfortable	Wicking, Fast drying, Stretchy for movement	Wicking, Dry, Consistent body temperature
Cost	$24.99 (markdown) $35.00 (retail)	$22.00 (retail)	$39.99 (retail)
Brand or Private Label	Brand	Private Label	Brand
Retail or Specialty	Specialty	Specialty	Specialty

Table 3.5 – Weight and Basis Weight for Test Fabric (5" X 5" samples); Garment Weight Included (in grams)

Sample	Replicate 1 (grams)	Replicate 2 (grams)	Replicate 3 (grams)	Replicate 4 (grams)	Average (grams)	Basis Wt. (oz/yd^2)	Garment Weight (grams)
A	3.082	3.056	3.045	3.138	3.080	5.633	232.710g
B	2.166	2.150	2.161	2.223	2.175	3.978	124.380g
C	1.730	1.774	1.719	1.730	1.738	3.179	129.852g
D	2.558	2.510	2.524	2.514	2.527	4.620	175.158g
E	2.271	2.285	2.232	2.247	2.259	4.131	142.729g
F	2.830	2.834	2.832	2.782	2.820	5.165	181.259g
G_b	1.807	1.812	1.740	1.789	1.787	3.268	143.928g
G_f	2.234	2.285	2.232	2.247	2.259	4.081	143.928g

Sample Cutting

Aside from the shirts that were purchased to fit Coppelius's 40 inch chest, two other shirts of each type were purchased at the largest sizes available in the retail store. This was done in order to have as much fabric as possible to work with for the fabric level tests. From these shirts, fabric samples would be cut to test on smaller scale testing than Coppelius. The samples were cut from the garment and they were marked with their abbreviations in order to identify the fabric while minimizing the application of marker ink. Additionally, the samples were always marked on the exterior side, leaving the unmarked side designated as the skin side. This prevented the skin side, which will be the subject of the testing, from being marked by the ink; this was done to avoid the possibility that the results could be affected by ink on the skin/testing side of the fabric.

All samples were cut with the front of the shirt facing up, and the top of the shirt the farthest from the cutter, with the shirt tail closest to the table's edge. This ensures that all samples are cut in the garment orientation, with markings on the top left corner of each sample. To prepare samples for the testing three 20cm by 20cm squares were cut for use in the Kawabata Evaluation System (KES). Four 5 inch by 5 inch samples were cut for use in the KES thickness tester, and in the Thermolabo Testing. Also a circular die of 3.5 inches in diameter was used to cut 10 circular samples for use in the Gravimetric Absorbency Tester (GATTS) Test, as well as in the drying test. The sample cutting method can be seen in Figure 3.1.

Figure 3.1 - Sample Cutting Pattern

Testing

The Textile Protection and Comfort Center (TPACC), at NC State's College of Textiles, has all the necessary testing equipment to perform the necessary physical fabric level and garment level tests for this research. All testing was performed in the TPACC labs with the cooperation and supervision of their trained and professional staff. The first testing to be done was the fabric level testing. This was followed by the garment level manikin testing; dry manikin testing was done first, and the wet manikin testing followed.

Fabric Level Testing

The two phases of quantitative comfort measurement began with the fabric level testing phase. This phase consisted of four types of tests each geared at measuring a different aspect of comfort and discovering how the sample set measured up in each aspect. The first test was the Kawabata Evaluation System (KES). This system measures the hand properties of the fabric with five tests performed on four different machines. The second type of test performed was the Kawabata Thermolabo Test, also called the guarded sweating hot plate test. This test measures the cooling and breathability properties of the fabric. The third test type performed at the fabric level was the Gravimetric Absorbency Testing System (GATS) which is primarily used in the measurement of the moisture management properties of the fabric. The forth type of test on the fabric was a follow up of the GATS test, and is called the drying test. This also measures an aspect of the moisture management properties of the fabric. These tests collectively speak to the comfort of the fabric, while the manikin speaks to the same comfort parameters, (with the exception of hand), at the garment level.

Fabric Weights

The weight of the garments were taken based on the ASTM D 3776 method for weighing fabric, with one deviation from the method being sample size and replications. In method D 3776, three samples are weighed with dimensions 20cm X 20cm whereas in this research four samples with dimensions 5" X 5" were weighed. The samples were weighed using an Uster Autosorter III Mettler PM460 scale with a Delta Range accurate to the nearest 0.000 grams. The scale was tared between each measurement and the average of the four basis weight figures, as calculated from the four scale readings, was reported as the basis weight. The samples were weighed in grams and converted to fabric basis weight which carries units of oz./yd^2. The conversion calculation is below:

Basis weight = (grams of sample * 45.72) / 25

Kawabata Hand Evaluation System

One of the four measurable comfort parameters which were asked about in the survey is soft hand or “soft material” as it was worded in the questionnaire. This wording was chosen in order to deal in terms more familiar to the consumer. The most advanced system in use to measure the various aspect of fabric hand is the Kawabata Evaluation System (KES); it is the only measurement of hand included in this research, as there is no garment-level hand measurement system. Within the Kawabata system there are four different machines. The machines are called the KES-FB1 Tensile and Shear Tester, the KES-FB2 Bending Tester, the KES-FB3 Compression Tester, and the KES-FB4 Surface Tester. KES-FB1 is a machine that performs two different tests; as the name suggests the shearing test and the tensile test are performed using the KES-FB1 tensile and shearing tester. This is the only one of the four machines that performs two separate tests. The remaining machines perform one test each.

As with all testing in this research, the samples were continuously conditioned and tested in a controlled atmosphere of 21ºC and 65% Relative Humidity. Four of the five KES tests are performed both in the warp direction and in the fill direction. The only test that is not performed bi-directionally is the compression test as this test is performed down onto the fabric rather than across a direction of the fabric. Testing across the fabric requires separate testing for warp and fill directions, in order to gather a true representation of the fabric's hand properties.

KES-FB1 Kawabata Shearing Test.

The KES Shearing test is designed to determine how the fabric responds to flat torsion, which is applied by parallel forces that are asserted at opposite ends of the fabric and in opposing directions. This applies stress to the yarns being tested, weather it be the warp or fill direction. The size of the fabric samples used in this test is a square sample of 20cm X 20cm measurement. Three replications were performed in each direction; three samples were tested in the warp direction and three in the fill direction.

Before the test begins the fabric is loaded onto the KES-FB1 shear tester, which is shown in figure 3.2. A constant tension of 10gf/cm is placed on the sample to hold it fast during the test. These parallel forces move in opposite directions until they have caused the yarns in the fabric, which are perpendicular to the forces, to be moved to an angle of 8º from the resting point or true perpendicular. Figure 3.3 depicts the action described above which takes place in this test.

The measure generated by this test is called Shear Stiffness and is represented by the symbol (G). The units of Shear Stiffness are (gf/cm * degree). Shear Stiffness is a measure of how easily the fibers in the fabric slide against one another when under this shear stress. The lower the G value the less resistance there is to the shearing which denotes a softer fabric. This is also an indicator of a fabric which will have a better draping property. For athletic purposes a lower G is a plus due to the decreased resistance to movement. This decreased resistance means greater mobility in the garment during activity.

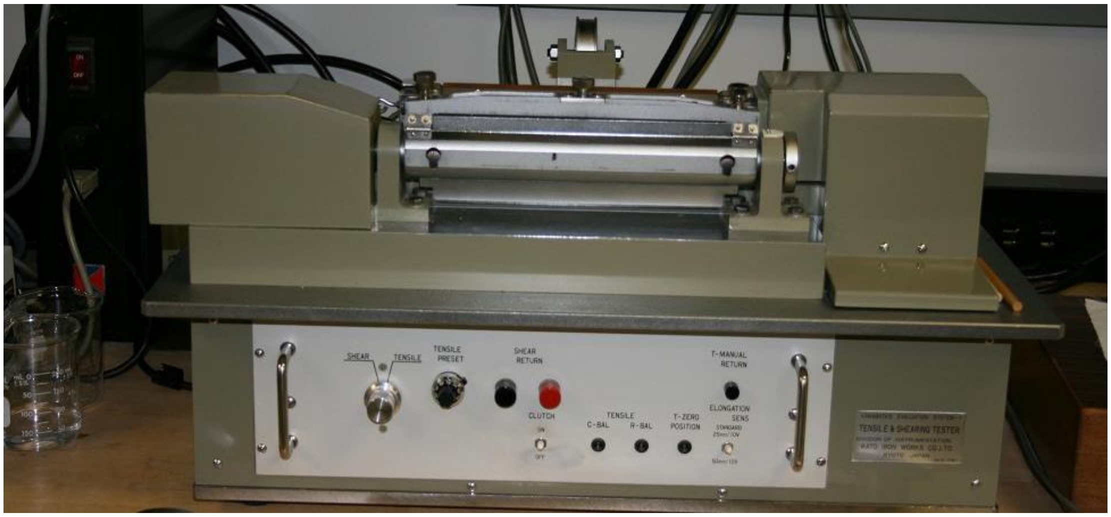

Figure 3.2 - KES-FB1 Tensile and Shear Tester

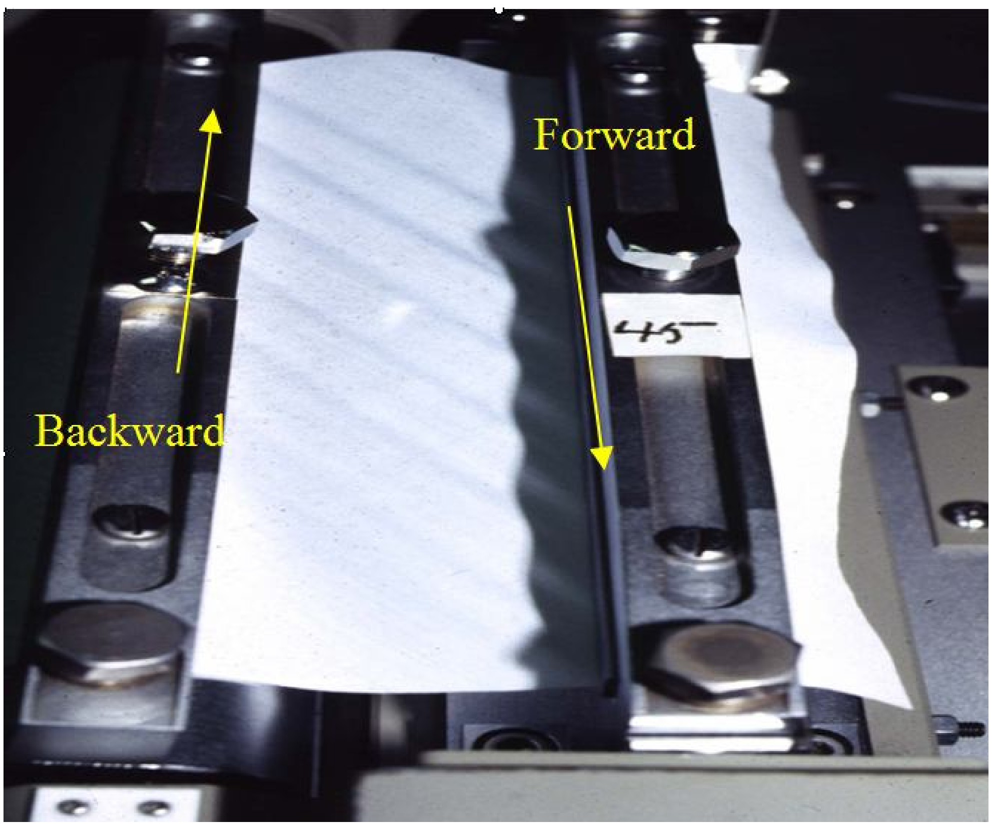

Figure 3.3 - Kawabata Shear Test Action

Source: Liston, G. (2007). *Sample report on TPACC comfort testing*

KES-FB1 Kawabata Tensile Test.

The Tensile Test is a bit simpler in concept than the Shear Test, but it is performed on the same machine; the KES-FB1 Tensile and shear tester, which is shown in figure 3.2. The same size sample of 20cm X 20cm is used. This test is also performed for both the warp and fill directions with three replications in each direction. The concept of this test is that the fabric is held fast on one end and on the opposite end a force is applied in the perpendicular direction to the hold point. The force applied to the fabric increases to a maximum load of 500gf/cm.

There are two measures generated by this test. The first is percent extensibility or percent stretch and is represented by the symbol (%EMT). This measure tells the amount of strain at the point when the force has reached the maximum level. A higher %EMT denotes a 'stretchy' fabric that yields to the force in an elastic action. For example a %EMT of 100% would be a fully elastic fabric which yielded fully under the load applied, while a %EMT of 0% would be a fully rigid fabric which did not yield at all under the load applied. It is important to note that the term 'yield' here does not mean break, as the 500gf/cm force applied is too light to break most fabrics, rather it means an internal deformation, or stretch, to accommodate the force applied. High %EMT is also ideal for athletic garments as an elastic fabric provides less resistance to movement.

The other measure provided by this test is the Tensile Resilience and is represented by the symbol (%RT). This measure tells how well the fabric recovers from the stretch applied at the beginning of the test, once that force is removed. A higher %RT would denote a fabric that has a greater recovery from the stretch experienced in the test. High %RT is a positive attribute for an athletic garment due to the need for this type of fabric to stretch with movement and return to its original state.   An image of the action which takes place in this test is seen in Figure 3.4.

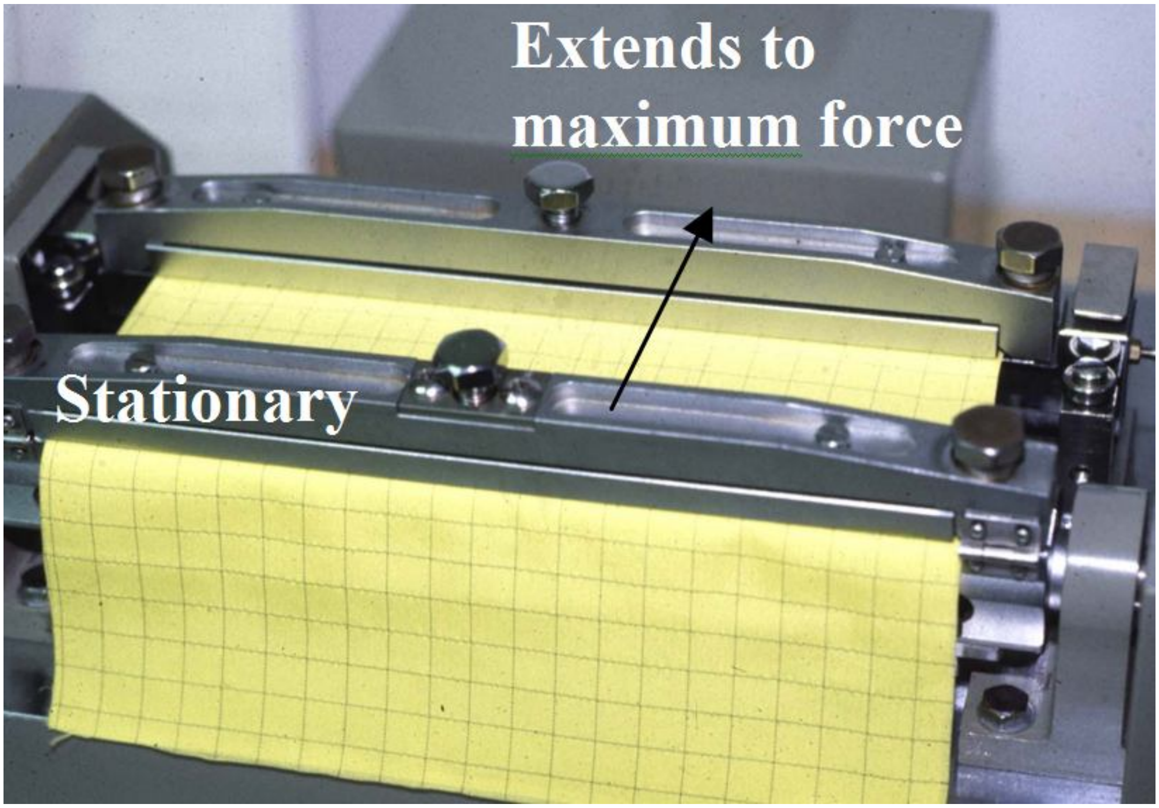

Figure 3.4 - Kawabata Tensile Testing Action

Source: Liston, G. (2007). *Sample report on TPACC comfort testing*

KES-FB2 Kawabata Bending Test.

The Kawabata Bending Test is performed on the KES-FB2 Bending Tester. This test is done in three replications of warp and three replications of fill, also using three 20cm X 20cm fabric samples. This test is performed as the fabric is fastened firmly into one stationary hold point, and to another hold point which rotates about the axis of the stationary hold point. This moving point bends the fabric to approximately 150º from resting point.

The KES-FB2 measures the force required to bend the fabric to that point in both directions, meaning the fabric is bent to 150º in one direction and then the moving point travels back past the resting point and to 150º in the other direction.

The measure provided by the Bending Test is called Bending Rigidity and is represented by the symbol (B). The units of Bending rigidity are ($gf*cm^2/cm$) which reflect bending rigidity per unit fabric width. This value is what indicates the amount of resistance the fabric gave to the 150º bend. A higher B value represents a fabric that has a greater stiffness and a greater resistance to bending motions, while a lower B value represents a fabric that gives less resistance to bending motions, and displays lower stiffness, which is ideal for athletic use. This is also a good predictor of drape. Images of the KES-FB2 Bending tester and of the test action in the Bending Test are shown in Figures 3.5 and 3.6.

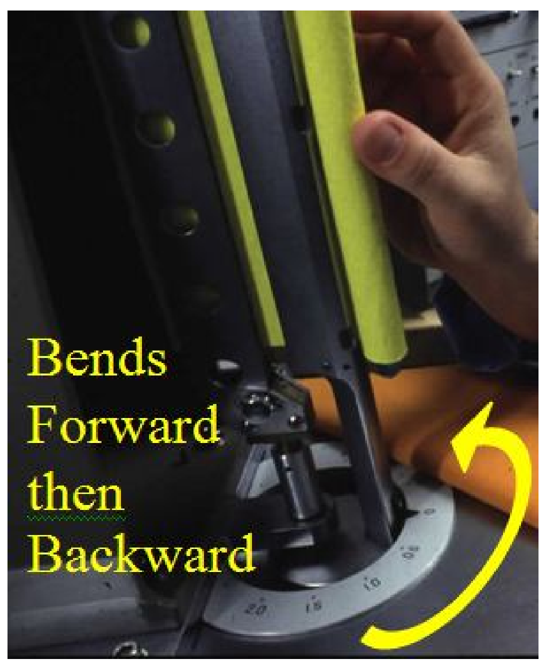

Figure 3.5 - KES-FB2 Bending Tester **Figure 3.6 - Kawabata Bend Test Action**

Source (Fig 3.6): Liston, G. (2007). *Sample report on TPACC comfort testing*

KES-FB3 Kawabata Compression Test.

The KES-FB3 Compression tester performs the Kawabata Compression Test. This test differs from the other KES tests as it is the only test that uses a differing sample size. This test also differs in that it is done only in one direction because warp and fill do not apply in this test as it is done by applying pressure onto the face of the fabric, with the skin side facing downward. There are three 5" X 5" samples used in this test, to provide three replications of test data. The test operates with small $2cm^2$ circle in the bottom of the surface of the tester. A small column also $2cm^2$ then slowly lowers onto the fabric at the location of this circle. The column lowers at a rate of 1mm/sec and eventually applies a force of $50gf/cm^2$ to the fabric, and during the process the KES-FB3 machine measures the compression properties of the $2cm^2$ area of fabric being impacted.

There are three measures provided by the Kawabata Compression Test. The first is Compressibility, which is denoted by the symbol (%EMC). This value represents the percentage of compression as calculated by comparing the initial thickness of the fabric to the thickness of the fabric when it is under the full 50 gf/cm^2 load. The higher the %EMC value the greater the fabric's compressibility is, while a lower %EMC represents a fabric which resists compression. A higher %EMC is a plus for general wear-comfort, due to the impact that compressibility has on the sensation of softness.

Another measure provided by this test is Compressional Resilience which is represented by the symbol (%RC). This value is also expressed as a percentage, and measures the percent recovery the fabric demonstrates after the force has been removed. This is achieved by comparing the thickness before the force is applied to the thickness after the force is removed. A higher %RC shows that a fabric has greater resiliency to spring back to its initial thickness after having been subjected to a downward force upon its face. A lower %RC shows that a fabric has a low recovery capability from such a force.

The final measure provided by the Kawabata Compression Test is Thickness. The thickness of the $2cm^2$ area is measured at the point at which the force has reached only 0.5 gf/cm^2, which is essentially at initial contact between the column and the fabric surface. This value is used in the calculation of both %EMC and %RC, and gives a general understanding of how thick the fabric is. Images of both the KES-FB3 Compression Tester and of the action of the Compression Test are seen in Figures 3.7 and 3.8.

Figure 3.7 - KES-FB3 Compression Tester

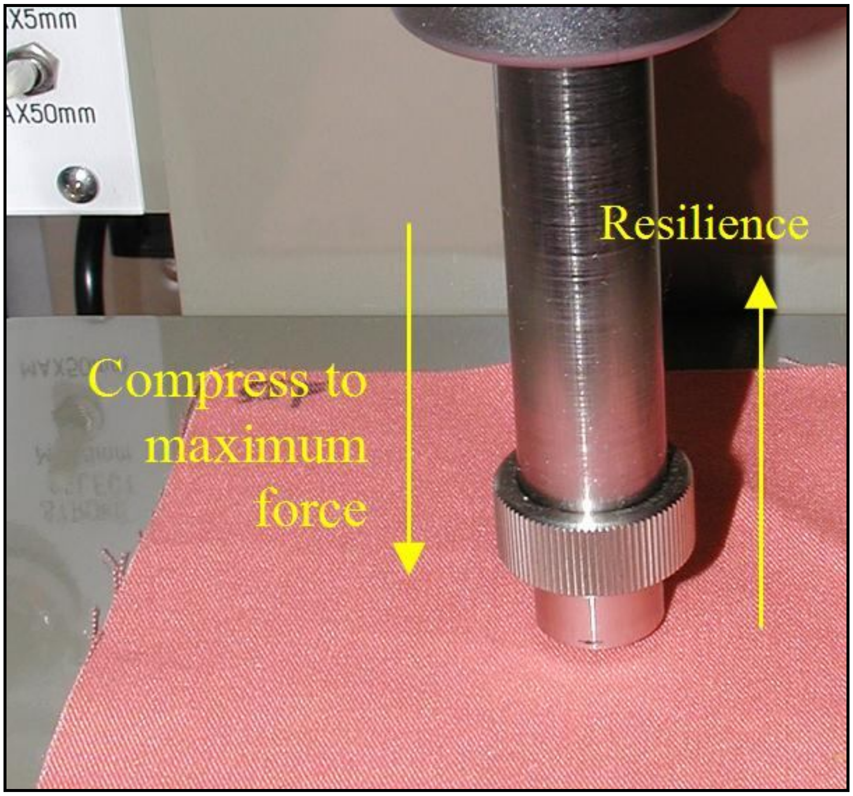

Figure 3.8 - Kawabata Compression Test Action.

Source: Liston, G. (2007). *Sample report on TPACC comfort testing*

KES-FB4 Kawabata Surface Test.

The Kawabata Surface Test is performed on the KES-FB4 Surface Tester. Three replications are performed in each the warp and fill directions. The fabric samples used in this test are again the 20cm X 20cm square fabric samples. One difference with the surface tester is that the samples are mounted with the skin side facing up, as opposed to the rest of the KES tests which have the skin side of the fabric facing downward. This is done in order to measure the surface properties of the side of the fabric which will be coming in contact with skin while being worn in a garment.

This test is performed by clamping the fabric onto a roller and having the fabric span an open area. The fabric is draped down over another roller where a clip, weighing 120 grams, is placed to hang from the other end of the fabric. This allows a steady light tension to remain on the fabric in order that the surface of the fabric in the open area may remain flat and not droop into the opening. The roller then turns, which drags the fabric across the open area. Two different probes touch the fabric from the top (on the skin side) and measure two distinct properties as the fabric is dragged beneath them. One probe is the Roughness Probe and the other is the Friction Probe. These probes can be seen in Figure 3.10.

Two measures are provided by the surface test; one measure is provided by each of the two probes. The Friction Probe measures the Coefficient of Friction which is a measure represented by the symbol (MIU). This frictional measurement is a value that can range from 0-1. A higher MIU denotes a fabric that has a high degree of friction and resists the drag. A lower MIU represents a 'smoother' fabric which has low resistance to drag and a lower amount of friction. The other measure provided by this test is Geometric Roughness as symbolized by (SMD). The units of the SMD are in microns. A higher SMD measurement corresponds to a more rough fabric in terms of geometric shape. A lower SMD represents a 'flatter' fabric which has less geometric shapes which pose as obstacles to drag. Both lower SMD and MIU are positives for athletic use, and they cause less impact on irritation of the skin during highly active motion. The KES-FB4 Surface Tester is shown in Figure 3.9 and the action which takes place during the Kawabata Surface Test is shown in Figure 3.10.

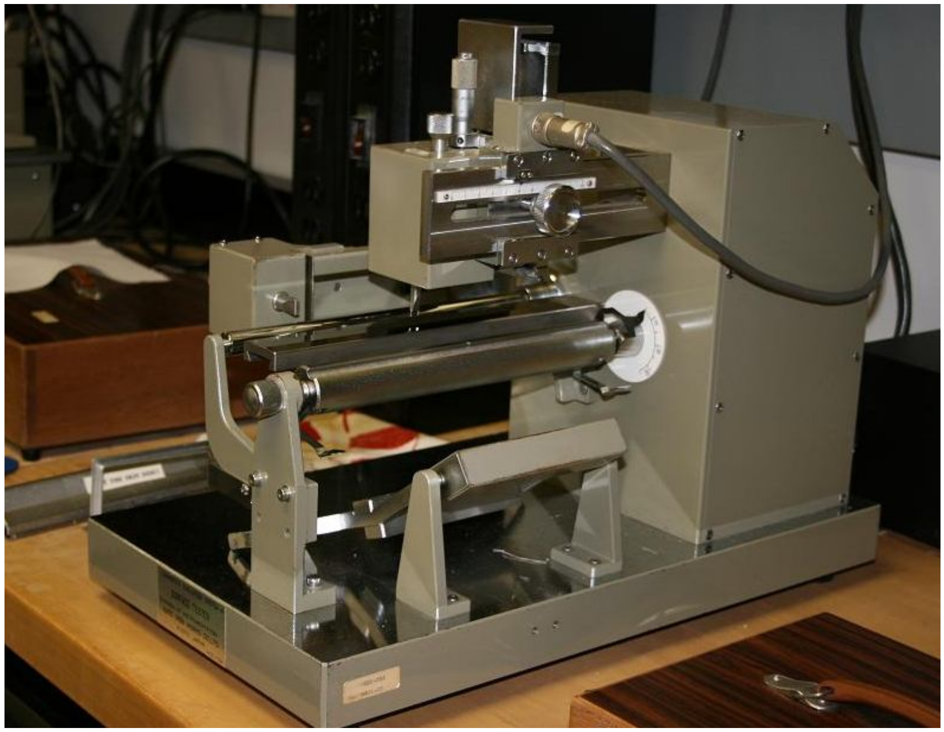

Figure 3.9 - KES-FB4 Surface Tester

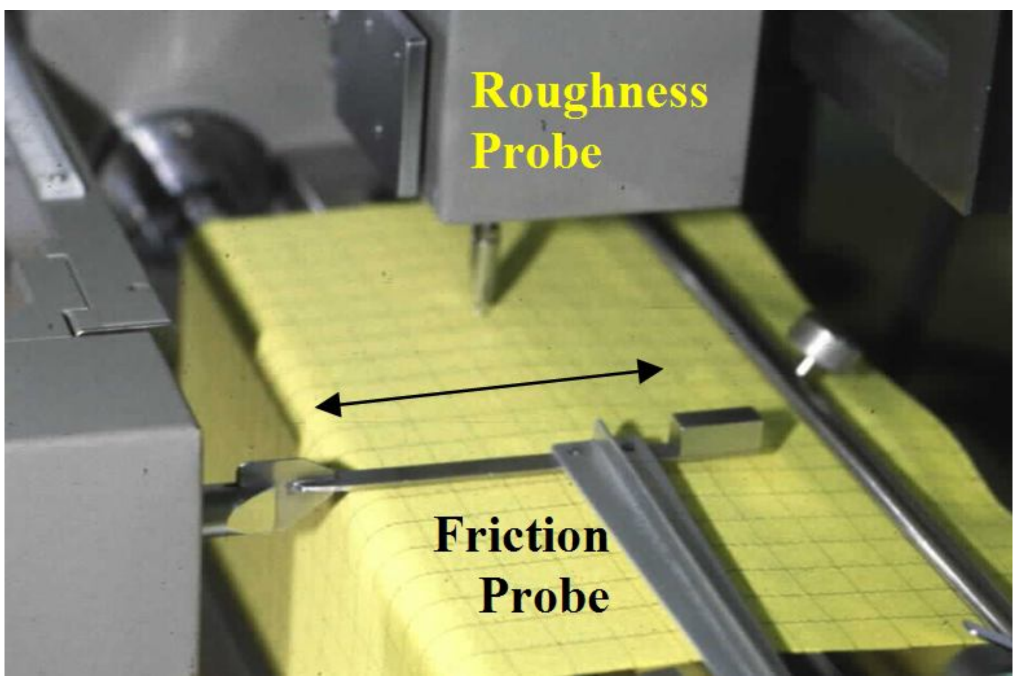

Figure 3.10 - Kawabata Surface Test Action.
Source: Liston, G. (2007). *Sample report on TPACC comfort testing*

Kawabata (Thermolabo) - Small Hot Plate

While this test shares the name Kawabata with the KES system, it measures a very different fabric quality. The KES system is concerned with the quantitative measurement of fabric hand, while the Kawabata Thermolabo Unit, also known as the 'Sweating Guarded Hot Plate' or 'Small Hot Plate', is concerned with the quantitative measurement of the cooling ability and the breathability of the fabric. In short the Thermolabo is designed to quantitatively measure the Thermal Comfort Properties of the fabric. This test is performed on the Kawabata KESF-TL-2C unit, and like all testing in this study it is performed in a controlled environment at 21ºC and 65%RH. This test uses three 5" X 5" fabric samples to provide three replications of test data. This test is not performed directionally in terms of warp and fill because the nature of this test is a 'through-fabric test' and not an 'along-fabric test'.

There are two versions of this test, a Dry Thermolabo Test and a Wet Thermolabo test. In the dry test the hotplate produces heat but does not produce moisture. In the wet test the hot plate produces heat, while it also emits water from pores in the plate to maintain the moisture level of a pre-wetted membrane, in order to simulate the sweating skin of a human. The fabric is tested skin side down as the hot plate is meant to simulate the behavior of human skin in both dry and wet conditions. A fan is placed at the top of an enclosed space to provide to airflow onto the surface of the fabric during testing. The hot plate produces heat and the fan is used in order to adjust the temperature of the plate. The term 'guarded hot plate' is used because the hot plate is kept in an enclosed space to prevent air movement near the testing area from affecting the test. Another reason for this guard is to allow the air flow rate to be constant and unimpeded by the surrounding environment. This is important as the air flow is an integral part of this test. An image of the Thermolabo unit is in Figure 3.11.

Figure 3.11 - Kawabata Thermolabo Unit KESF-TL-2C.

Source: Liston, G. (2007). *Sample report on TPACC comfort testing*

Dry Thermolabo Testing.

The dry Thermolabo test is performed first, and uses no moisture. The heater is turned on in the hot plate as is the fan at the top of the unit. The fan is adjusted such that the bare plate maintains a temperature of 35ºC when the heater is using in the range of 2.8-2.9

Watts of power to maintain 35ºC. The actual measurement output by the Thermolabo unit is the wattage (W) required to maintain this temperature. Thus the power required to keep a bare plate at 35ºC is higher than the wattage necessary to keep a fabric covered (insulated) plate at 35ºC because the fabric will hold in some amount of this heat from escaping into the surrounding air. With this measurement capability the insulating capacity of the fabric can be ascertained. A measure that is derived from the dry Thermolabo test is the Thermal Resistance value, represented by the unit (clo). The origin of 'clo' is that it was determined that 1 clo was the Thermal Resistance capacity of the typical men's business suit. So given the nature of the product in this research the expectation is for all values of clo to be less than 1. Each test was performed for a 5 minute period at the end of which the Wattage measurement was taken.

Wet Thermolabo Testing.

The wet version of the Thermolabo Test is very similar to the dry version with the exception of a pre-wetted membrane being placed over the top of the hot plate before the fabric is placed on the plate. This membrane is designed to hold moisture and to reflect wet skin at 35ºC. The hot plate itself very slowly emits water from holes in the plate in order to maintain the moisture level of the membrane between tests. The water flow is turned off during the 5 minute tests and the moisture level is replenished between tests. This is done to simulate sweating skin, as sweating skin is a continual source of moisture preventing the hot skin from evaporating the sweat. Due to the presence of the moisture the plate is inclined to be cooled like sweating skin, so the wattage required to maintain 35ºC is much higher in the wet test than in the dry test. The required wattage is a range from 9.4-9.8 watts. The plate is returned to this condition between each test. Once fabric insulates this, then the wattage required to maintain 35ºC will go down.

There are a few measures that come from the wet Thermolabo test as combined with the results from the dry Thermolabo test. One of these is the Permeability Index represented by the symbol i_m. This index indicates the permeability of a fabric to allow the passage of moisture and heat through the fabric. Permeability Index is rated on a scale of 0-1. A Permeability Index of 0 denotes a fabric that is completely impermeable to the passage of moisture or heat through its surface. A Permeability Index of 1 denotes a fabric that is completely permeable to allowing the passage of moisture and heath through its surface. While it is impossible for a fabric to have a permeability Index of 1, the higher the permeability index the better a fabric is suited for athletic performance in a hot climate, because it will allow sweat and heat to move away from the skin surface. The formula for the Permeability Index as developed by Crank is below.

<u>Permeability Index:</u>

$i_m = 0.0607\ (E/H)\ (T_s-T_a)/(P_s-P_a)$ where:

E = heat transfer rate (watts/$m^2 \cdot \Delta {}^\circ T$) due to moisture evaporation, (Wet Heat Transfer - Dry Heat Transfer)
H = heat transfer rate (watts/$m^2 \cdot \Delta T$) due to heat, (Dry Heat Transfer)
T_s = temperature on the skin surface, (35˚C)
T_a = temperature of the ambient environment,
P_s = water vapor pressure (kPa) on the skin surface,
$P_s(T_s) = \exp[16.6536 - 4030.183/(T_s+235)]$,
$P_s(T_a) = \exp[16.6536 - 4030.183/(T_a+235)]$,
P_a = water vapor pressure (kPa) in the ambient environment,
$P_a(T_a) = (RH/100)[P_s(T_a)]$, and
RH = relative humidity of the test condition (Crank, 1975).

Another measure that is gained from combining the results of the wet and dry Thermolabo tests is the "Comfort Limits". Comfort Limits are represented by the symbol (q). There are three Comfort Limits; minimum, comfort, and maximum. All three limits are measured in units (watt/m^2). Comfort limits can also be called Total Heat Loss (THL). Minimum (q_{min}) is the total heat loss associated with a completely dry skin surface. Comfort (q_{comf}) is the total heat loss associated with skin that has 20% moisture. This measure is designed to reflect a normal skin condition at a resting state. Maximum (q_{max}) is the total heat loss the skin experiences with 100% skin moisture. This is designed to reflect an extremely high activity or stressed state. In general the total heat loss would be desirable to be a higher number for athletic use in hot climates. The Thermolabo does many things on the fabric level that the sweating manikin does on the garment level, and it is interesting to compare the two figures in order to determine how the fabric behaves in a garment configuration on the body of a manikin. The formula for the comfort limits are listed below as developed by Woodcock.

Comfort Limits:

$$Min = (6.46/I)\ (T_S - T_a) < Mn < (6.46/I)\ [(T_S - T_a) + 3.3\ i_m (P_S - P_a)] = Comf$$

$$Max = (6.46/I)\ [(T_S - T_a) + 16.5\ i_m\ (P_S - P_a)]$$ where:

I = thermal resistance (R_h; Clo)

i_m = Permeability Index

T_S = temperature on the skin surface, (35˚C)

T_a = temperature of the ambient environment

P_S = water vapor pressure (kPa) on the skin surface,

$$P_S\ (T_S) = \exp\ [16.6536 - 4030.183/(T_S+235)]$$

$$P_S\ (T_a) = \exp\ [16.6536 - 4030.183/(T_a+235)]$$

P_a = water vapor pressure (kPa) in the ambient environment,

$$P_a\ (T_a) = (RH/100)[P_S(T_a)]$$

RH = relative humidity of the test condition (Woodcock, 1962).

Modified Gravimetric Absorbency Testing System (GATS)

While the Thermolabo is concerned with the ability of the fabric to move heat and moisture away from the skin, the Modified Gravimetric Absorbency Testing System (GATS) is concerned solely with the moisture management properties of the fabric. There are five replications performed on this test which is also non directional as it is concerned with the passage of moisture from the skin side of the fabric through to the face side of the fabric. The skin side is placed down onto the testing surface due to the nature of the test, which is to simulate sweating skin. The size of fabric sample used in this test is a circular dye-cut sample of a 3.5” diameter. Also important to note is that this test is performed in a controlled environment of 21ºC and 65% RH.

There is no heat generated in this test, only the constant supply of moisture from which the fabric can pull water. This test apparatus consists of a Sartorius® LP620S Scale, accurate to 0.000 grams, on top of which sits a reservoir. In this reservoir is iodized water. A tube runs from this reservoir to the bottom of a platform. In a circular aperture in this platform sits a perforated glass plate. The glass plate has been aerated and has a great number of tiny holes similar to foam. The aerated nature of this glass allows water to be drawn via capillary action from the bottom up to the top of the plate. The water supply remains constant as the plate is at a lower level than the reservoir, meaning that the water flow is driven by gravity. This, however, is not where the term gravimetric is originated for the test. This term, meaning pertaining to measurement by weight, is used because the water evaporation and absorption is measured by the weight change in the reservoir. An image of the GATS apparatus is in Figure 3.12.

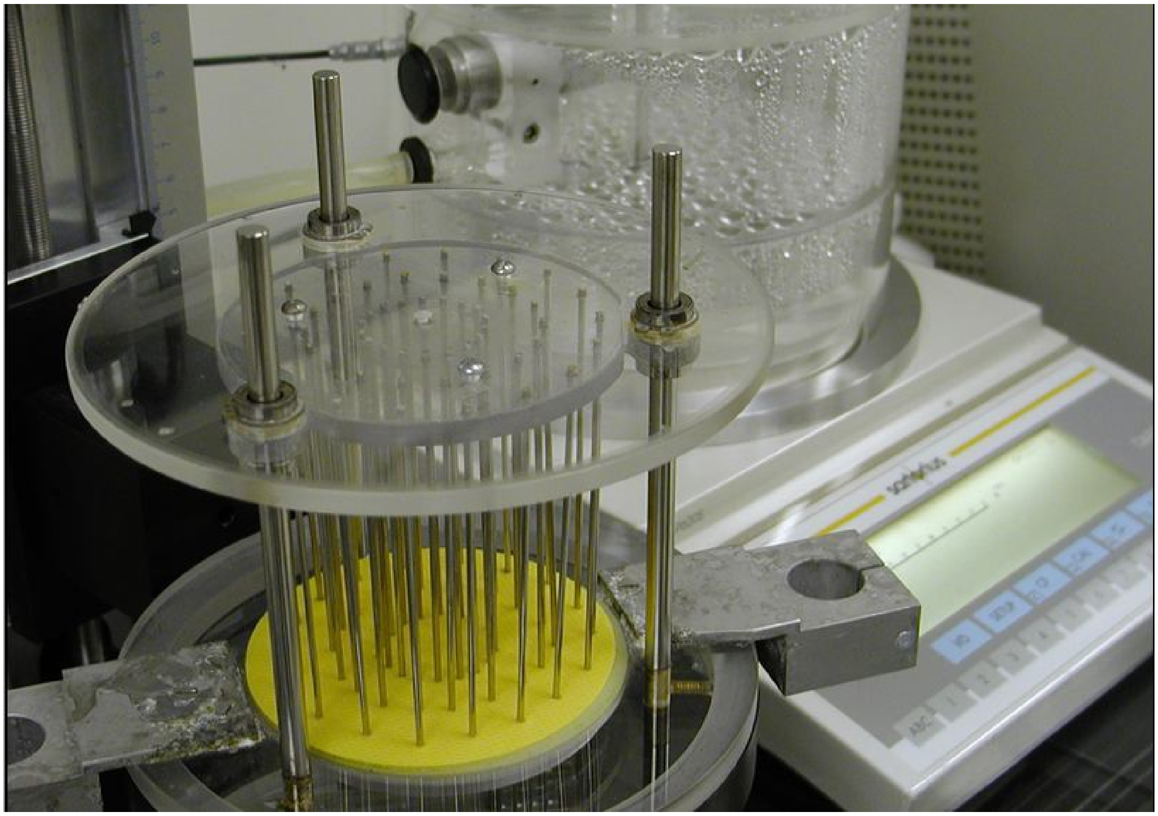

Figure 3.12 - Gravimetric Absorbency Testing System (GATS) - Apparatus.

Source: Liston, G. (2007). *Sample report on TPACC comfort testing*

The term used in conjunction with the GATS test is ‘demand wettability’. This refers to the steady supply of water that is available to the fabric via the perforated glass plate. With a constant and monitored supply of water in place it is possible to measure the wicking ability of the fabric as well as the absorption capacity of the fabric. There is a 1.5 m/s air flow applied to the specimen test plate during the test, which lasts for 1000 seconds or a little over 16 and a half minutes. This allows evaporation to take place more readily. A Hotwire Thermo-Anemometer from ExTech Instruments® is used to accurately measure the air flow across the test area.

There are many measures provided by the GATS test despite the only measurement during the test being weight change. The specimen weight is measured on a Mettler® LJ16 Moisture Analyzer, which is accurate to the nearest 0.000 grams, and is recorded both while dry (W_d) and after the test while fully saturated (W_w). From these two numbers an important measure that can be gathered is the Capacity, represented by the symbol (C), of the fabric. Capacity here refers to the amount of water in units of grams that the fabric sample could hold. Capacity is calculated by subtracting the dry sample weight from the wet sample weight ($C = W_w - W_d$) leaving only the water weight absorbed by the sample. On Figure 3.13 the area before the slope changes represents the graphical depiction of capacity; about 4 grams in the example provided in Figure 3.13.

The weight in water evacuated from the reservoir by the fabric is graphed in real time as the test progresses. The first portion of the test has a rapid incline in water evacuated due to the absorption of the water into the sample. After the sample has become saturated the line flattens out to a much shallower incline as the rest of the water evacuation is due solely to evaporation. These two phases of water evacuation on the graph intersect, and at the point of intersection is where the measure Time is recorded. Time is represented by the symbol (T). This is the measure of the time at which the two segments of the graph intersect, or the time at which the fabric stops absorbing and evaporation becomes the primary means of fluid evacuation. An example graph from this research is show in Figure 3.13 to illustrate the graphical nature of the water evacuation. On this graph the two phases, absorption, and evaporation, can be clearly distinguished based on the slope of the line.

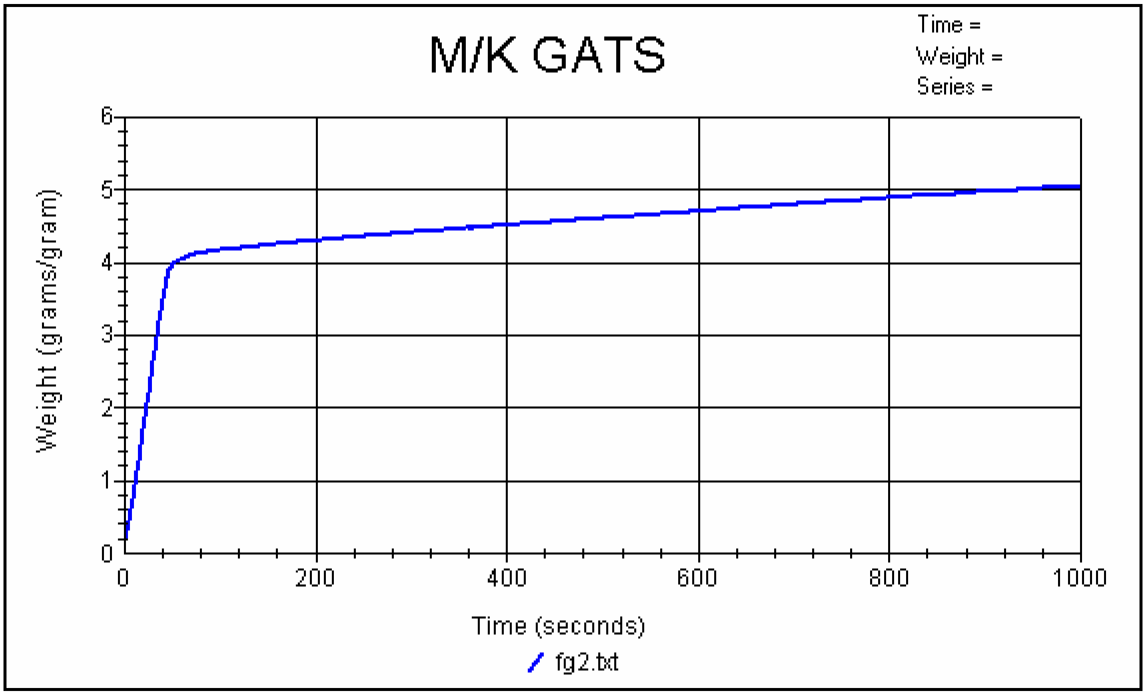

Figure 3.13 - Graphical Representation of Water Evacuation in GATS Test.

The next measure is Volume evacuated, denoted by the symbol (V). This is the total amount of water evacuated during the full length of the test. This number reflects the combination of water evacuated due to absorption and water evacuated due to evaporation. On Figure 3.13 the top point on the line represents the total water evacuated during the test, about 5 grams in that particular example. The units of Volume are in grams. This amount is used in the calculation of subsequent measures. Another measure is Absorbency Rate, which is denoted by the symbol (Q). The units for Absorbency Rate are (g/min). This is measured during the early phase of the test where the fabric is absorbing the water. The final measure generated from the GATS test is Percent Evaporation. This is represented by the symbol (E_p). Percent evaporation is a figure that indicates the ratio of evaporated moisture to moisture absorbed. The formula for percent evaporation is: [((V-C)/V) * 100]. This formula uses the capacity and volume measures to calculate percent evaporation.

Additional Possible Measures.

A couple of other measures could also be extrapolated from the testing data generated by the GATS test. These measures could be referred to as Power measures. One is the Absorptive Power, which I will denote with the symbol (P_a). Absorptive Power would be the measure of how much water a fabric can absorb as compared to that fabric's dry weight. This measure gives the 'pound-for-pound power' of the fabric to absorb moisture. This would be a percentage that would indicate the ratio of the amount of water that fabric is capable of absorbing to that fabric's dry weight. Both of these ingredients are pre-existing measures in this test. The formula for Absorptive Power would be [$(C/W_d) * 100$]. This means that if a fabric absorbs more than it's dry weight in water it is possible to have a P_a of over 100%. This allows for a good comparison from one fabric type to another to show that while one fabric may absorb more water than another, if it is a much heavier fabric, then perhaps the benefit would be to go with a lighter weight fabric that absorbs slightly less water but is a more powerfully absorbing medium on a per weight basis than the heavier fabric.

The other possible measure can be referred to as Evaporative Power, which I will denote with the symbol (P_e). This is very similar to Absorptive Power, but it is the ratio of the amount of water the fabric has allowed to evaporate (V-C) to that fabric's dry weight. The formula for Evaporative Power would be [$(V-C)/W_d * 100$]. These two measures can be compared to one another for a fabric to give an idea weather a fabric's Volume evacuated is more due to the capacity of that fabric to absorb, or the evaporative wicking power of that fabric. These measures also are a strong standard bearing comparison point for the cumulative moisture management properties of a group of fabrics, such as the sample set in this research.

Drying Test

The purpose of the drying test is to determine how much time is required for a saturated sample of fabric to return to a dry condition. This test is performed in a conditioned atmosphere of 21°C and 65% RH. Three replications are done on this test with the same circular dye-cut 3.5" diameter samples as the samples used in the GATS Test. This test is done in conjunction with the GATS test, which provides the Capacity amount of water which the 3.5" diameter fabric samples are capable of absorbing. With this value it is possible to fully saturate the fabric samples with no excess water to adversely affect the drying test.

The apparatus for this test is a Mettler-Toledo PB303-S scale which is covered on the top and on three sides, and is accurate to the nearest 0.000 grams. The fourth side remains open to allow air flow through the test area. The side opposite the open end has a mounted computerized fan which blows air at a rate of 0.5 m/s. This is measured with the Hotwire Thermo-Anemometer from ExTech Instruments®. An image of this apparatus is shown in Figure 3.14. The TPACC lab at NC State has three of these units, allowing for three tests to be run at once. On the scale is mounted a circular tin pan of slightly larger than 3.5" diameter. The fabric is placed in this pan and a small wire weight is placed on top of the fabric to prevent it from blowing off the test area during testing. When the fabric and weight are in place, the balance is tared to 0.000g. At this point the fans have been calibrated to 0.5

m/s and turned off. This is done to prevent the scale from having oscillations in readings as the water is added. The capacity amount of water is then added onto the sample, leaving the scale to measure only the weight of the water as the remaining tin, fabric, and small wire weight have been tared. Once the water has been placed on the fabric the test begins. Figure 3.14 shows a picture of the apparatus used in the drying test.

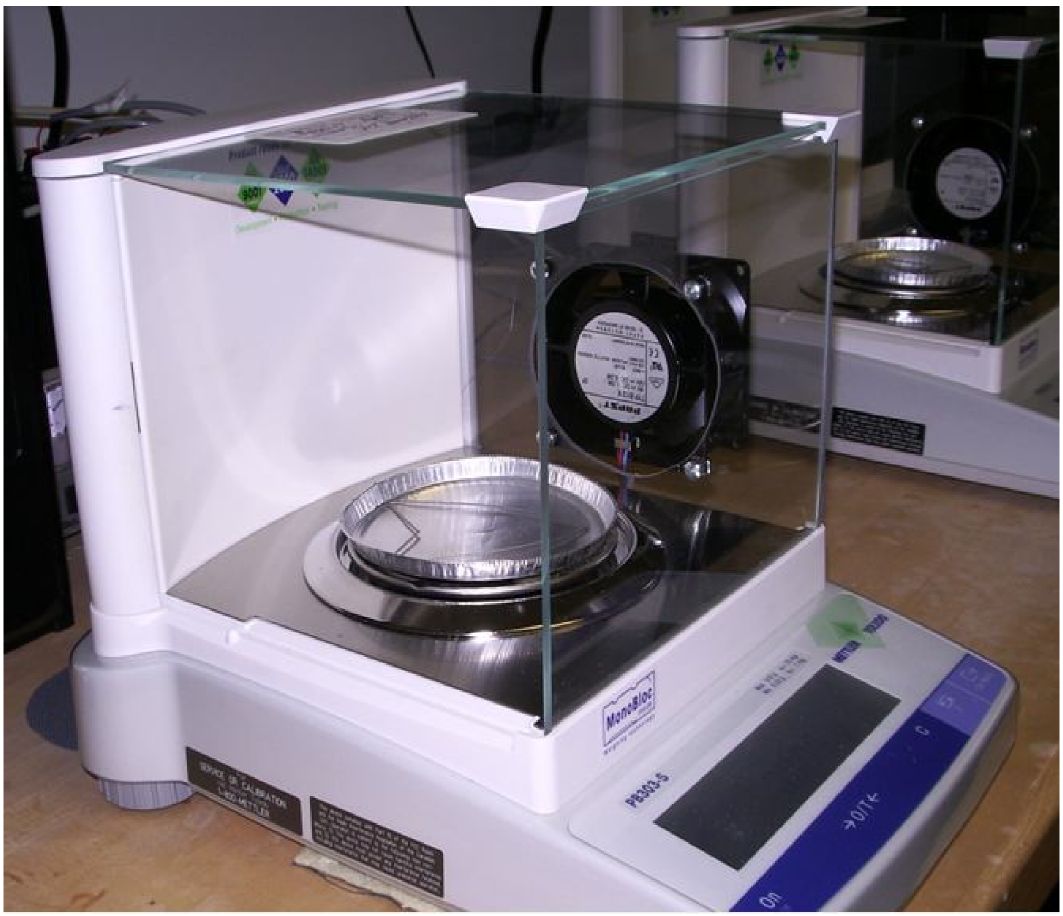

Figure 3.14 - Drying Test Instrumentation.

Source: Liston, G. (2007). *Sample report on TPACC comfort testing*

Every ten minutes the fan stops, and the computer monitors the weight of the scale. The fans restart after 60 seconds which allows the scale readings to steady as they are recorded by the computer. This cycle repeats until the scales read 0.000g signaling that all of the capacity moisture has been evaporated. The output measure of this test is Drying Time, which is represented by the symbol (D). This measure is useful for comparing the time required to dry a fabric. The average of three drying test replications is used to report the drying time for that fabric. In athletic uses this is an important measure because while one fabric may be superior in absorption characteristics, if it is slow to dry then that fabric may actually be less desirable to the athlete in terms of keeping the athlete dry.

Additional Possible Measure.

One more measure can be added to the measure of drying time. A measure called Drying Rate can be calculated. This measure is represented by the symbol (D_r). This measure can be calculated with two pre-existing measures, one from the GATS test, and one from the Drying Test. Capacity from the GATS test can be divided by the drying time from the Drying test in order to allow a comparison of how fast a fabric evaporates away its moisture. The units of this measure would be (g/min). The formula for Drying Rate would be (C/D). This allows for an even comparison of drying time, as a fabric which may hold more water will often take more time to dry. This measure allows for a per-minute comparison of how fast each fabric allows the moisture inside to evaporate. This is one way to tell if drying time is solely a function of Capacity or if there are more factors in play.

Garment Level Testing (Advanced Sweating Manikin)

While fabric level testing has many things it can reveal about the comfort properties of the test subjects, all of these tests are done with flat samples of fabric on flat surfaces. The garment level testing phase of this research attempts to take these tests to the 3rd dimension and utilize a manikin to test garments made of these same fabrics. With a garment there are air pockets and spaces that are between the test surface and the fabric due to draping, whereas in fabric level testing the full surface of the fabric is in full contact with the full surface of the test area. Having the fabric in garment configuration adds a new element. Garment testing helps to bring the quantitative measures of the fabric testing stage one step closer to the qualitative experience of the athlete who uses these products.

The Garment testing in this research was performed on the NCSU Advanced Sweating Manikin, which is also housed in the TPACC lab at the College of Textiles at NC State University. The location of the NCSU manikin is inside a state-of-the-art environmental chamber in the TPACC lab which has full control over temperature and humidity. This chamber is maintained by Environmental Specialties Inc®. Inside this chamber there are three temperature sensors which hang from the ceiling around the manikin. One sensor is on each side of the manikin while a third is located in front of the manikin. All testing with the NCSU Sweating Manikin was performed with conditions set at 21ºC and 65% RH. This was done in order to match the conditions with those used in the fabric level survey. With matching environmental conditions for the fabric level and garment level, testing is possible to make comparisons from fabric to garment. It is possible to see what effect garment construction has on the performance of the fabric once it is being measured as a three-dimensional full piece garment. A photo of the NCSU Coppelius Advanced Sweating Thermal Manikin is shown in Figure 3.15.

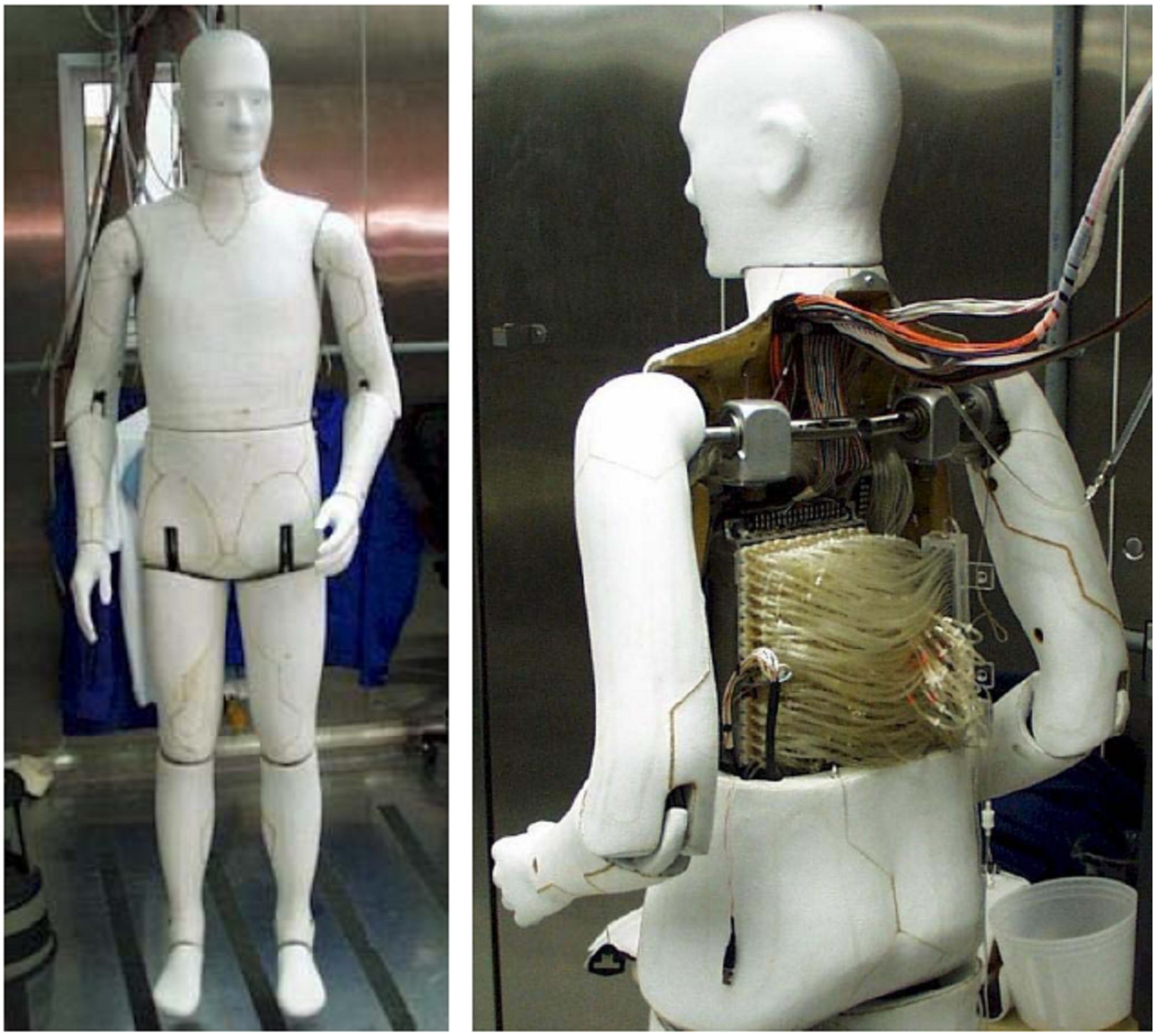

Figure 3.15 - Coppelius NCSU Advanced Sweating Thermal Manikin.

Source: Ross, K. A. (2005). *Evaluation of an instrumented sweating manikin for predicting heat stress in firefighters' turnout ensembles* from http://www.lib.ncsu.edu/theses/available/etd-02022006-113326/unrestricted/etd.pdf

In the photo of Coppelius, you can see from the rear view of the manikin the internal structure of the water supply tubes as the rear panel has been removed in order to show the inner workings of the manikin. This manikin also has metallic strips running beneath its surface which appear as faint lines in Figure 3.15. These strips are the thermal aspect of Coppelius as they provide the heat to simulate human body heat which is exhibited in skin. With the moisture and heat aspects combined, Coppelius is equipped as the most advanced type of measurement tool for the quantitative evaluation of clothing comfort. The heating wires, as well as the sweating function, can be controlled to affect individual sections on the manikin. In 2005 Ross developed a diagram shown in Figure 3.16 to illustrate the different sections of the Coppelius sweating Thermal Manikin.

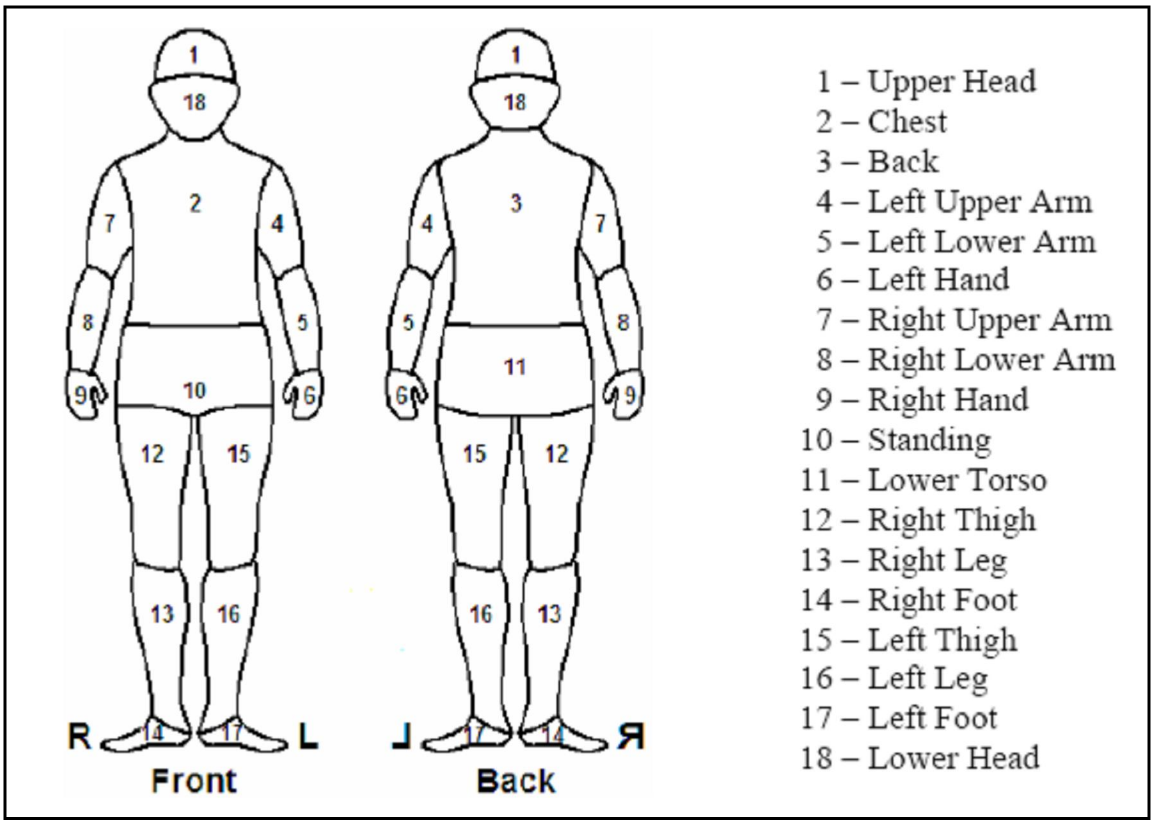

Figure 3.16 - Section Diagram of Coppelius Sweating Manikin.

Source: Ross, K. A. (2005). *Evaluation of an instrumented sweating manikin for predicting heat stress in firefighters' turnout ensembles* from http://www.lib.ncsu.edu/theses/available/etd-02022006-113326/unrestricted/etd.pdf

In this research not all segments of the manikin are used as the research is not concerned with them all due to the nature of the product being tested. The product in this research is short sleeved athletic performance t-shirts, so the sections used in this study are only those covered when a short sleeved t-shirt is worn. The four main body panels (2, 3, 10 and 11) are used as well as the two upper arm panels (7, and 4).

The operation of the temperature control for the manikin is done via computer which is connected to the manikin’s internal mechanism. One sensor per section is on the manikin which sends back the temperature reading. The computer than adjusts the wattage of the power source accordingly; if the manikin is not warm enough the wattage is increased in an on/off fashion (Barker R. L. et al., 1998). Coppelius also has 187 simulated sweating ‘glands’ distributed over the entire surface of the manikin. A cross-sectional image of one of these sweat glands is shown in Figure 3.17. The only locations without sweating capability on Coppelius are the hands, feet, and head.

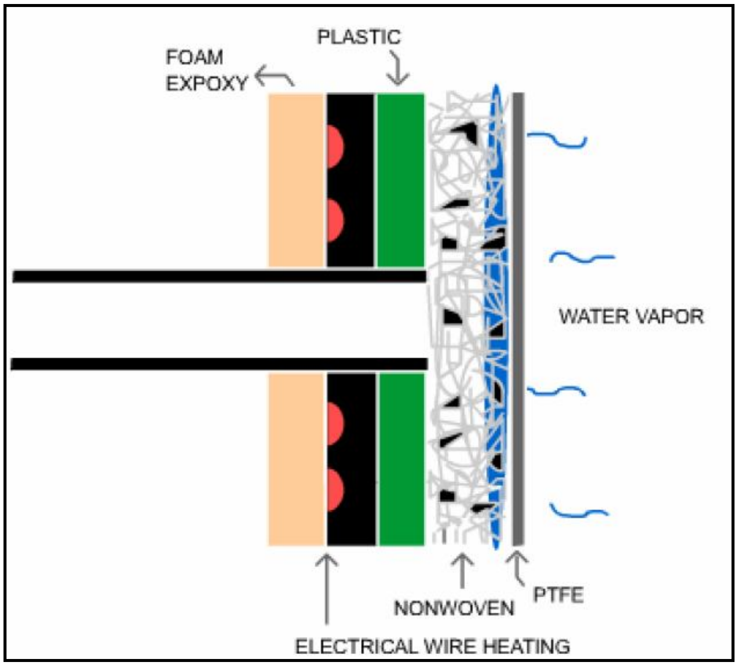

Figure 3.17 - Sweat Gland Cross-Section from Coppelius

Source: Ross, K., Deaton, S., & Barker, R. *Sample report on characterization of test garments using the NCSU sweating manikin test system from TPACC*

Each sweat gland receives its water supply from the water reservoir placed outside the environmental chamber. The valves that open and close the flow of water to the sweat glands are controlled by the computer which is given an input of desired 'sweating rate'. The flow of water metered out by the computer is continuous during wet, or sweating, tests and is intended to simulate the sweating function of a human (Barker R. L. et al., 1998). The sweating rate can be controlled from no sweat up to a sweating rate of (300 g/m^2 * h).

The skin surface of the manikin has a nonwoven material which absorbs the water from the sweat gland and spreads it across a larger space to distribute the water from the gland. On top of this nonwoven is a 'micro-porous' membrane which acts as the 'skin' surface and allows the distributed moisture to penetrate to the exterior of the manikin

(Meinander, 1997). On top of the manikin's skin is highly absorbent netting which helps to further distribute the moisture across the manikin's surface. The body of the manikin is sized to simulate a man who has: a chest circumference under the arms of 40", waist size of 34.25", a 30.5" inseam, and a sleeve inseam of 20.75". The manikin is also equipped with prosthetic joints in the elbows, hips, and knees in order to ease the process of dressing the manikin. Even though there are joints on this manikin all testing is done with the manikin in a stable and static condition. This means that the manikin cannot be used for motion testing. Coppelius is one step closer to human wear testing, but he cannot be used to simulate the movements of a human subject. As a side note, this research was the last conducted on the Coppelius manikin at NCSU. Shortly after Garment testing was completed a new Sweating Manikin was installed in the TPACC environmental chamber.

Thermal Resistance (Dry) Manikin Testing

Two types of tests are performed with the Sweating Manikin, the first of which is the dry manikin testing. This test is designed to follow the procedures outlined in ASTM test standard F 1291, called "*Standard Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin*". In the dry manikin test the sweat glands are left turned off and the heater wires are the primary function of the manikin. The manikin was dressed with a t-shirt and with a pair of men's size large (40) shorts from Road Runner®. The shorts had a 100% Supplex® nylon shell, and a 100% Coolmax® polyester liner. The environmental chamber conditions were set at 21ºC and 65% RH. The test is run four a period of about one hour as the temperature is given time to stabilize before the measurements are recorded, which takes place over a thirty minute time frame. All of the garments were maintained in the conditioned chamber during testing, being continuously conditioned at the same test conditions of 21ºC and 65% RH. The manikin's 'skin' temperature was set at 35ºC and (similar to the Thermolabo test) the power needed to maintain 35ºC was measured throughout the test. This value was used in conjunction with known values such as skin temperature, manikin surface area, air temperature, and relative humidity to calculate the measures of the dry manikin test.

There are two measures that are associated directly with the dry version of the manikin test. The main measure is Thermal Resistance which is represented by the symbol (R_t). This is a measure of how much the fabric resists the escape of heat from the surface of the manikin. Another way of putting it is this measures the thermal insulation capacity of the garment. For athletic applications in hot climates a lower resistance to heat escape is desired, as heat must leave the body in order for the athlete to maintain an acceptable core body temperature during activity. One difference between this measure as recorded in Thermolabo testing and as recorded in testing with the manikin is that air pockets between the fabric and the manikin also are an impacting factor, whereas the Thermolabo test had fabric in full direct contact with the hot plate. With the aforementioned measurements in place, and the Wattage reading from the dry manikin test it is possible to calculate Thermal Resistance with the following formula:

Thermal Resistance:

$$R_t = \frac{(T_s - T_a)\,A}{H}$$ where:

R_t = Total thermal resistance of garment plus air pockets.

- With Units: (ºC*m^2/W),

H = Cumulative power (in dry test) for areas of interest. (Watts),

T_s = Temperature of the manikin surface. (35ºC),

T_a = Temperature of the chamber environment. (21ºC), and

A = Cumulative area of manikin segments being evaluated. (m^2)

(ASTM, 2004a).

From this formula the Thermal Resistance is calculated. From the Thermal Resistance value the next measure provided by the dry test is calculated. This measure is called 'clo'. Clo is a unit developed to express Thermal Resistance in a more communicable way. One clo unit represents the amount of thermal insulation power of the typical men's business suit. The formula for clo is: [Clo = R_t * 6.45]. With the ability to communicate that a garment has a certain insulating power in relation to the typical men's business suit it much easier to convey the concept of Thermal Resistance than if one were to tell the thermal resistance value in units of (ºC*m^2/W). With the Thermal Resistance value calculated the wet testing was the next step.

Wet Manikin Testing

Test method ASTM F 2370, which is called ***"**Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin"* is the standard by which the wet testing was performed. This test was also performed at 21ºC and 65% RH with Coppelius in the environmental chamber. The preparation for the wet test is much more involved than for the dry test. Water is heated to around 40ºC in a large beaker, and sprayed onto the surface of Coppelius. If the water were any cooler it would cause the surface temperature of the manikin to cool to the point where it would take a long time in order for the temperature to return to 35ºC for testing. This water is used to saturate the surface of the manikin in order to provide enough moisture so that the sweat glands only must provide a continual sweat-like flow of moisture during testing, rather than a saturation which would again take an exorbitant amount of time to achieve. The manikin was sweating at a rate of (200 g/m^2 * h) for this test. Once the manikin has been saturated, it is quickly dressed with t-shirt and shorts and the chamber is quickly evacuated and closed in order to minimize the impact of the human presence of the technician in the chamber. The garments for the wet test were also constantly stored in a conditioned environment of 21ºC and 65% RH inside the environmental chamber in order to keep the garments at the testing environment condition.

Much like the dry manikin test the wet manikin test requires some time to allow the temperature of the manikin to stabilize at 35ºC in order to take a reading of the wattage values needed to maintain the 'skin' temperature at 35ºC. Once the temperature has stabilized, and the manikin is sweating, the data is recorded for 30 minutes. The values gathered in this test are used in conjunction with the Thermal Resistance value from the dry test to calculate several measures which tell a couple of different things about the fabric being tested. Once the test was complete the garment was removed from the manikin and weighed on a Mettler® PM1200 scale, which is accurate to the nearest 0.000 grams, in order to determine their moisture weight gain, or how much water they had absorbed during the testing.

The main measure developed by the wet manikin test is Total Evaporative Resistance. This measure is symbolized by the icon (R_{et}). The units of the measure R_{et} are ($kPa*m^2/W$). Total Evaporative Resistance is the measure of how much the fabric and air resist the escape of moisture from the surface of the manikin into the surrounding environment. Just as in the dry test the computer measured the manikin surface temperature as well as the surrounding air temperature near the manikin. These measures when combined with the Thermal Resistance from the dry test allow for the calculation of evaporative resistance in the formula below.

Total Evaporative Resistance:

$R_{et} = [(P_s - P_a) * A] / [H_e - (T_s - T_a) * A / R_t]$, where

R_{et} = Total evaporative resistance of clothing ensemble and air layer (kPa·m²/W),

P_s = Water vapor pressure at the manikin's sweating surface. (kPa),

P_a = Water vapor pressure in the air surrounding the manikin. (kPa),

A = Cumulative surface areas of interest on the sweating manikin. (m²),

H_e = Cumulative power usage in sweating areas of interest. (Watts),

T_s = Temperature of the manikin surface. (ºC),

T_a = Temperature of the air surrounding the manikin (ºC), and

R_t = Total thermal resistance of the clothing ensemble and surface air layer (ºC·m²/W) (ASTM, 2004b).

Once Evaporative Resistance has been calculated it is then possible to calculate a few other measures. One of those measures is the Permeability Index. This measure is represented by the symbol (i_m). Permeability Index as measured by the sweating manikin is the same quantifier as the Permeability Index measured by the Thermolabo Test. It is a measure of the moisture/heat permeability of the fabric on a scale from 1-0, where 0 denotes a fabric which is completely impermeable to heat and moisture, and a permeability index of 1 denotes a fabric which is totally permeable to moisture and heat. Once again, for the purposes of the product under study in this research, higher permeability index values closer to 1 are desired as the athlete benefits from the release of moisture and heat in order to prevent their core temperature from climbing too high during strenuous activity. The formula for Permeability Index is: [$i_m = (R_t/R_{et}) * 0.061$].

Another important measure developed by the combination of the wet and dry manikin test is that of Total Heat Loss, which is represented by the symbol (THL). Total heat loss is a measure of exactly what the name suggests. It is the amount of heat in Watts that is released into the atmosphere from the surface of the manikin.

Total Heat Loss:

$$THL = [(P_s - P_a) / R_{et}] + [(T_s - T_a) / R_t]$$

P_s = Water vapor pressure at the surface of the manikin (kPa),

P_a = Water vapor pressure in atmosphere surrounding the manikin (kPa),

A = Cumulative area of the manikin sections being evaluated (m_2),

Q_t = Total Heat Loss, with units: (W/m_2),

T_s = Temperature at the manikin surface (35 °C),

T_a = Temperature of the test atmosphere(23 °C), and

R_t = Thermal resistance of the garment and surface air layer (°C/m_2/W).

When the environmental testing conditions are the same for both the dry and the wet manikin tests, the formula above can be simplified and reduced to the formula below.

Total Heat Loss Simplified:

$$THL = H_e / A$$

H_e = power input for the evaporative testing (wet) condition (W)

A = total area of the manikin being evaluated (m_2)

Clothing Materials

There were seven garments used in this study. All were short sleeve t-shirts and all were for the purpose of running. In this section Images of the Coppelius manikin will be shown under testing condition wearing each of the t-shirts in the sample set detailed above. This is to give a visual understanding of the garments and fabrics that are being referred to throughout this report. These photos also provide some level of understanding of the construction of each of the garments used as well as an understanding of the set up of the testing environment inside the environmental chamber.

Figure 3.18 – Coppelius with Garment A

Figure 3.19 - Coppelius with Garment B

Figure 3.20 - Coppelius with Garment C

Figure 3.21 -Coppelius with Garment D

	
Figure 3.22 - Coppelius with Garment E	**Figure 3.23 - Coppelius with Garment F**

Figure 3.24 - Coppelius with Garment G

Evaluation

Once the data has been gathered from the physical testing phase, it is necessary to look at what this data conveys about the garments in the sample set. Each data set has anywhere from three to five replications, depending on the test, and compares the data from each of the seven garments in the garment level manikin testing or eight different fabrics (including front and back for the G garment) in the fabric level testing. A statistical method for comparing the results of these tests, which individually have a uniform number of replications, is necessary in order to gather meaningful insight from the data. This allows for an understanding of whether the results from one sample are really significantly different from the results from another sample. It also allows for the determination of whether their results are too close to determine any real difference attributed to anything other than random variation within the testing.

Significant Difference

The method chosen to analyze each test's data set is a subset of Analysis of Variance (ANOVA). This method is called the Tukey Test or the Tukey-Kramer HSD (Honestly Significantly Different) Test, and is well suited to look into data in order to compare the means of a sample set in order to determine the real difference which exists therein (Montgomery, 2005). This test is an exact alpha-level test when the number of replications are all the same within the sample set of fabrics tested (SAS Institute Inc., 2007). Tukey's Test utilizes the studentized range statistic which is calculated in the formula below:

Studentized Range Statistic:

$q = (y^{bar}_{max} - y^{bar}_{min}) / \sqrt{MS_E/\eta}$ where:

y^{bar}_{max} = largest sample mean in sample set,

y^{bar}_{min} = smallest sample mean in sample set,

MS_E = mean square error, and

η = number of replications (Montgomery, 2005).

Tukey's test identifies two means within a sample set as different from one another if the absolute value of their sample difference is greater than the number calculated in the formula below:

Tukey's Significant Difference Measure:

$T_\alpha = q_\alpha(a,f)\,(\sqrt{MS_E/\eta})$ where:

q = studentized range statistic,

α = .05 (for 95% Confidence Level)

a = number of levels of the factor,

f = degrees of freedom,

MS_E = mean square error, and

η = number of replications (Montgomery, 2005).

The data graphs reported in this study show all data points for each test measure as well as a visual comparison tool, which included in the JMP 7.0 software that was used to analyze this data. The visualization called the 'comparison circles plot' takes the form of circles on the right side of each graph (SAS Institute Inc., 2007). There is one circle for each shirt/fabric in the chart. The size of the circles represents the precision of the data points, and the locations of the circles represent the location on the graph of the group mean for the replications of that fabric or garment. If the data points exhibit a high degree of precision among the replications, then that fabric/garment's representative circle will be much smaller than if the data points were spread over a wide range. This is also a function of the number of replications in that sample. For the majority of tests in this study the number of replications in each test is uniform across all samples; the GATS testing however has one sample that has seven replications as compared to five replications for all other samples. This is reflected in the comparison circles plot with a smaller circle.

These circles also provide an idea of how different any given sample's mean is from any other sample's mean within the test set. If the two circles have an outside tangential intersection of less than 90º they are significantly different, while if that same angle is greater than 90ºC or if these circles overlay one another then they are not significantly different. An example image in Figure 3.25 provides further visual explanation of this concept.

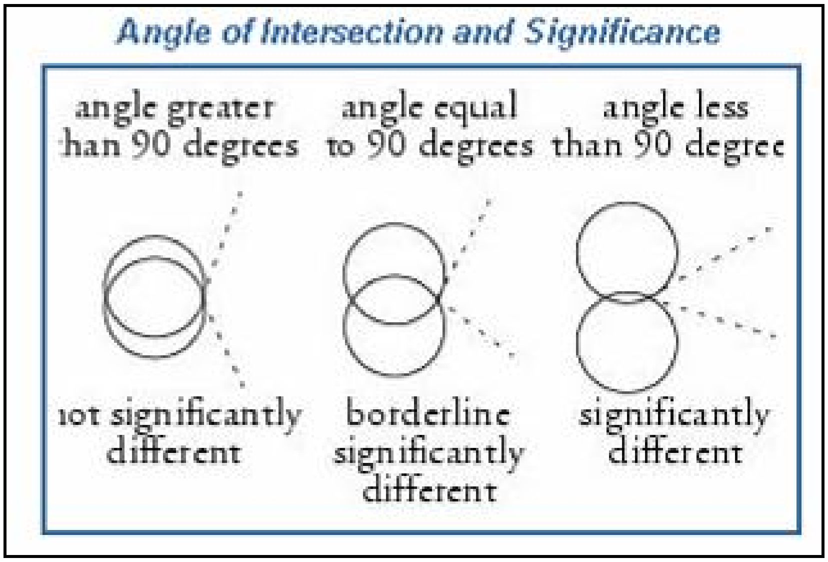

Figure 3.25 - Comparison Circles Plot Example

Source: SAS Institute Inc. (2007). *JMP 7.0 help document*

There are instances where the circles are close to the 90º threshold, and when this occurs it is difficult to decipher visually whether they are significantly different or not. In this case the answer to if the two are significantly different can be found in the "LSD Threshold Matrix" (SAS Institute Inc., 2007). This is a matrix of comparisons between each of the samples in the set with a number representing their comparison. A negative number represents two samples that are not significantly different while a positive value represents two samples that are significantly different from one another. These numbers are developed by taking the Least Significant Difference (LSD) value from each pair and subtracting that from the absolute difference calculated from the data (Abs(Dif)-LSD). If the absolute difference is smaller than the Least Significant Difference then the number will return negative, representing a pair that is not significantly different.

Correlation of Measures

Further analysis is gained from using the JMP 7.0 program in order to determine whether the data output from two different measures correlate with one another or if they are unrelated to one another. The Scatterplot Matrix function on JMP 7.0 is useful for this purpose. It shows the graphical plots of every combination of measures that are input into the comparison. Within each plot is displayed the correlation ranging from 0 to 1. A correlation of 0 represents two measures that are completely independent of one another and a correlation of 1 meaning that they are fully correlated show linear dependence between the two measures. There are also density ellipses around each plot to show the general relationship of the two measures. This allows visual detection of the relationship; if the ellipses are linear then they reflect a linear relationship which points to the two measures being correlated. On the Scatterplot Matrices in this study all relationships with a 75% correlation or greater (a correlation value of .7500 or more) are shaded in gray. All ellipses and correlation values are set to 95% Confidence Levels. Figure 3.26 gives an example of one of these correlation plots.

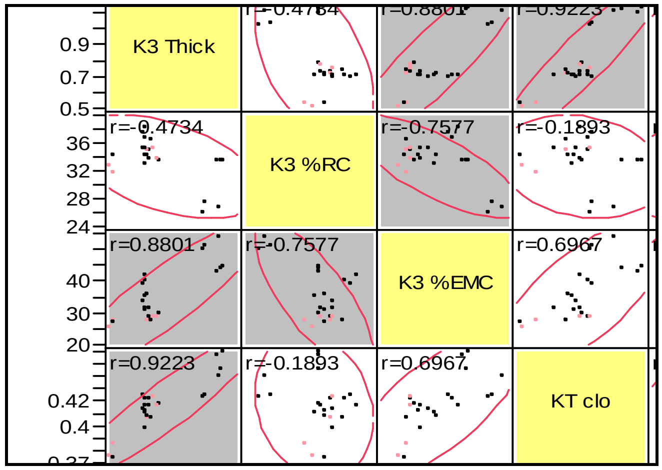

Figure 3.26 – Correlation Scatterplot Example

Merging of Market Survey and Physical Testing Results.

The final step of the evaluation phase was to determine what was learned when the results of the consumer market survey were combined with the results from the testing phase. The testing data at this point had been determined as to what tests were significantly different and which ones were not; now the opportunity was to take the test measures which showed discernable difference and apply them to the measurement of how well the fabrics and garment meet the comfort demand of the marketplace. This was done with the US group as well as with the International group. Within each of these groups the testing phase results were reviewed in light of the comfort demands of both the male and female target groups within the larger survey population. The comfort requirements of the full population groups on both sides of the market survey were also reviewed.

This was done by placing extra emphasis on looking at the results from the physical qualitative comfort testing results for the comfort parameters which had been identified as most important by each consumer group. The measures relating to moisture management, for example, would be given more importance if moisture management was identified as highly important by the consumer group of interest. There were too many test measures to perform an actual quantitative rank, due to the high number of measures in the testing phase and the fact that these measure both were done on differing scales as well as the fact that superior performance was determined by a higher value for some measures, such as moisture capacity, and by a lower value for other measures, such as drying time. Due to the high number of measure variables across all tests and test measures there was not sufficient time to create a methodology for developing a quantitative rank, rather the samples were qualitatively assessed in terms of how well they performed in the areas which were highlighted as important by the consumer.

Verifying Marketing Claims

The garments were also compared on how well they met their marketing claims. Fore example, a shirt may have had the claim on its labeling that it had ‘superior moisture management’ or ‘high stretch for mobility’. With the testing results in hand, it is possible to look back at the earlier phase of the project where the marketing claims of the garments were laid out, and to determine how true those claims were in relation to the performance of the other garments in the sample set.

CHAPTER IV

RESULTS AND DISCUSSION

Survey Results

Data tables are arranged such that they organize the responses to each question by age and gender. There were six age categories with results for males and females in each category. There was also separate data for responses from those in the United States and from those who were International respondents. Within the data for the United States there was also an iteration of the data that was reported by Income Level. There were 12 categories of income levels and this allowed for comparison based on household income of the respondents from the United States.

Research Objective Results – Market Survey

As a prelude to the results discussion for the market survey, it is helpful to revisit the Research Objectives stated in chapters one and three. In this section, research objective three, which is met in the market results chapter, will be restated and the key findings pertaining to that objective will be given. This serves as a summary preview to the data analysis which is discussed later in more detail. Note: research objectives one and two were met in the review of literature in chapter two while objectives four five and six were met in the chapter three methodology section.

RO3: Perform a market survey to collect information on the qualitative comfort descriptors most important to athletic apparel consumers, and to quantify the significance of the athletic apparel market.

Key Findings:

- 38,263 people responded to this survey; 23,308 from outside the United States, and 14,955 from within the United States.
    - 29,713 were female and 8,550 were male. Both groups were heavily female.
- Almost 2/3 of respondents have purchased t-shirt for athletic purposes.
    - The two target groups in the International group were:
        - Males: age 13-17 with 80% having made this purchase.
        - Females: age 13-17 with 78.9% having made this purchase.
    - The two target groups in the US group were:
        - Males: age 25-34 with 75% having made this purchase.
        - Females: age 18-24 with 72.2% having made this purchase.
    - In the oldest age groups the males were more likely to have made this purchase, while in younger groups the male and female propensity for this purchase was nearly equal.
- The vast majority of consumers have purchased apparel with comfort in mind.
    - 96.8% of US respondents and 96.2% of International respondents.
    - Men were slightly less likely (~ 93%) than women (~97%) to have purchased apparel with comfort in mind.

- The wealthiest Americans ($200,000+) were least likely to purchase with comfort in mind.

- Purchase decision parameters for both US and International groups were ranked:
  - With Price most important, followed by Fit, Comfort, Style/Color, Moisture Management, and Other being least important; in descending order of importance.
- Comfort decision parameters were ranked:
  - By the US group with Fit most important, followed by Soft Hand, Breathable, Cooling, Moisture Management, and Other as least important.
  - By the International group with Fit most important, followed by Breathable, Soft Hand, Cooling, Moisture Management, and Other as least important.
  - Soft Hand was more valued by the US group, while Breathable was more valued by the International group.
- Moisture management was valued:
  - Much less overall than the expectation, which was developed by the performance claims in the market.
  - More by males than females
  - More by the International group than by the US group.
- Fit was by far the most important comfort aspect for the consumers. This is not a measurable parameter within this project.

Respondent Demographic Information

There were 23,308 respondents from the International side of the survey; meaning those consumers from countries outside the United States. Of these individuals, a total of 6,303 were males and 17,005 were females. In Table 4.1 are the numbers of respondents in each category, both age and gender are listed. There are six age categories ranging from the 13-17 years old category, all the way to 55 years and above category. One interesting thing to note is the obvious difference between the number of male and female respondents. A 73% majority of the respondents were female, while males accounted for only 27%. According to Marshal Cohen of NPD, most NPD surveys have a smaller sample size than this survey and a closer gender ratio. However, there are always more females than males in the typical NPD survey (Cohen, 2008). Another clearly evident factor is that there are more respondents as the age brackets increase; with only 92 individuals between the age of 13 and 17 years old; this increases with each consecutive increasing age bracket. The top age bracket accounted for 30.7% of respondents, with 7,161 individuals at 55 years and older.

Table 4.1 - Demographic Layout of International Survey Respondents
(number and percentage)

Age (and % of all ages)	**Male** (count and %)	**Female** (count and %)	**Total**
13-17 (0.4%)	**35** (38.0%)	**57** (62.0%)	**92** (100%)
18-24 (5.8%)	**137** (10.1%)	**1,214** (89.9%)	**1,351** (100%)
25-34 (14.9%)	**480** (13.8%)	**2,988** (86.2%)	**3,468** (100%)
35-44 (21.0%)	**904** (18.5%)	**3,984** (81.5%)	**4,888** (100%)
45-54 (27.2%)	**1,678** (26.4%)	**4,670** (73.6%)	**6,348** (100%)
55+ (30.7%)	**3,069** (42.9%)	**4,092** (57.1%)	**7,161** (100%)
All Ages (100%)	**6,303** (27.0%)	**17,005** (73.0%)	**23,308** (100%)

There were 14,955 respondents from the United States. This group was also heavily weighted toward the female demographic. In fact the disparity between males and females was even greater among US respondents as 85% were female and merely 15% were male. The US group was also weighted toward older respondents. This was not as strong of a difference as among the International respondents. The percentage of respondents internationally that were in the three oldest groupings was 78.9%. Compare this to only 53.6% in the three oldest groups for the US respondents. Table 4.2 shows the demographic information for the respondents from the United States.

Table 4.2 - Demographic Layout of U.S.A. Survey Respondents
(number and percentage)

Age (% of all ages)	**Male** (count and %)	**Female** (count and %)	**Total**
13-17 (8.5%)	**152** (12.0%)	**1120** (88.0%)	**1272** (100%)
18-24 (19.1%)	**106** (3.7%)	**2747** (96.3%)	**2853** (100%)
25-34 (18.8%)	**112** (4.0%)	**2698** (96.0%)	**2810** (100%)
35-44 (5.2%)	**39** (5%)	**746** (95.0%)	**785** (100%)
45-54 (20.5%)	**142** (4.6%)	**2922** (95.4%)	**3064** (100%)
55+ (27.9%)	**1696** (40.7%)	**2475** (59.3%)	**4171** (100%)
All Ages (100%)	**2247** (15%)	**12708** (85.0%)	**14955** (100%)

Respondent Household Income Information (USA)

The survey was returned by NPD with age and gender information for both the International and US groups. For the US group an additional delineation was provided along the lines of household income. This grouping was for adults only as minors are not able to provide any information on household income. This means that both the group for males age 13-17 and the group for females age 13-17 were exempted from this results display format. A total of 13,811 US respondents were included in the household income table of responses. As would be expected it is the moderate income groups that have the largest percentage of representation in this data. The largest group consists of individuals having between $35,000 and $44,000 annual household income. Those groups which do not represent at least 10% of the total US survey are those below $24,000 per year household income and those above

$75,000 annual household income. The smallest two groups are those above $150,000 household income per year at about 0.3% each for a total of about 0.6% of US survey respondents having more than $150,000 annual household income. Table 4.3 shows the number of individuals by income level that were represented in the US market survey. Once again, household income data was only available for the US survey and is not included in the International survey; as such this data represents the United States only.

Table 4.3 - Household Income Data for US Survey Respondents
(Count for each; and % of total US group)

< $15,000	**$15k - $24k**	**$25k - $29k**	**$30k - $34k**	**$35k – $44k**	**$45k - $49k**
887 (6.4%)	600 (4.3%)	1494 (10.8%)	1965 (14.2%)	2575 (18.6%)	1540 (11.2%)
$50k - $59k	**$60k - $74k**	**$75k – $99k**	**$100k–$149k**	**$150k-$199k**	**$200,000 +**
2018 (14.6%)	2139 (15.5%)	319 (2.3%)	196 (1.4%)	38 (0.3%)	40 (0.3%)

Analysis of Survey Goals

The analysis of the data gathered by NPD has two purposes. The first purpose is to gain an understanding as to how important comfort factors are to the consumer. This will aid in emphasizing test results of highly desirable comfort parameters over those which are identified as less desirable by the consumers in the survey. The second purpose of the survey is to garner an understanding of the market for performance athletic apparel.

Within the questionnaire there are three types of questions providing three types of uniquely useful data. The first question type is purchase history which allows insight into the consumer's purchasing history and therefore into their purchasing tendencies. With the purchase history data, for the purchase of a t-shirt for athletic purposes, it is possible and useful to identify target demographic groups from within the full survey population and have the ability to declare them as a core market. Knowing the core market groups allows the apparel company to know exactly which demographic groups they should be aiming their marketing efforts toward.

The next type of question is about purchase decision parameters. This question asks the consumer what things are considered when deciding weather or not to purchase apparel. These questions deal with both general purchase decisions and with comfort purchase decisions. These questions are valuable to see how important purchase decision aspects are when they are presented to the consumer as merely one item in a more a comprehensive list.

The third type of question is the most crucial to this study and asks the consumers specifically about the importance of each comfort feature when purchasing a t-shirt. This type of question is important because the response that can be used to add special emphasis to the quantitative fabric and garment comfort test results, from the tests performed in NCSU's TPACC laboratories. With the core consumer identified, it is then possible to track their answers to these comfort feature questions and provide tailored performance assessments of the garments being tested, for each of these target groups or for the entire survey group.

Purchase History Results

There are two purchase history questions in the consumer research instrument. The first purchase history question asks the consumer if they have ever purchased apparel with comfort in mind. Tables 4.4 through 4.6 show the results of this question. The second purchase history question deals with the prior purchase of t-shirts for athletic use. Tables 4.7 through 4.9 contain the data generated by this question.

Comfort Purchase History

The first thing that is evident from the data is that comfort is absolutely paramount in apparel. The vast majority of consumers from both the US and International survey groups indicate that they have purchased apparel with comfort in mind. The US group has a slightly higher percentage at 96.8% than the International group at 96.2% indicating that they have purchased apparel with comfort in mind.

One interesting thing in this question to note is that the men in both groups are slightly less likely to have considered comfort when purchasing apparel. This goes against the conventional thought that women are more likely to sacrifice comfort for other things such as brand and style. The percentage of men who said they have purchased apparel with comfort in mind is 93.0% and 92.6% for the International group and the US group respectively. Compare that to the 97.5% and 97.6% of women from the International and US groups respectively that said they have purchased apparel with comfort in mind. Tables 4.4 and 4.5 show the data for the International and US groups respectively.

Within the US group, the income group that is most likely to have made a purchase with comfort in mind is the $50,000 - $59,000 income group where only 2.6% said ‘no’, while the group least likely to purchase with comfort in mind was the $200,000+ income group where a relatively large 10% said ‘no’. Table 4.6 shows the data for comfort purchase history in the US by income level.

Table 4.4 – Comfort Purchase History (International)

Have Ever Purchased Apparel With Comfort in Mind (International) (By Age and Gender … In %)				
Age	Gender	**Yes**	**No**	**Total**
13-17	M	91.4	8.6	100%
	F	89.5	10.5	100%
18-24	M	92.0	8.0	100%
	F	97.8	2.2	100%
25-34	M	91.7	8.3	100%
	F	97.3	2.7	100%
35-44	M	92.1	7.9	100%
	F	97.3	2.7	100%
45-54	M	93.3	6.7	100%
	F	97.6	2.4	100%
55+	M	93.3	6.7	100%
	F	97.5	2.5	100%
Total	**M**	**93.0**	**7.0**	**100%**
	F	**97.5**	**2.5**	**100%**
All	**M & F**	**96.2**	**3.8**	**100%**

Table 4.5 – Comfort Purchase History (USA)

Have Ever Purchased Apparel With Comfort in Mind (U.S.A.) (By Age and Gender … In %)				
Age	Gender	**Yes**	**No**	**Total**
13-17	M	85.5	14.5	100%
	F	93.4	6.6	100%
18-24	M	91.5	8.5	100%
	F	96.7	3.3	100%
25-34	M	85.7	14.3	100%
	F	97.2	2.8	100%
35-44	M	84.6	15.4	100%
	F	97.5	2.5	100%
45-54	M	95.8	4.2	100%
	F	98.2	1.8	100%
55+	M	93.1	6.9	100%
	F	98.3	1.7	100%
Total	**M**	**92.6**	**7.4**	**100%**
	F	**97.6**	**2.4**	**100%**
All	**M & F**	**96.8**	**3.2**	**100%**

Table 4.6 – Comfort Purchase History (USA by Income)

Have Ever Purchased Apparel With Comfort in Mind (U.S.A.) (By Income Level … In %)			
Income (In Thousands)	**Yes**	**No**	**Total**
< $15,000	95.0	5.0	100%
$15 - $24	96.3	3.7	100%
$25 - $29	96.9	3.1	100%
$30 - $34	97.2	2.8	100%
$35 - $44	97.3	2.7	100%
$45 - $49	96.8	3.2	100%
$50 - $59	97.4	2.6	100%
$60 - $74	97.2	2.8	100%
$75 - $99	95.6	4.4	100%
$100 - $149	94.4	5.6	100%
$150 - $199	92.1	7.9	100%
$200,000 +	90.0	10.0	100%
Total	**96.8**	**3.2**	**100%**

Athletic t-shirt Purchase History - Target Consumer Groups

The second purchase decision question dealt with the history of making a t-shirt purchase for athletic use. This question allows for the identification of target (or core) consumer groups, because those who respond in the affirmative to this question will more likely be in the market for performance athletic t-shirts because they already have bought this type of product in the past. Identifying these core groups will also allow for a look at what they, as a core consumer group, value in terms of comfort parameters.

Combining the knowledge of who uses the product most with an understanding of their values of comfort will help in selecting the best candidate test garment to meet the needs of the core market demographic for this product. Once these groups were identified their views on all of the parameters of comfort were tracked and compared with that of the larger total survey group. Tables 4.7 through 4.9 contain the data for this purchase history question.

International Core Groups:

Looking at the International group first it is interesting to note that age plays a big role in whether or not people have made this type of purchase. It is clear within the International group that the males and females from the youngest group, ages 13-17, are the most likely consumers of this product by a wide margin over the next most likely group. 80% of the males age 13-17 have made this type of purchase, while 78.9% of females age 13-17 have also made this purchase in the past. (The nearest male and female groups to these two had 72.7% and 71.3% respectively who made this indication.)

US Core Groups:

Turning to the US survey results, age is once again a noticeable factor in determining how apt the consumer is to make the purchase of performance athletic t-shirts. While the international group has a more clearly discernable pattern from youngest to oldest the US group has its highest numbers of people who have made athletic t-shirt purchased in the younger categories but not in the youngest group. The male target age group is those age 25-34 with 75% indicating as prior purchase. The female target consumer group is those age 18-24 with 72.2% of respondents in that age bracket indicating a previous purchase. (The nearest male and female groups to these two had 71.8% and 72.0% respectively that made this indication.)

Table 4.7 – T-shirt Purchase History (USA)

Have Ever Purchased T-shirt for Athletic Use (U.S.A.) (By Age and Gender … In %)				
Age	Gender	**Yes**	**No**	**Total**
13-17	M	65.8	34.2	100%
	F	68.8	31.3	100%
18-24	M	67.9	32.1	100%
	F	**72.2**	**27.8**	**100%**
25-34	**M**	**75.0**	**25.0**	**100%**
	F	72.0	28.0	100%
35-44	M	71.8	28.2	100%
	F	65.4	34.6	100%
45-54	M	69.7	30.3	100%
	F	57.1	42.9	100%
55+	M	56.3	43.7	100%
	F	47.7	52.3	100%
Total	**M**	**59.1**	**40.9**	**100%**
	F	**62.7**	**37.3**	**100%**
All	**M & F**	**62.1**	**37.9**	**100%**

Table 4.8 – T-shirt Purchase History (International)

Have Ever Purchased t-shirt for Athletic Use (International) (By Age and Gender … In %)				
Age	Gender	**Yes**	**No**	**Total**
13-17	**M**	**80.0**	**20.0**	**100%**
	F	**78.9**	**21.2**	**100%**
18-24	M	71.5	28.5	100%
	F	71.3	28.7	100%
25-34	M	72.7	27.3	100%
	F	68.4	31.6	100%
35-44	M	66.6	33.4	100%
	F	64.6	35.4	100%
45-54	M	60.4	39.6	100%
	F	58.0	42.0	100%
55+	M	58.2	41.8	100%
	F	48.4	51.6	100%
Total	**M**	**61.4**	**38.6**	**100%**
	F	**60.0**	**40.0**	**100%**
All	**M & F**	**60.4**	**39.6**	**100%**

Table 4.9 – T-shirt Purchase History (USA by Income)

Athletic Use (U.S.A.) (By Income Level … In %)			
Income (In Thousands)	**Yes**	**No**	**Total**
< $15,000	65.4	34.6	100%
$15 - $24	57.0	43.0	100%
$25 - $29	57.4	42.6	100%
$30 - $34	59.8	40.2	100%
$35 - $44	60.8	39.2	100%
$45 - $49	61.3	38.7	100%
$50 - $59	64.0	36.0	100%
$60 - $74	65.2	34.8	100%
$75 - $99	68.4	31.6	100%
$100 - $149	68.4	31.6	100%
$150 - $199	70.3	29.7	100%
$200,000 +	70.0	30.0	100%
Total	**62.1**	**37.9**	**100%**

Purchase Decision Results

The purchase decision questions allow the consumer to give an indication as to what is important to them when they consider making a purchase of apparel. Two questions of this style were asked. These questions both read: "Which of the following factors are important to you when purchasing apparel?" The first question was about general purchase factors and gave the options: price, fit, comfort, moisture management, style/color, and other. The second question was about the comfort related aspects a person considers when making an apparel purchase and gave the options: moisture management, cooling, soft hand, good fit, breathable, and other. Tables 4.10 through 4.15 at the end of this section show the results for these two questions as reported separately for the International group and the US group.

General Purchase Decision

Beginning with the general purchase decision question, the ranking of attributes considered when making an apparel purchase was the same for both groups and is: (Price 1, Fit 2, Comfort 3, Style/Color 4, Moisture Management 5, and Other 6). Price fit and comfort are extremely close in terms of importance to both groups with 84.3% International and 86.2% US choosing price as a factor considered; 84.0% International and 86.1% US choose fit as a factor considered, and 82.6% International and 82.2% US choosing comfort as a factor considered. The next highest rated aspect is style/color at 66.6% International and 70.1% US. While the US rates style/color about 4% higher than the International group, the International group rates Moisture Management higher than the US by about the same margin.

Price.

Price is valued more by females by a 6.1% margin in the International group and by a 10.4% margin in the US group. Price is valued more in the US group by a margin of 1.9% over the International group. Price is essentially tied with fit for first place in both groups. As expected, price was considered increasingly important to the decreasingly wealthy in the household income data from the US group.

Fit.

Fit is also favored by females by a 9.5% margin internationally and by an 8.5% margin in the US. Fit is favored more by the US group overall than the International group by a margin of 2.1%. Fit was fairly evenly valued by all income groups in the US.

Comfort.

Comfort is also favored more by females in both groups, by a 2.3% margin in the International group and a 5.3% margin in the US group. Overall the International group rates comfort higher than the US group by a margin of 0.4%, a very small difference. Comfort is essentially valued at 80% or more by all income groups in the US, with the exception of the two wealthiest groups who surprisingly value comfort less than their peers.

Style/Color.

Style/Color carries the most stark gender contrast, with females favoring this aspect by wide margins over males. Females in the International group favored style/color by a 16.5% margin over their male counterparts while US females favored style/color by a 16.9%

margin over their male counterparts. The US group overall favored style/color more than the International group by a 3.5% margin. Style/color was valued by all income groups in the US at about the same rate.

Moisture Management.

Moisture Management was an interesting aspect in this question because it was aimed at getting an idea of how consumers valued Moisture Management, in specific, over other more general aspects like price and fit. Moisture Management did not receive the same attention as price/fit/comfort but it did receive 12.1% from the International group and 8.4% from the US group. This shows that the International consumer is more aware of the value of Moisture Management than the US consumer by a margin of 3.7%. Moisture Management is also the lone purchase decision aspect that garnered more attention from men than from women. Males favored Moisture Management by a 2.6% margin internationally and by a 0.9% margin in the US. Moisture Management was fairly even among income groups within the US but was slightly more favored by groups making more than $50,000 annually.

Comfort Purchase Decision

Turning now to the comfort aspect purchase decision question; this question was included in purchase decision because the question is asked in the context of purchasing apparel in general, rather than the target product which is t-shirts. This question also is asked in the context of deciding upon a purchase. The ranking of the aspects by the International group is: (Fit 1, Breathable 2, Soft Hand 3, Cooling 4, Moisture Management 5, and other 6). The ranking by the US group is: (Fit 1, Soft Hand 2, Breathable 3, Cooling 4, Moisture

Management 5, and Other 6). The difference between the two rankings is that the International group placed Breathable slightly higher than Soft Hand, while the US group placed Soft Hand above Breathability.

Fit.

Fit was the runaway favorite in this question at almost 20% points higher than the second place item in both groups. Fit was preferred by the International group more than by the US group by a 0.9% margin. Fit was also preferred by women more than men by a 2.0% margin internationally and by a 3.4% margin in the US. Fit was highly favored by all income groups, but interestingly was favored least by the groups $100,000-$149,000 and $150,000-$199,000 by a margin of about 6% less than any other group.

Soft Hand.

Soft Hand was preferred by the US by a margin of 6.5% more than the International group. Soft Hand was also chosen by women more than men by a 4.7% margin in the International group, and by a margin of 4.3% in the US group. Soft Hand was most highly favored by the middle income groups in the US.

Breathability.

Breathable was chosen more by the International group by a margin of 4.1% more than the US group. Females were more likely to choose Breathable by a 7.7% margin in the International group, and a 13% margin in the US group. Breathable was very evenly supported across the board for the income groups in the US.

Cooling.

Cooling was also favored by the International group more than by the US group by a margin of 4.1%. Men were more likely to choose Cooling as an important purchase decision by a margin of 2.2% in the International group and 0.6% in the US group. The $200,000+ top income group in the US favored Cooling by a wide margin over most other income groups, while their nearest peers, the $100,000-$149,000 and the $150,000-$199,000 groups valued cooling the least of all income groups.

Moisture Management.

A noticeable aspect of this data is that Moisture Management is not a highly valued comfort aspect, in the minds of the consumers in both groups, as compared to the other options. This may suggest that marketing efforts for performance athletic t-shirts have yet to educate the consumer as to what makes these products work so well. Moisture Management was once again valued more by the International group in this question than it was by the US group by a margin of 5.9%. Moisture Management also was valued by men more than women in this question by a margin of 1.7% internationally and 2.2% in the US. Moisture Management was valued evenly among income groups in the US with the exception of the top two which placed grater value on moisture management than their peers. All data tables for the purchase decision questions are in Tables 4.10 through 4.15.

Table 4.10 – General Apparel Purchase Decision Factors (International)

Important Factors When Purchasing Apparel (International) (By Age and Gender … % that chose each factor)								
Age	Gender	**Price**	**Fit**	**Comfort**	**Moisture Management**	**Style/Color**	**Other**	Total
13-17	M	68.6	71.4	68.8	14.3	80.0	11.4	314.3
	F	82.5	70.2	75.4	12.3	78.9	10.5	329.8
18-24	M	80.3	69.3	81.8	14.6	77.4	5.1	328.5
	F	89.2	88.4	81.8	10.3	81.4	2.7	353.8
25-34	M	80.2	75.6	79.8	17.3	69.6	3.3	325.8
	F	89.7	86.9	79.9	11.0	75.1	2.7	345.1
35-44	M	82.6	73.7	78.2	15.6	57.2	2.4	309.7
	F	86.3	85.5	80.9	11.9	68.5	2.1	335.2
45-54	M	79.9	75.1	79.1	13.8	50.5	2.5	301.0
	F	84.4	86.2	84.5	11.7	68.1	2.2	337.1
55+	M	78.8	79.8	82.7	13.1	52.6	2.1	309.1
	F	83.7	87.3	87.0	11.2	70.8	1.8	341.7
Total	**M**	**79.8**	**77.1**	**80.9**	**14.0**	**54.5**	**2.4**	**308.7**
	F	**85.9**	**86.6**	**83.2**	**11.4**	**71.0**	**2.2**	**340.4**
All	**M & F**	**84.3**	**84.0**	**82.6**	**12.1**	**66.6**	**2.3**	**331.8**

Table 4.11 – General Apparel Purchase Decision Factors (USA)

Important Factors When Purchasing Apparel (U.S.A.) (By Age and Gender … % that chose each factor)								
Age	Gender	**Price**	**Fit**	**Comfort**	**Moisture Management**	**Style/Color**	**Other**	Total
13-17	M	71.7	63.8	63.8	10.5	68.4	10.5	288.8
	F	84.1	82.6	76.8	7.1	82.7	6.6	339.9
18-24	M	73.6	60.4	62.3	7.5	61.3	6.6	271.7
	F	89.6	86.5	78.1	7.0	77.9	2.9	342.0
25-34	M	70.5	70.5	69.6	14.3	63.4	8.0	296.4
	F	89.0	87.4	79.2	8.0	75.8	2.3	341.5
35-44	M	76.9	71.8	69.2	10.3	48.7	5.1	282.1
	F	89.4	87.4	83.4	10.5	69.3	2.7	342.6
45-54	M	80.3	78.2	76.1	11.3	55.6	6.3	307.7
	F	86.6	87.4	87.7	9.0	68.4	1.6	340.9
55+	M	77.8	80.9	79.5	8.7	55.1	2.1	304.1
	F	85.3	88.5	87.1	8.5	69,8	2.1	341.3
Total	**M**	**77.4**	**78.9**	**77.7**	**9.2**	**55.8**	**3.0**	**301.9**
	F	**87.8**	**87.4**	**83.0**	**8.3**	**72.7**	**2.3**	**341.5**
All	**M & F**	**86.2**	**86.1**	**82.2**	**8.4**	**70.1**	**2.4**	**335.4**

Table 4.12 – General Apparel Purchase Decision Factors (USA by Income)

Important Factors When Purchasing Apparel (U.S.A.) (By Income Level … % that chose each factor)							
Income (In Thousands)	**Price**	**Fit**	**Comfort**	**Moisture Management**	**Style/Color**	**Other**	Total
< $15,000	86.9	83.9	79.7	7.6	71.8	4.3	334.2
$15 - $24	90.0	84.2	82.0	8.8	69.3	2.8	337.2
$25 - $29	87.5	84.1	82.0	8.0	67.9	2.1	331.7
$30 - $34	87.4	85.0	82.2	7.3	68.5	2.1	332.6
$35 - $44	87.4	87.2	81.9	8.6	70.8	2.3	338.3
$45 - $49	86.9	85.9	82.5	7.3	69.8	1.8	334.2
$50 - $59	83.9	87.1	83.4	9.4	69.3	2.4	335.5
$60 - $74	84.8	87.3	82.9	8.7	72.8	1.9	338.4
$75 - $99	79.6	83.7	79.9	8.8	68.7	3.1	323.8
$100 - $149	74.5	86.7	80.6	11.7	66.3	2.0	321.9
$150 - $199	78.9	81.6	73.7	7.9	71.1	7.9	321.1
$200,000 +	72.5	92.5	77.5	10.0	72.5	5.0	330.0
Total	**86.2**	**86.1**	**82.2**	**8.4**	**70.1**	**2.4**	**335.4**

Table 4.13 – Comfort Aspects Identified as Important (International)

Comfort Factors Considered Most Important (International) (By Age and Gender … % that chose each factor)								
Age	Gender	**Moisture Management**	**Cooling**	**Soft Material**	**Good Fit**	**Breathable**	**Other**	Total
13-17	M	28.6	57.1	51.4	74.3	60.0	8.6	280.0
	F	36.8	50.9	61.4	75.4	77.2	14.0	315.8
18-24	M	39.4	62.0	51.8	81.0	66.4	5.8	306.6
	F	32.1	43.8	52.8	86.4	72.9	6.6	294.6
25-34	M	35.6	54.6	51.9	82.1	70.2	6.7	301.0
	F	31.2	42.9	57.4	84.5	70.4	6.2	292.7
35-44	M	31.4	48.0	54.8	81.0	61.3	6.3	282.7
	F	30.7	44.9	60.6	82.2	67.9	6.6	292.9
45-54	M	31.2	48.9	57.8	81.3	61.5	5.4	286.1
	F	29.0	48.7	65.5	83.6	67.0	6.3	300.1
55+	M	29.7	46.6	61.4	81.5	57.2	7.0	283.4
	F	26.1	47.7	70.8	82.6	65.4	6.9	299.6
Total	**M**	**31.0**	**48.4**	**58.6**	**81.4**	**60.2**	**6.4**	**285.9**
	F	**29.3**	**46.2**	**63.3**	**83.4**	**67.9**	**6.5**	**296.6**
All	**M & F**	**29.8**	**46.8**	**62.0**	**82.8**	**65.8**	**6.5**	**293.7**

Table 4.14 – Comfort Aspects Identified as Important (USA)

Comfort Factors Considered Most Important (U.S.A.) (By Age and Factor … % that chose each factor)								
Age	Gender	**Moisture Management**	**Cooling**	**Soft Material**	**Good Fit**	**Breathable**	**Other**	Total
13-17	M	38.8	55.3	53.9	75.0	67.1	4.6	294.7
	F	26.8	48.8	57.2	81.5	69.1	6.3	289.8
18-24	M	32.1	50.0	46.2	72.6	62.3	1.9	265.1
	F	24.6	41.2	60.4	83.2	68.7	4.3	282.3
25-34	M	26.8	36.6	56.3	80.4	57.1	1.8	258.9
	F	23.8	37.4	63.7	83.0	65.2	4.0	277.1
35-44	M	30.8	41.0	64.1	74.4	56.4	10.3	276.9
	F	27.7	44.6	73.6	83.9	63.5	6.0	299.5
45-54	M	28.2	50.0	63.4	75.4	62.0	7.0	285.9
	F	24.0	46.3	74.6	82.3	64.8	6.9	298.8
55+	M	25.1	42.7	66.8	79.7	48.5	8.8	271.6
	F	20.7	44.7	77.3	80.6	55.2	8.7	287.2
Total	**M**	**25.8**	**43.2**	**64.9**	**79.0**	**50.7**	**8.0**	**271.7**
	F	**23.6**	**42.6**	**69.2**	**82.4**	**63.7**	**5.9**	**287.4**
All	**M & F**	**23.9**	**42.7**	**68.5**	**81.9**	**61.7**	**6.2**	**285.0**

Table 4.15 – Comfort Aspects Identified as Important (USA by Income)

Comfort Factors Considered Most Important. (U.S.A.) (By Income Level … % that chose each factor)							
Income (In Thousands)	**Moisture Management**	**Cooling**	**Soft Material**	**Good Fit**	**Breathable**	**Other**	Total
< $15,000	26.2	44.8	63.9	81.1	63.3	6.5	285.6
$15 - $24	25.3	43.8	66.8	82.5	66.2	5.4	289.9
$25 - $29	22.2	42.4	67.5	81.2	61.5	5.9	280.8
$30 - $34	22.8	44.4	68.5	81.9	60.3	6.4	283.9
$35 - $44	25.1	44.4	68.5	82.3	62.4	6.0	288.4
$45 - $49	23.3	43.8	68.7	81.0	60.2	6.3	283.3
$50 - $59	23.3	40.4	69.2	81.9	62.4	6.7	283.9
$60 - $74	24.4	40.2	70.5	82.1	60.6	6.2	284.0
$75 - $99	22.2	42.2	67.9	83.2	59.0	7.3	281.9
$100 - $149	23.5	37.8	65.8	75.5	55.1	6.1	263.8
$150 - $199	27.0	37.8	59.5	75.7	62.2	16.2	278.4
$200,000 +	33.3	51.3	61.5	89.7	64.1	7.7	307.7
Total	**23.9**	**42.7**	**68.5**	**81.9**	**61.7**	**6.2**	**285.0**

Comfort Feature Results

There are five questions in this genre and they all pose the question of importance of each of five comfort aspects in the form of a likert scale, with options Not Important (1), Important (2), and Very Important (3). The five comfort aspects asked about in these questions are the same aspects which were included in the second purchase decision question; (Moisture Management, Cooling, Soft Hand, Good Fit, and Breathable). The comparisons here will be made based on the percentage of consumers who responded with "Very Important" as this shows a strong positive opinion towards a particular comfort parameter.

In the International group the ranking of comfort parameters was: (Fit 72.9%, Breathable 47.4%, Soft Hand 45.7%, Cooling 35.7%, and Moisture Management 23.0%). The ranking of comfort attributes by the US group was: (Fit 74.9%, Soft Hand 54.3%, Breathable 47.6%, Cooling 35.0%, and Moisture Management 18.6%) So in these rankings it is clear that the top 'measurable' comfort aspects are Soft Hand and Breathable. These two are not in the same order for both groups, but they do represent the top two for both the International and US groups.

The target consumer groups' responses to these comfort questions will be used in order to asses the garments' testing performance in light of survey results. The result is the ability to tailor a recommendation of which of the garments in the study performed the best for each one of the different target consumer groups, as well as for the International and US groups as a whole.

The result of this market survey is a much greater understanding not of what the physical testing data will be, but what it will mean for who are producing, marketing, and selling these products. When looking at all comfort aspects combined it is clear that Fit and Mobility was the run away winner in the mind of the consumer. This aspect will not be measured in the study. With that in mind the ranking of these aspects (fit included) has been provided in one consolidated table in Table 4.16. All individual tables of data for the comfort aspects are included in the Appendix in section A.1. The specific differences in demographic and income groups are discussed for each comfort feature below.

Moisture Management

The International group put more value on Moisture Management with 23.0% saying that it was very important, compared to 18.6% in the US group that said it is very important. In terms of gender the numbers are even, with both groups having nearly equal male and female response. Older consumers are also less likely to rate Moisture Management favorably. Moisture Management is interestingly valued most by the opposite ends of the income level spectrum in the US. The lowest group of < $15,000 per year and the highest group of $200,000+ rate it at over 20% 'Very Important' while the lowest rating comes from a middle income group at 17% 'Very Important'.

Cooling

Cooling is a comfort aspect that is viewed more favorably by the International group, but by a very thin margin of 0.7%. Cooling is a comfort characteristic where men and women have differing opinions from one group (US) to the other (International). In the

International group men favor Cooling by a 0.6% margin, whereas in the US group women favor cooling by a 1.3% margin. Age was not an obvious factor in this group, as the various age groups have a very similar view of Cooling. Cooling is fairly evenly valued by most income groups in the US with the exception of the two highest income groups which represent $150,000+ annually. These two groups rated Cooling lower than the rest of the US group.

Soft Hand

Soft Hand is heavily favored by those in the US group by 8.6% more than favored by those in the International group. In both groups women clearly favor Soft Hand more than men. In the International group this is true by an 8.2% margin and is the case by a 9.5% margin in the US group. Age did come into play in the response to Soft Hand. Older consumers were more likely to place a high value on Soft Hand than were younger consumers. This was the case in both the International and US groups. In terms of household income, Soft Hand performed similarly to Cooling. The majority of the income groups held a positive rating in the lower to mid 50% range while the top two income groups rated Soft Hand much lower at 43.2% and 39.5% respectively.

Fit

Fit was the most valued comfort aspect by far, and was given more importance by the US group than by the International group by a 2.0% margin. Once again women were more favorable of Fit than were their male counterparts. This was the case in the International group by a 7.4% margin and in the US group by a 10.9% margin. Age does play a role in the

International group but in an interesting way. The most supportive of Fit are young women, while the least supportive of Fit are young men. This may be due to the fashion trends of close fitting apparel for young women and loose fitting apparel for young men. Income was a factor in the ratings given to Fit and Mobility. The groups making $99,000 and less rated Fit averaging in the mid 70's percentage range, while the three groups representing $100,000+ averaged in the upper 60's range of positive support for Fit and Mobility.

Breathability

By a very narrow margin of 0.2% the US group favored Breathability more than the International group. Females gave a greater amount of importance to Breathable as a comfort parameter than did males by an 11.2% margin in the International group and a 14.7% margin in the US group. There was a general trend of the wealthier Americans supporting Breathability less than the middle class and lower class respondents.

Table 4.16 - Summary of Comfort Factor Importance for Selected Target Groups

Positive ('very important') ratings for total groups and target groups.						
Comfort Aspect	**Int. Total**	**Int. Males 13-17 yrs.**	**Int. Females 13-17 yrs.**	**U.S. Total**	**U.S. Males 25-34 yrs.**	**U.S. Females 18-24 yrs.**
Moisture Management	23.0%	22.9%	31.6%	18.6%	25.0%	18.3%
Cooling	35.7%	37.1%	38.6%	35.0%	33.0%	30.9%
Soft Hand	45.7%	31.4%	40.4%	54.3%	36.6%	44.3%
Fit and Mobility*	72.9%	62.9%	80.7%	74.9%	64.3%	76.0%
Breathable	47.4%	37.9%	54.4%	47.6%	43.8%	52.5%
*This comfort parameter is not a materials parameter and will not be quantitatively measured in this study						

Testing Results

The results of the survey give a clear understanding of the importance consumers place on various performance aspects of comfort. With the consumer input in place, the testing phase is where the sample set of fabrics and garments are put to the test in terms of what the consumers want them to provide. This is where the shirts, which are all sold for the same purpose, can be differentiated based on how they performed in the physical comfort testing phase of the study.

Fabric Level Testing

The first tests performed were the fabric level tests. These tests took the fabric properties one by one and tested for the characteristics that had been built into the product at the fabric level. The fabric's comfort characteristics translate directly into the comfort properties of the garment which are highly important in this products category. The tests used in the fabric level testing phase were the Kawabata Hand Evaluation System (KES), the Kawabata guarded sweating hot plate (Thermolabo), and the Gravimetric Absorbency Testing System (GATS) with an accompanying drying test. These tests together reveal the properties of the fabric that speaks to the issues addressed in the consumer survey, and will be useful in comparing to the results obtained through garment level testing with the NCSU Sweating Manikin. All test measures discussed in chapter three were recorded in tabular format showing all data points. The tables not shown in chapter four will be included in section A.2 of the appendix. The Analysis of Variance information for all test measures, as well as the Tukey-Kramer Honestly Significant Difference (HSD) information, for all tests will also be included in section A.2 of the appendix, as well as bar charts of data averages for all test measures.

The results of the simple structural properties of the fabric are the best means to begin reporting on the testing results at the fabric level. Below are tables giving information on the weight and the thickness of the fabrics involved in the fabric level testing for this study. The heaviest two fabrics in the testing weighed in at over 1.0 grams for the 3.5" diameter circular samples. The 100% cotton shirt was the heaviest fabric, with the F sample also weighing in at over 1.0 grams. The lightest fabrics in this sample set weighed less than 0.75 grams. The lightest was the fabric used in the C shirt; however this fabric was not significantly lighter than the fabric from the back panel of the G shirt. The remaining shirts weighed in at between 0.75 grams and 1.0 grams.

The fabric thickness for the samples in this study were interesting in that while the 100% cotton (A) shirt was one of the heaviest and thickest shirts, the F shirt was one of the heaviest, but was at the same time the thinnest shirt. This speaks to the density of the fabric used in the F shirt. A look at the fabrics from the G shirt shows that while they have very similar thicknesses, they have differing weights. This speaks to the open structure of the back panel of the shirt due to it being significantly lighter than the front panel yet nearly the same thickness. The measurements for fabric weight had more precision of data points than did the data for fabric thickness. This is represented by the smaller size of the Tukey-Kramer comparison circles, and may be explained by the fact that fabric weight had a sample size of five samples, while thickness had a samples size of only three samples. Dry fabric sample weights are shown in Figure 4.1, and fabric thickness is shown in Figure 4.2.

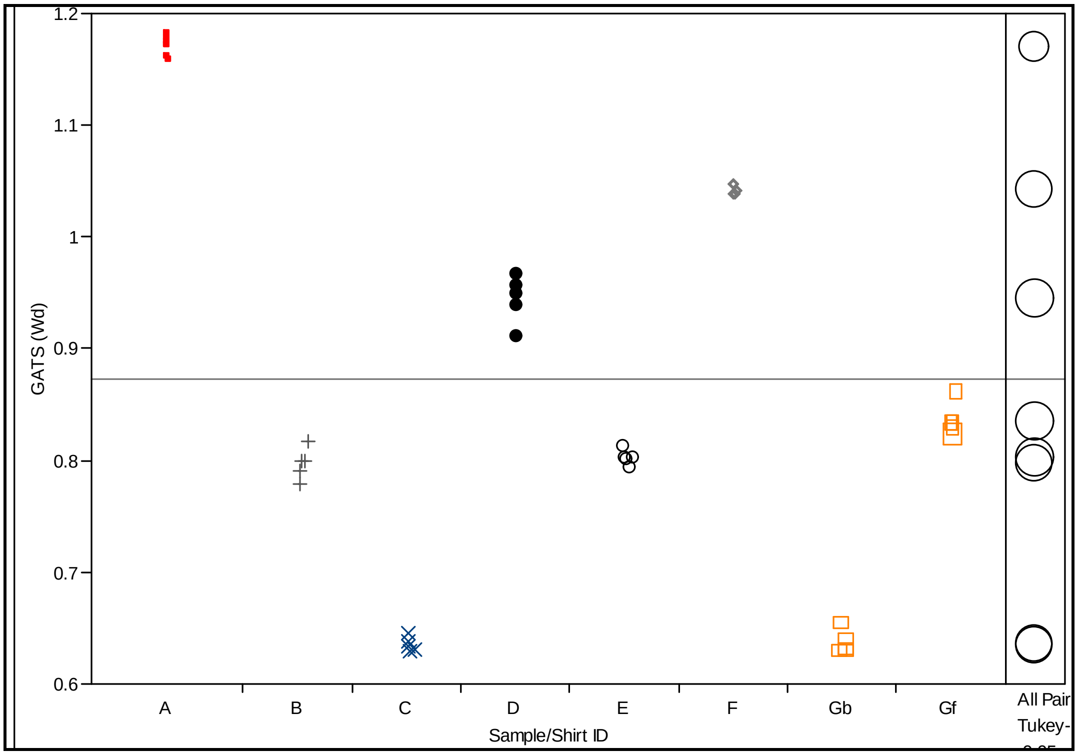

Figure 4.1 - Dry Fabric Weights (3.5 inch diameter samples) – (in grams)

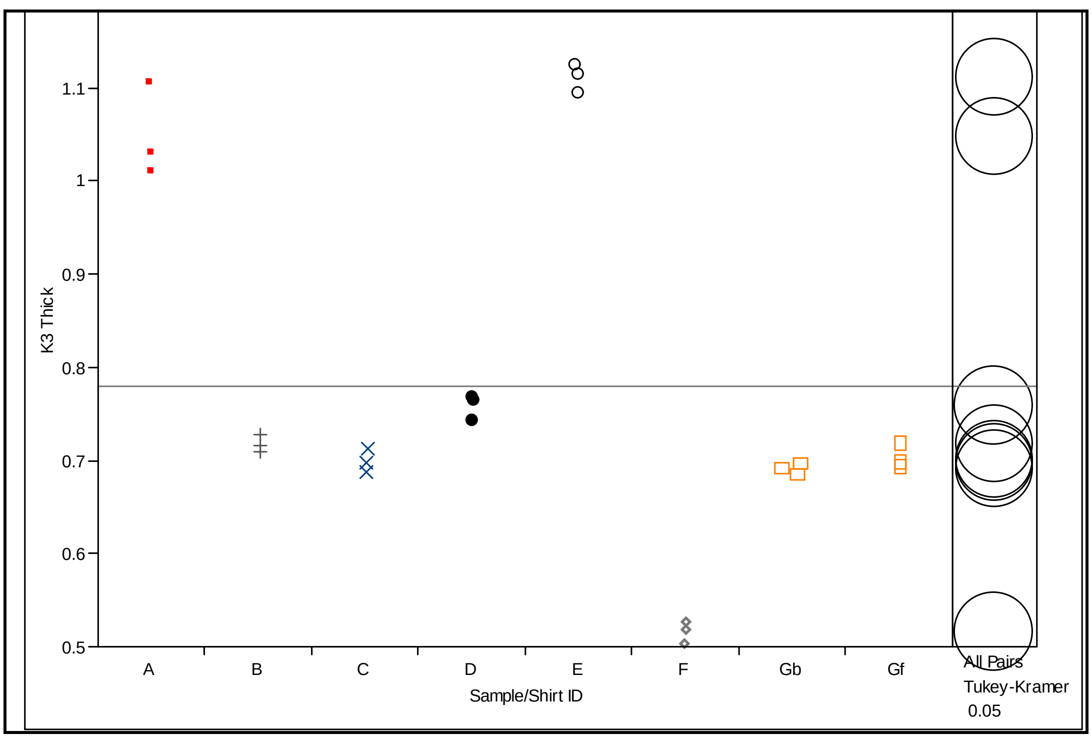

Figure 4.2 - Fabric Thickness (mm)

Kawabata Hand Evaluation System.

The next five sections of this chapter are concerned with the results from the five tests in the Kawabata Hand Evaluation System (KES). The (KES) tests are designed with the hand of the fabric in mind. This is an important aspect of wear comfort and was valued by the consumers in the comfort survey. 'Soft Material' as it was worded in the consumer survey, was a close second place to Breathability in value placed on comfort parameters by International consumers, and was a clear first place among consumers from the United States. The five tests in the KES are all concerned with fabric hand and in this study are all very important indicators to a comfortable product for performance athletic wear. Many of the tests in the KES are performed separately for the warp and the fill directions. The results of these tests will be reported only for the Warp direction. All results not discussed in these sections will be provided in section A.2.1 of the Appendix. It is also important to note that all specific values given in the text of this section are averaged from warp and fill values combined, and may not visually match up with the charts which reflect only warp direction values.

K1 Kawabata Shearing Results.

The Kawabata shearing test provides data on how much resistance a garment puts up to movement in the plane of the fabric. This gives an indicator as to how much a fabric would resist the movements of the athlete when wearing garments constructed of these fabrics. The ideal fabric for a product in the performance athletic apparel market will provide the least amount of resistance to movement during physical activity. This measure is recorded in units of gram force per centimeter time degree of displacement, from the perpendicular.

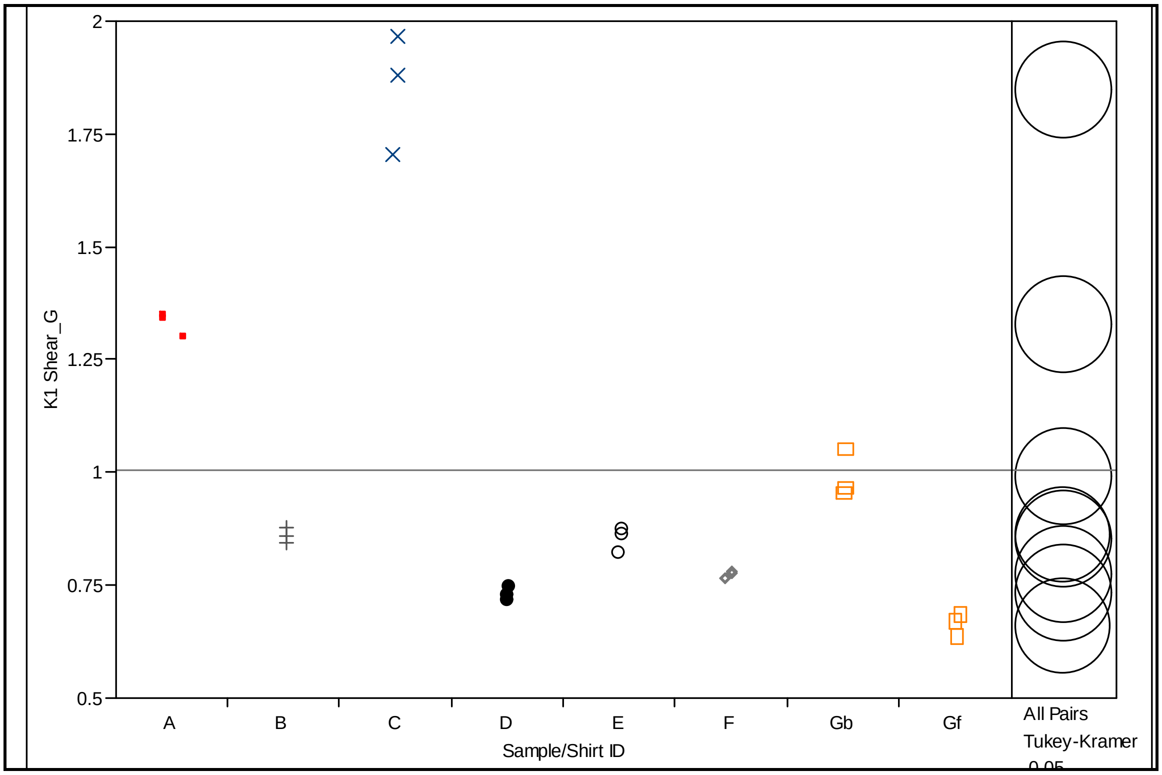

Figure 4.3 - Fabric Shear Stiffness (G) – (gf/cm * degree) – Warp Direction

The C garment is by far the stiffest fabric in the test group. The 100% cotton (A) shirt is the next stiffest fabric in the group. After these two fabrics, the rest of the group is very close in terms of stiffness results. The B, D, E, F, and G fabrics are nearly identical in terms of having a low resistance to movement. The front panel of the G fabric is, however, less rigid than the back panel fabric, which may be due to the closer knit structure and higher potential for yarns 'straightening' within the knit structure.

K1 Kawabata Tensile Results.

The Kawabata Tensile test yields two measures. The most important measure is a continuation of the discussion on resistance to movement. In this instance the resistance is in the direction perpendicular to the plane of the fabric. %EMT is a measure that is called Percent Extensibility, and determines how much a fabric will stretch under a load of 500 gf/cm. This allows a comparison and even a prediction of how well the fabrics would allow for stretch in motion during athletic activity. A higher value is desirable, when looking at Percent Extensibility for athletic apparel, as it will offer less resistance to movement.

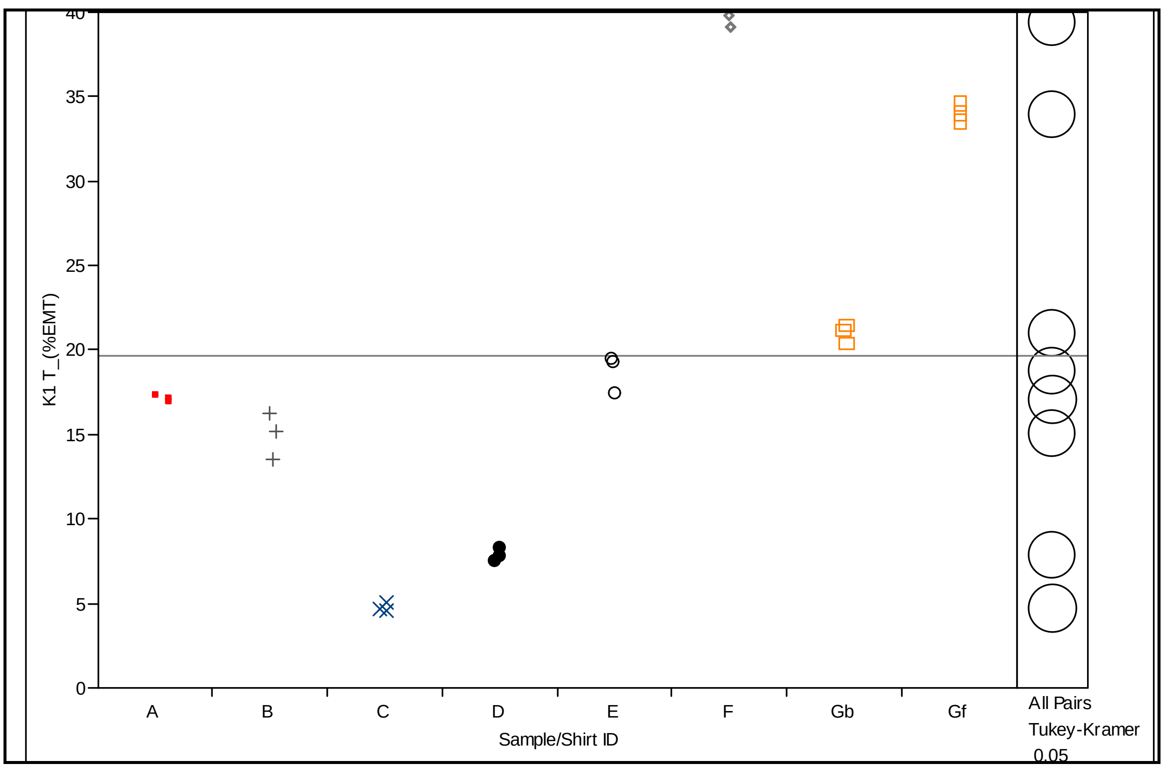

Figure 4.4 - Fabric Percent Extensibility (%EMT) – Warp Direction

The F shirt has exhibited the highest percent stretch at a 34.807% stretch value. The second highest stretching fabric is the front panel of the G shirt which had a value of 27.771% extensibility, which was significantly more than the back panel which had a 21.624% stretch. This is likely due to the open structure of the back panel having less ‘straightening potential’ to enhance stretch. The least stretching fabrics in this study were the from the C shirt, which is logical given the tensile stiffness values for the same shirt. Also the D shirt had a low degree of stretch which is less expected given its low degree of stiffness from the shear test. These values all had a high degree of precision as is evidenced by the small circles on the Tukey-Kramer comparison, despite the small samples size of only three replications.

K2 Kawabata Bending Results.

The Bending test is another stiffness indicator of the fabric. This test yields information on how easily the fabric bends to move with the body as well as an idea of how stiff the fabric will be, in units of (gf * cm^2/cm), which is bending rigidity per unit of fabric width. An ideal athletic fabric will have a low bending resistance value, in order to provide more ease and comfort of motion. Figure 4.5 contains all data points measured in the bending test.

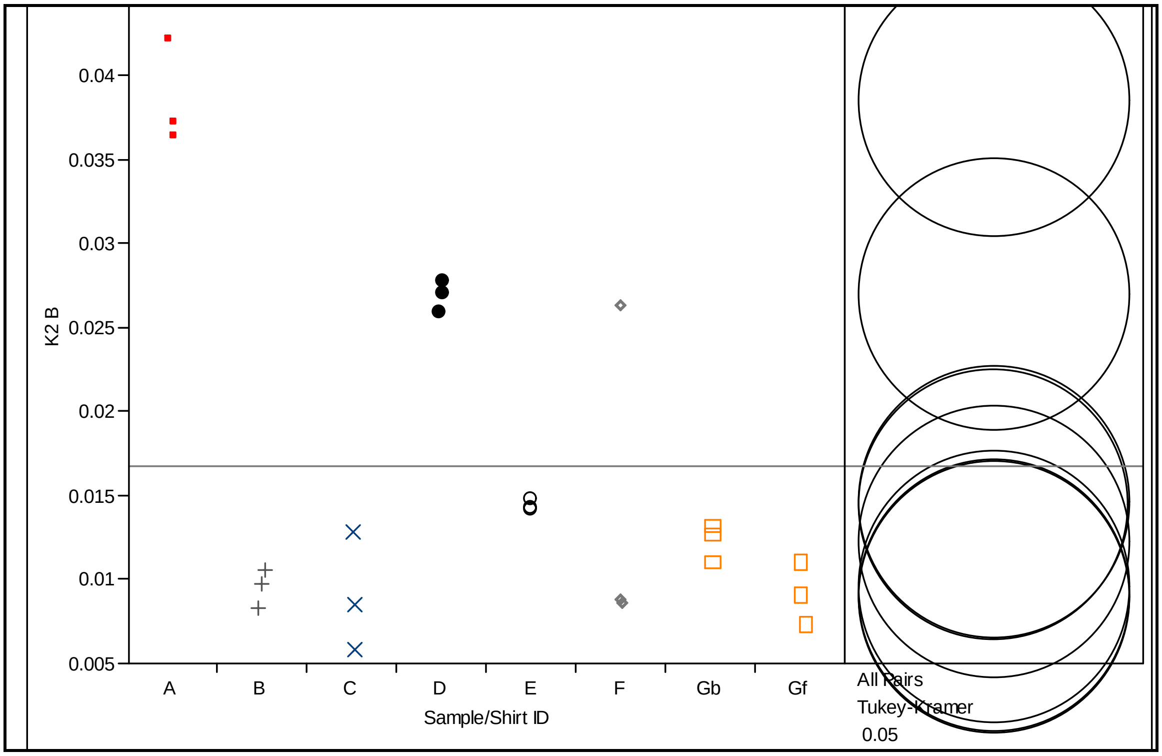

Figure 4.5 – Fabric Bending rigidity (B) – Warp Direction

The two fabrics which provide the most resistance to bending are those from the 100% cotton shirt, and the D shirt. These two would provide less mobility with the athlete. The 'higher resisting' of these two is the 100% cotton shirt; the D shirt's results are between the most rigid of the cotton shirt and the least rigid samples. The rest of the sample set is very close to one another in terms of bending results. There are none that set themselves apart as the least rigid, and from the three-replication tests these values are not very precise as can be seen by the large size of the Tukey-Kramer circles. The front and back panels of the G garment performed nearly equal in the bending test. This may be due to the yarn bending properties which exists in both fabrics.

K3 Kawabata Compression Results.

The Kawabata Compression test gives an idea of how much the fabric will yield under the touch of the hand pressing down onto the fabric surface. This is the only test in the KES that is unidirectional, meaning that it is not tested or reported separately for warp and fill directions. The measure from this test that yields the most information regarding the hand comfort sensation is Compressibility. %EMC is the value representing compressibility and it represents the degree to which the fabric can be 'smashed' when pressed. A higher degree of compressibility is desirable for a soft hand sensation, which is important next to the skin in activities consistent with performance athletic apparel purposes.

The 100% cotton shirt returned the highest compressibility results of the test group at 51.114%. This is most likely due to its thickness. %EMC is expressed as a percentage of the original thickness that was able to be compressed, making less dense and thicker fabrics easier to compress. The next most compressible fabrics are E, and G_b. The least compressible fabrics in this study are B, D, and F as they returned very similar results around 25% - 30%. The density of F that was discussed earlier is the most likely reason for its low compressibility value. The back panel fabric from the G shirt was more compressible than the front panel fabric, which may be due to the open knit structure of the back panel as compared to the front panel fabric. The (%EMC) values are shown in Figure 4.6.

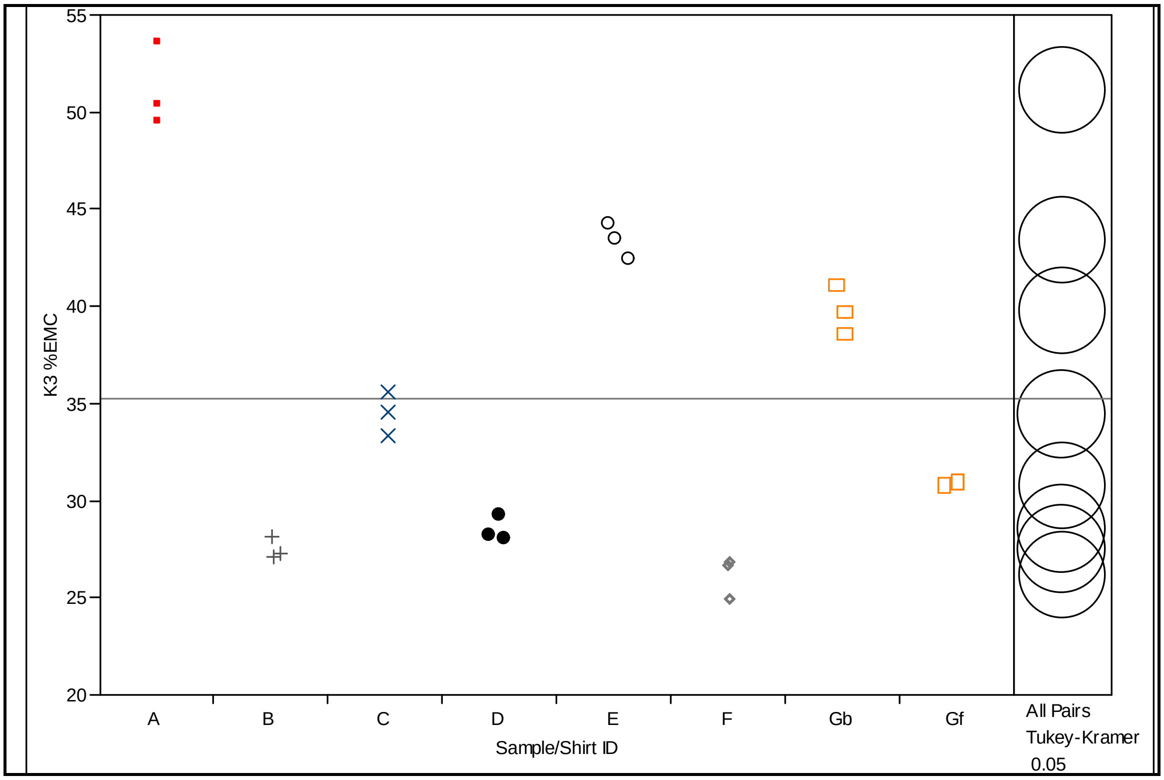

Figure 4.6 - Fabric Compressibility (%EMC) – Warp Direction

K4 Kawabata Surface Results.

Surface characteristics are the most logical aspect of fabric hand as they deal with roughness versus smoothness of the fabric. Rough and smooth are major determinants of how soft a fabric is. The term used in the consumer survey was 'soft material' meaning that surface characteristics are the most important of the Kawabata measures for this study due to the fact that this portion of fabric hand was most directly addressed in the consumer comfort survey. The measure that best represents softness of hand is SMD which is the measure showing the roughness of the fabric. A higher SMD is indicative of a rougher fabric, while a lower SMD is indicative of a smoother fabric and is more desirable for most types of apparel including athletic apparel. Figure 4.7 shows the values of roughness from the testing.

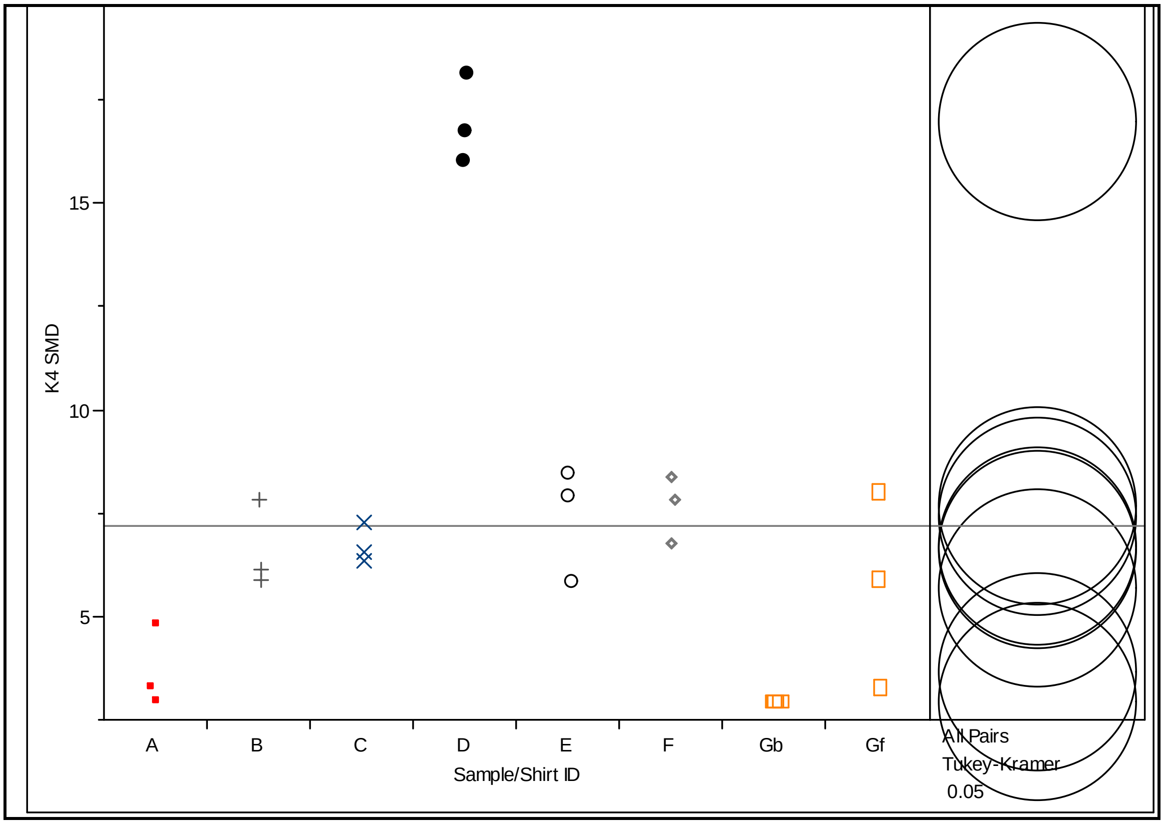

Figure 4.7 – Fabric Surface Roughness (SMD) – (in microns) – Warp Direction

The roughest fabric in this test was the fabric from the D shirt. This fabric stood far out above the rest of the samples at 13.1133 microns. The rest of the fabrics were a jumble and performed equally in terms of roughness at about the 7 micron level. The cotton shirt performed well supporting the commonly held position that cotton is known for its soft hand. For quite some time synthetic fabrics have been trying to duplicate the hand of cotton. The smoothest two fabrics were the back panel of the G shirt and the cotton shirt, but not significantly smoother than any of the other smoother shirts with the exception of F and E which were both statistically more rough than both the cotton shirt and the back panel of the G shirt.

The KES Scorecard

The KES system is the leading fabric hand measurement system and has many different measures of fabric hand, which is one of the comfort parameters consumers were asked to evaluate in the consumer comfort survey. The performance of an individual fabric can be lost when comparing so many tests where some perform higher in certain tests while others are higher in different tests. This section aims to give the big picture of which fabrics had the highest overall hand performance. The two highest performers in the KES from looking at the overall picture were the fabrics from the G and the F shirts. These fabrics had consistently strong performances in all test measures. The F shirt was a bit heavier than many of the other shirts but was high in stretch, surface smoothness, and had low bending and shear rigidities. The G fabrics were rarely the best performers in any given test measure, however they were near the top performers in each category, making for a high overall hand evaluation.

The two lowest performers in the sample were the fabrics from the 100% cotton shirt and the D shirt. The cotton shirt was heavy, had high rigidity values in the bend and shear tests, and was average in terms of stretch. The point must be made that this fabric is the only non-polyester one in the group and therefore is expected to perform differently than the field. The D shirt was very rough on the surface, a bit heavy, and had average to low values on stretch and rigidity in the bend and shear tests. Table 4.17 contains information as to the highest and lowest performing samples in each of the reported KES test measures.

Table 4.17 – Kawabata Evaluation System Scorecard

	Shear Stiffness (G)	Percent Extensibility (%EMT)	Bending Rigidity (B)	Fabric Compressibility (%EMC)	Surface Roughness (SMD)
Highest Performers	C, A	* F, G_f	A, D	* A, E, G_b	D
Lowest Performers	* G_f	C, D	* Others	B, D, F	* A, G_b
* = Desirable					

Kawabata Thermolabo – Small Hotplate Results

The Thermolabo hot plate test is performed in two rounds. The first round is the dry run, and the second is the wet run where the hot plate is in sweating mode. These two runs work together to determine several interesting measures. From the dry run alone comes the thermal resistance measure of 'clo'. From the data gathered in the wet and dry runs together comes the permeability index as well as the Q_{max} value which represents the total heat loss allowed by a fabric.

Dry Thermolabo Results.

The dry test results provide data on how much the fabric alone, with no moisture in play, resists the escape of heat from the plate to the atmosphere. This is done to simulate how much the fabric would resist the escape of body heat through the fabric into the environment. These tests are unidirectional tests in that they do not have separate iterations for warp and fill fabric directions; rather they are done through the plane of the fabric in the perpendicular direction. The measure generated from the dry test that is most easily communicated is the clo value because one clo unit represents the thermal resistance of the typical men's business suit. The clo values are shown in Figure 4.8. A higher clo value is less desirable for athletic apparel as this indicates that a fabric resists the release of body heat.

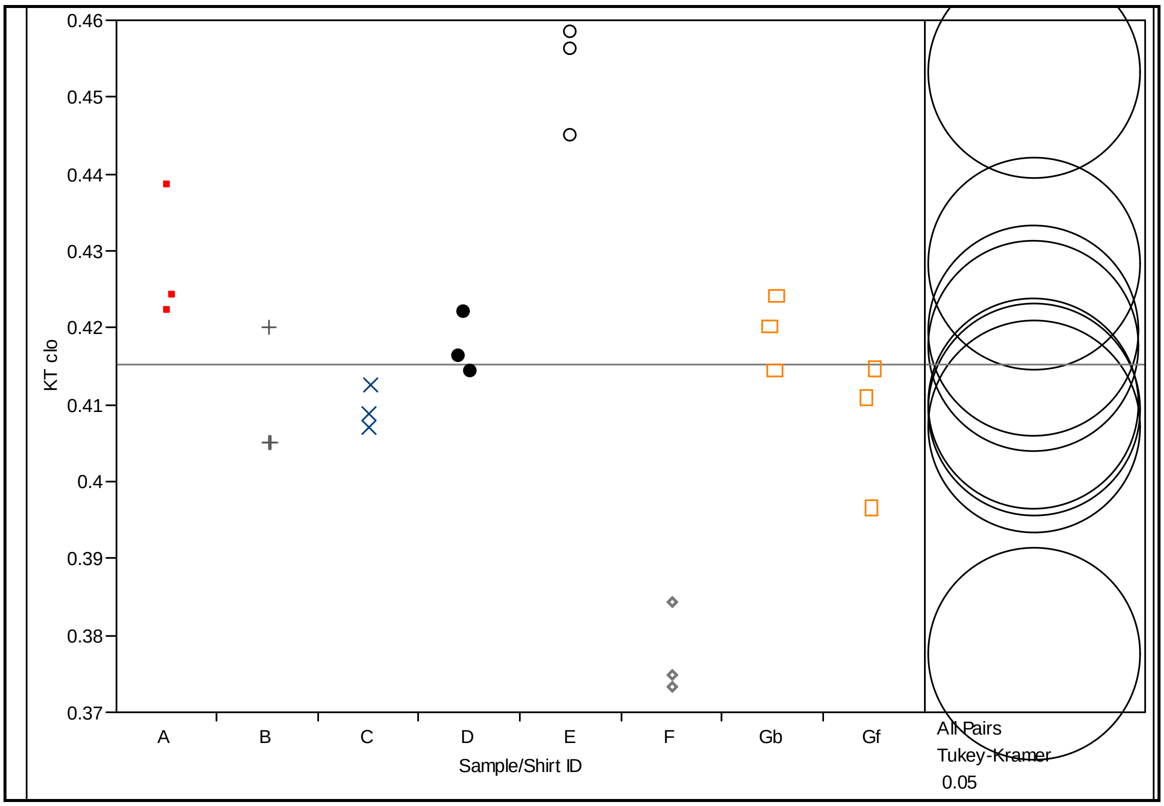

Figure 4.8 - Fabric (clo) Value – Thermolabo

The highest and lowest performing fabrics in this test for thermal resistance are clearly identifiable. The lowest resisting fabric is that from the F shirt, which measures at a value of 0.377 clo. This means that this shirt theoretically provides roughly 37% of the dry insulation power of a typical men's business suit. The highest resisting fabric in this category is that from the E shirt. This fabric has a clo value of 0.453 giving it about 45% the dry insulation power of the typical men's suit. The remaining fabrics are in a jumble at around 0.41 to 0.42 clo. These fabrics all have significantly less insulation power than a men's business suit, but in the athletic apparel market, every bit of extra thermal resistance matters, so the F fabric provides desirable characteristics in this sample group.

Wet Thermolabo Results.

The wet version of the Thermolabo test is done with the plate 'sweating' as to simulate the effect of sweat on human skin in the thermal resistance category. This allows for a comparison of how well a fabric allows the 'sweat' to enhance the cooling effect of the overall heat exchange between 'skin' and surrounding environment. One of the most useful measures that are generated, from the data in the wet and dry Thermolabo tests combined, is the Permeability Index. This value gives a comparison of how much the fabric allows the passage of heat and moisture in the vapor form. The results for Permeability Index, however, were not well differentiated as the entire sample group performed at between approximately 0.40 and 0.50. The highest performing fabric was the E fabric which was significantly different than the three lowest performers, but not statistically significant in difference from the rest of the group.

Since this measure did not yield sufficient differentiation among the sample set, the other measure which takes wet and dry Thermolabo test data into account is a better indicator for comparison. The other major measure from the combination of sweat and dry Thermolabo testing is the Total Heat Loss value. This value indicates the total amount of heat that is allowed to escape the body at a fully wet condition, and is appropriate for this study due to the nature of the products being tested which will be used when the body is sweating at a relatively high rate. The Total Heat Loss value is expressed in Watts and is a pure measure of basic body core temperature release into the atmosphere, which makes this measure the most valuable measure generated by the Thermolabo testing. Figure 4.9 shows the Total Heat Loss values for the sample set.

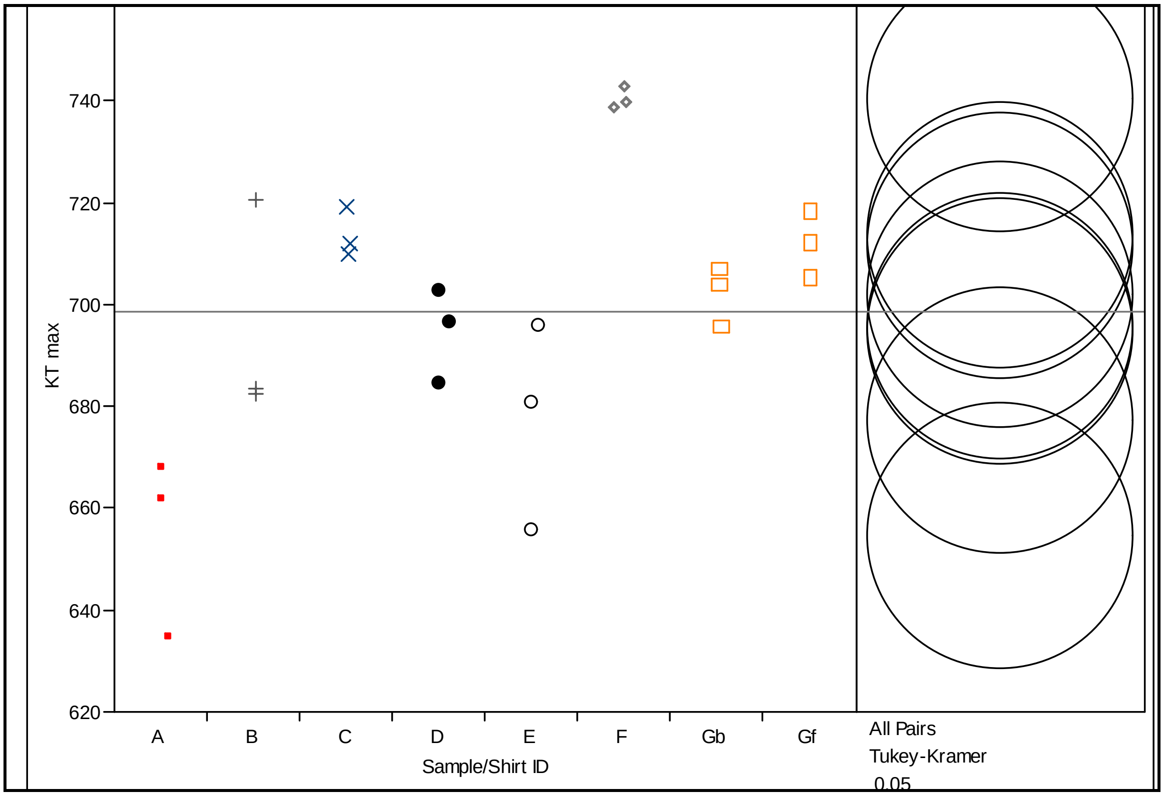

Figure 4.9 – Fabric Total Heat Loss (THL) - (Watts/m^2) – Thermolabo

The highest performer of the group is the F fabric which allows 740 watts/m^2 to escape in fully wet conditions. The rest of the fabrics are less discernable as to the significance of how their performances were differentiated. The lowest performer was the 100% cotton fabric which allowed only 655 watts/m^2 to escape through the fabric in the wet condition. This may be due to the low wicking performance of cotton, as it becomes saturated and holds the moisture from evaporating into the environment, which is the chief cooling force of sweating skin. The remaining fabrics are jumbled at around 700 wats/m^2 released. The two G fabrics had very similar performance in both Thermal Resistance and Total Heat Loss, which is most likely due to the same yarn being used in both fabrics. This shows that an open structure does not necessarily release significantly more heat, or water vapor than a closed knit structure of the same material.

The Thermolabo Scorecard

The Thermolabo test has two measures that have been looked at here which are able to be differentiated from one fabric sample to another. The Thermolabo test gives a great indication of how well a fabric breathes and cools, which are two of the comfort parameters which were posed to the consumer in the consumer comfort survey. The purpose of this section is to keep track of how well each sample performed in the Thermolabo testing. The highest performing shirt in the Thermolabo test was easily the fabric from the F shirt. This fabric had results that were the top of the sample set for Thermal Resistance as it had a very low thermal resistance. This fabric also had high results in the Total Heat Loss test as it allowed the most overall heat release during the Thermolabo testing.

The two lowest performing shirts were equally identifiable as they had high values of Thermal Resistance which on the body would prevent the athlete from cooling. They also both showed very low Total heat Loss values, indicating that for both the wet and dry conditions, they would do a poor job at allowing the athlete to cool their body temperature whether wet or dry. These low performing samples were the fabrics from the 100% cotton shirt and from the E shirt. The lowest overall performing fabric in the Thermolabo testing is the 100% cotton (A) shirt. This is because Total Heat Loss is such an important measure within the Thermolabo testing and THL is the measure where the cotton shirt performed quite low. Table 4.18 contains a representation of the performance of the measures reported from Thermolabo testing.

Table 4.18 – Thermolabo Scorecard

	Thermal Resistance (clo)	**Total Heat Loss (i_m)**
Highest Performers	E	* F
Lowest Performers	* F	A
* = Desirable		

Gravimetric Absorbency Testing System (GATS) Results

The GATS test is the primary fabric-level measurement for Moisture Management. This test is concerned with how well a fabric pulls or absorbs moisture off a plate which has moisture on demand much like sweating skin. Just as sweating skin has a continuous supply of moisture, the GATS test has a continual source of moisture from which the fabric samples can pull water. Several measures are developed from measuring the amount of water that is evacuated from this continuous supply during the 16 minute test. Some of the best indicators of moisture management properties include: Capacity and Percent Evaporation. The additional measures of Absorptive and Evaporative Power which were discussed in chapter three will also be looked at.

Capacity is the amount of water that the fabric can hold as measured by the subtraction of the dry sample weight from the wet sample weight. This allows for a comparison of how much perspiration the fabric would pull away from the skin; a higher value is more desirable for athletic wear. In Figure 4.10, there are many samples jumbled at the top with around 3 to 4 grams capacity for the 3.5” diameter fabric samples. The top two performers are the E fabric and the D fabric which had significantly higher results in terms of statistical significance than G_b, C, F, and A. The lowest performing fabric in this measure is clearly the 100% cotton (A) fabric, which held only 1.8993 grams of water in its 3.5” diameter sample. Of the polyester fabrics, F is the lowest performer as it holds 2.2848 grams of water in its 3.5” diameter sample. The two G Samples are very similar in performance with the front panel having a slight edge over the back panel, possibly due to its higher fabric density from the tighter knit structure. Figure 4.10 contains the data points for the Absorbency Capacity measure.

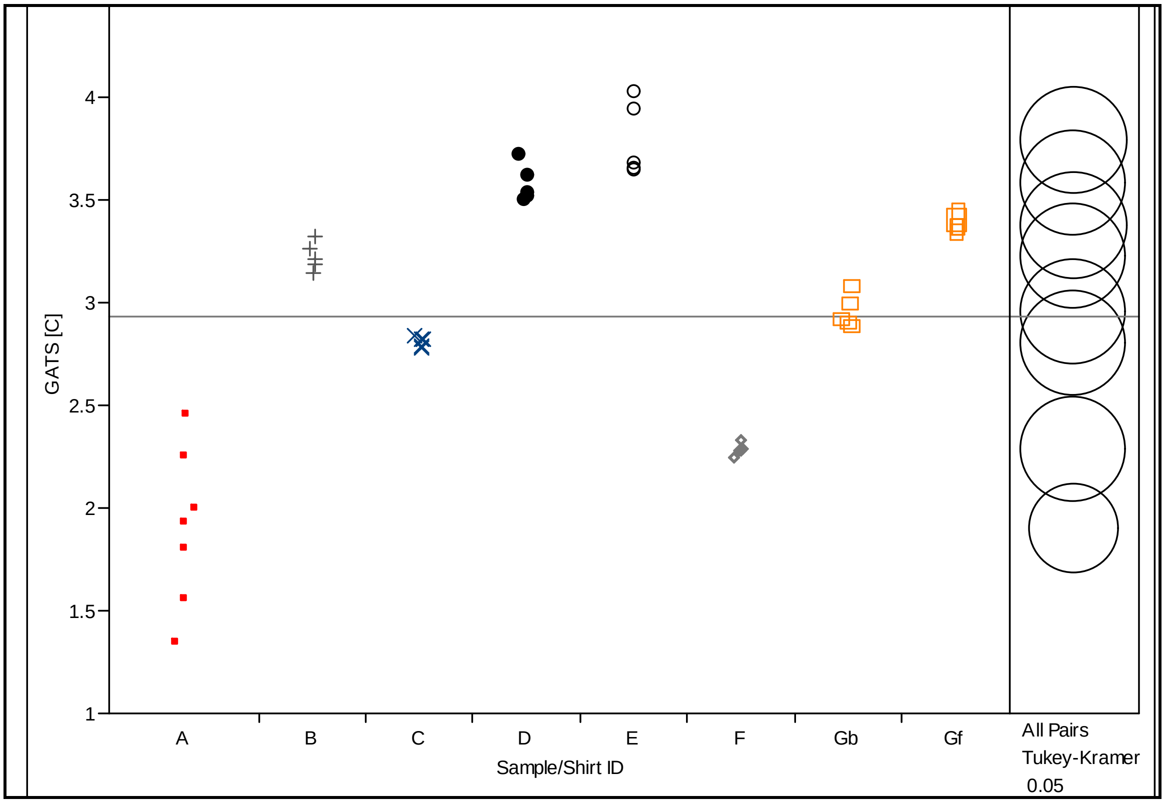

Figure 4.10 – Fabric Absorbency Capacity (C) - (in grams) - GATS

The Percent Evaporation value indicates the percentage of the water removed from the continuous water supply, which is removed via evaporation. The remaining amount is the Capacity value discussed above. Absorption Rate had values that were all over the map and resulted in no differentiation from one fabric to the next. While the Percent Evaporation values are a bit more jumbled than the capacity values, they are much more distinguishable than the Evaporation Rate values, and a few fabrics outperformed the rest. For the Evaporation rate Figure 4.11 shows the data collected for each fabric. A higher value of Percent Evaporation is preferable in athletic apparel because it tells that a fabric is causing high amounts of evaporation for the amount of water it removes from the skin. This cools the skin of the athlete.

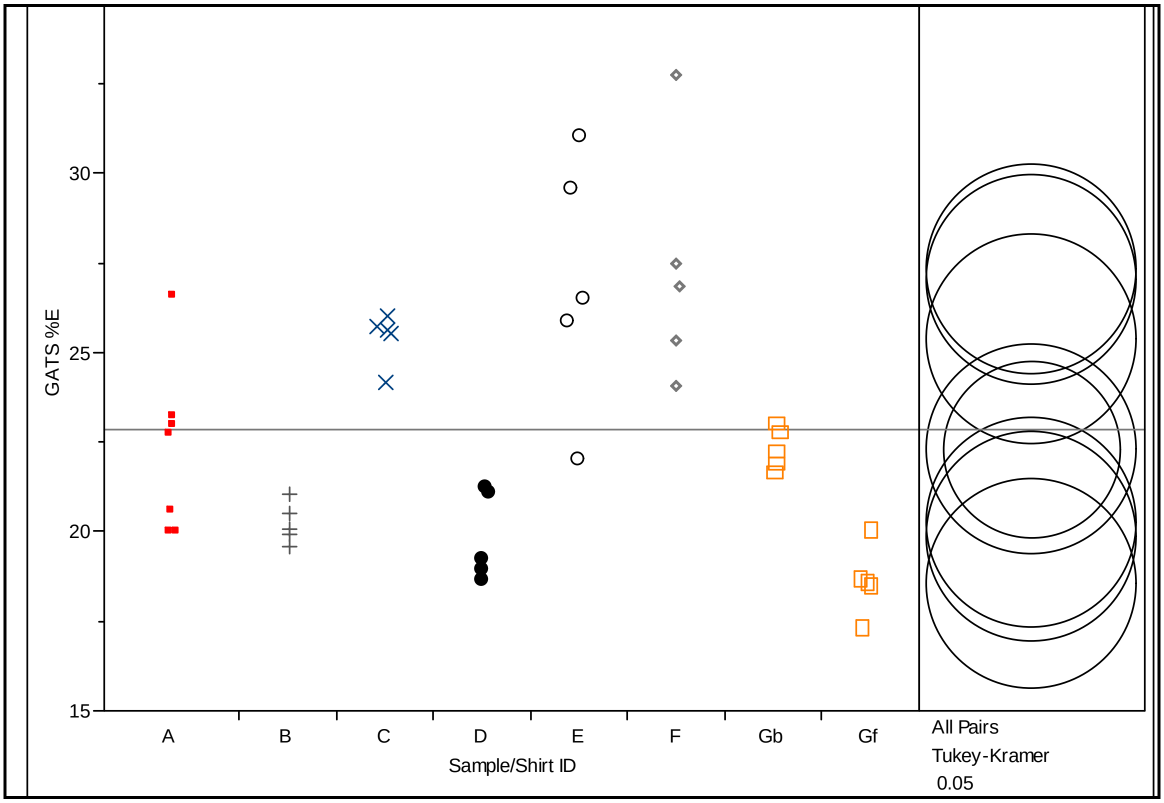

Figure 4.11 - Fabric Percent Evaporation (E_p) – GATS

The highest performing fabrics in this test measure were the E fabric as well as the F fabric. These two had just over 27% evaporation as a percentage of volume of water evacuated from the water supply. The lowest performing fabrics in terms of Percent Evaporation were the front panel from the G shirt, the D shirt, and the B shirt. These results are very similar for all fabrics as the lowest performers had only about 8% less Percent Evaporation than did the top performing garments. The bottom five performing fabrics for example are all too similar in terms of Percent Evaporation Results to claim that they are significantly different based on a five replication sample size.

In the chapter three discussions on the GATS system, two additional measures were formulated in order to give evaporation and absorption values as a percentage of dry fabric weight. The use of this is to show how well the fabrics trade off when considering their initial weights as compared to their Moisture Management performance. These two measures are Absorptive Power, which takes water absorbed (Capacity) as a percentage of the dry weight, and Evaporative Power, which takes weight of water evaporated as a percentage of dry Weight. This allows for a pound-for-pound comparison of the power each fabric has to absorb water and to evaporate water and removes the additional variable of differing fabrics weights by working on a percentage basis from those weights.

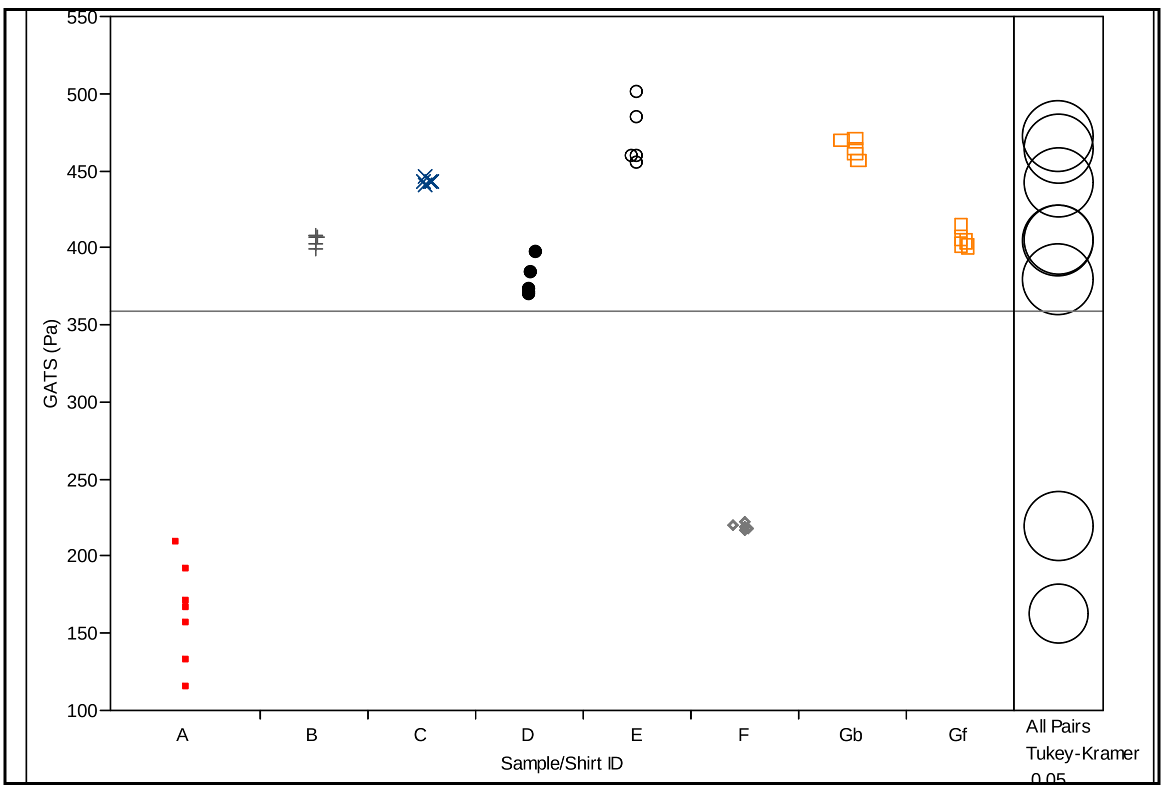

Figure 4.12 – Fabric Absorptive Power (% P_a) – GATS

The strongest of the fabrics in terms of absorbing water on demand were performing at nearly 440% to 470%, as a percentage of their dry weight. The top three performing fabrics in this category were the fabrics from the E shirt, the back panel of the G shirt, and the C shirt. These three were statistically higher in performance than the rest of the fabrics. The lowest performing fabrics, from the 100% cotton (A) shirt and the F shirt, were easier to identify as they absorbed only between approximately 160% and 220% of their initial dry weight in water; all other samples absorbed at least 375%. The back panel of the G had a significantly higher absorptive power than did the front panel. This is more a reflection of how light its dry weight was than a reflection of its superior absorption power over the more closed knit structure of the front panel.

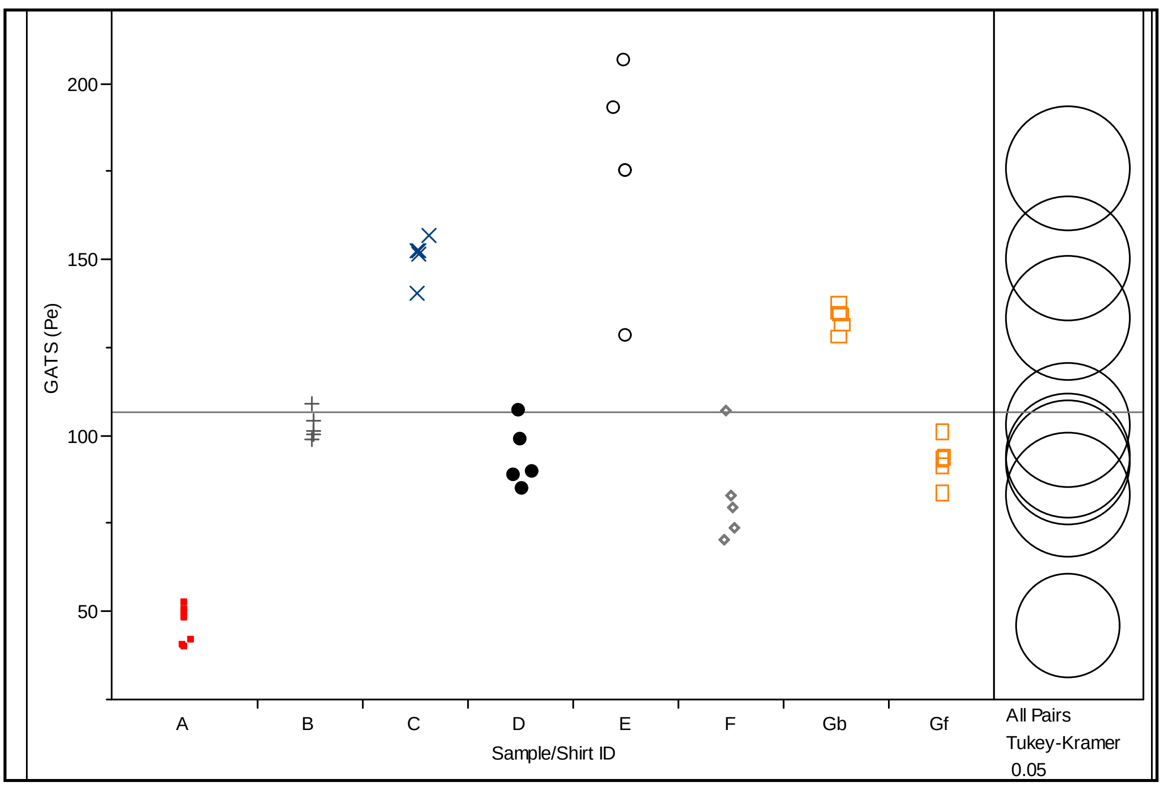

Figure 4.13 – Fabric Evaporative Power (% P_e) – GATS

The Evaporative Power is a similar measure to the Absorptive Power in that it returns results as a percentage of the dry fabric weight. The only difference is it takes the weight of water evaporated by the fabric rather than absorbed by the fabric. This measure is significant because evaporation is cooling, which means that the more evaporation a fabric can provide the better in athletic use. The top performing fabrics in this study for Evaporative Power were the same three top performers from Absorptive Power with results between 150% and 175%. The lowest performers were also the same as the lowest performers from Absorptive Power, with results between 45% and 85%.

The difference lies in the middle. The amount of differentiation from the second highest to the second lowest performer is much less in the Evaporative Power Measure. This is possibly due to the fact the evaporation is quite dependant upon air flow which was uniform for all fabrics in this test. The back panel from the G shirt also has more Evaporative Power than its front panel counterpart. Once again this is most likely due to the light dry weight more than to any discrepancy in the amounts of water evaporated between the two. Additional GATS results are in section A.2.3 of the Appendix. There are charts graphing the moisture evacuation from the reservoir against time. There are also bar graphs which show the averages for all samples.

Drying Test Results

The GATS test is coupled well with the drying test which determines how long it takes for the fully saturated fabric to return to a fully dried state under a constant rate of air flow. Two measures have been discussed in chapter three regarding the drying test. The primary measure is drying time, which is simply the amount of time it took three samples to go from fully saturated to fully dry, via evaporation, while under a steady air flow. The other measure is drying rate. This allows for comparison from one fabric to the next not on how quickly it goes from saturated to dry but the pace at which it evaporates the moisture.

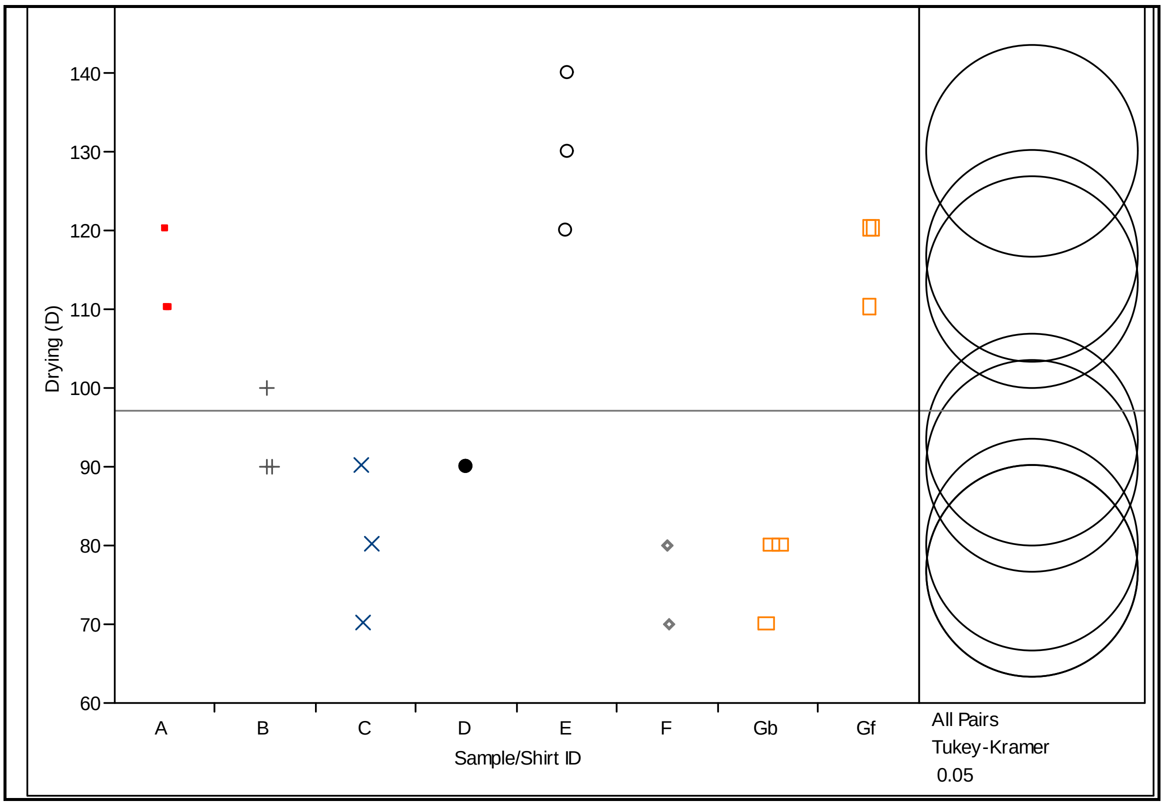

Figure 4.14 – Fabric Drying Time (minutes)

The top performing fabrics in terms of drying time are very close together. An easier identifier is to discuss those fabrics which took the longest time to dry. These are the lowest performers with drying times averaging around 120 minutes. The slowest drying fabrics were from the E shirt, the 100% Cotton shirt (A), and the front panel of the G Shirt. The rest of the fabrics took anywhere from 70 minutes to 90 minutes to dry. A faster drying time is a function of how well the fabric evaporates away moisture as well as how much capacity the fabric holds in grams of water. Drying Rate, on the other hand has only the speed of evaporation as its main factor. The capacity of water held is not a factor and allows for a simple comparison of how fast a drying pace each fabric has. Figure 4.15 has a graphical representation of the Comparison of Drying times for all fabrics. The individual graphs of drying time are included in section A.2.3 of the Appendix. This gives a visual comparison of both how long it took for the fabrics to fully dry as well as a visual representation of how much water weight the fabrics held when fully saturated. The slope of these lines as they dry could be considered a visual representation of the rate at which they dried. The D fabric in Figure 4.15 seems to have the steepest decline in water weight, meaning that it had the fastest drying rate.

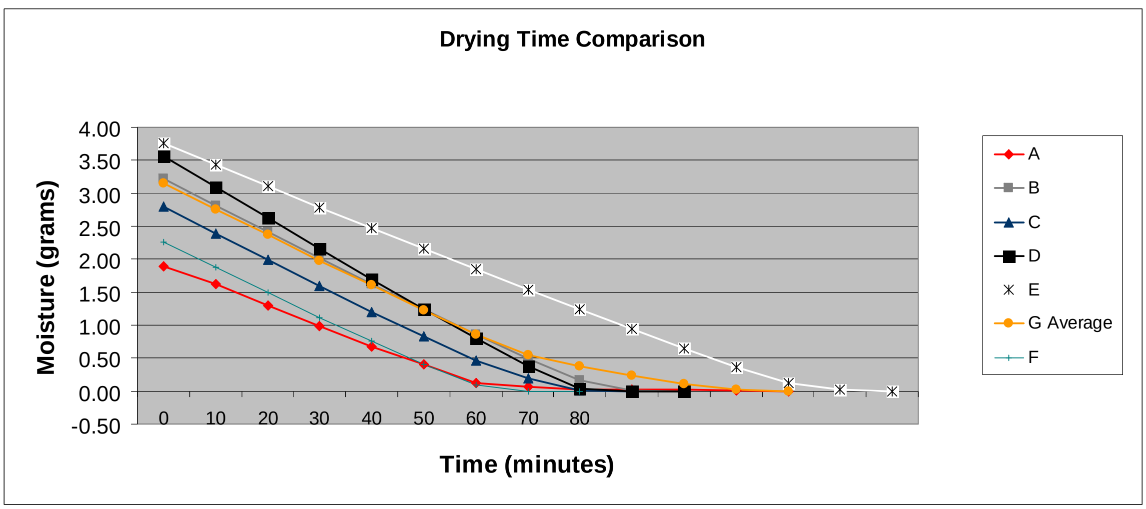

Figure 4.15 – Fabric Drying Time Comparison

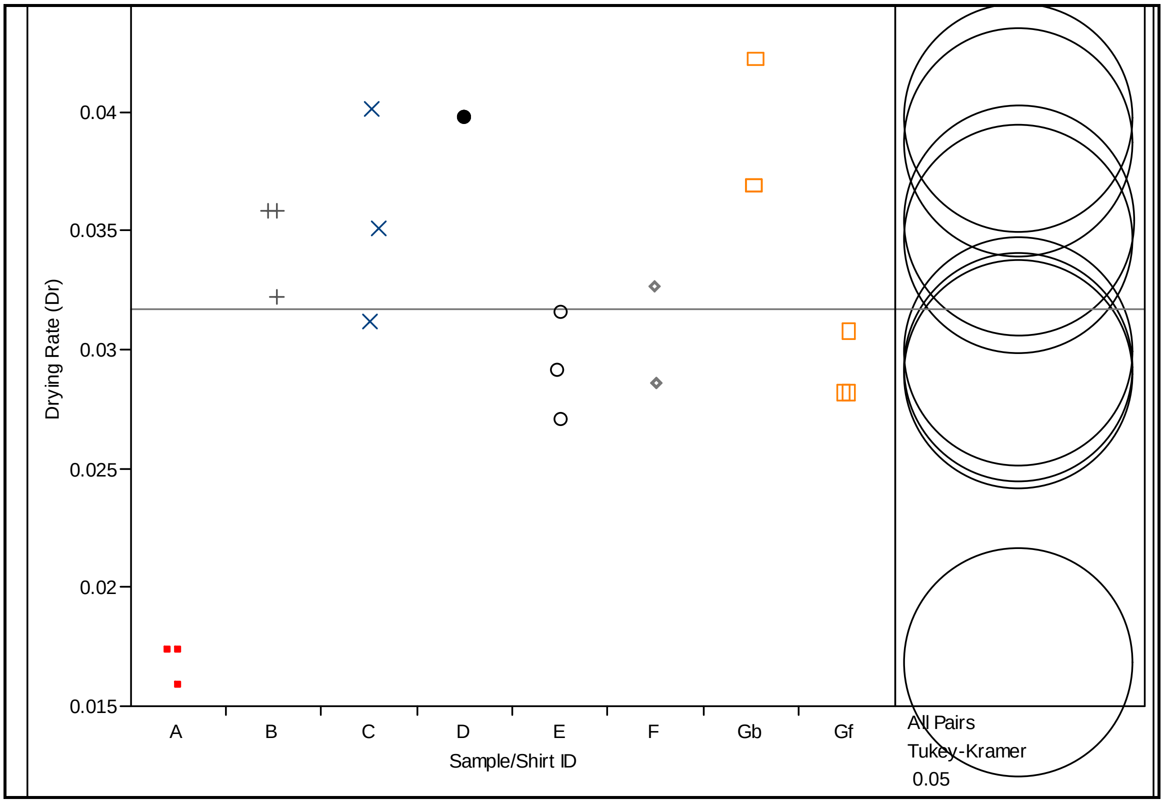

Figure 4.16 – Fabric Drying Rate (g/min)

The fabrics with the fastest drying rates are more desirable as the fastest drying rate will come closest to keeping up with the human sweating rate in an effort to keep the skin dry and cool. Two fabrics have the fastest drying rates of the group; they are the fabric from the D shirt and from the back panel of the G shirt, with drying rates of about 0.04 g/min. The slowest drying fabric is by far the 100% cotton shirt with a rate of 0.0168 g/min. The cotton shirt is slow to dry due to the hydrophilic nature of the cotton fibers themselves which draw the moisture into the interior of the fiber making it harder to evaporate, while the rest of the fabrics, the poorest of which have a drying rate of 0.0290 g/min, are polyester and do not allow penetration of moisture into the fiber structure. The open knit construction of the back panel of the G garment had a faster drying rate than did its closed knit front panel. This is most likely due to the openness of the structure allowing more air to flow into the fabric providing more air-to-fiber contact, thus improving evaporation.

The Moisture Management Scorecard

The highest performing fabrics in terms of Moisture Management are judged based on the results from both the GATS and Drying tests. Moisture Management was the other comfort parameter that the consumers responded to on the consumer comfort survey. The importance of good Moisture Management for an athletic garment is paramount as it is tied to both the cooling effect from perspiration as well as to avoiding negative tactile sensations in fabric hand. The highest performing fabric in terms of Moisture Management was the E fabric as it had very high absorption and evaporation values. The E fabric did have some average drying results, but not low enough to negate the very strong results from absorption and evaporation values. The next highest fabric with consistently high, but not top, results was the C fabric which was strong in some absorption and evaporation measures as well as strong in drying times.

The lowest performing fabric was from the 100% cotton (A) shirt. This fabric exhibited very low results for absorption and evaporation. This was most likely due to the fact that cotton absorbs water into the fibers rather than along the surface of the fiber. The A cotton fabric also had low results in drying time and drying rate; this is attributable to the same characteristics that give it poor absorption and evaporative qualities. While all of the polyester fabrics were close together in terms of performance in Moisture Management, the two fabrics that had the lowest results were the B fabric as well as the G fabric. These performed near the bottom of the polyester fabrics in both evaporative/absorptive and drying time/rate tests with no results at the top for any of the aforementioned measures. Table 4.19 contains a synopsis of the Moisture Management Scorecard.

Table 4.19 – Moisture Management Scorecard

	Capacity (C)	**Percent Evaporation (E_p)**	**Absorptive Power (% P_a)**	**Evaporative Power (% P_e)**	**Drying Time**	**Drying Rate**
Highest Performers	* E, D	* E, F	* E, G_b, C	* E, G_b, C	E, G_f, A	*D, G_b
Lowest Performers	A, F	Others	A, F	A, F	* Others	A
* = Desirable						

Garment Level Testing

While fabric level testing is valuable to gain an understanding of the comfort properties the fabrics have to contribute to the wear comfort of the garment, it is the garment itself that is worn by the athlete and the garment is 3-dimensional unlike the fabrics samples that had been tested thus far. The NCSU Sweating Thermal Manikin is capable of performing many of the same tests to produce many of the same measures as the fabric level tests, only it can perform them on full piece garments. The Manikin was designed to address the shortcomings of fabric testing which involved no drape characteristics which are seen in a garment. This drape contributes spaces of air between the fabric and the skin; this is something that is not taken into account in fabric level testing. The results of the manikin will be compared with the fabric level performance from each of the fabrics which came from the same garments which are used in the garment level testing.

There are several measures generated by the garment level testing. Much like the Thermolabo, dry testing is done first, followed by wet or ‘sweating’ testing. The manikin can be viewed as a human shaped version of the guarded sweating hot plate, only there is no constant air flow onto the manikin as there is for the Thermolabo apparatus. The three most useful measures generated by the manikin are clo, Permeability Index, and Total Heat Loss. Total heat loss is the most telling measure as it reveals exactly what the name says, the total amount of heat allowed to escape by the garment.

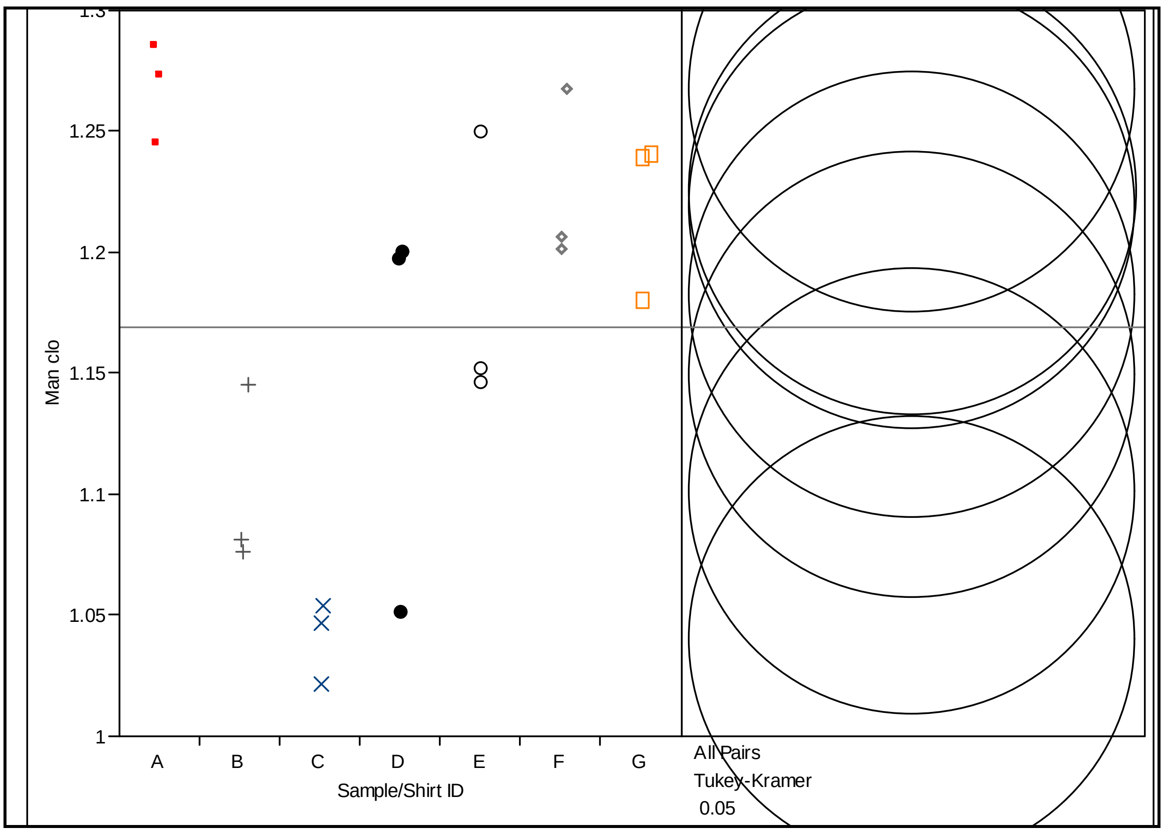

Figure 4.17 - Clo – Garment Level

The clo values from the manikin are noticeably non-varied. The results for the garments are extremely close to one another. The top performing garment is different in a statistical sense from only the bottom four performing garments, and the highest clo value garment is statistically different from only the lowest two clo value garments. It is important to note again that the highest value of clo is the less desirable garment in terms of athletic apparel, while the lowest clo value is indicative of an ideal performing garment for athletic apparel. The lowest clo garment was the C fabric, which had a clo value of 1.04, followed closely by the B garment at a clo value of 1.10. The highest clo garment was the 100% cotton garment with a clo value of 1.27. The highest clo polyester garment was the F shirt with a clo of 1.23, followed closely by the G shirt which had a clo of 1.22. The clo values from the garment level testing were quite a bit higher than the values from the fabric level testing. This difference is attributable to the presence of air in the environment between the manikin's 'skin' and the fabric. This air layer is not in play during fabric level testing.

The Permeability Index values for the garment level testing are tantamount to the Permeability Index values from the Thermolabo test. This measure tells how well the garment allows moisture vapor to escape through to the surrounding atmosphere. The higher the Permeability Index value the better the garment is prepared for athletic use as it will allow the athlete's body to cool as well as to help it remain dry. The issue with the permeability index values is that they are so close to one another that there is no statistically significant difference even between the top and bottom performing garments.

Finally the most important measure for the garment level study is the Total Heat Loss (THL). This value allows for an understanding of how well the garment allows the body to cool by giving a value in (watts/m^2) of heat released through the garment. The Total Heat

Loss values seen in Figure 4.18 are again very similar across the sample set, but the top two performing garments and the bottom two performing garments are statistically different from one another. The Total Heat Loss value is one that should be maximized for the athletic garment, thus higher values are better

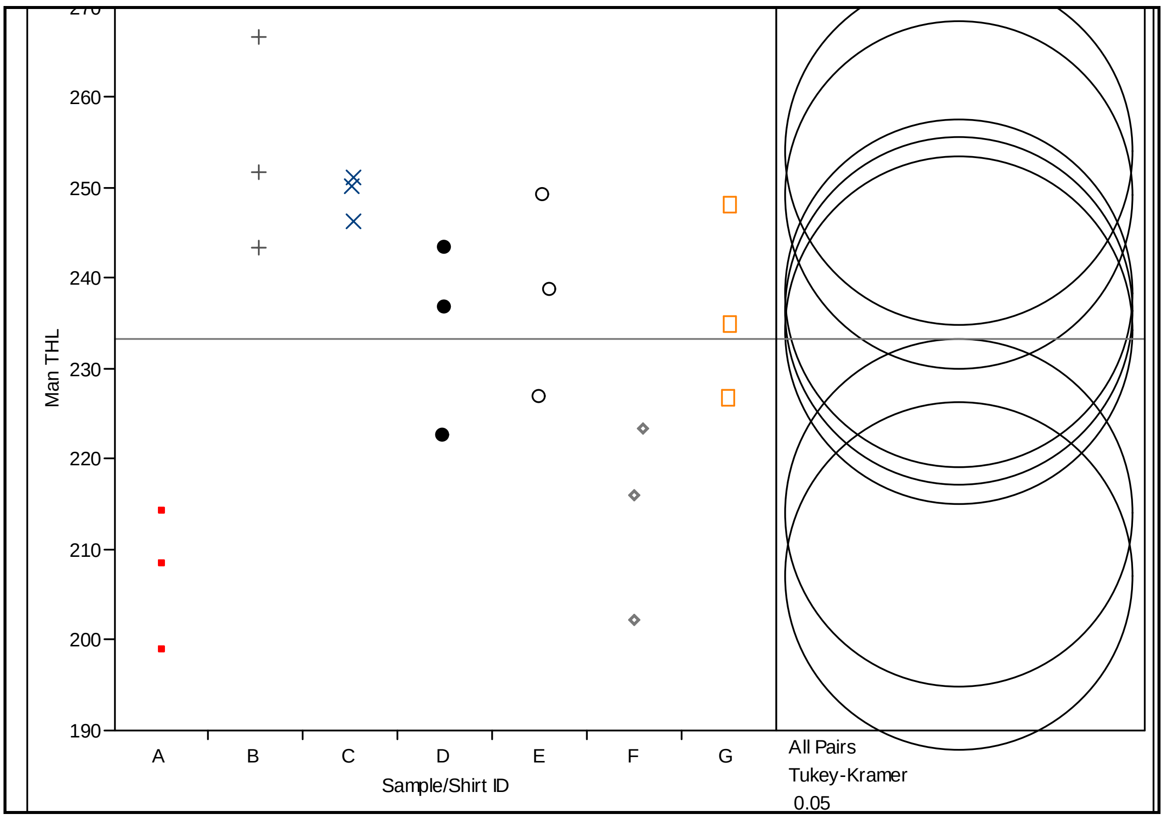

Figure 4.18 - Total Heat Loss (THL) – Garment Level

The highest performing garment in terms of Total Heat Loss was the B garment with a THL of 253.93, followed by the C garment with a THL value of 249.08. The lowest performing garments in the Total Heat Loss category were the 100% cotton shirt with a THL value of 207.04, followed by the lowest performing polyester garment which was the F garment with a THL value of 213.91. The values are all quite a bit lower than the THL values from the fabric level testing on the Thermolabo. This is due to the presence of air to buffer these results and provide further insulation.

The garment weight before and after the wet manikin testing was also tracked in order to get an idea of how much moisture weight each garment picked up due to the wet manikin testing. Table 4.20 and Figure 4.19 show how much moisture each garment picked up. Weight gain in a running shirt is about as undesirable as weight gain in the runner. Having an increased weight of garment makes movement much more difficult for the athlete, therefore the least amount of weight gain for a shirt; the better suited that shirt is for athletic use. The highest amount of moisture gained by any garment in the sample set was 58.937 grams. This was the amount of weight picked up by the 100% cotton garment. This is due to the hydrophilicity of the cotton fiber and its water absorption capabilities, which in athletic use is a hindrance. The polyester shirt which gained the most water weight was the G shirt which gained 34.75 grams of water weight. The shirt which gained the least amount of water weight was the B shirt which gained only an average of 24.26 grams of water weight. All weight gain values are averaged over the three test replications.

Table 4.20 - Shirt and Shorts Weight – Wet and Dry (grams)

Sample ID	Test 1		Test 2		Test 3		Average		Dry Shirt
	Shirt	**Shorts**	**Shirt**	**Shorts**	**Shirt**	**Shorts**	**Shirt**	**Shorts**	
A	273.328	162.862	310.298	176.390	291.314	171.525	**291.647**	**170.259**	232.710
B	144.946	161.172	151.979	168.771	149.004	164.122	**148.643**	**164.688**	124.380
C	167.120	169.473	154.482	165.665	151.912	161.849	**157.838**	**165.662**	129.852
D	201.763	159.882	210.683	162.750	202.040	174.400	**204.829**	**165.677**	175.158
E	172.766	169.052	163.392	157.403	193.373	166.131	**176.510**	**164.195**	142.729
F	211.659	166.865	208.917	163.884	214.259	162.748	**211.612**	**164.499**	181.259
G	170.728	161.689	166.001	167.315	199.305	166.766	**178.678**	**165.257**	143.928
** Note: Average Dry Weight of 5 shorts used = 143.928*									

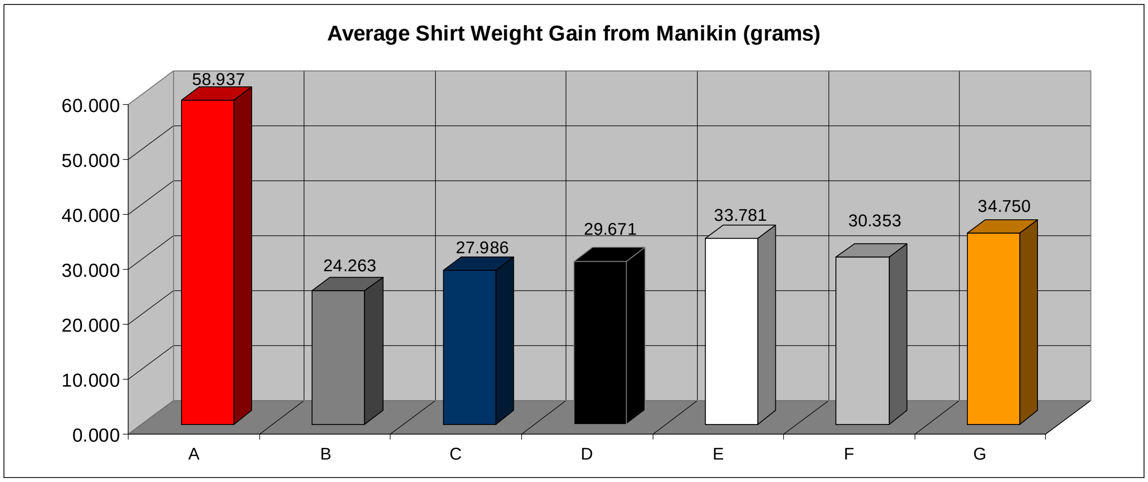

Figure 4.19 - Shirt Weight Gain (grams)

Manikin Testing Scorecard

When determining how well the garments fared in the garment level manikin testing it is necessary to have a look at how well they performed in the three measures of clo, THL, and weight gain which were looked at here. A garment which is ideal for athletic use will have a low clo value, a high Total Heat Loss, and a low weight gain value. The lowest performing garment is the easiest to identify due to the consistently low performance of the 100% cotton (A) shirt. This shirt had the lowest performance due to the fact that it had the highest clo value of the group, the lowest Total Heat Loss of the group, and the highest weight gain of the group. These attributes are all due to the cotton fiber's characteristics which, while they are more suitable than many other materials, are inferior to performance engineered polyester fibers in terms of athletic apparel performance.

The top performing shirts in the manikin testing were the B shirt and the C shirt. The B shirt had a low clo value, a very high Total Heat Loss, and a very low weight gain. The C shirt had a very low clo value, a high Total Heat Loss, and a low weight gain. These two shirts displayed very strong characteristics which are desirable in an athletic garment. The rest of the shirts were nearly all the same when total manikin performance was looked at. The lowest performing shirts of the polyester group were the F shirt as well as the G shirt. These shirts had relatively high values for clo, relatively low values for Total Heat Loss, and relatively high values for weight gain. Table 4.21 contains a synopsis of the Manikin testing scorecard.

Table 4.21 – Manikin Testing Scorecard

	Thermal Resistance (clo)	**Total Heat Loss (THL)**	**Garment Weight Gain**
Highest Performers	**A**	*** B, C**	**A**
Lowest Performers	*** C**	**A, F**	*** B**
* = Desirable			

Overall Testing Performance Scorecard

A look at the overall performance of each of these garments is difficult to state quantitatively given the high number of measures (over 30) by which they have been compared in the areas of fabric hand, breathability, cooling, and moisture management. The best means by which to compare these garments is to make a qualitative analysis by using the performance characterizations which have already been made in each different test results section. This will allow for a comparison of the garments based on how well they did in terms of each of the comfort parameters used in the consumer comfort survey. Table 4.22 shows the highest and lowest performing garments from each phase of testing. Table 4.22 is developed from a combination of the results presented in the scorecard information in tables 4.17 through 4.19 and in scorecard table 4.21.

Table 4.22 – Overall Testing Scorecard

	KES Hand Results	Thermolabo Results	GATS Results	Manikin Results	Overall Performance
Highest	F G	F	E	B C	**F** **C**
Lowest	D A	E A	A	A	**A** **D**
* 'Highest' here refers to top performers in desirable measures					

The top overall performing garments in the testing phase were the C garment and the F garment. The C garment exhibited average fabric hand results, but had very strong breathability, cooling and moisture management results. The C garment also had strong manikin garment level test results, likely due to its open knit construction. The F shirt had average moisture management and manikin results, but exhibited very high results in both fabric hand and in fabric level breathability and cooling.

The lowest overall performing garment in this study was the 100% cotton (A) shirt which was at a disadvantage to its engineered polyester peers in all categories. The cotton shirt was included as an interesting addition to the sample in order to compare the modern fabrics with the traditional cotton t-shirt. While the cotton shirt was not marketed as a performance garment as were the other garments in this study, the results show that an untreated cotton shirt does not match up overall to the newer offerings in the athletic apparel market, namely the synthetics such as polyester which can be made to produce much greater results for athletic comfort and performance. Also important to note is that this study cannot speak definitively on the performance of 100% cotton shirts, as only one shirt of 100% cotton fabrication was included, and was included in order to build in some diversity of test results; it served that purpose well.

The polyester shirt which had the lowest showing was the D shirt which is a private label brand. This shirt was very much hampered by low fabric hand results. It also had only average breathability and cooling results on the fabric level in the Thermolabo testing. The moisture management results and the garment level testing actually had strong measures for this shirt, but not enough to overcome the low hand and questionable breathability results; these few good qualities were not enough to measure up to the other polyester shirts. The B, E, and G shirts all had average to high results in all comfort measures, and were not far behind the overall rating of the C and F shirts.

Discussion on Survey-Relevant Performance

The performance of the garments overall has been reviewed as well as their performance in each of the four comfort parameters which were included in the consumer comfort survey. The purpose of this section is to take a look at each of the consumer target markets which were identified in the survey results section and to determine which shirts were best suited to meet the demands of each target market as based on their performance in the comfort areas which were most important to each market group. There were a total of six groups which were viewed as target groups in the consumer survey as based on their high likelihood of being customers of the performance apparel market. This likelihood again was determined by previous purchase history. There are two overall major groups within the consumer survey; there is the United States (US) group and the International group. Within each group three target consumer groups have been identified; there is one target male group and one target female group, as well as the entire group itself with no regard to purchase history. The value placed on the comfort parameters by each of these groups can be seen in Figure 4.16 in the consumer survey section of this chapter.

The need for a garment that matches up with the comfort demands of the consumer is highlighted by the profit possibilities for hitting this target. The age demographic data from the *Household Spending* book suggests that the average American spent $110.03 per year on active sportswear in 2003, while their income demographic data says that the average American spent $121.05 on active sportswear in 2003 (New Strategist Publications, Inc, 2005). While this data is from 2003, the information from *Just-Style's* global market review (2006) suggests that this value is growing. *Just-Style* predicts that that the performance segment alone within the larger sportswear market will grow to $4.29 Billion by the year 2012. (Global market review of performance apparel- forecast to 2012 – 2006 edition, 2006)

Relative Performance for the United States Group

The first target group within the US to look at is the Males ages 25-34 years old, as 75% of this group had purchased a t-shirt in the past for athletic use. The individuals in this group ranked the comfort parameters in decreasing importance as: Breathability (43.8%), Soft Hand (36.6%), Cooling (33.0%), and Moisture Management (25.0%), with the percentage value reflecting the percentage of respondents in this group which said the parameter was 'very important'. The ideal garment from this study for this group would be the F shirt which has excellent breathability traits as well as soft hand values that are among the highest in the test group. This shirt had less impressive results in the moisture management testing as well as in the cooling category, but those two traits were valued less by this target group.

The next target group within the US side is females ages 18-24. Of the respondents in this group, 72.2% had purchased a t-shirt in the past for athletic use. The comfort parameters valued by the women in this group were: Breathability (52.5%), Soft Hand (44.3%), Cooling (30.9%), and Moisture Management (18.3%). The ideal garment for this group is also the F garment as; again, it has excellent Breathability and soft hand characteristics. It is logical to predict that this garment would do very well among any groups which place Breathability and Soft hand at the top of their list of comfort characteristics. This is the case for most of the target groups from the consumer survey.

The US group as a whole had 62.1% of the respondents who had purchased a t-shirt in the past for athletic purposes. The comfort parameters which were valued by the US group as a whole were: Soft Hand (54.3%), Breathability (47.6%), Cooling (35.0%), and Moisture Management (18.6%). The F shirt is also ideal for the overall US group because its two strong points are Breathability and Soft Hand. For the overall US group these two have switched places from the ranking of the two gender-based target groups, but they still remain the top two.

Relative Performance for the International Group

The first target group in the International side of the consumer panel is the group of Males ages 13-18 years old. Of the individuals in this group, 80% had purchased a t-shirt for athletic purposes in the past. This is the strongest target group in the entire survey in terms of strength of purchase history for this product type. The comfort characteristics from the survey were rated by this group as: Breathability (37.9%), Cooling (37.1%), Soft Hand (31.4%), and Moisture Management (22.9%). This is the only one of the six target groups with a differing top two comfort characteristics. Breathability is still at the top; however cooling is second place in lieu of Soft Hand. This means that the ideal garment for this group would be the C shirt. This shirt has strong breathability results as well as excellent cooling results from the manikin testing. The results for Soft Hand were less impressive but this was given less importance by this target group than by other groups.

The next target group within the International side of the Consumer Survey was the Female group ages 13-18. There were 78.9% of the members of this target group which had purchased a t-shirt in the past for athletic purposes. The priorities for comfort characteristics from this group were: Breathability (54.4%), Soft Hand (40.4%), Cooling (38.6%), and Moisture Management (31.6%). These priorities match up best with the F shirt which once again is the ideal performing shirt for this group from this study’s test sample group. The strong Breathability and Soft Hand results give the F shirt the strongest position for this group.

The overall International group had 60.4% of respondents which had previously made the purchase of a t-shirt for athletic purposes. The comfort parameters which were most valued by the International group as a whole were: Breathability (47.4%), Soft Hand (45.7%), Cooling (35.7%), and Moisture Management (23.0%). For this last group the F shirt was once again the highest performing shirt for the needs of the International group as a whole. The two shirts which were identified in this study as the best overall performers were not surprisingly the strongest shirts to match up with the comfort demands of the consumers in the consumer market survey. This is due mainly to the fact that Moisture Management was so undervalued by the consumers. If Moisture Management were given more importance by the consumers, the E shirt may have been the favorite of some of the target groups. Table 4.23 shows a synopsis of which garments best met the comfort preferences of the 6 consumer groups in this survey.

Table 4.23 – Top Garments for Identified Consumer Groups

Consumer Group	Most Valued Measurable Comfort Attributes	Top Garment From Sample Set
All United States Respondents	(1) Soft Hand (2) Breathable	F Garment
United States Males; Age 25-34	(1) Breathable (2) Soft Hand	F Garment
United States Females; Age 18-24	(1) Breathable (2) Soft Hand	F Garment
All International Respondents	(1) Breathable (2) Soft Hand	F Garment
International Males; Age 13-17	(1) Breathable (2) Cooling	C Garment
International Females; Age 13-17	(1) Breathable (2) Soft Hand	F Garment

Analysis of Test Measure Correlations

An analysis was done with the JMP® 7.0 program from SAS® in order to determine how well the results from various measures gathered in the different testing phases correlate to one another. Several tables of correlations were developed to compare test measures across different test phases. Test correlations for the measures within each test phase were also performed and the tables for these can be found in the corresponding appendix sections for those test phases. The primary concern of this section is to compare measures from differing test types. An even more important purpose of this section is to compare the results of test measures from the fabric level testing to the results for similar measures which were gathered from the garment testing phase. This allows a comparison of how well the manikin correlates to the testing from the various fabric level tests.

Each of the correlation tables have the name of the measures being compared shaded in yellow. The boxes with the name of the test measures are arranged diagonally from top left to bottom right. The correlation results for any two measures are in the box where the row from one measure intersects the column from the measure with which it is being compared. The same correlations are on the top side of the diagonal line of measures as are on the bottom side of that line. The difference between the correlations on the top side of the diagonal line from the bottom side of the diagonal line is the axis which each measure's data is on for the comparison. For example on the top side of the diagonal line, measure A would be on the x axis, while measure B would be plotted on the y axis; this would be reversed for the correlation plot on the bottom side of the diagonal line. This arrangement allows each measure to be compared to each of the other measures with its data as the x axis as well as its data on the y axis.

Each correlation pair is labeled with its correlation value ranging from 0.0 to 1.0, with 1.0 being exact correlation. All correlations greater than 0.75 have been shaded gray in order to apply an arbitrary 'cut-off' point for correlations which will be considered 'strong'. This allows for easy visual identification of strongly correlated values. All correlations are not conclusive; confirmation of the validity and statistical significance of these correlations would require further testing to compare measures of interest against one another.

One important note is that a correlation table for manikin and Thermolabo results is not included in this report. The reason is that none of the test measures from the manikin correlated with any of the measures from the Thermolabo testing. This was the case despite the fact that these two testing type measure many of the same fabric properties. The most likely cause of this is that the manikin testing was done for a sample set of garments that did not have a uniform garment construction. Some shirts had side panels and some did not. Some side panels were of an open knit construction such as a mesh while others were not. This high level of differentiation did not exist in Thermolabo testing where al samples were solid fabric from the main (usually front) fabric sections of the garment.

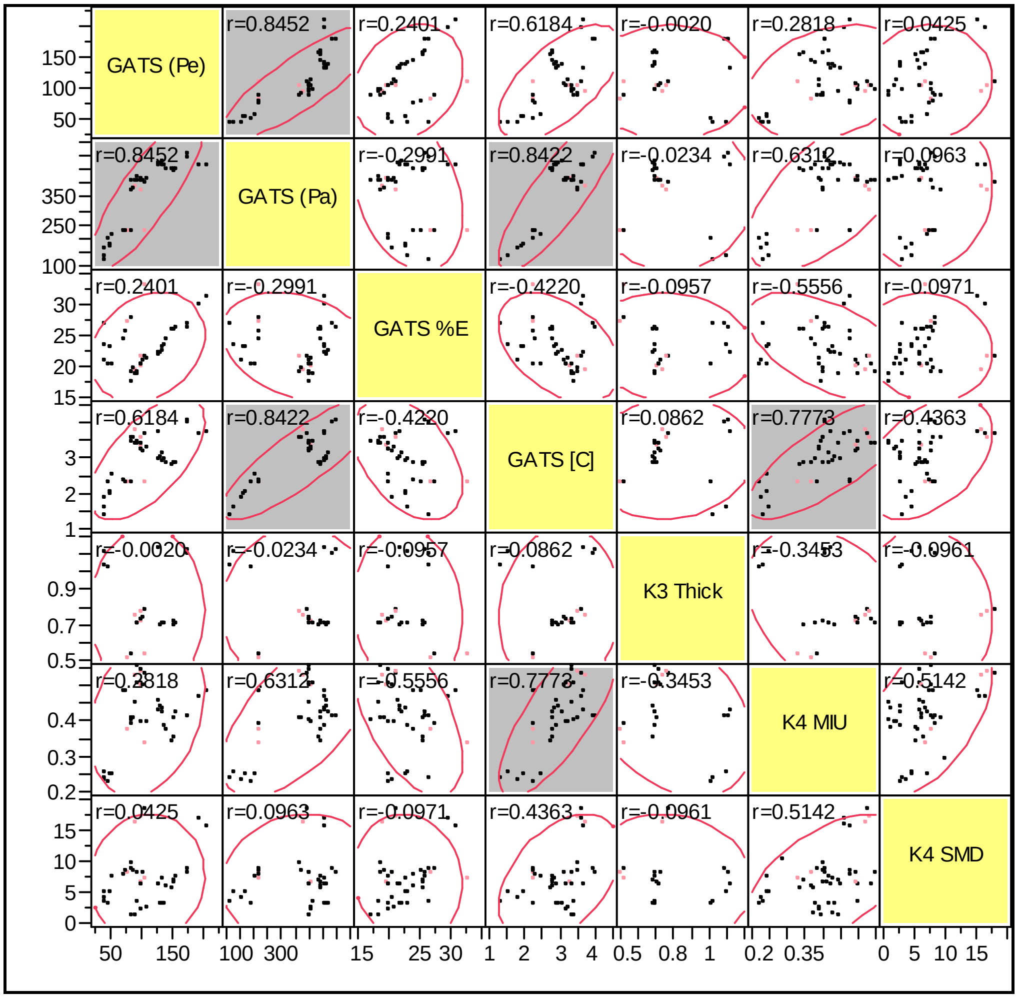

Figure 4.20 - Surface and Thickness vs. Evaporation and Absorption Measures
(correlations over 0.7500 in gray)

Figure 4.20 shows the correlations between the KES measures which relate to the surface properties and thickness of the fabric, as correlated to the GATS measures which deal with absorption and evaporation qualities. The most interesting correlation to note from this graph is that the Coefficient of Friction (MIU), correlates with the Capacity of the fabric to absorb water. This possibly speaks to the roughness of the fabric coinciding with more surface area within the fabric which would allow more water to be absorbed by the fabric. This correlation could also be a random occurrence.

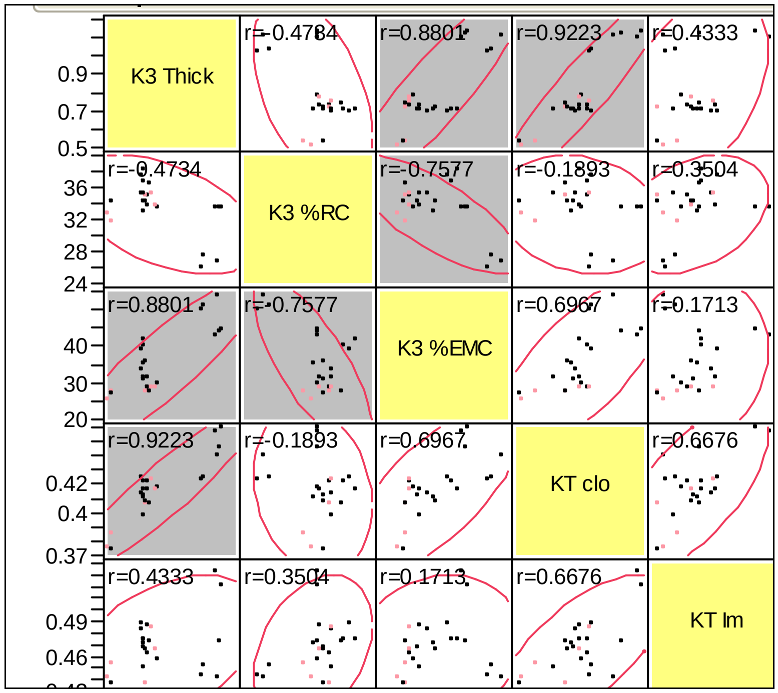

Figure 4.21 - Thickness and Compressibility vs. Permeability and clo Measures
(correlations over 0.7500 in gray)

Figure 4.21 shows correlations for the KES measures Thickness (K3 Thick) and Compressibility (K3 %EMC and K3 %RC) to the Thermolabo measures of clo (KT clo) and Permeability Index (KT Im). The interesting correlation in this set is the very strong correlation between fabric thickness and Thermal Resistance (clo). This shows an expected correlation which demonstrates that a thicker fabric will result in more resistance to the escape of heat from the body.

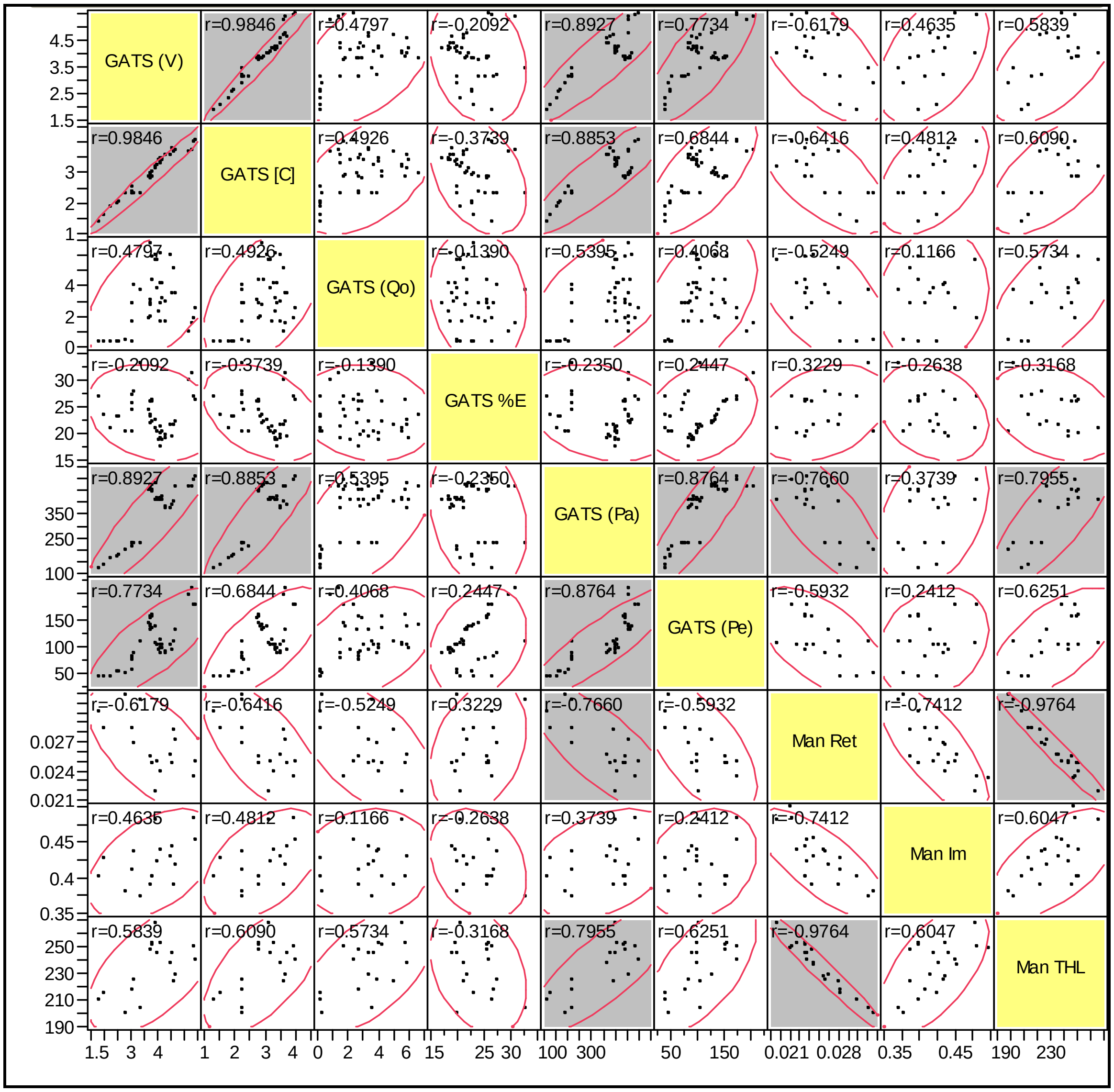

Figure 4.22 - Manikin Measures vs. GATS Measures
(correlations over 0.7500 in gray)

Figure 4.22 compares the measures from the manikin garment level testing to the results from the GATS fabric level testing. Two of the correlations above 0.75 which cross from GATS to the manikin are the correlations between the Absorptive Power measure from the GATS testing and both the Thermal Resistance and Total Heat Loss measures from the manikin testing. The relationship between Absorptive Power and thermal resistance is an inverse relationship, which makers sense given that the more moisture pulled away from the skin the less thermal resistance exists. Likewise the correlation between Absorptive Power and Total Heat Loss is a positive correlation which also makes sense given that the taking of moisture away from the skin increases the amount of heat which can be released from the body.

The relationship between Absorptive Power and the manikin measures were the only two correlations above 0.75 which were identified when comparing manikin measures to those from other test types. The likely cause of this is the normalizing effect that the three-dimensional garment has on the results which otherwise are straightforward in the fabric level testing. This normalizing effect is most likely due to the presence of air pockets between the manikin's 'skin' and the fabric layer; this air layer is not a factor in the fabric level testing. Testing with 'compression' performance athletic shirts would remove the influence of these air pockets as they would fit tightly against the surface of the manikin. This would be a test which may provide a more even comparison of manikin results to fabric level test results.

CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

The purpose of this study was to determine the attributes of athletic apparel which are most necessary in order for an athletic apparel garment to be comfortable. Another objective of this study was to make use of the NCSU thermal sweating manikin in order to test the comfort attributes of performance athletic apparel, and to make use of several fabric level comfort tests which could be used for comparison with the manikin garment level testing results. This process was begun by means of consumer input via a consumer comfort survey, which was implemented by NPD and included 38,263 total respondents. This survey gave valuable insight as to what aspects of comfort were most important to the consumer. This insight also provided understanding as to which comfort testing methods were most important to include with the manikin testing in order to put the candidate garments to the test as defined by the needs of the consumer.

Another valuable aspect of the survey was an ability to get an idea of the size of the athletic apparel market, as well as the growth potential of this market. In the survey 62.1% of the 14,955 respondents from the United States and 60.4% of the 23,308 respondents from outside the United States said they have purchased t-shirts in the past for athletic use. Also in both the US and International groups, the younger age groups had purchased athletic t-shirts more than their older counterparts which suggests a trend of growth for the athletic apparel market. In addition to this the value of comfort was confirmed in the survey as 96.8% of the

US survey group and 96.2% of the International survey group said that they have purchased apparel with comfort in mind.

The test methods chosen to compliment the manikin testing were the Kawabata Hand Evaluation System (KES), the Kawabata guarded sweating hot plate (Thermolabo), and the Gravimetric Absorbency Testing System (GATS) with an accompanying drying test. These tests covered the four major objectively measurable comfort aspects which were evaluated by the consumers in the consumer comfort survey.

The garments chosen to be tested in this study were selected based on several points of criteria. Garments were purchased from both specialty retailers whom specialize in performance athletic merchandise, as well as from mass retailers who do not. Garments were selected from large name brand companies within the athletic apparel market as well as from private label brands from retail companies. Garment prices in the set ranged from $7.68 to $39.99. The final set of test garments included seven different garments, purchased from four different retail locations, from seven different companies, made in seven different countries.

Conclusions

Key Findings:

The following sections are the essential points learned in this research. There are three sections of findings; those related to the survey, those related to general testing results, and those related to the manikin.

Survey Findings:

The survey taught much about what the consumer values in the comfort of this product. It also gave valuable insight into the feeling the consumer has towards comfort in general. The vast majority of consumer value comfort even in general apparel purchases. The consumer also gave their own description of hat comfort is to them for this product, by means of their importance placed on 5 different comfort parameters. Soft Hand, and Breathability were the most valued of the 4 measured parameters in this study.

- 38,263 people responded to the survey
    - Almost 2/3 of respondents have purchased t-shirt for athletic purposes.
    - The vast majority of consumers have purchased apparel with comfort in mind.
- Purchase decision parameters for both US and International groups were ranked:
    - With Price most important, followed by Fit, Comfort, Style/Color, Moisture Management, and Other being least important; in descending order of importance.
    - Soft Hand was more valued by the US group, while Breathable was more valued by the International group, in terms of comfort parameters.

- Moisture management was valued much less overall than the expectation, which was developed by the performance claims in the market. Fit was by far the most important comfort aspect for the consumers, though it was not a measurable parameter within this project.

Testing Findings

The testing phase showed that the tests used in this research are indeed able of discerning differences in each of the comfort parameters the tests are designed to measure. This also showed that there was a difference in the performance of the samples within the sample set; showing that this small representation of the athletic performance apparel market did not all perform the same, showing that they are not all the same in terms of performance in various comfort tests.

- The test measures in this research provided statistically sound differentiation of measurements across the sample set showing that certain samples outperformed others in each of the testing phases.
- In Moisture Management the E garment had the strongest performance with high results in moisture capacity as well as percent evaporation and absorptive and evaporative power as a percentage of dry fabric weight. By contrast the lowest performer was the A garment with low moisture capacity and drying rate values.
- In Breathability and Cooling the F garment was the highest performer in the fabric level testing with low thermal resistance values and high total heat loss values. The C garment was the highest performer in Breathability and Cooling at the garment level testing with

low thermal resistance and high total heat loss values. The lowest performing garments in the fabric level testing were the A garment and the E garment which had high thermal resistance and low total heat loss values respectively. In manikin testing the lowest performers was the A garment which had high thermal resistance, low total heat loss, and high garment weight gain.

- In Fabric Hand the F and G garments were the top performers with high percent extensibility values and surface roughness values. The lowest performers in fabric hand were the C and D garments with low percent extensibility values, and high surface roughness values and stiffness values.
- Based on expected differences within the testing phase, and consumer identified comfort priorities, the highest performing samples were the F and C garments.
    - The F garment had high hand results, and thermal results, and for this reason was identified as the best sample garment to meet the comfort preferences of 5/6 of the survey-identified target demographic groups.
    - The C garment had high manikin thermal results (especially in the very important measure of Total Heat Loss [THL]), and met the comfort preferences of the other 1/6 of the survey-identified target demographic groups.
- The lowest performing garment in the sample set overall was the 100% cotton (A) garment, which was not intended for or marketed toward the same end use as the rest of the sample set which was polyester.
- The lowest performing garments within the performance samples was the D garment which had low hand measures, and average thermal and moisture management properties. Sample D did however have the fastest frying rate.

Manikin Findings

The manikin has been shown to be an extremely valuable test method in this research. The reason that the manikin is so important, particularly in this research, is that the manikin measures the full garment. This takes into account all of the physical differences which are in place within this sample set; the garment construction, fabric, and yarn levels, and measures them on an even plane. The manikin is able to do this because it can provide a total heat loss (THL) value for the full garment, which is more accurate in that it takes into account all construction, fabric, and yarn characteristics, and simply measures the performance of each garment. THL is so important because it give information on the breathability and cooling of the garment in one measure.

- The manikin results and the fabric level results did not correlate with a great deal of strength. This is expected due to all of the differences between samples beyond the fabric level which exist in this research. This is also a primary reason for the importance of the manikin in comfort testing. Fabric from one sample garment may be far superior to fabric from another sample in fabric testing, but on the manikin the garments as a whole may be equally effective. The manikin allowed for a measurement of the 'big picture' of how the samples performed. This 'big picture' may have been missed had the testing been done only at the fabric level.
- The manikin is the preferred means of thermal and evaporative testing due to the fact that the manikin takes into account garment construction, which includes fabric drape, less than 100% 'skin' contact, and air pockets in the areas where the fabric is not contacting the skin. The manikin also is capable of measuring three of the four measurable comfort

parameters in this research which were evaluated by the consumers. Only fabric hand is not measured by the manikin.

Research Objectives

Research Objectives one and two were met in the Review of Literature. Research Objective three was achieved with the completion of the consumer market survey, due to the help of NPD. The consumer comfort survey's most surprising result was that Moisture Management is the lowest valued comfort aspect out of the four evaluated, which were Fabric Hand, Breathability, Cooling, and Moisture Management. Breathability is the most highly valued comfort aspect by the consumers on the International side of the survey, with Soft Hand the second most valued comfort aspect in the survey. Fabric Hand was the most important aspect for those consumers in the United States, while Breathability was their second most valued comfort aspect. Cooling is the third most important comfort aspect as ranked by both the International and US groups. Moisture Management was chosen as the least important of the four by both groups as it was rated 'very important' by only 23% of International respondents and only 18.6% of US respondents.

Target consumer groups were identified within the survey. These groups were followed throughout the survey as to the values they placed on comfort aspects. There was one male and one female target group within each of the sides of the survey, the International and US sides. The entirety of each group was also used as a target group to use for a comparison of the full survey population on the International side of the survey against the full population of the US side of the survey. The two were also included in order to be compared with the two target groups within each side of the survey. Each group's comfort preferences were used in conjunction with the testing results from those preferences in order to identify garments from the testing sample set which were best suited to meet the needs of that particular target group.

The size of the athletic apparel market was shown to be large as well as growing (New Strategist Publications, Inc, 2005), (*Global market review of performance apparel - forecast to 2012 - 2006 edition*, 2006). The performance segment of the athletic apparel market was also shown to be significant and growing with *Just-Style* predicting a $4.29 Billion segment within the United States alone by the year 2012.

Research Objectives four through nine were all successfully met by the testing phase of this research. Some general assumptions, however, must be stated before discussing the testing results. The most important assumption is that the tests included in this research generate reliable information as to the differentiation of performance among any given sample set. There were several measures which did in fact provide statistically significant differentiation among the sample set. This is an important result in itself, but the fact remains that infallible test methods are a necessary assumption of this research. The results of the testing phase were mixed depending on which portion of the testing phase is being looked at. Table 4.22 shows the top performing garments for each testing stage as well as the lowest performing shirts for each testing stage. The lowest performer overall was the 100% cotton (A) garment which was included for the purpose of comparing modern materials with cotton which has been the traditional standard bearing material for the athletic apparel market. The cotton shirt was consistently the lowest, or one of the two lowest performing shirts in each stage of testing. The lowest performing garment of the remaining shirts in the study, which were all polyester shirts, was the D shirt from Dick's Sporting Goods®, which was purchased for $24.99. The results of this study show that all of the polyester shirts outperformed the cotton shirt when looking at the full body of testing together.

Research Objective ten was met with the combination of the results from the testing phase and the consumer survey phase of the study. The top overall performing shirt in the study was the F garment which is a private label brand, and was also identified as the shirt to fit the consumer demands of five out of the six identified target consumer groups. This shirt was purchased at a cost of $22.00. The other top performing garment was the C shirt which is a private brand sold only at Target® retailers. This shirt was also identified as the best suited garment to meet the needs of one of the six target consumer groups. The C garment was purchased at a cost of $14.99. Figure 5.1 gives a graphical representation of how the goals from Figure 1.1 were met, and what results were generated.

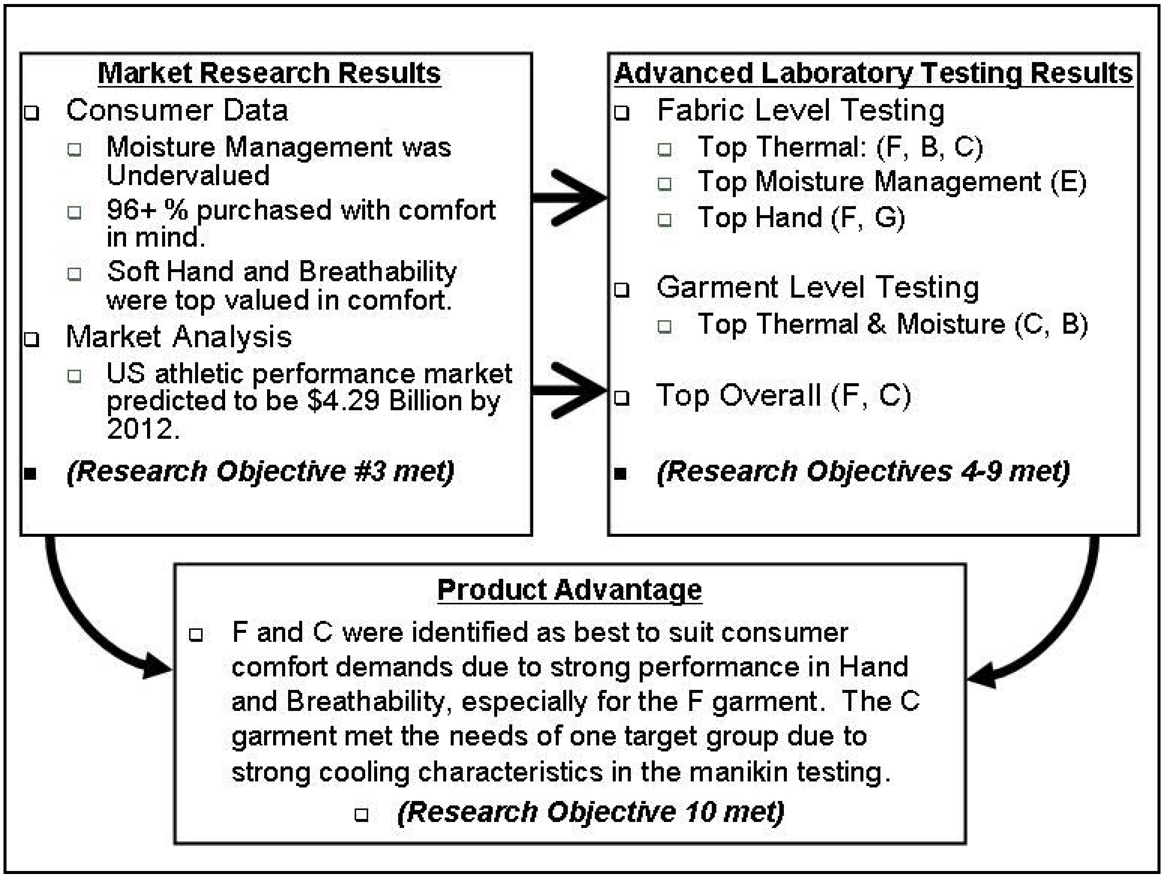

Figure 5.1 – Results of the Comfort Study

Recommendations and Future Research

This project covered many valuable areas of comfort from consumer input by one of the best companies in consumer surveying to fabric level and garment level quantitative comfort testing with some of the most advanced test methods available. The broad scope of this research provides some limitations as listed in chapter one, however it also provides opportunity for further work.

From the market survey side of this research the recommendations are to take advantage of the tremendous size of the survey in this research by allowing more time for this data to be vetted out and to continue to discover new things the survey has revealed about the consumers. The survey had over 38,000 respondents so validity is not in question. The only limitation within this research project was the time available to work with the survey data. An entire project could be devoted to the data from this particular survey, but as a mere segment of this project the survey was not taken advantage of to the degree to which it could have been. There is much more this survey has to say about the consumer, both within and beyond the scope of this project. To the size of the market it is recommended to follow up on the market growth trends predicted in the *Just-Style* report, especially to the year 2012, in order to see how the growth of the performance segment of the athletic apparel market has developed as compared to the *Just-Style* prediction.

The results from the fabric level testing did not necessarily correlate to results from the garment level manikin testing. The manikin testing takes into account the comfort measures from the Thermolabo testing for the most part, and none of the Thermolabo measures had strong correlations with the manikin results. The hypothesis to this is that the air layer between the manikin's skin surface and the fabric has a neutralizing effect on the results of the garments. A recommendation for testing this hypothesis is to purchase compression performance athletic t-shirts to test at the manikin garment level and on the fabric level to determine how well the manikin behaves when there is no presence of air pockets between the manikin and the shirt.

Both the fabric level and manikin garment level comfort testing phases have informative value. The fabric level tests reveal properties about the material while the manikin testing has the ability to evaluate the garment as a full piece. The assumption for this portion of the results is that the manikin will return more reliable results due to the fact that it takes garment shape and construction into account which includes the air pockets between fabric and ‘skin’ which have most likely had a strong impact on the outcome of the testing results. The shortcoming of this manikin is that it is a static manikin which does not move during testing. Movement would simulate the air to fabric interaction which would take place during real human activity. It is advisable to run some tests with a walking manikin in order to include this element in the testing.

Highly recommended follow up research to this study is to take the same research model from this study and include a human wear trial. With data from a human wear trial it becomes possible to determine weather the fabric level testing results more accurately predict human wear trial comfort response, or if manikin testing results more accurately predict human wear trial comfort response. It will also be possible to determine if the results from a human wear trial confirm or refute the input from the consumers as to what really is important in comfort of athletic apparel. The comparison between what people want and what they respond well to would allows much educational benefit to apparel companies who are trying to market these products. For instance, it is widely thought that Moisture Management is very important to the comfort perception in this product category; however the consumers in the consumer comfort survey poorly rated Moisture Management in their survey assessment of what they think is important in the comfort of athletic t-shirts. This seems to point to the need of the marketing entities within the performance apparel companies to increase efforts to educate the public on the benefit of the performance characteristics in their products such as Moisture Management. Confirmation of the importance of Moisture Management via the completion of a human wear trial would also confirm the need to improve the marketing effort to educate the consumer public on Moisture Management.

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Appendix

A.1 Consumer Survey

This section is for the tables which show the results from the consumer survey which deal with the comfort parameters reviewed by the consumer respondents. The following tables are summarized in Table 4.16 in chapter 4. These are the full results of the responses of all ages, genders, and income levels (US only) in both the International and US groups. At the end of this section is included the survey instrument used for this research.

Table A.1 – Importance of Moisture Management (USA)

Importance of Moisture Management in T-shirts (U.S.A.) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	24.3	48.0	27.6	100%
	F	23.2	50.8	26.0	100%
18-24	M	30.2	38.7	31.1	100%
	F	18.3	52.3	29.4	100%
25-34	M	25.0	50.9	24.1	100%
	F	17.8	53.4	28.8	100%
35-44	M	20.5	51.3	28.2	100%
	F	21.7	50.4	27.9	100%
45-54	M	20.4	57.0	22.5	100%
	F	20.3	51.0	28.7	100%
55+	M	17.2	52.4	30.5	100%
	F	17.2	48.8	34.0	100%
Total	**M**	**18.5**	**51.9**	**29.6**	100%
	F	**18.6**	**51.4**	**30.0**	100%
All	**M & F**	**18.6**	**51.5**	**29.9**	100%

Table A.2 – Importance of Moisture Management (International)

Importance of Moisture Management in T-shirts (International) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	22.9	57.1	20.0	100%
	F	31.6	49.1	19.3	100%
18-24	M	25.5	56.9	17.5	100%
	F	21.1	55.2	23.7	100%
25-34	M	24.8	53.8	21.5	100%
	F	22.7	52.1	25.2	100%
35-44	M	25.3	52.0	22.7	100%
	F	24.1	51.3	24.6	100%
45-54	M	23.3	52.7	24.0	100%
	F	23.6	49.9	26.5	100%
55+	M	21.8	51.9	26.3	100%
	F	21.9	48.5	29.6	100%
Total	**M**	**23.0**	**52.4**	**24.6**	100%
	F	**23.0**	**50.6**	**26.4**	100%
All	**M & F**	**23.0**	**51.1**	**25.9**	100%

Table A.3 – Importance of Moisture Management (USA by Income)

Importance of Moisture Management in T-shirts (U.S.A.) (By Income Level … In %)				
Income (In Thousands)	**Very Important**	**Important**	**Not Important**	**Total**
< $15,000	20.7	50.9	28.4	100%
$15 - $24	19.4	50.7	29.9	100%
$25 - $29	18.2	51.1	30.7	100%
$30 - $34	18.7	50.0	31.3	100%
$35 - $44	19.7	51.1	29.2	100%
$45 - $49	18.6	52.9	28.5	100%
$50 - $59	17.0	53.5	29.5	100%
$60 - $74	17.3	52.4	30.3	100%
$75 - $99	17.8	48.1	34.1	100%
$100 - $149	18.6	47.9	33.5	100%
$150 - $199	18.9	56.8	24.3	100%
$200,000 +	20.5	53.8	25.6	100%
Total	**18.6**	**51.5**	**29.9**	100%

Table A.4 – Importance of Cooling (USA)

Importance of Cooling in T-shirts (U.S.A.) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	42.1	42.8	15.1	100%
	F	38.3	45.6	16.1	100%
18-24	M	39.6	43.4	17.0	100%
	F	30.9	51.3	17.8	100%
25-34	M	33.0	51.8	15.2	100%
	F	28.7	52.7	18.6	100%
35-44	M	38.5	51.3	10.3	100%
	F	38.2	46.2	15.5	100%
45-54	M	36.6	53.5	9.9	100%
	F	41.9	45.9	12.3	100%
55+	M	33.3	50.1	16.6	100%
	F	38.5	47.7	13.8	100%
Total	**M**	**33.9**	**50.1**	**15.9**	100%
	F	**35.2**	**49.2**	**15.6**	100%
All	**M & F**	**35.0**	**49.3**	**15.7**	100%

Table A.5 – Importance of Cooling (International)

Importance of Cooling in T-shirts (International) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	37.1	57.1	5.7	100%
	F	38.6	40.4	21.1	100%
18-24	M	36.5	56.9	6.6	100%
	F	29.8	51.6	18.6	100%
25-34	M	34.8	51.3	14.0	100%
	F	29.7	52.6	17.8	100%
35-44	M	39.5	48.1	12.4	100%
	F	33.0	51.4	15.7	100%
45-54	M	36.1	50.3	13.6	100%
	F	39.7	47.3	13.0	100%
55+	M	35.3	49.9	14.8	100%
	F	39.2	46.9	13.9	100%
Total	**M**	**36.1**	**50.0**	**13.9**	100%
	F	**35.5**	**49.4**	**15.1**	100%
All	**M & F**	**35.7**	**49.5**	**14.8**	100%

Table A.6 – Importance of Cooling (USA by Income)

Importance of Cooling in T-shirts (U.S.A.) (By Income Level … In %)				
Income (In Thousands)	**Very Important**	**Important**	**Not Important**	**Total**
< $15,000	32.9	51.7	15.4	100%
$15 - $24	38.9	43.6	17.6	100%
$25 - $29	35.8	49.5	14.7	100%
$30 - $34	36.2	48.7	15.1	100%
$35 - $44	36.0	49.0	15.0	100%
$45 - $49	36.2	47.9	15.9	100%
$50 - $59	33.2	51.2	15.6	100%
$60 - $74	33.6	49.9	16.5	100%
$75 - $99	32.5	51.9	15.6	100%
$100 - $149	30.4	49.0	20.6	100%
$150 - $199	29.7	56.8	13.5	100%
$200,000 +	25.6	56.4	17.9	100%
Total	**35.0**	**49.3**	**15.7**	100%

Table A.7 – Importance of Soft Hand (USA)

Importance of Soft Hand in T-shirts (U.S.A.) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	36.8	44.7	18.4	100%
	F	43.1	48.2	8.7	100%
18-24	M	31.1	55.7	13.2	100%
	F	44.3	49.9	5.9	100%
25-34	M	36.6	50.0	13.4	100%
	F	51.3	44.3	4.4	100%
35-44	M	43.6	51.3	5.1	100%
	F	59.7	37.8	2.5	100%
45-54	M	47.2	47.9	4.9	100%
	F	63.1	34.3	2.6	100%
55+	M	47.8	45.9	6.3	100%
	F	63.4	33.7	2.9	100%
Total	**M**	**46.2**	**46.9**	**6.9**	100%
	F	**55.7**	**40.4**	**3.8**	100%
All	**M & F**	**54.3**	**41.4**	**4.3**	100%

Table A.8 – Importance of Soft Hand (International)

Importance of Soft Hand in T-shirts (International) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	31.4	54.3	14.3	100%
	F	40.4	49.1	10.5	100%
18-24	M	36.5	48.9	14.6	100%
	F	38.9	52.8	8.3	100%
25-34	M	32.5	54.4	13.1	100%
	F	43.6	50.3	6.1	100%
35-44	M	42.7	49.6	7.7	100%
	F	47.7	47.9	4.4	100%
45-54	M	39.3	52.6	8.0	100%
	F	49.4	46.8	3.8	100%
55+	M	40.3	51.7	8.0	100%
	F	52.2	44.1	3.6	100%
Total	**M**	**39.7**	**51.8**	**8.5**	100%
	F	**47.9**	**47.5**	**4.6**	100%
All	**M & F**	**45.7**	**48.6**	**5.7**	100%

Table A.9 – Importance of Soft Hand (USA by Income)

Importance of Soft Hand in T-shirts (U.S.A.) (By Income Level … In %)				
Income (In Thousands)	**Very Important**	**Important**	**Not Important**	**Total**
< $15,000	47.0	47.8	5.3	100%
$15 - $24	55.2	38.9	5.9	100%
$25 - $29	56.6	39.1	4.3	100%
$30 - $34	53.6	42.4	3.9	100%
$35 - $44	55.1	41.0	3.9	100%
$45 - $49	56.0	39.3	4.6	100%
$50 - $59	54.3	42.2	3.5	100%
$60 - $74	54.9	41.1	4.0	100%
$75 - $99	51.3	43.3	5.4	100%
$100 - $149	54.6	38.7	6.7	100%
$150 - $199	43.2	51.4	5.4	100%
$200,000 +	35.9	56.4	7.7	100%
Total	**54.3**	**41.4**	**4.3**	100%

Table A.10 – Importance of Fit and Mobility (USA)

Importance of Good Fit and Mobility in T-shirts (U.S.A.) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	68.4	23.7	7.9	100%
	F	73.6	23.8	2.6	100%
18-24	M	72.6	21.7	5.7	100%
	F	76.0	22.7	1.3	100%
25-34	M	64.3	30.4	5.4	100%
	F	76.0	23.0	1.0	100%
35-44	M	56.4	35.9	7.7	100%
	F	76.7	22.5	0.8	100%
45-54	M	66.2	30.3	3.5	100%
	F	77.5	20.9	1.6	100%
55+	M	65.6	31.6	2.8	100%
	F	76.7	21.5	1.8	100%
Total	**M**	**65.7**	**31.0**	**3.2**	100%
	F	**76.6**	**22.0**	**1.4**	100%
All	**M & F**	**74.9**	**23.4**	**1.7**	100%

Table A.11 – Importance of Fit and Mobility (International)

Importance of Good Fit and Mobility in T-shirts (International) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	62.9	28.6	8.6	100%
	F	80.7	17.5	1.8	100%
18-24	M	69.3	27.7	2.9	100%
	F	75.3	23.4	1.3	100%
25-34	M	66.9	30.8	2.3	100%
	F	76.7	22.3	1.0	100%
35-44	M	69.0	29.5	1.4	100%
	F	72.8	25.7	1.4	100%
45-54	M	67.7	30.2	2.1	100%
	F	74.9	23.8	1.3	100%
55+	M	66.9	31.0	2.2	100%
	F	75.3	23.1	1.5	100%
Total	**M**	**67.5**	**30.5**	**2.1**	100%
	F	**74.9**	**23.8**	**1.3**	100%
All	**M & F**	**72.9**	**25.6**	**1.5**	100%

Table A.12 – Importance of Fit and Mobility (USA by Income)

Importance of Good Fit and Mobility in T-shirts (U.S.A.) (By Income Level … In %)				
Income (In Thousands)	Very Important	Important	Not Important	Total
< $15,000	73.4	25.0	1.6	100%
$15 - $24	75.5	22.6	1.9	100%
$25 - $29	76.3	21.9	1.8	100%
$30 - $34	74.1	24.3	1.6	100%
$35 - $44	76.7	21.9	1.5	100%
$45 - $49	73.0	25.3	1.7	100%
$50 - $59	75.3	23.6	1.1	100%
$60 - $74	74.6	23.4	1.9	100%
$75 - $99	76.1	21.7	2.2	100%
$100 - $149	69.1	28.9	2.1	100%
$150 - $199	64.9	35.1	0.0	100%
$200,000 +	71.8	25.6	2.6	100%
Total	**74.9**	**23.4**	**1.7**	100%

Table A.13 – Importance of Breathability (USA)

Importance of Breathability in T-shirts (U.S.A.) (By Age and Gender … In %)					
Age	Gender	Very Important	Important	Not Important	Total
13-17	M	46.7	41.4	11.8	100%
	F	55.2	39.8	5.0	100%
18-24	M	45.3	43.4	11.3	100%
	F	52.5	43.6	3.9	100%
25-34	M	43.8	42.9	13.4	100%
	F	49.4	46.1	4.5	100%
35-44	M	38.5	53.8	7.7	100%
	F	46.9	47.9	5.2	100%
45-54	M	45.1	48.6	6.3	100%
	F	52.6	42.3	5.1	100%
55+	M	33.0	55.1	12.0	100%
	F	44.9	47.2	7.9	100%
Total	**M**	**35.1**	**53.4**	**11.6**	100%
	F	**49.8**	**44.9**	**5.3**	100%
All	**M & F**	**47.6**	**46.2**	**6.2**	100%

Table A.14 – Importance of Breathability (International)

Importance of Breathability in T-shirts (International) (By Age and Gender … In %)					
Age	Gender	**Very Important**	**Important**	**Not Important**	**Total**
13-17	M	37.1	42.9	20.0	100%
	F	54.4	38.6	7.0	100%
18-24	M	46.7	48.2	5.1	100%
	F	54.9	41.7	3.5	100%
25-34	M	46.7	47.1	6.3	100%
	F	50.6	45.6	3.8	100%
35-44	M	43.3	50.1	6.6	100%
	F	49.6	45.3	5.0	100%
45-54	M	40.1	52.8	7.1	100%
	F	49.9	44.8	5.3	100%
55+	M	36.0	53.8	10.2	100%
	F	50.4	43.4	6.2	100%
Total	**M**	**39.2**	**52.4**	**8.4**	100%
	F	**50.4**	**44.5**	**5.1**	100%
All	**M & F**	**47.4**	**46.6**	**6.0**	100%

Table A.15 - Importance of Breathability (USA by Income)

Importance of Breathability in T-shirts (U.S.A.) (By Income Level … In %)				
Income (In Thousands)	**Very Important**	**Important**	**Not Important**	**Total**
< $15,000	50.9	43.8	5.3	100%
$15 - $24	52.7	41.9	5.4	100%
$25 - $29	49.1	44.8	6.0	100%
$30 - $34	48.3	45.3	6.4	100%
$35 - $44	47.7	46.7	5.6	100%
$45 - $49	46.4	46.9	6.7	100%
$50 - $59	46.4	47.6	6.0	100%
$60 - $74	45.2	47.9	7.0	100%
$75 - $99	47.1	46.8	6.1	100%
$100 - $149	41.8	49.0	9.3	100%
$150 - $199	45.9	48.6	5.4	100%
$200,000 +	41.0	48.7	10.3	100%
Total	**47.6**	**46.2**	**6.2**	100%

Comfort of Athletic T-Shirts

1) Which of the following factors are important to you when purchasing apparel?
(choose all that apply)

Price	Fit	Comfort
Moisture Management	Style/Color	Other

2) Have you ever purchased apparel with comfort in mind? (yes/no)

3) Have you ever purchased a t-shirt for sports/athletic use? (yes/no)

4) Which of the following factors do you consider to be the most important?
(choose all that apply)

Moisture Management	Cooling	Soft Material
Good Fit and Mobility	Breathable	Other

5) How important are the following features in t-shirts?
(choose only one option per feature)

▪ **Moisture Management**	Very Important	Important	Not Important
▪ **Cooling**	Very Important	Important	Not Important
▪ **Soft Material**	Very Important	Important	Not Important
▪ **Good Fit and Mobility**	Very Important	Important	Not Important
▪ **Breathable**	Very Important	Important	Not Important

A.2 Quantitative Comfort Testing Data

The purpose of this portion of the appendix is to include an exhaustive display of the data from the physical quantitative comfort testing. All statistical analysis for each testing measure will be provided, which included an Analysis of Variance table as well as a Tukey Kramer matrix of significant difference. Graphs of the averages of the data points which are shown in graphs in chapter four will be provided for all measures. Graphs of data points and Tukey HSD circles will be provided for all measures not discussed in chapter 4. For some sections, additional visual charts for the data are also included.

A.2.1 Kawabata Evaluation System (KES) Data

This section will display all data pertaining to the Kawabata Evaluation System. The bi-directional tests discussed in chapter four were only shown for Warp-Direction results. This section will include Fill-Direction results, as well as results for measures not discussed in chapter 4. Bar charts of data for bi-directional tests reflect the value of warp and fill results averaged together, which is a common method used by the TPACC lab. Statistical analysis tables for all measures are included.

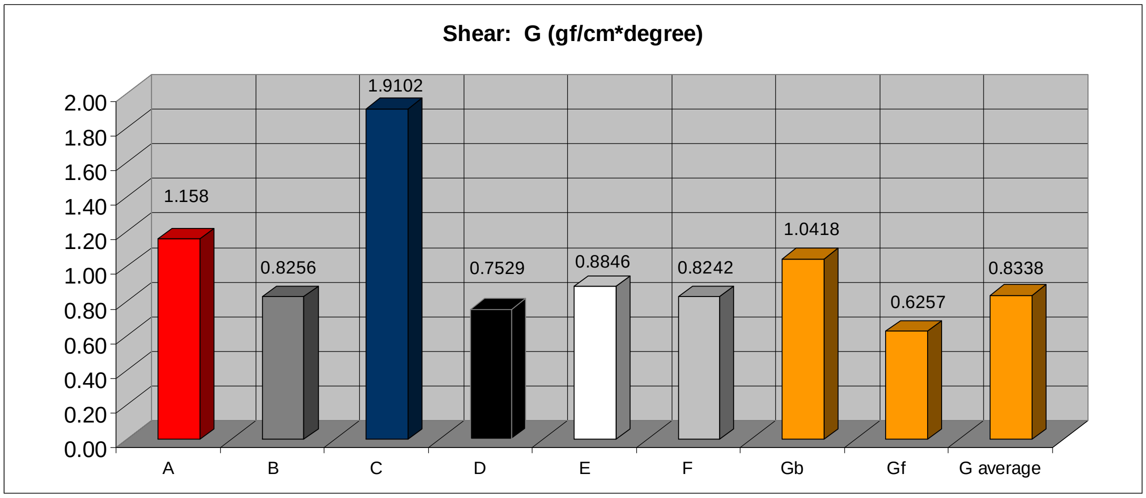

Figure A.1 – Data Average for Shear Stiffness (G)

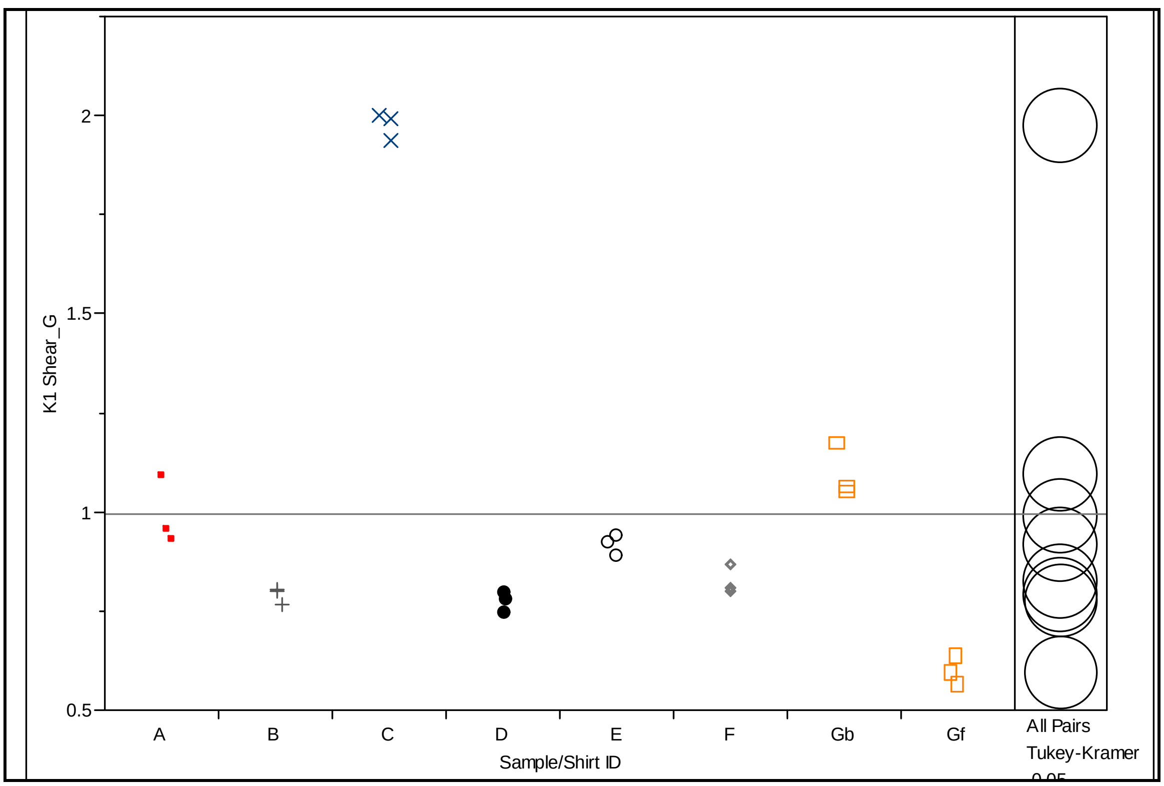

Figure A.2 – Data Points of Shear Stiffness (gf/cm * degree) – Fill Direction

Table A.16 – Analysis of Variance for Shear (G) – Warp Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	3.3128874	0.473270	161.6768	<.0001*
Error	16	0.0468361	0.002927		
C. Total	23	3.3597236			

Table A.17 – Analysis of Variance for Shear (G) – Fill Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	3.7658545	0.537979	241.0633	<.0001*
Error	16	0.0357071	0.002232		
C. Total	23	3.8015616			

Table A.18 – Tukey HSD Matrix for Shear (G) – Warp Direction

Abs(Dif)-LSD

	C	A	Gb	B	E	F	D	Gf
C	-0.1529	0.3669	0.7048	0.8330	0.8411	0.9191	0.9628	1.0349
A	0.3669	-0.1529	0.1850	0.3132	0.3213	0.3993	0.4430	0.5151
Gb	0.7048	0.1850	-0.1529	-0.0248	-0.0167	0.0614	0.1051	0.1772
B	0.8330	0.3132	-0.0248	-0.1529	-0.1448	-0.0668	-0.0231	0.0490
E	0.8411	0.3213	-0.0167	-0.1448	-0.1529	-0.0749	-0.0312	0.0409
F	0.9191	0.3993	0.0614	-0.0668	-0.0749	-0.1529	-0.1093	-0.0372
D	0.9628	0.4430	0.1051	-0.0231	-0.0312	-0.1093	-0.1529	-0.0808
Gf	1.0349	0.5151	0.1772	0.0490	0.0409	-0.0372	-0.0808	-0.1529

Positive values show pairs of means that are significantly different.

Table A.19 – Tukey HSD Matrix for Shear (G) – Fill Direction

Abs(Dif)-LSD

	C	Gb	A	E	F	B	D	Gf
C	-0.1335	0.7455	0.8510	0.9235	1.0160	1.0497	1.0653	1.2475
Gb	0.7455	-0.1335	-0.0281	0.0444	0.1369	0.1706	0.1862	0.3685
A	0.8510	-0.0281	-0.1335	-0.0610	0.0314	0.0651	0.0807	0.2630
E	0.9235	0.0444	-0.0610	-0.1335	-0.0411	-0.0074	0.0082	0.1905
F	1.0160	0.1369	0.0314	-0.0411	-0.1335	-0.0998	-0.0842	0.0980
B	1.0497	0.1706	0.0651	-0.0074	-0.0998	-0.1335	-0.1179	0.0643
D	1.0653	0.1862	0.0807	0.0082	-0.0842	-0.1179	-0.1335	0.0487
Gf	1.2475	0.3685	0.2630	0.1905	0.0980	0.0643	0.0487	-0.1335

Positive values show pairs of means that are significantly different.

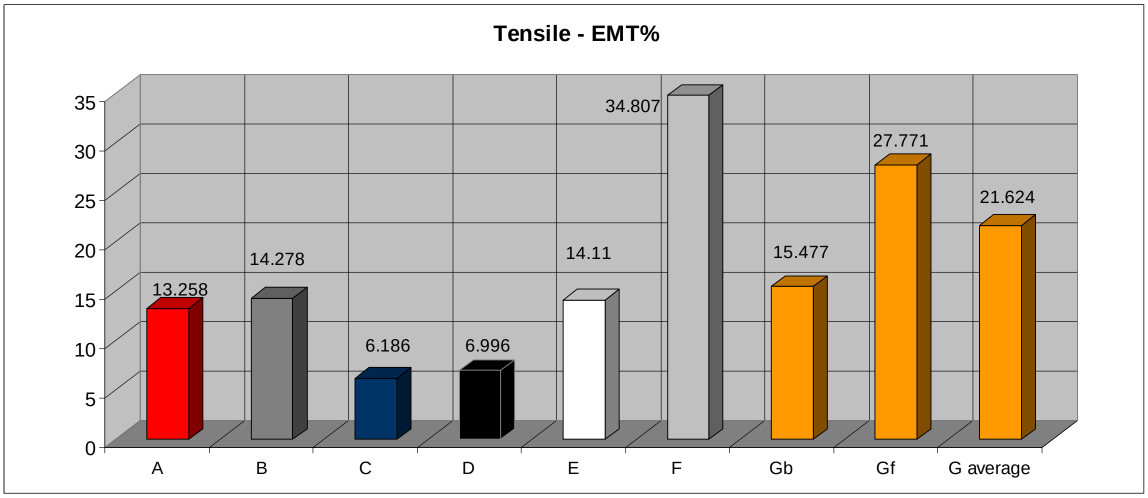

Figure A.3 – Data Average for Tensile (%EMT)

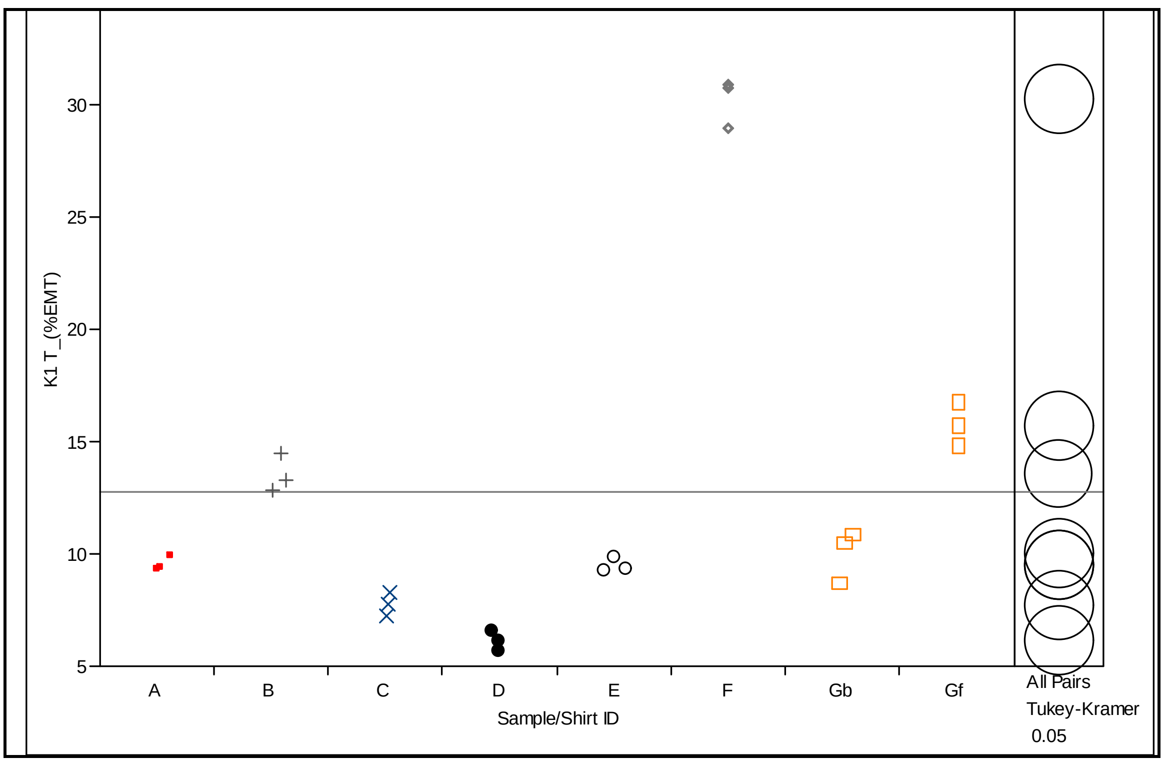

Figure A.4 – Data Points of Tensile (%EMT) – Fill Direction

Table A.20 – Analysis of Variance for Tensile (%EMT) – Warp Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	1238.7627	176.966	290.0770	<.0001*
Error	16	9.7611	0.610		
C. Total	23	1248.5238			

Table A.21 – Analysis of Variance for Tensile (%EMT) – Fill Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	2958.9492	422.707	832.8022	<.0001*
Error	16	8.1212	0.508		
C. Total	23	2967.0703			

Table A.22 – Tukey HSD Matrix for Tensile (%EMT) – Warp Direction

Abs(Dif)-LSD

	F	Gf	B	Gb	A	E	C	D
F	-2.208	12.376	14.483	18.039	18.532	18.539	20.333	21.889
Gf	12.376	-2.208	-0.101	3.456	3.949	3.956	5.750	7.306
B	14.483	-0.101	-2.208	1.349	1.842	1.849	3.643	5.199
Gb	18.039	3.456	1.349	-2.208	-1.715	-1.708	0.086	1.642
A	18.532	3.949	1.842	-1.715	-2.208	-2.201	-0.406	1.149
E	18.539	3.956	1.849	-1.708	-2.201	-2.208	-0.414	1.142
C	20.333	5.750	3.643	0.086	-0.406	-0.414	-2.208	-0.652
D	21.889	7.306	5.199	1.642	1.149	1.142	-0.652	-2.208

Positive values show pairs of means that are significantly different.

Table A.23 – Tukey HSD Matrix for Tensile (%EMT) – Fill Direction

Abs(Dif)-LSD

	F	Gf	Gb	E	A	B	D	C
F	-2.014	3.473	16.399	18.632	20.344	22.354	29.509	32.687
Gf	3.473	-2.014	10.912	13.145	14.857	16.867	24.022	27.200
Gb	16.399	10.912	-2.014	0.219	1.931	3.941	11.097	14.274
E	18.632	13.145	0.219	-2.014	-0.302	1.708	8.864	12.041
A	20.344	14.857	1.931	-0.302	-2.014	-0.004	7.152	10.329
B	22.354	16.867	3.941	1.708	-0.004	-2.014	5.142	8.319
D	29.509	24.022	11.097	8.864	7.152	5.142	-2.014	1.163
C	32.687	27.200	14.274	12.041	10.329	8.319	1.163	-2.014

Positive values show pairs of means that are significantly different.

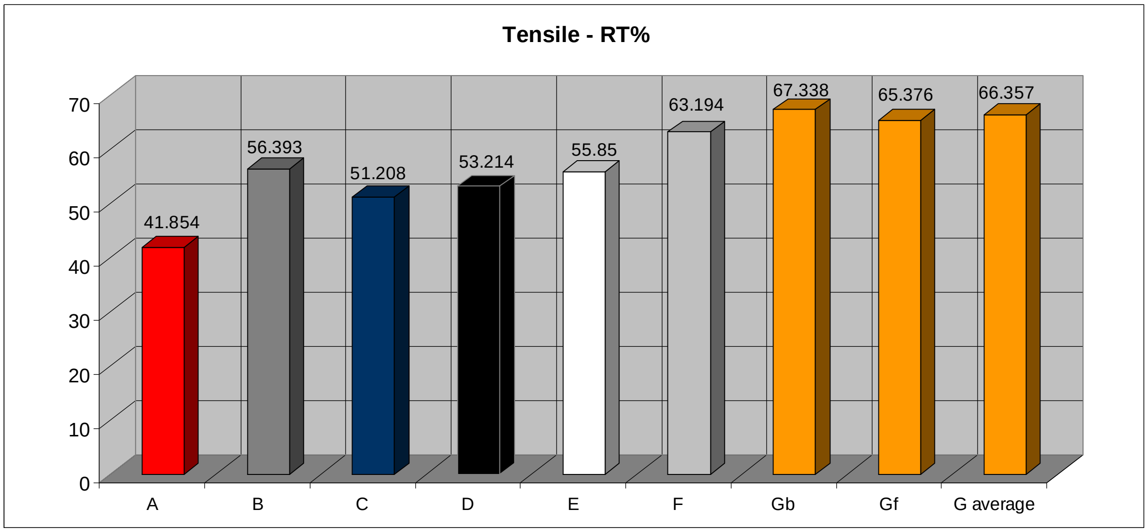

Figure A.5 – Data Average for Tensile (%RT)

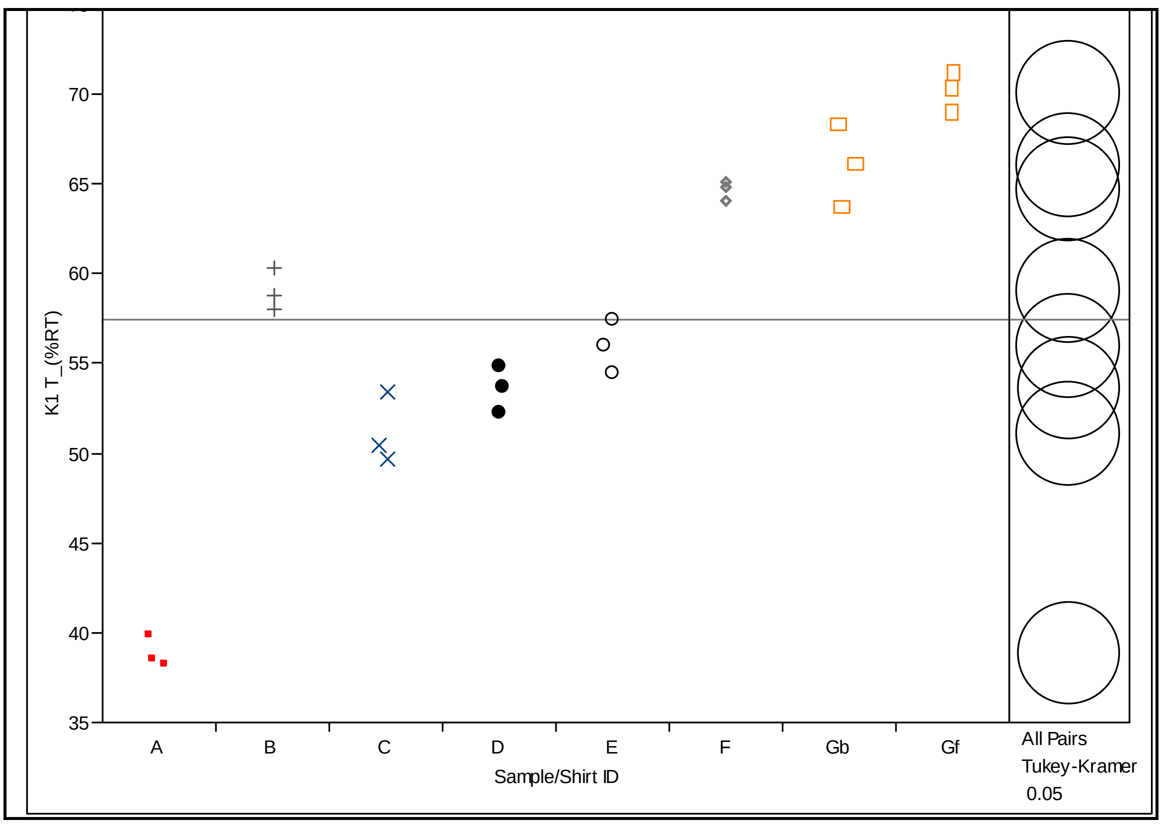

Figure A.6 – Data Points of Tensile (%RT) – Warp Direction

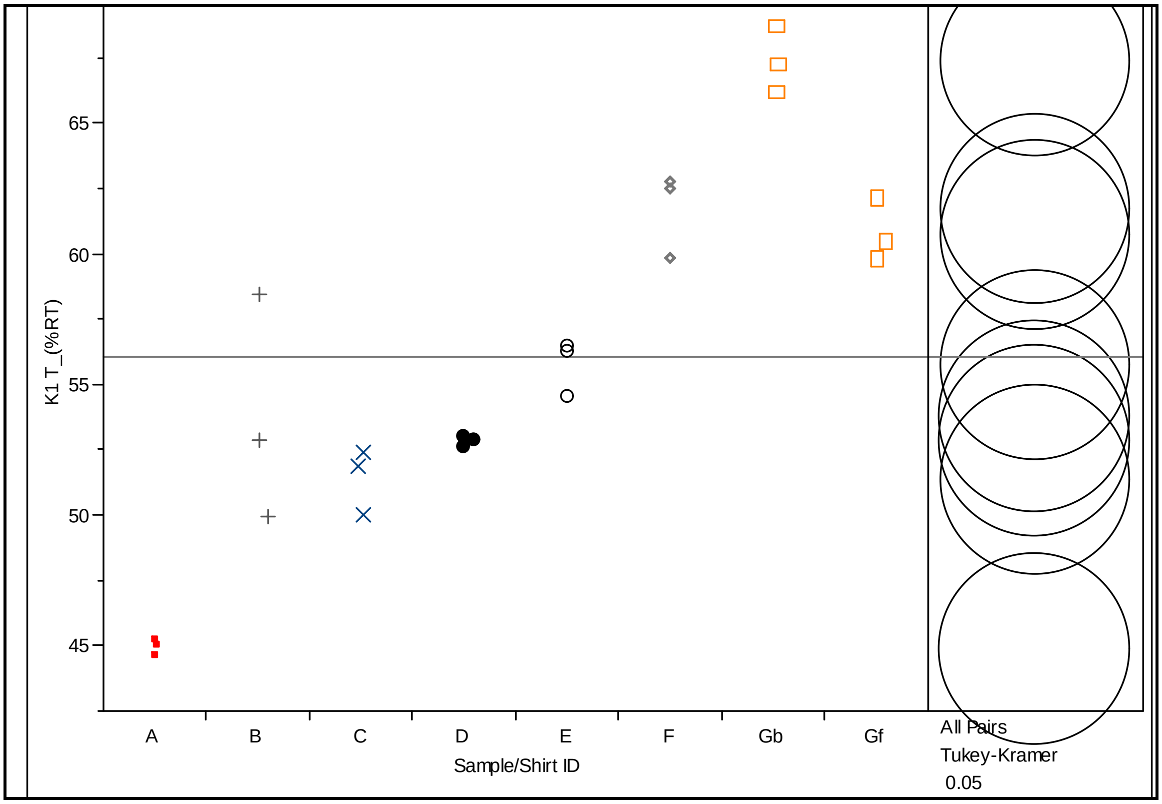

Figure A.7 – Data Points of Tensile (%RT) – Fill Direction

Table A.24 – Analysis of Variance for Tensile (%RT) – Warp Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	2073.9024	296.272	139.5888	<.0001*
Error	16	33.9594	2.122		
C. Total	23	2107.8618			

Table A.25 – Analysis of Variance for Tensile (%RT) – Fill Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	1031.3555	147.336	43.4650	<.0001*
Error	16	54.2364	3.390		
C. Total	23	1085.5919			

Table A.26 – Tukey HSD Matrix for Tensile (%RT) – Warp Direction

Abs(Dif)-LSD

	Gf	Gb	F	B	E	D	C	A
Gf	-4.118	-0.084	1.245	6.899	9.955	12.320	14.854	27.104
Gb	-0.084	-4.118	-2.789	2.865	5.921	8.286	10.820	23.070
F	1.245	-2.789	-4.118	1.535	4.591	6.956	9.490	21.741
B	6.899	2.865	1.535	-4.118	-1.063	1.303	3.837	16.087
E	9.955	5.921	4.591	-1.063	-4.118	-1.753	0.781	13.031
D	12.320	8.286	6.956	1.303	-1.753	-4.118	-1.584	10.666
C	14.854	10.820	9.490	3.837	0.781	-1.584	-4.118	8.132
A	27.104	23.070	21.741	16.087	13.031	10.666	8.132	-4.118

Positive values show pairs of means that are significantly different.

Table A.27 – Tukey HSD Matrix for Tensile (%RT) – Fill Direction

Abs(Dif)-LSD

	Gb	F	Gf	E	B	D	C	A
Gb	-5.205	0.433	1.433	6.410	8.381	9.318	10.796	17.253
F	0.433	-5.205	-4.205	0.772	2.743	3.680	5.158	11.615
Gf	1.433	-4.205	-5.205	-0.227	1.744	2.680	4.159	10.616
E	6.410	0.772	-0.227	-5.205	-3.233	-2.297	-0.818	5.638
B	8.381	2.743	1.744	-3.233	-5.205	-4.268	-2.790	3.667
D	9.318	3.680	2.680	-2.297	-4.268	-5.205	-3.726	2.731
C	10.796	5.158	4.159	-0.818	-2.790	-3.726	-5.205	1.252
A	17.253	11.615	10.616	5.638	3.667	2.731	1.252	-5.205

Positive values show pairs of means that are significantly different.

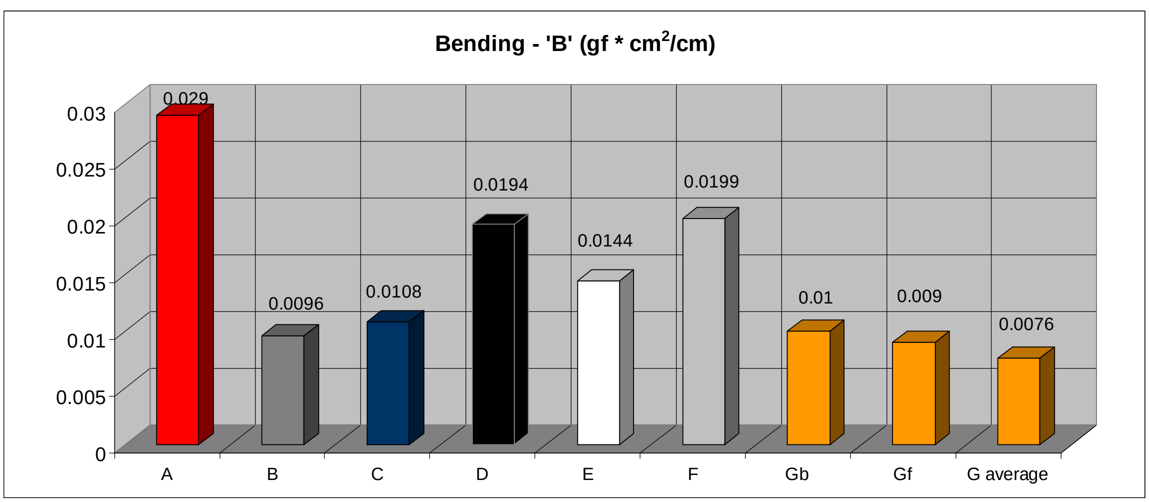

Figure A.8 – Data Average for Bending (gf * cm^2/cm)

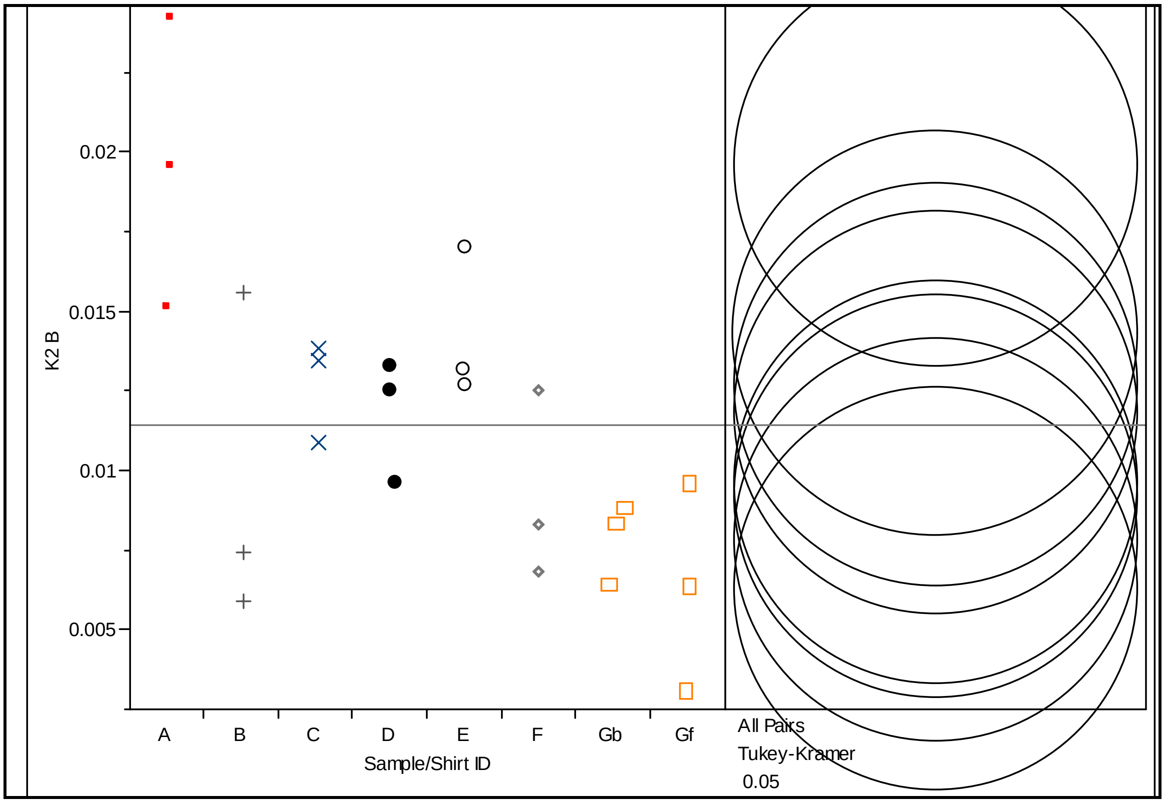

Figure A.9 – Data Points of Bending (B) – Fill Direction

Table A.28 – Analysis of Variance for Bending (B) – Warp Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.00234596	0.000335	20.2388	<.0001*
Error	16	0.00026495	0.000017		
C. Total	23	0.00261091			

Table A.29 – Analysis of Variance for Bending (B) – Fill Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.00037334	0.000053	5.2778	0.0028*
Error	16	0.00016169	0.000010		
C. Total	23	0.00053503			

Table A.30 – Tukey HSD Matrix for Bending (B) – Warp Direction

Abs(Dif)-LSD

	A	D	F	E	Gb	B	Gf	C
A	-0.01150	0.00010	0.01246	0.01260	0.01480	0.01750	0.01803	0.01810
D	0.00010	-0.01150	0.00086	0.00100	0.00320	0.00590	0.00643	0.00650
F	0.01246	0.00086	-0.01150	-0.01137	-0.00917	-0.00647	-0.00594	-0.00587
E	0.01260	0.00100	-0.01137	-0.01150	-0.00930	-0.00660	-0.00607	-0.00600
Gb	0.01480	0.00320	-0.00917	-0.00930	-0.01150	-0.00880	-0.00827	-0.00820
B	0.01750	0.00590	-0.00647	-0.00660	-0.00880	-0.01150	-0.01097	-0.01090
Gf	0.01803	0.00643	-0.00594	-0.00607	-0.00827	-0.01097	-0.01150	-0.01144
C	0.01810	0.00650	-0.00587	-0.00600	-0.00820	-0.01090	-0.01144	-0.01150

Positive values show pairs of means that are significantly different.

Table A.31 – Tukey HSD Matrix for Bending (B) – Fill Direction

Abs(Dif)-LSD

	A	E	C	D	B	F	Gb	Gf
A	-0.00899	-0.00369	-0.00205	-0.00119	0.00098	0.00141	0.00278	0.00435
E	-0.00369	-0.00899	-0.00735	-0.00649	-0.00432	-0.00389	-0.00252	-0.00095
C	-0.00205	-0.00735	-0.00899	-0.00812	-0.00595	-0.00552	-0.00415	-0.00259
D	-0.00119	-0.00649	-0.00812	-0.00899	-0.00682	-0.00639	-0.00502	-0.00345
B	0.00098	-0.00432	-0.00595	-0.00682	-0.00899	-0.00855	-0.00719	-0.00562
F	0.00141	-0.00389	-0.00552	-0.00639	-0.00855	-0.00899	-0.00762	-0.00605
Gb	0.00278	-0.00252	-0.00415	-0.00502	-0.00719	-0.00762	-0.00899	-0.00742
Gf	0.00435	-0.00095	-0.00259	-0.00345	-0.00562	-0.00605	-0.00742	-0.00899

Positive values show pairs of means that are significantly different.

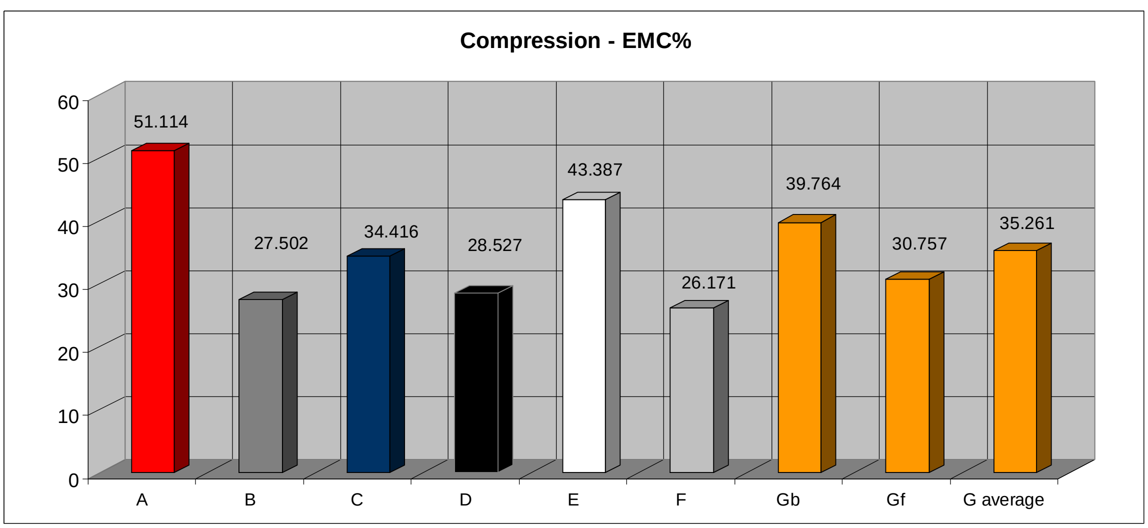

Figure A.10 – Data Average for Compression (%EMC)

Table A.32 – Analysis of Variance for Compression (%EMC)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	1640.3309	234.333	182.1916	<.0001*
Error	16	20.5790	1.286		
C. Total	23	1660.9099			

Table A.33 – Tukey HSD Matrix for Compression (%EMC)

Abs(Dif)-LSD

	A	E	Gb	C	Gf	D	B	F
A	-3.206	4.521	8.145	13.492	17.152	19.381	20.406	21.737
E	4.521	-3.206	0.418	5.766	9.425	11.655	12.679	14.010
Gb	8.145	0.418	-3.206	2.142	5.801	8.031	9.055	10.386
C	13.492	5.766	2.142	-3.206	0.453	2.683	3.707	5.039
Gf	17.152	9.425	5.801	0.453	-3.206	-0.976	0.048	1.379
D	19.381	11.655	8.031	2.683	-0.976	-3.206	-2.182	-0.851
B	20.406	12.679	9.055	3.707	0.048	-2.182	-3.206	-1.875
F	21.737	14.010	10.386	5.039	1.379	-0.851	-1.875	-3.206

Positive values show pairs of means that are significantly different.

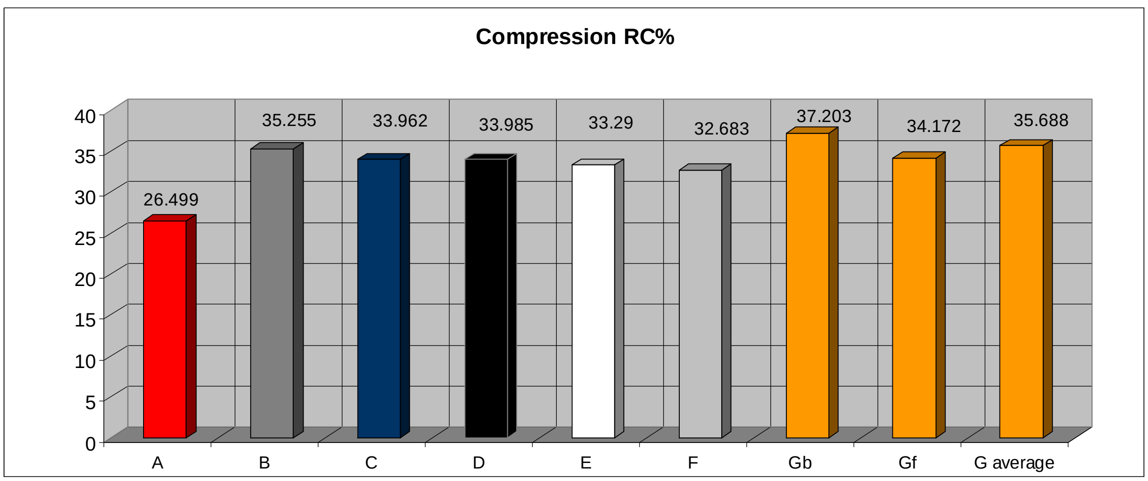

Figure A.11 – Data Average for Compression (%RC)

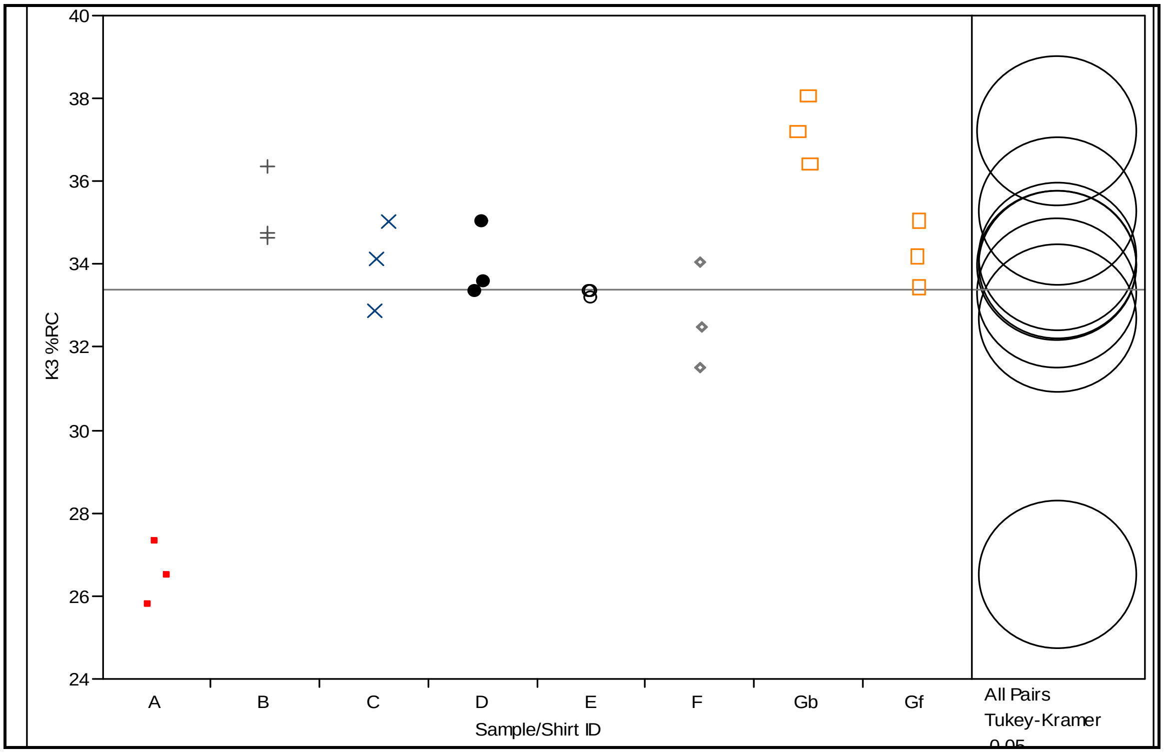

Figure A.12 – Data Points for Compression (%RC)

Table A.34 – Analysis of Variance for Compression (%RC)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	201.87280	28.8390	35.3228	<.0001*
Error	16	13.06303	0.8164		
C. Total	23	214.93583			

Table A.35 – Tukey Matrix for Compression (%RC)

Abs(Dif)-LSD

	Gb	B	Gf	D	C	E	F	A
Gb	-2.5542	-0.6067	0.4767	0.6630	0.6866	1.3583	1.9650	8.1486
B	-0.6067	-2.5542	-1.4708	-1.2845	-1.2609	-0.5892	0.0175	6.2011
Gf	0.4767	-1.4708	-2.5542	-2.3679	-2.3443	-1.6726	-1.0659	5.1177
D	0.6630	-1.2845	-2.3679	-2.5542	-2.5306	-1.8589	-1.2522	4.9314
C	0.6866	-1.2609	-2.3443	-2.5306	-2.5542	-1.8825	-1.2759	4.9077
E	1.3583	-0.5892	-1.6726	-1.8589	-1.8825	-2.5542	-1.9476	4.2360
F	1.9650	0.0175	-1.0659	-1.2522	-1.2759	-1.9476	-2.5542	3.6294
A	8.1486	6.2011	5.1177	4.9314	4.9077	4.2360	3.6294	-2.5542

Positive values show pairs of means that are significantly different.

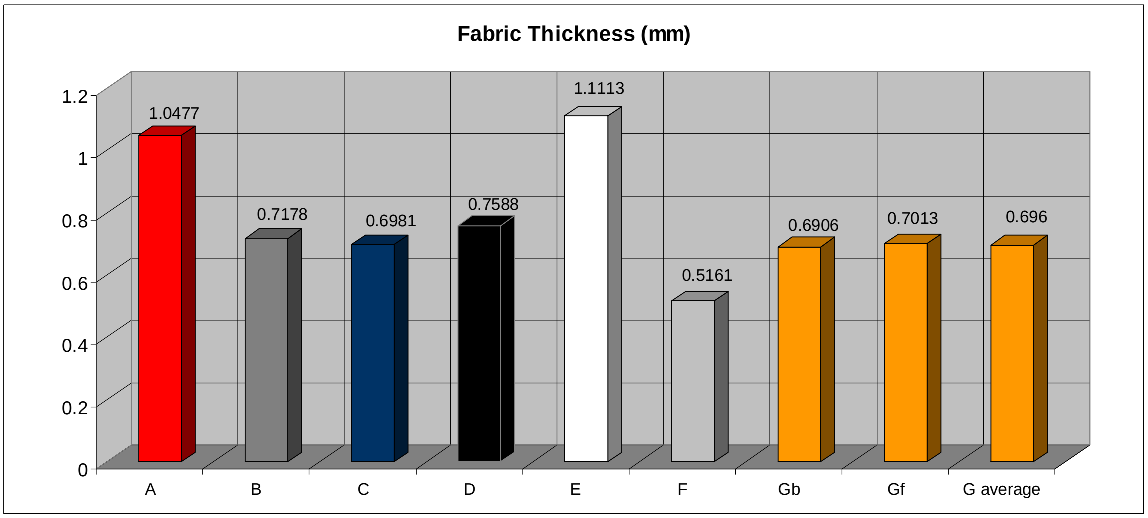

Figure A.13 – Data Average for Compression Thickness (mm)

Table A.36 – Analysis of Variance for Compression Thickness

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.82887194	0.118410	266.3736	<.0001*
Error	16	0.00711243	0.000445		
C. Total	23	0.83598437			

Table A.37 – Tukey HSD Matrix for Compression Thickness

Abs(Dif)-LSD

	E	A	D	B	Gf	C	Gb	F
E	-0.05960	0.00400	0.29290	0.33397	0.35047	0.35360	0.36107	0.53560
A	0.00400	-0.05960	0.22930	0.27037	0.28687	0.29000	0.29747	0.47200
D	0.29290	0.22930	-0.05960	-0.01853	-0.00203	0.00110	0.00857	0.18310
B	0.33397	0.27037	-0.01853	-0.05960	-0.04310	-0.03997	-0.03250	0.14203
Gf	0.35047	0.28687	-0.00203	-0.04310	-0.05960	-0.05647	-0.04900	0.12553
C	0.35360	0.29000	0.00110	-0.03997	-0.05647	-0.05960	-0.05213	0.12240
Gb	0.36107	0.29747	0.00857	-0.03250	-0.04900	-0.05213	-0.05960	0.11493
F	0.53560	0.47200	0.18310	0.14203	0.12553	0.12240	0.11493	-0.05960

Positive values show pairs of means that are significantly different.

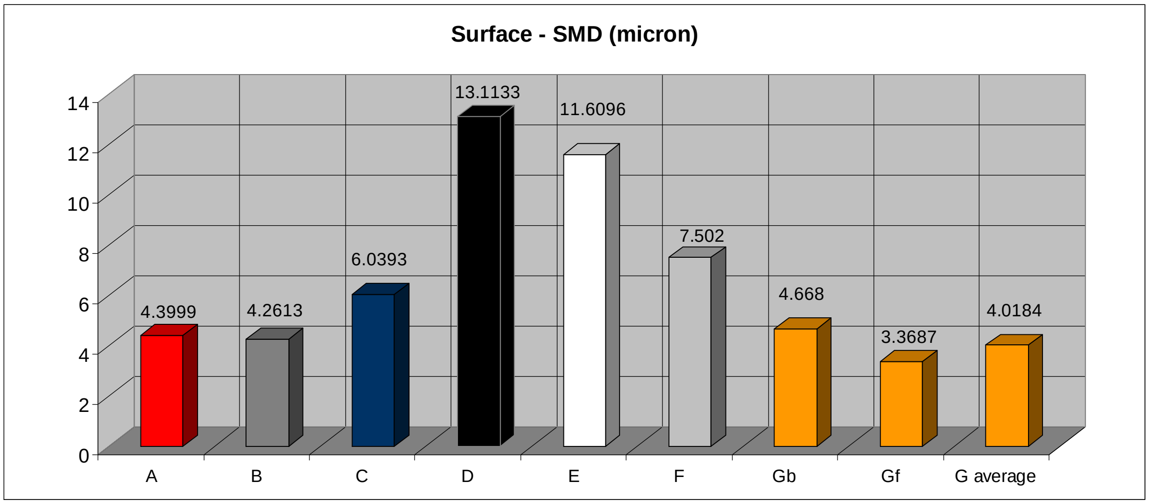

Figure A.14 – Data Average for Surface (SMD) (in microns)

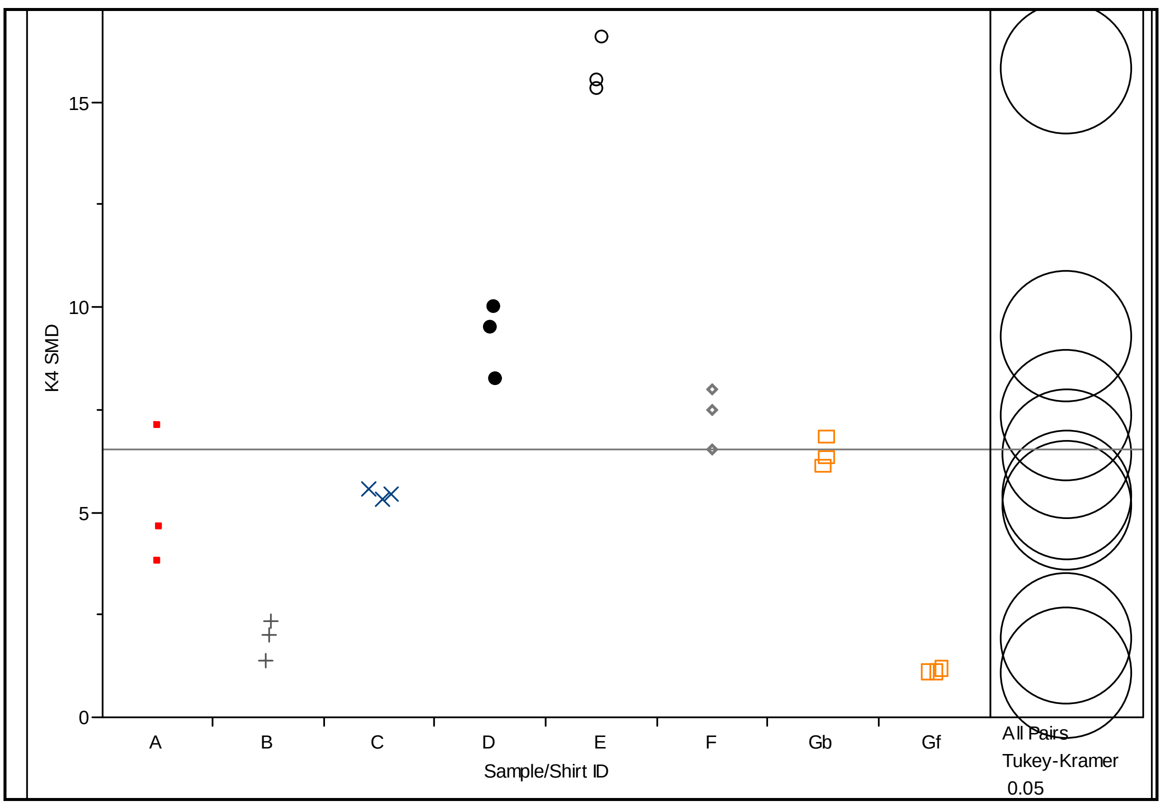

Figure A.15 – Data Points for Surface (SMD) – Fill Direction

Table A.38 – Analysis of Variance for Surface (SMD) – Warp Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	388.01600	55.4309	38.0232	<.0001*
Error	16	23.32506	1.4578		
C. Total	23	411.34107			

Table A.39 – Analysis of Variance for Surface (SMD) – Fill Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	445.20956	63.6014	98.7972	<.0001*
Error	16	10.30011	0.6438		
C. Total	23	455.50967			

Table A.40 – Tukey Matrix for Surface (SMD) – Warp Direction

Abs(Dif)-LSD

	D	F	E	C	B	Gf	A	Gb
D	-3.413	5.892	6.129	6.872	6.940	7.881	9.895	10.620
F	5.892	-3.413	-3.175	-2.433	-2.365	-1.424	0.590	1.315
E	6.129	-3.175	-3.413	-2.671	-2.602	-1.662	0.352	1.077
C	6.872	-2.433	-2.671	-3.413	-3.344	-2.404	-0.390	0.335
B	6.940	-2.365	-2.602	-3.344	-3.413	-2.473	-0.458	0.267
Gf	7.881	-1.424	-1.662	-2.404	-2.473	-3.413	-1.399	-0.674
A	9.895	0.590	0.352	-0.390	-0.458	-1.399	-3.413	-2.688
Gb	10.620	1.315	1.077	0.335	0.267	-0.674	-2.688	-3.413

Positive values show pairs of means that are significantly different.

Table A.41 – Tukey Matrix for Surface (SMD) – Fill Direction

Abs(Dif)-LSD

	E	D	F	Gb	C	A	B	Gf
E	-2.268	4.267	6.185	7.125	8.130	8.386	11.618	12.462
D	4.267	-2.268	-0.350	0.590	1.595	1.851	5.083	5.927
F	6.185	-0.350	-2.268	-1.328	-0.323	-0.067	3.165	4.009
Gb	7.125	0.590	-1.328	-2.268	-1.262	-1.007	2.225	3.070
C	8.130	1.595	-0.323	-1.262	-2.268	-2.013	1.219	2.064
A	8.386	1.851	-0.067	-1.007	-2.013	-2.268	0.964	1.809
B	11.618	5.083	3.165	2.225	1.219	0.964	-2.268	-1.423
Gf	12.462	5.927	4.009	3.070	2.064	1.809	-1.423	-2.268

Positive values show pairs of means that are significantly different.

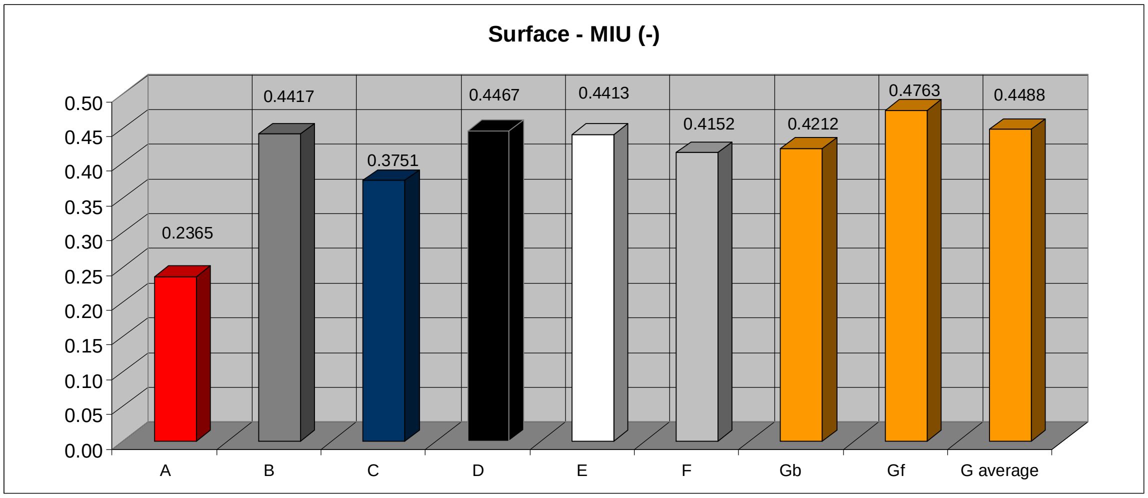

Figure A.16 – Data Average for Surface (MIU)

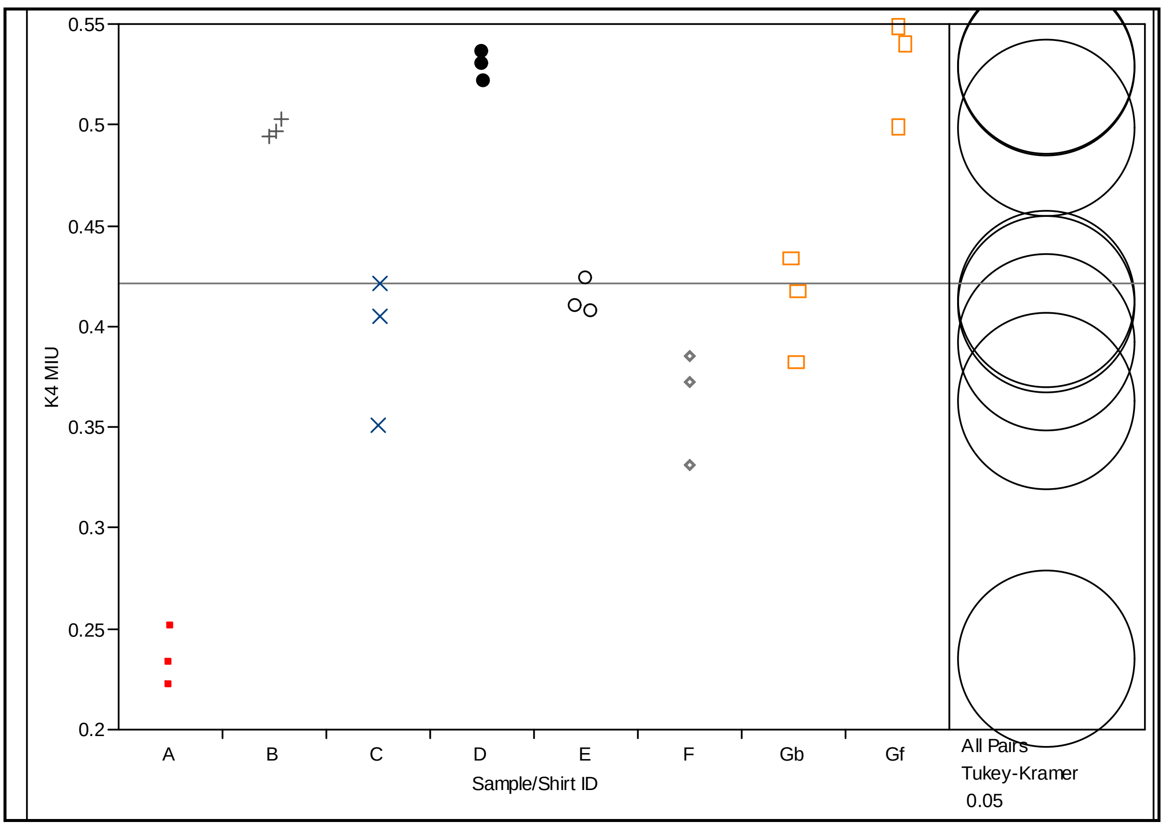

Figure A.17 – Data Points of Surface (MIU) – Warp Direction

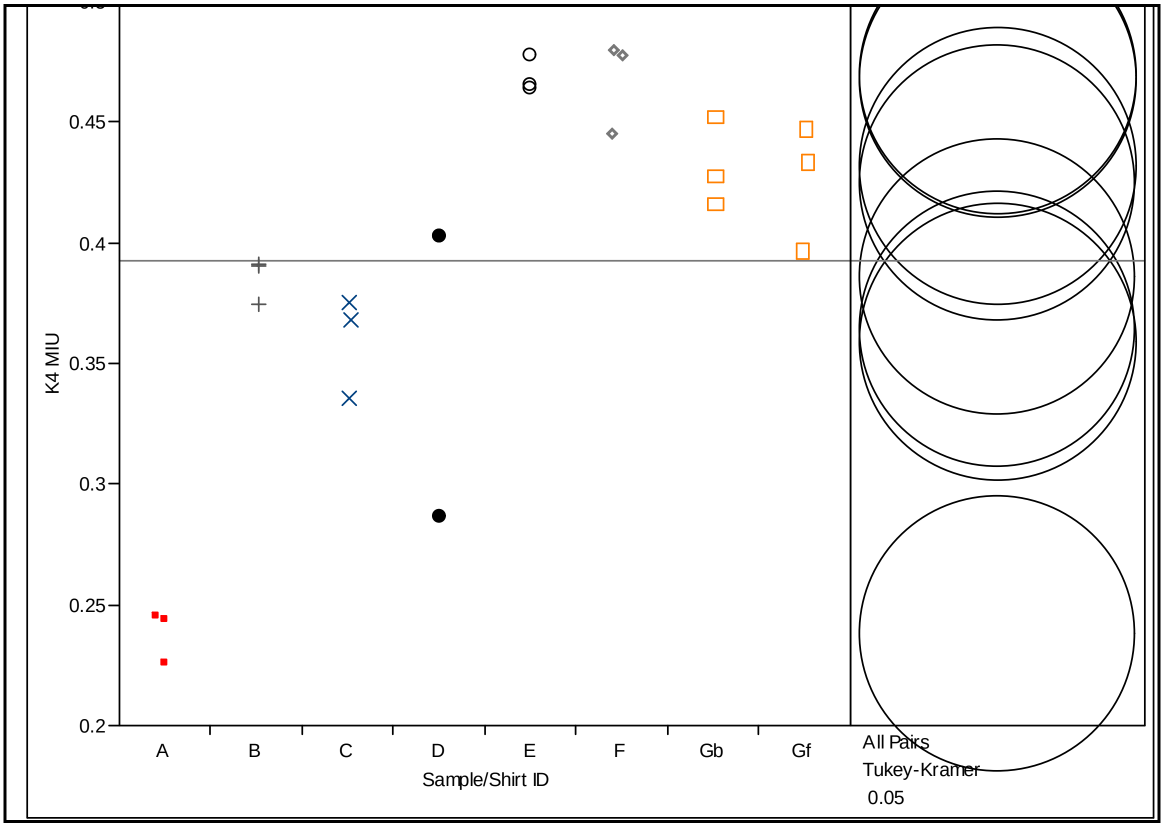

Figure A.18 – Data Points of Surface (MIU) – Fill Direction

Table A.42 – Analysis of Variance for Surface (MIU) – Warp Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.20435318	0.029193	59.8407	<.0001*
Error	16	0.00780561	0.000488		
C. Total	23	0.21215879			

Table A.43 – Analysis of Variance for Surface (MIU) – Fill Direction

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.11969635	0.017099	20.6525	<.0001*
Error	16	0.01324739	0.000828		
C. Total	23	0.13294374			

Table A.44 – Tukey HSD Matrix for Surface (MIU) – Warp Direction

Abs(Dif)-LSD

	D	Gf	B	E	Gb	C	F	A
D	-0.06244	-0.06137	-0.03097	0.05333	0.05610	0.07516	0.10393	0.23186
Gf	-0.06137	-0.06244	-0.03204	0.05226	0.05503	0.07410	0.10286	0.23080
B	-0.03097	-0.03204	-0.06244	0.02186	0.02463	0.04370	0.07246	0.20040
E	0.05333	0.05226	0.02186	-0.06244	-0.05967	-0.04060	-0.01184	0.11610
Gb	0.05610	0.05503	0.02463	-0.05967	-0.06244	-0.04337	-0.01460	0.11333
C	0.07516	0.07410	0.04370	-0.04060	-0.04337	-0.06244	-0.03367	0.09426
F	0.10393	0.10286	0.07246	-0.01184	-0.01460	-0.03367	-0.06244	0.06550
A	0.23186	0.23080	0.20040	0.11610	0.11333	0.09426	0.06550	-0.06244

Positive values show pairs of means that are significantly different.

Table A.45 – Tukey HSD Matrix for Surface (MIU) – Fill Direction

Abs(Dif)-LSD

	E	F	Gb	Gf	B	D	C	A
E	-0.08134	-0.07977	-0.04391	-0.03681	0.00209	0.02363	0.02899	0.14969
F	-0.07977	-0.08134	-0.04547	-0.03837	0.00053	0.02206	0.02743	0.14813
Gb	-0.04391	-0.04547	-0.08134	-0.07424	-0.03534	-0.01381	-0.00844	0.11226
Gf	-0.03681	-0.03837	-0.07424	-0.08134	-0.04244	-0.02091	-0.01554	0.10516
B	0.00209	0.00053	-0.03534	-0.04244	-0.08134	-0.05981	-0.05444	0.06626
D	0.02363	0.02206	-0.01381	-0.02091	-0.05981	-0.08134	-0.07597	0.04473
C	0.02899	0.02743	-0.00844	-0.01554	-0.05444	-0.07597	-0.08134	0.03936
A	0.14969	0.14813	0.11226	0.10516	0.06626	0.04473	0.03936	-0.08134

Positive values show pairs of means that are significantly different.

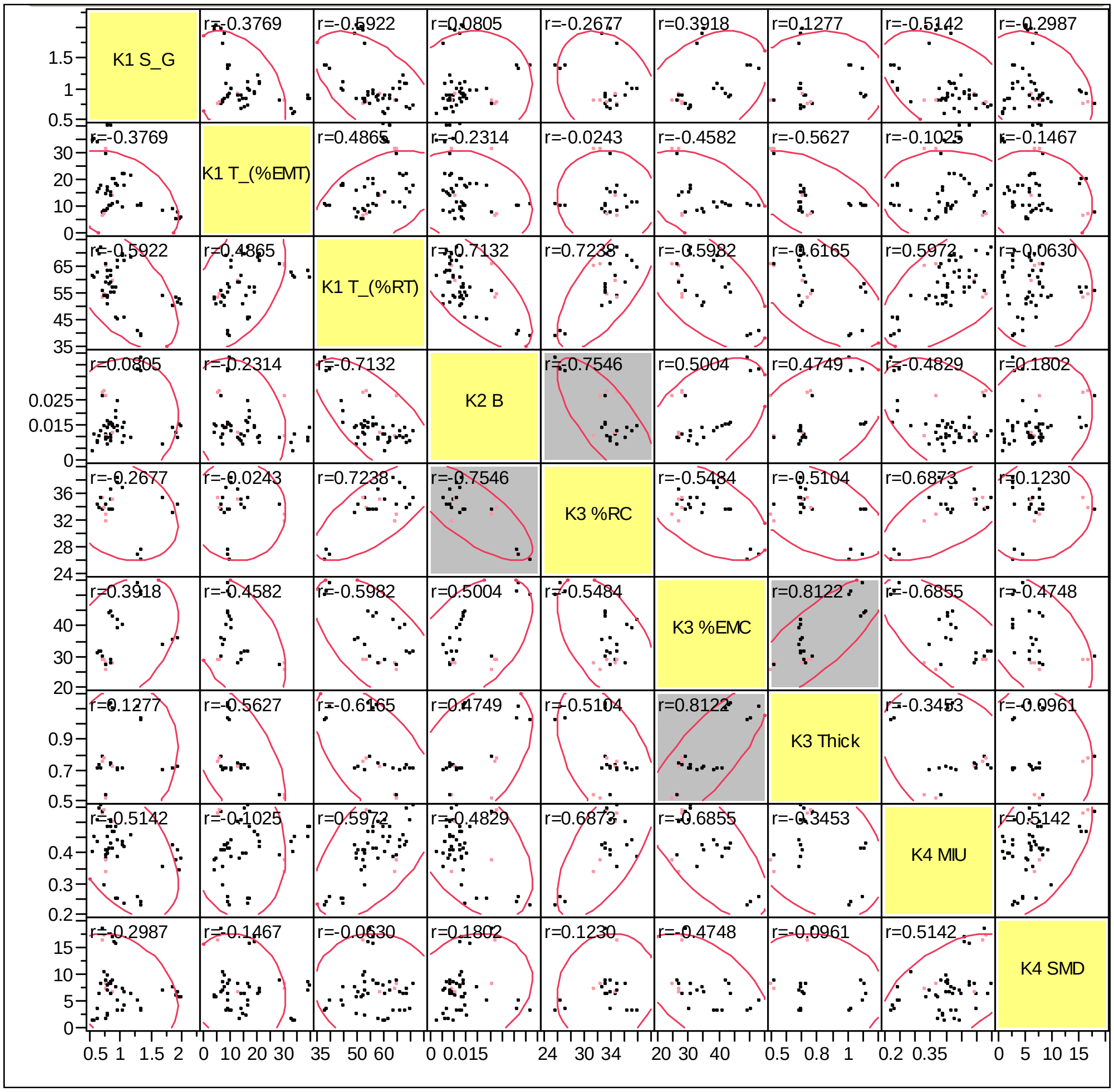

Figure A.19 – Correlation Table of all Kawabata Measures

A.2.2 Thermolabo Data

This section contains the values of data and statistical analysis tables for the Thermolabo Measures which were not covered in Chapter four. Also Bar Charts for data averages are provided for all Thermolabo Measures. No Bi-directional results are involved in the Thermolabo testing; all Measures are Uni-directional.

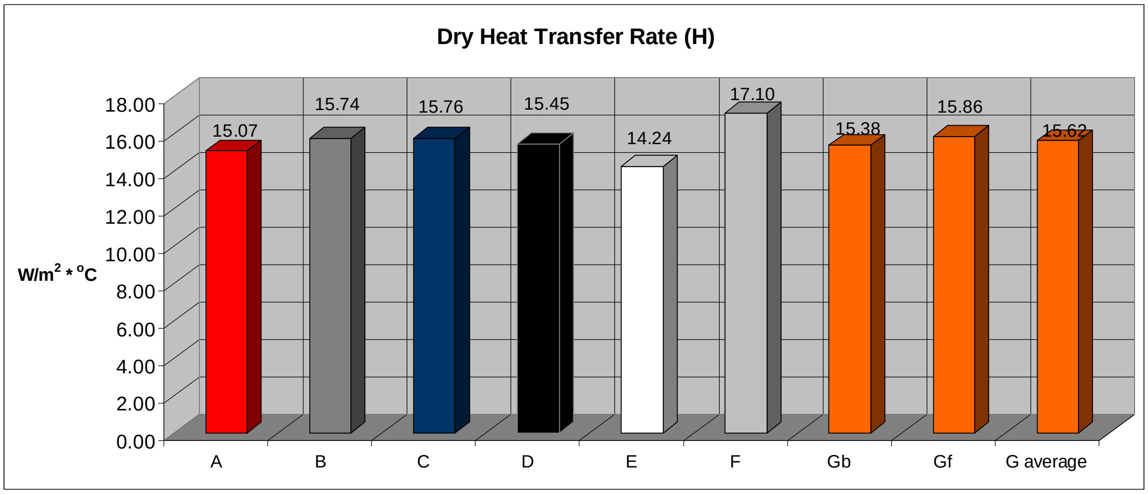

Figure A.20 – Data Average for Thermolabo Dry Heat Transfer Rate (H)

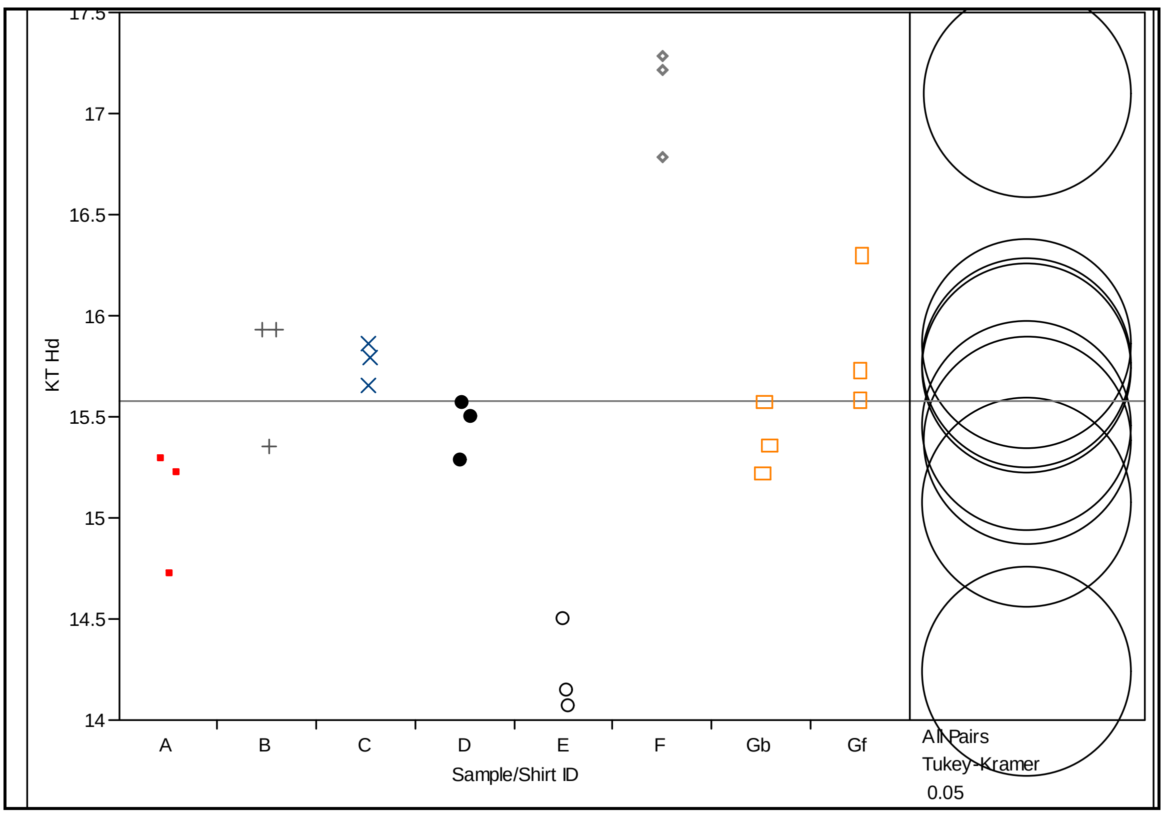

Figure A.21 – Data Points for Thermolabo Dry Heat Transfer Rate (H)

Table A.46 – Analysis of Variance for Thermolabo Dry Heat Transfer Rate

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	13.637543	1.94822	28.8190	<.0001*
Error	16	1.081633	0.06760		
C. Total	23	14.719175			

Table A.47 – Tukey HSD Matrix for Thermolabo dry Heat transfer Rate

Abs(Dif)-LSD

	F	Gf	C	B	D	Gb	A	E
F	-0.7350	0.5031	0.5984	0.6222	0.9079	0.9793	1.2888	2.1222
Gf	0.5031	-0.7350	-0.6397	-0.6159	-0.3302	-0.2588	0.0507	0.8841
C	0.5984	-0.6397	-0.7350	-0.7112	-0.4255	-0.3540	-0.0445	0.7888
B	0.6222	-0.6159	-0.7112	-0.7350	-0.4493	-0.3778	-0.0683	0.7650
D	0.9079	-0.3302	-0.4255	-0.4493	-0.7350	-0.6636	-0.3540	0.4793
Gb	0.9793	-0.2588	-0.3540	-0.3778	-0.6636	-0.7350	-0.4255	0.4079
A	1.2888	0.0507	-0.0445	-0.0683	-0.3540	-0.4255	-0.7350	0.0984
E	2.1222	0.8841	0.7888	0.7650	0.4793	0.4079	0.0984	-0.7350

Positive values show pairs of means that are significantly different.

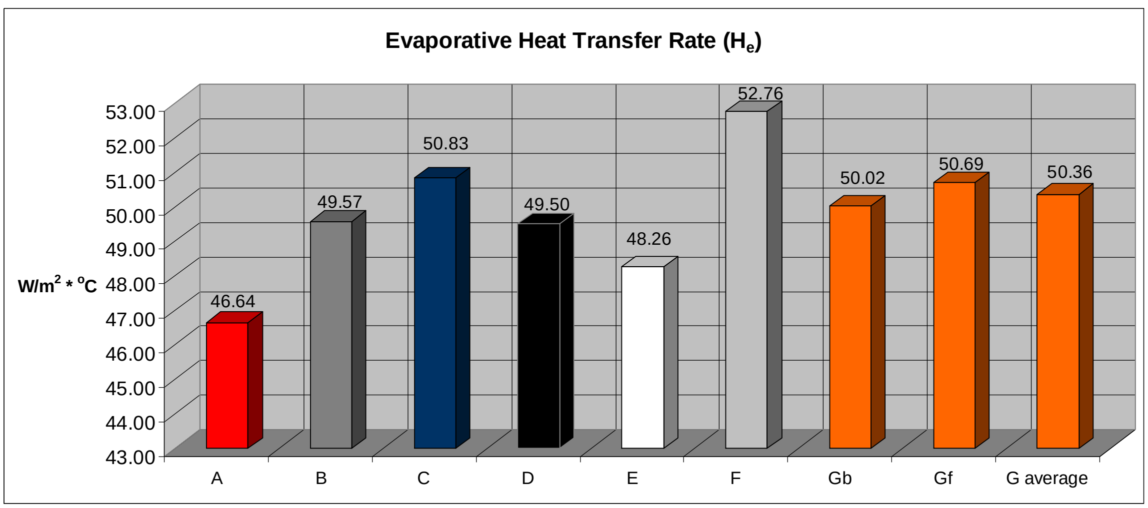

Figure A.22 – Data Average for Thermolabo Evaporative Heat Transfer Rate (H_e)

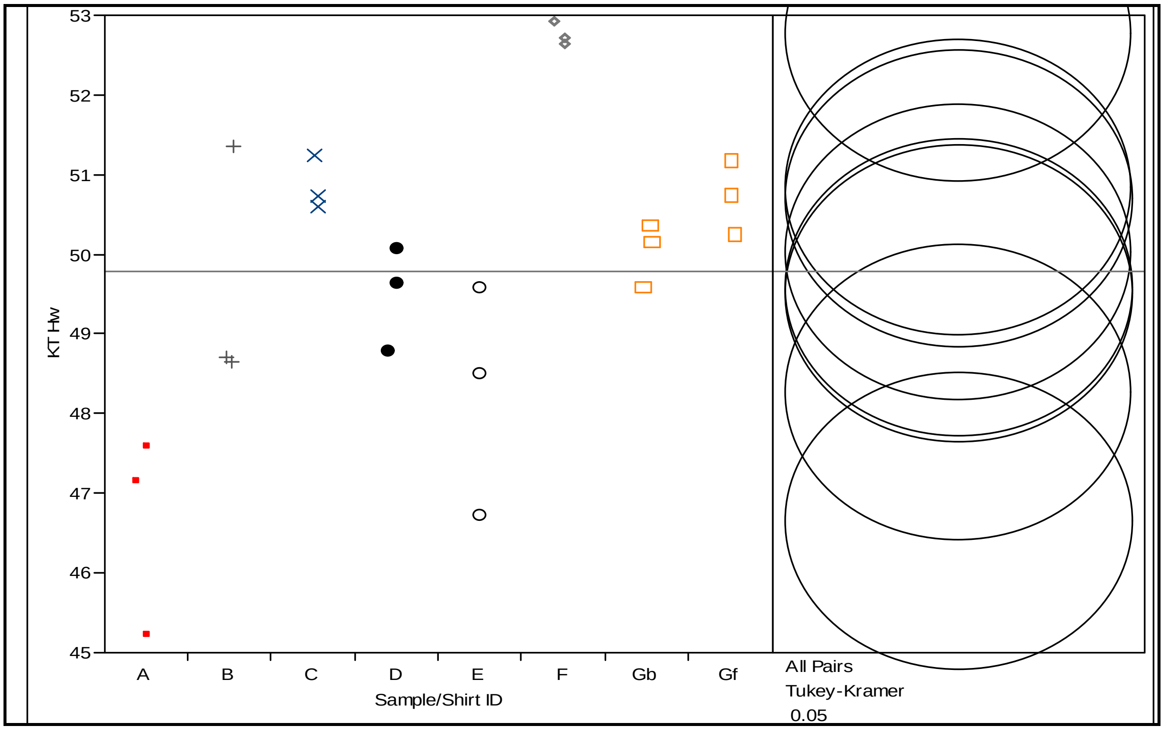

Figure A.23 – Data Points of Thermolabo Evaporative Heat Transfer Rate

Table A.48 – Analysis of Variance for Thermolabo Evaporative Heat Transfer Rate

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	69.472789	9.92468	11.3453	<.0001*
Error	16	13.996599	0.87479		
C. Total	23	83.469388			

Table A.49 – Tukey HSD Matrix for Thermolabo Evaporative Heat Transfer Rate

Abs(Dif)-LSD

	F	C	Gf	Gb	B	D	E	A
F	-2.6439	-0.7153	-0.5725	0.0942	0.5466	0.6180	1.8561	3.4751
C	-0.7153	-2.6439	-2.5011	-1.8344	-1.3820	-1.3106	-0.0725	1.5466
Gf	-0.5725	-2.5011	-2.6439	-1.9773	-1.5249	-1.4534	-0.2153	1.4037
Gb	0.0942	-1.8344	-1.9773	-2.6439	-2.1915	-2.1201	-0.8820	0.7370
B	0.5466	-1.3820	-1.5249	-2.1915	-2.6439	-2.5725	-1.3344	0.2847
D	0.6180	-1.3106	-1.4534	-2.1201	-2.5725	-2.6439	-1.4058	0.2132
E	1.8561	-0.0725	-0.2153	-0.8820	-1.3344	-1.4058	-2.6439	-1.0249
A	3.4751	1.5466	1.4037	0.7370	0.2847	0.2132	-1.0249	-2.6439

Positive values show pairs of means that are significantly different.

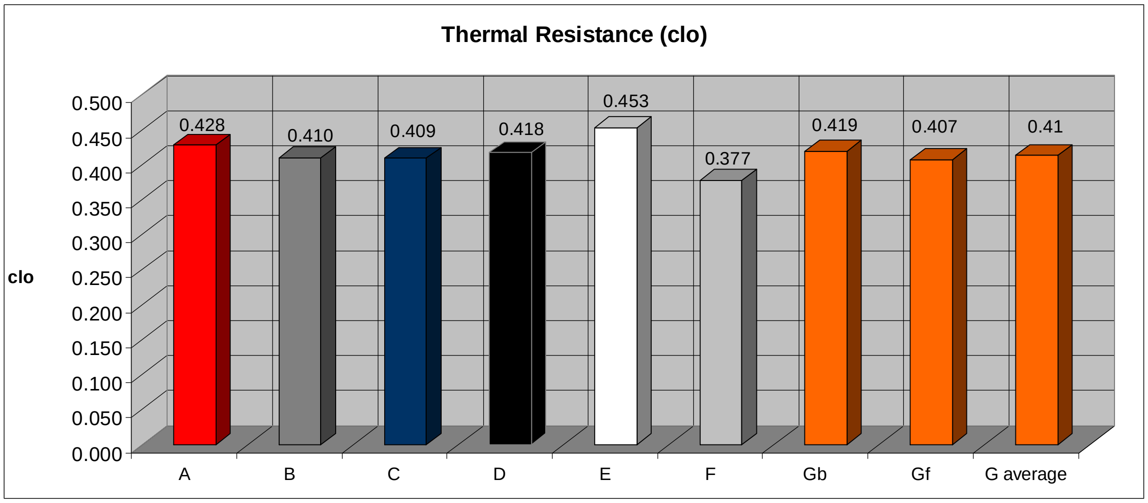

Figure A.24 – Data Average for Thermal Resistance (clo)

Table A.50 – Analysis of Variance for Thermal Resistance (clo)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.00956798	0.001367	28.4161	<.0001*
Error	16	0.00076962	0.000048		
C. Total	23	0.01033761			

Table A.51 – Tukey HSD Matrix for Thermal Resistance (clo)

Abs(Dif)-LSD

	E	A	Gb	D	B	C	Gf	F
E	-0.01961	0.00540	0.01410	0.01605	0.02354	0.02427	0.02658	0.05614
A	0.00540	-0.01961	-0.01091	-0.00895	-0.00147	-0.00074	0.00158	0.03113
Gb	0.01410	-0.01091	-0.01961	-0.01765	-0.01017	-0.00944	-0.00712	0.02243
D	0.01605	-0.00895	-0.01765	-0.01961	-0.01212	-0.01139	-0.00907	0.02048
B	0.02354	-0.00147	-0.01017	-0.01212	-0.01961	-0.01888	-0.01656	0.01300
C	0.02427	-0.00074	-0.00944	-0.01139	-0.01888	-0.01961	-0.01729	0.01227
Gf	0.02658	0.00158	-0.00712	-0.00907	-0.01656	-0.01729	-0.01961	0.00995
F	0.05614	0.03113	0.02243	0.02048	0.01300	0.01227	0.00995	-0.01961

Positive values show pairs of means that are significantly different.

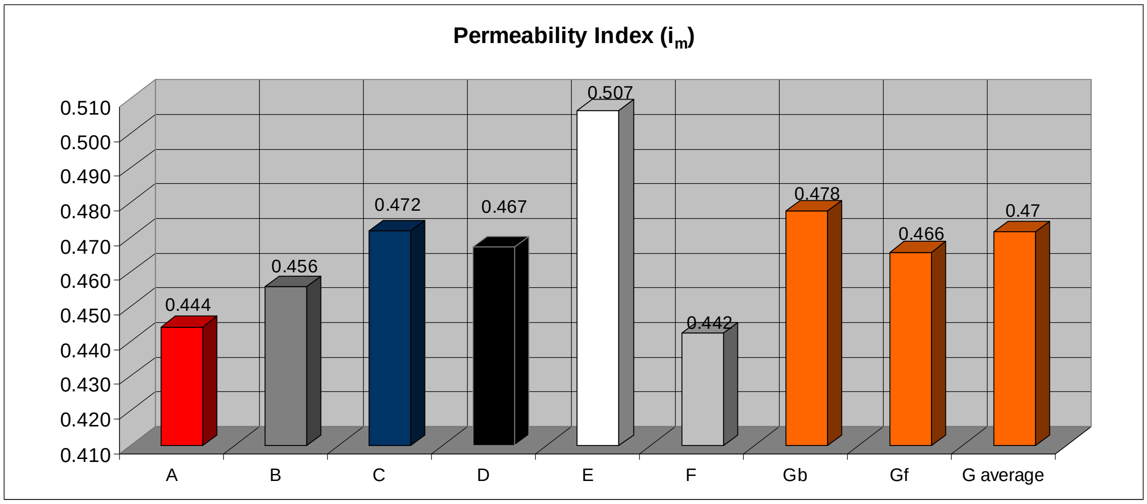

Figure A.25 – Data Average for Permeability Index (i_m)

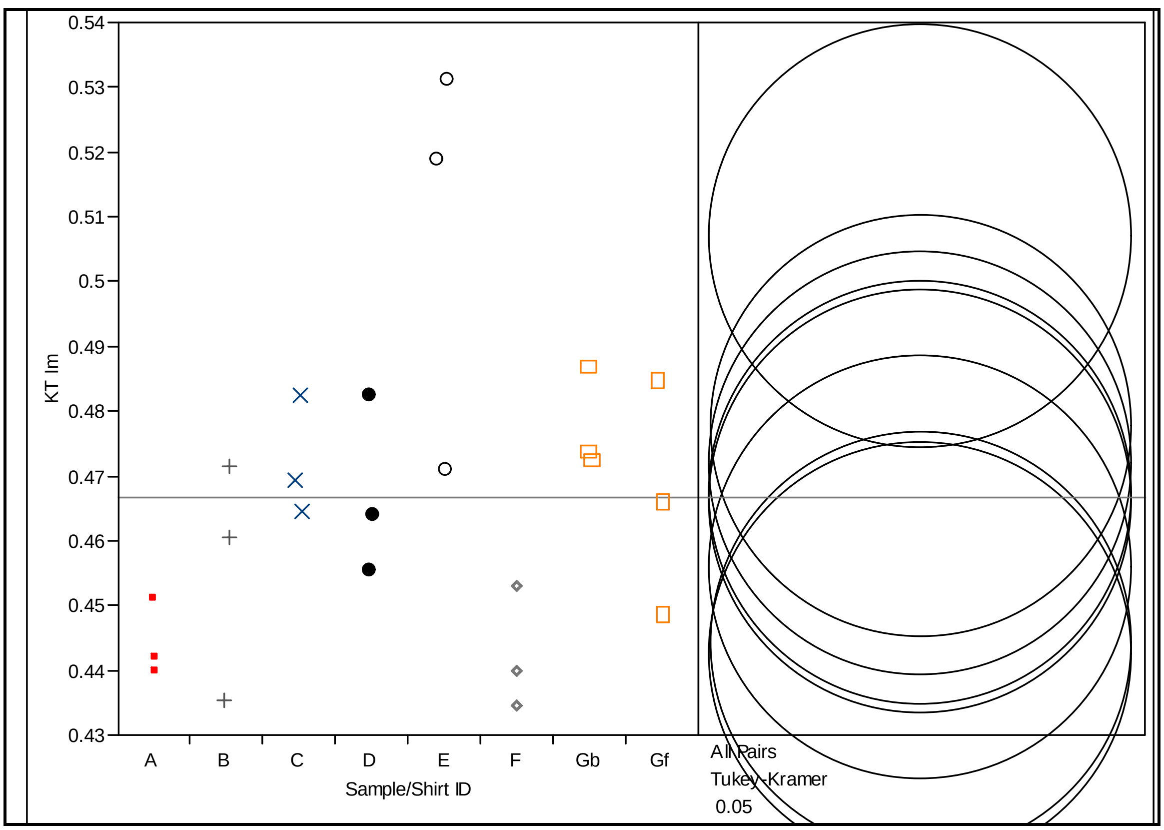

Figure A.26 – Data Points for Permeability Index (i_m)

Table A.52 – Analysis of Variance for Permeability Index (i_m)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.00895273	0.001279	4.7718	0.0046*
Error	16	0.00428842	0.000268		
C. Total	23	0.01324116			

Table A.53 – Tukey HSD Matrix for Permeability Index (i_m)

Abs(Dif)-LSD

	E	Gb	C	D	Gf	B	A	F
E	-0.04628	-0.01689	-0.01111	-0.00654	-0.00532	0.00484	0.01661	0.01825
Gb	-0.01689	-0.04628	-0.04050	-0.03593	-0.03471	-0.02454	-0.01278	-0.01114
C	-0.01111	-0.04050	-0.04628	-0.04171	-0.04049	-0.03033	-0.01856	-0.01692
D	-0.00654	-0.03593	-0.04171	-0.04628	-0.04505	-0.03489	-0.02313	-0.02149
Gf	-0.00532	-0.03471	-0.04049	-0.04505	-0.04628	-0.03612	-0.02435	-0.02271
B	0.00484	-0.02454	-0.03033	-0.03489	-0.03612	-0.04628	-0.03452	-0.03287
A	0.01661	-0.01278	-0.01856	-0.02313	-0.02435	-0.03452	-0.04628	-0.04464
F	0.01825	-0.01114	-0.01692	-0.02149	-0.02271	-0.03287	-0.04464	-0.04628

Positive values show pairs of means that are significantly different.

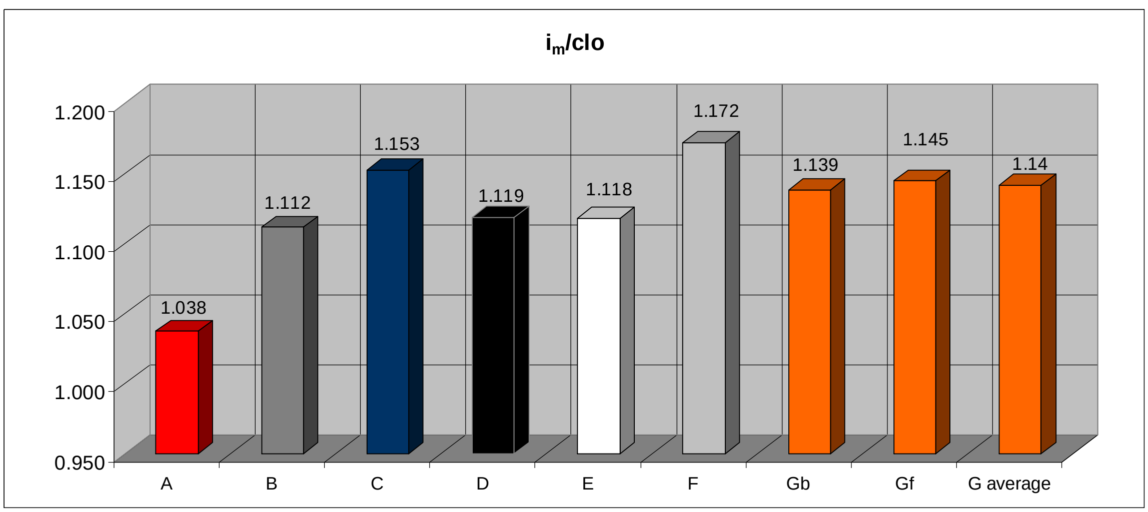

Figure A.27 – Data Average for (i_m/clo)

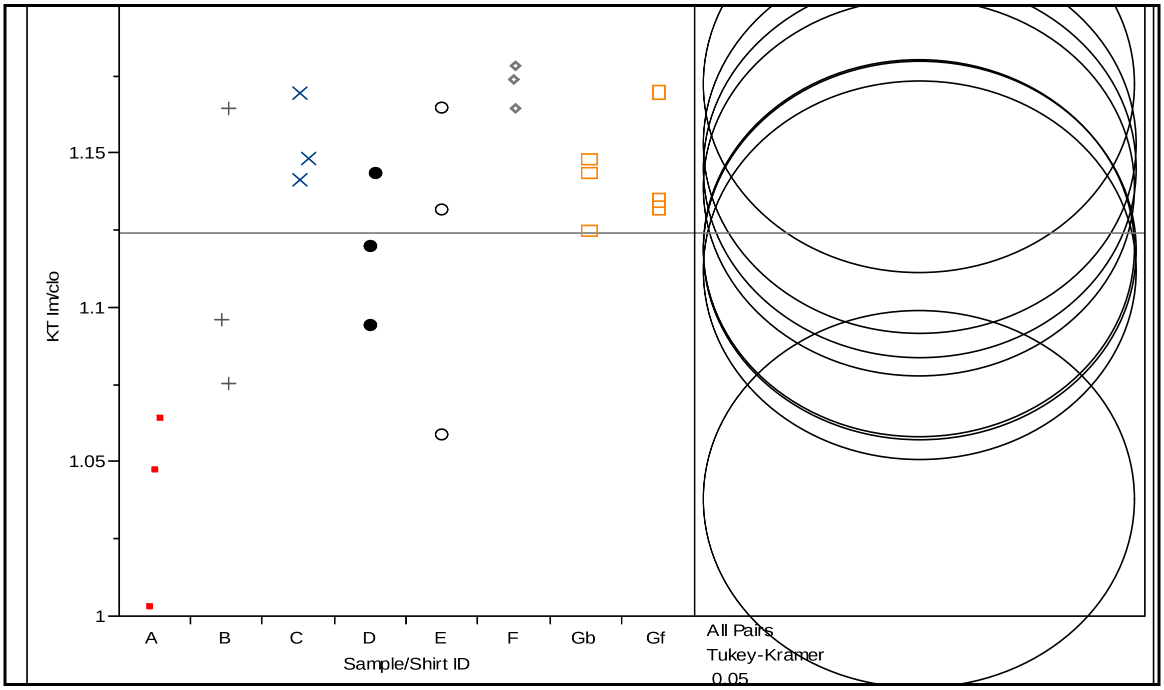

Figure A.28 – Data Points for (i_m/clo)

Table A.54 – Analysis of Variance for (i_m/clo)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.03436440	0.004909	5.1917	0.0031*
Error	16	0.01512947	0.000946		
C. Total	23	0.04949387			

Table A.55 – Tukey HSD Matrix for (i_m/clo)

Abs(Dif)-LSD

	F	C	Gf	Gb	D	E	B	A
F	-0.08693	-0.06736	-0.05954	-0.05328	-0.03371	-0.03293	-0.02667	0.04767
C	-0.06736	-0.08693	-0.07910	-0.07284	-0.05328	-0.05250	-0.04623	0.02810
Gf	-0.05954	-0.07910	-0.08693	-0.08067	-0.06110	-0.06032	-0.05406	0.02028
Gb	-0.05328	-0.07284	-0.08067	-0.08693	-0.06736	-0.06658	-0.06032	0.01402
D	-0.03371	-0.05328	-0.06110	-0.06736	-0.08693	-0.08614	-0.07988	-0.00554
E	-0.03293	-0.05250	-0.06032	-0.06658	-0.08614	-0.08693	-0.08067	-0.00633
B	-0.02667	-0.04623	-0.05406	-0.06032	-0.07988	-0.08067	-0.08693	-0.01259
A	0.04767	0.02810	0.02028	0.01402	-0.00554	-0.00633	-0.01259	-0.08693

Positive values show pairs of means that are significantly different.

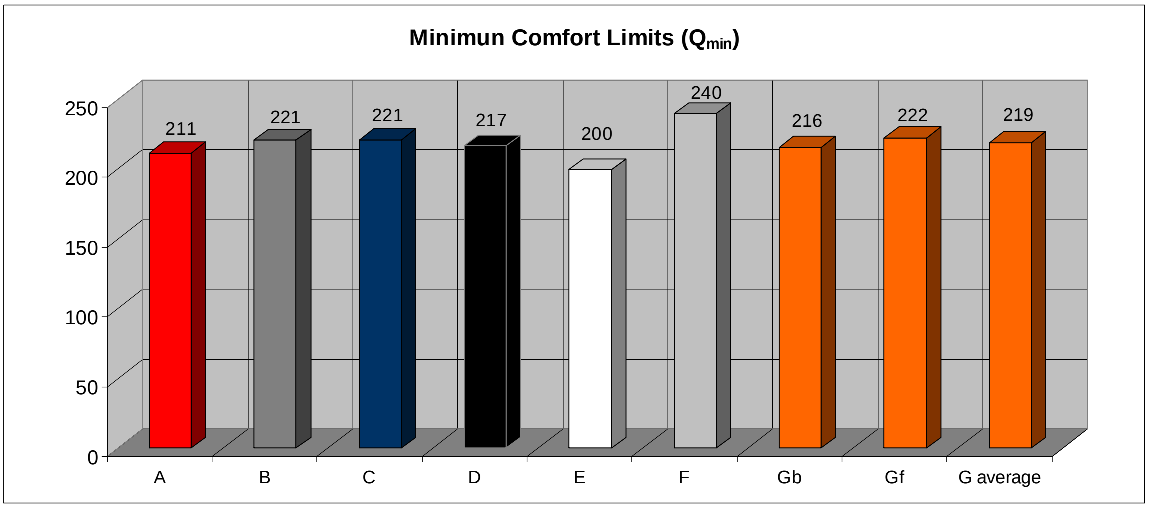

Figure A.29 – Data Average for Minimum (dry) Comfort Limit (q_{min})

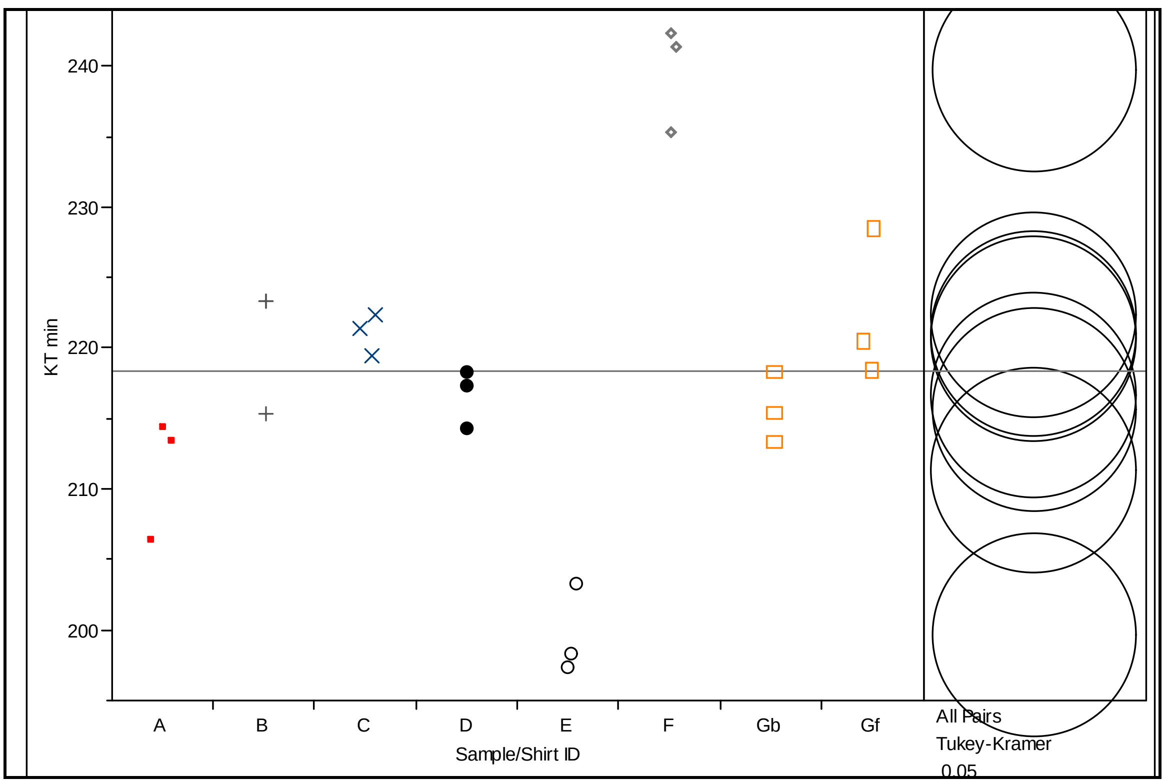

Figure A.30 – Data Points for Minimum (dry) Comfort Limit (q_{min})

Table A.56 – Analysis of Variance for Minimum (dry) Comfort Limit (q_{min})

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	2679.9125	382.845	28.8190	<.0001*
Error	16	212.5516	13.284		
C. Total	23	2892.4641			

Table A.57 – Tukey HSD Matrix for Minimum (dry) Comfort Limit (q_{min})

Abs(Dif)-LSD

	F	Gf	C	B	D	Gb	A	E
F	-10.303	7.053	8.388	8.722	12.727	13.728	18.067	29.749
Gf	7.053	-10.303	-8.968	-8.634	-4.629	-3.628	0.711	12.393
C	8.388	-8.968	-10.303	-9.969	-5.964	-4.963	-0.624	11.058
B	8.722	-8.634	-9.969	-10.303	-6.298	-5.297	-0.958	10.724
D	12.727	-4.629	-5.964	-6.298	-10.303	-9.302	-4.963	6.719
Gb	13.728	-3.628	-4.963	-5.297	-9.302	-10.303	-5.964	5.718
A	18.067	0.711	-0.624	-0.958	-4.963	-5.964	-10.303	1.379
E	29.749	12.393	11.058	10.724	6.719	5.718	1.379	-10.303

Positive values show pairs of means that are significantly different.

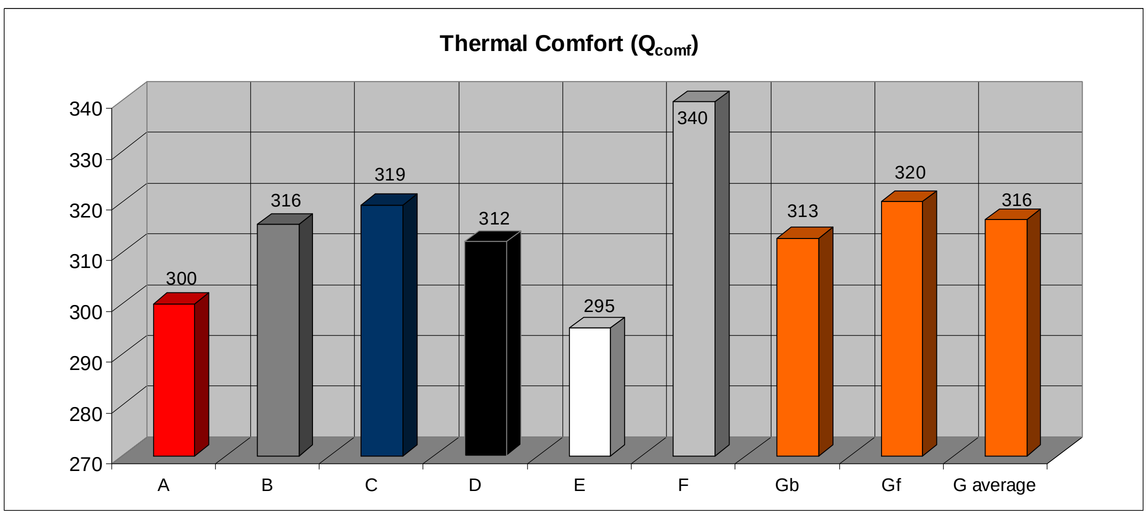

Figure A.31 – Data Average for Comfort (20% moisture)

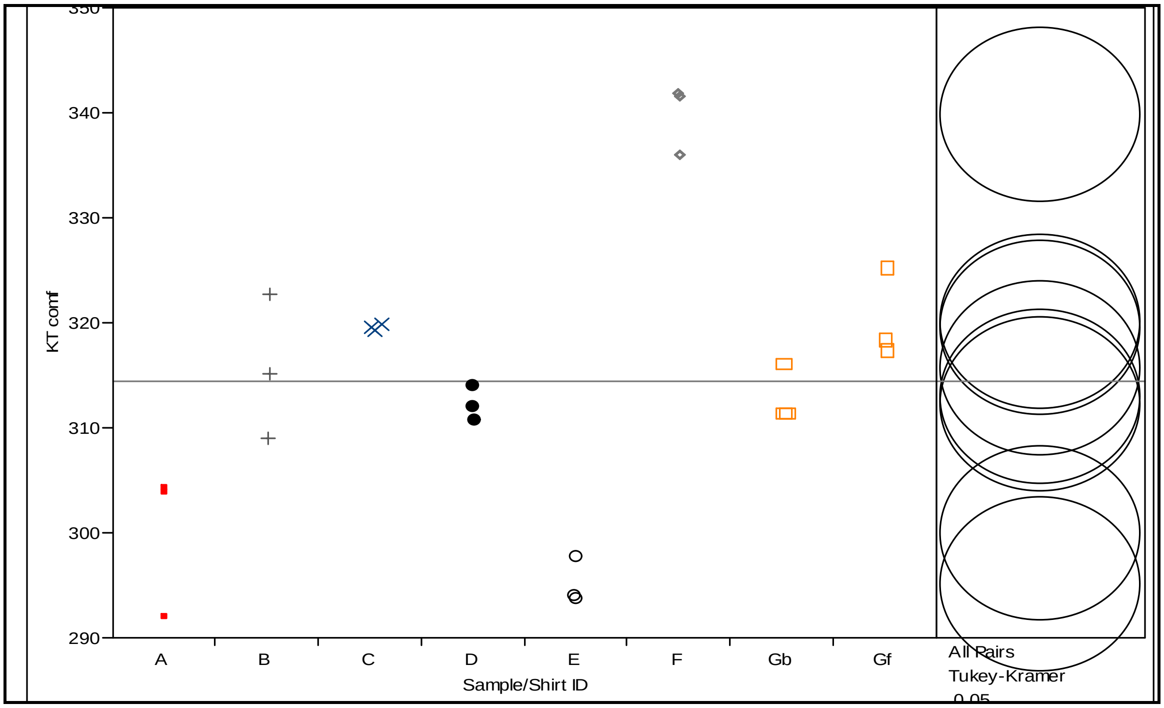

Figure A.32 – Data Points for Comfort (20% moisture)

Table A.58 – Analysis of Variance for Comfort (20% moisture)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	3876.2921	553.756	31.6416	<.0001*
Error	16	280.0143	17.501		
C. Total	23	4156.3064			

Table A.59 – Tukey HSD Matrix for Comfort (20% moisture)

Abs(Dif)-LSD

	F	Gf	C	B	Gb	D	A	E
F	-11.826	7.870	8.537	12.347	15.080	15.750	28.044	32.839
Gf	7.870	-11.826	-11.159	-7.349	-4.616	-3.945	8.348	13.144
C	8.537	-11.159	-11.826	-8.015	-5.282	-4.612	7.681	12.477
B	12.347	-7.349	-8.015	-11.826	-9.092	-8.422	3.871	8.667
Gb	15.080	-4.616	-5.282	-9.092	-11.826	-11.156	1.138	5.933
D	15.750	-3.945	-4.612	-8.422	-11.156	-11.826	0.468	5.263
A	28.044	8.348	7.681	3.871	1.138	0.468	-11.826	-7.030
E	32.839	13.144	12.477	8.667	5.933	5.263	-7.030	-11.826

Positive values show pairs of means that are significantly different.

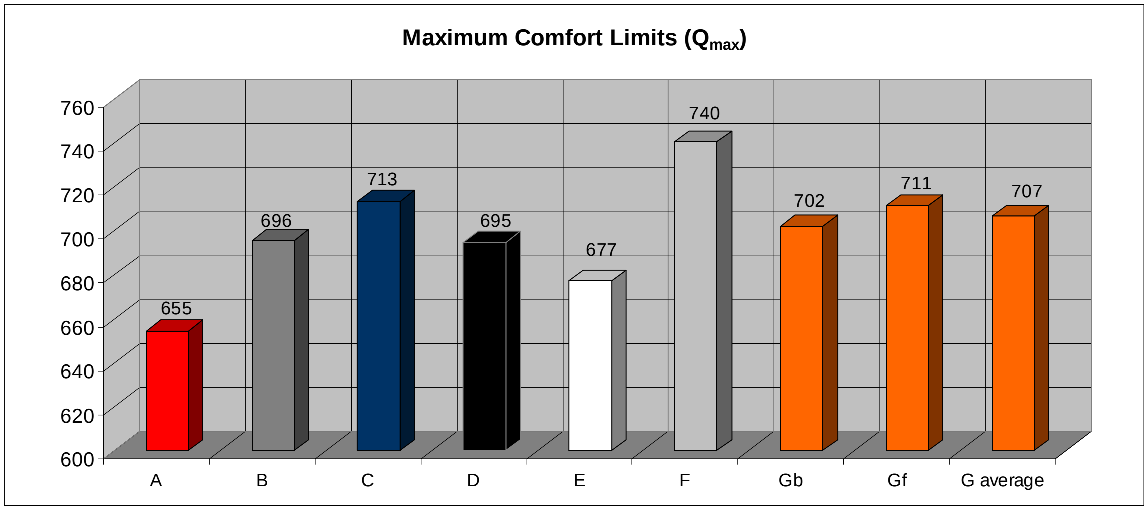

Figure A.33 – Data Average for Total Heat Loss (q_{max}) – (in Watts/m^2)

Table A.60 – Analysis of Variance for Total Heat Loss (q_{max})

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	13678.805	1954.12	11.3336	<.0001*
Error	16	2758.677	172.42		
C. Total	23	16437.483			

Table A.61 – Tukey HSD Matrix for Total Heat Loss (q_{max})

Abs(Dif)-LSD

	F	C	Gf	Gb	B	D	E	A
F	-37.118	-10.070	-8.062	1.287	7.646	8.643	25.999	48.749
C	-10.070	-37.118	-35.110	-25.761	-19.402	-18.405	-1.049	21.701
Gf	-8.062	-35.110	-37.118	-27.769	-21.409	-20.413	-3.056	19.693
Gb	1.287	-25.761	-27.769	-37.118	-30.759	-29.762	-12.406	10.343
B	7.646	-19.402	-21.409	-30.759	-37.118	-36.122	-18.765	3.984
D	8.643	-18.405	-20.413	-29.762	-36.122	-37.118	-19.762	2.988
E	25.999	-1.049	-3.056	-12.406	-18.765	-19.762	-37.118	-14.369
A	48.749	21.701	19.693	10.343	3.984	2.988	-14.369	-37.118

Positive values show pairs of means that are significantly different.

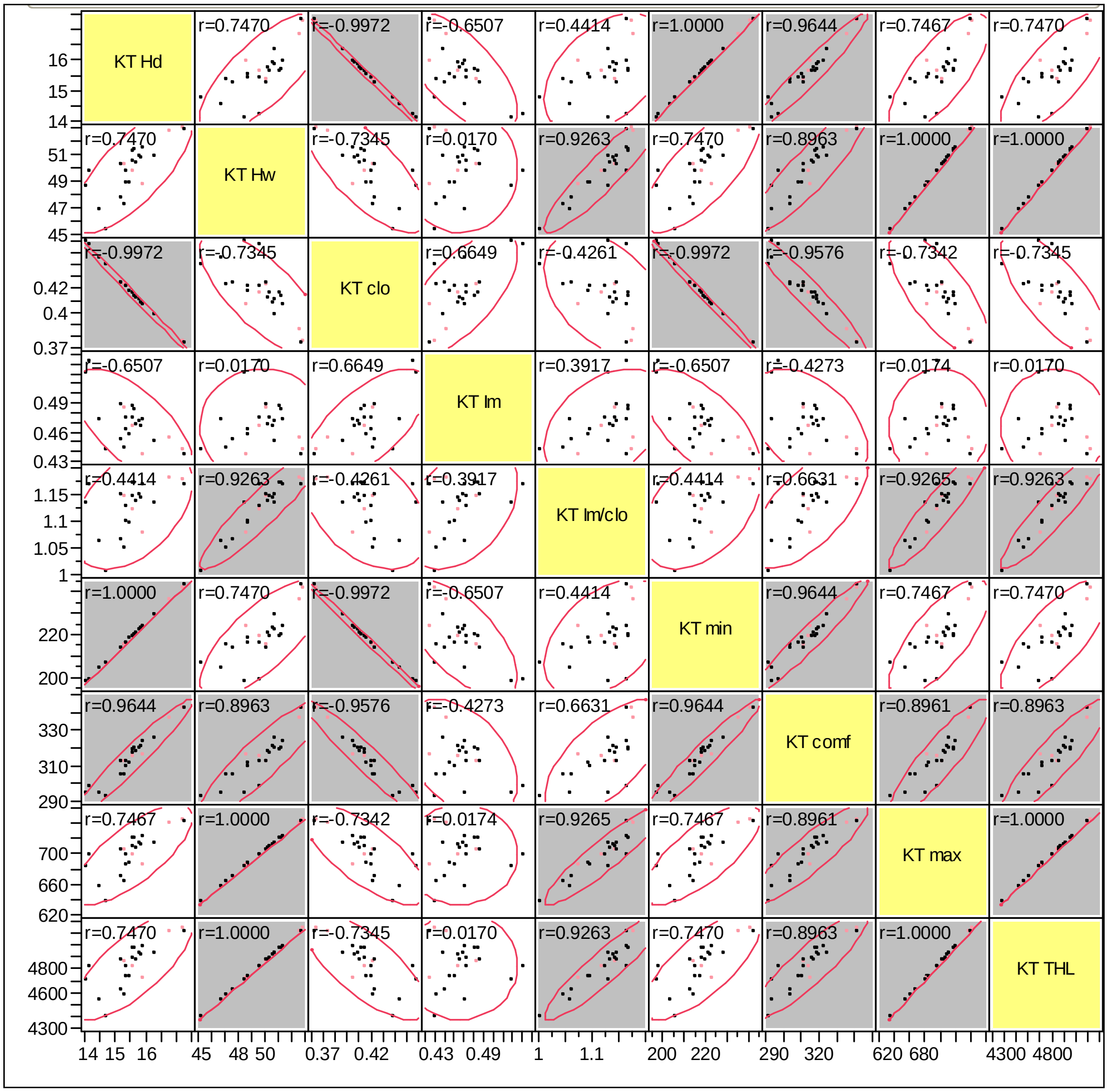

Figure A.34 – Correlation Table of all Thermolabo Measures

A.2.3 Gravimetric Absorbency Testing System (GATS) Data

This section is for the purposes of providing statistical analysis tables and data average graphs for all measures in the Gravimetric Absorbency Testing System (GATS) Test. Data Point graphs will be provided for all measures not discussed in chapter 4. All GATS measures are unidirectional, requiring no delineation of warp and fill.

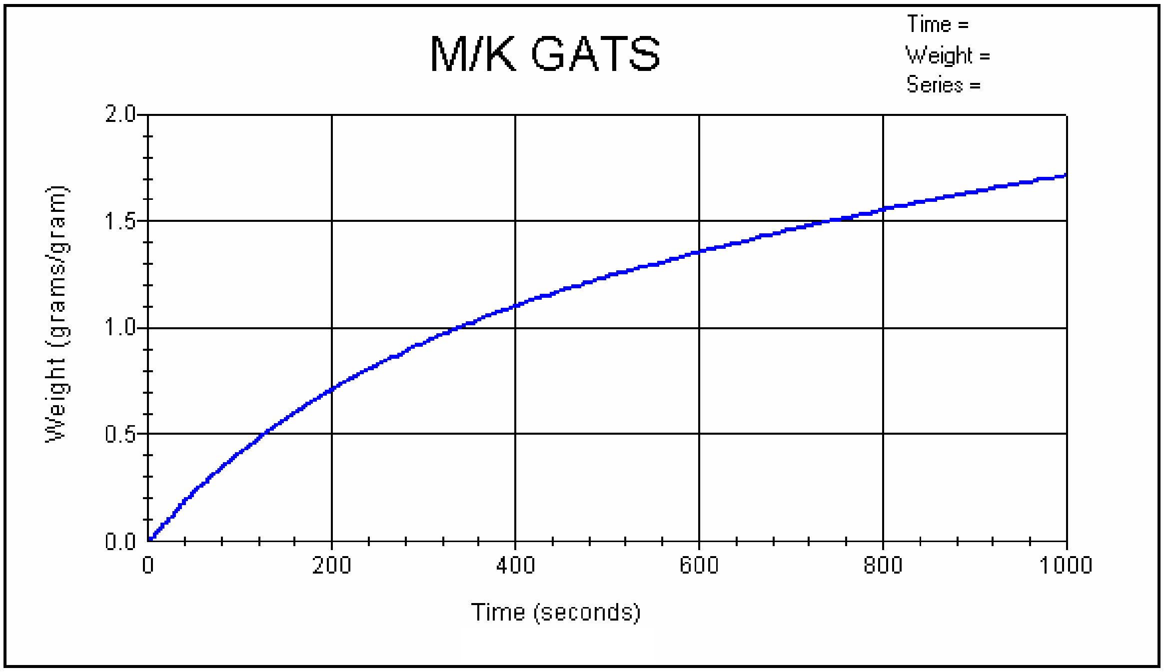

Figure A.35 – GATS Graph for 100% Cotton Garment A Fabric

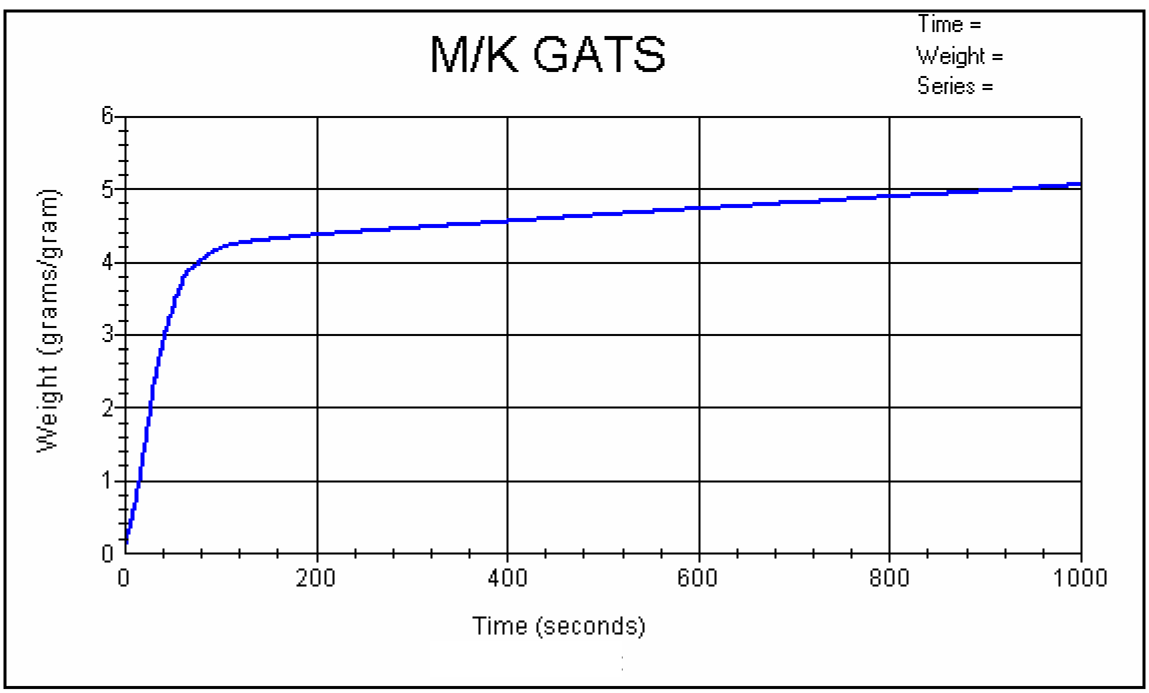

Figure A.36 – GATS Graph for Garment B Fabric

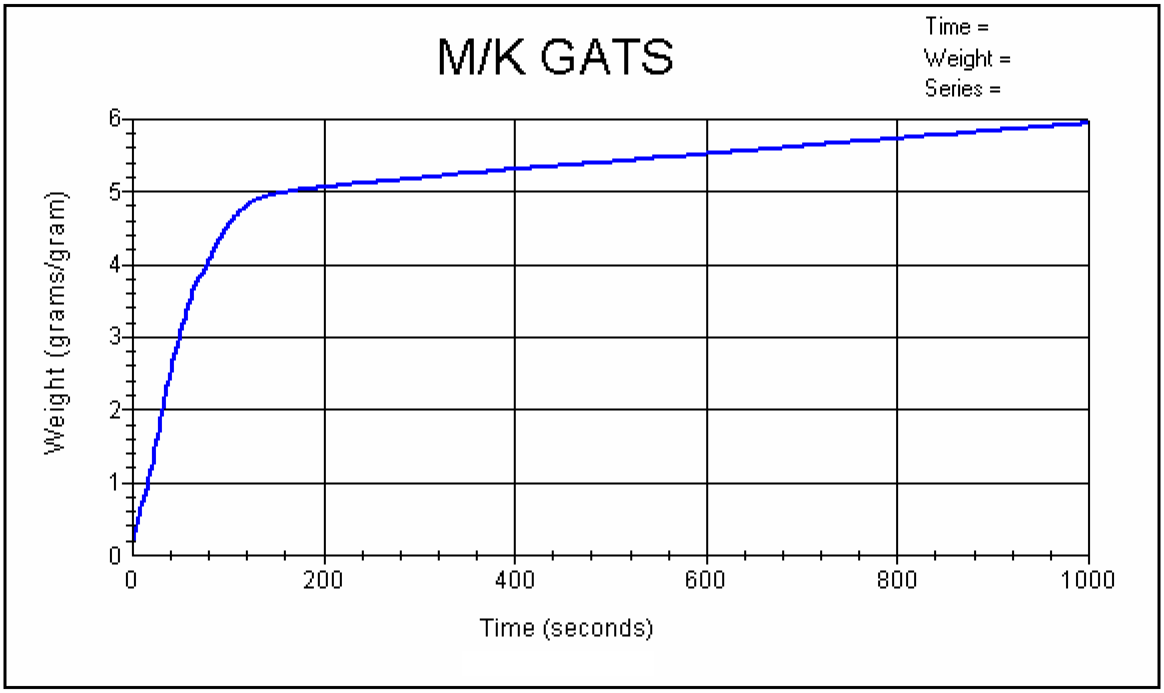

Figure A.37 – GATS Graph for Garment C Fabric

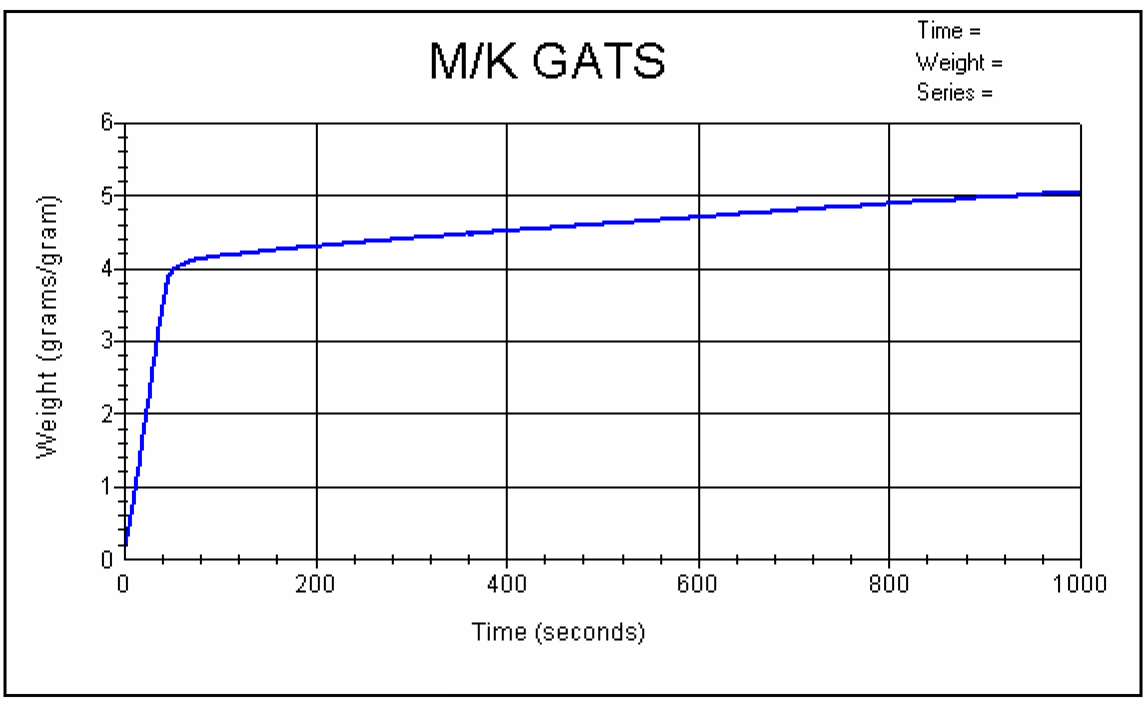

Figure A.38 – GATS Graph for Garment D Fabric

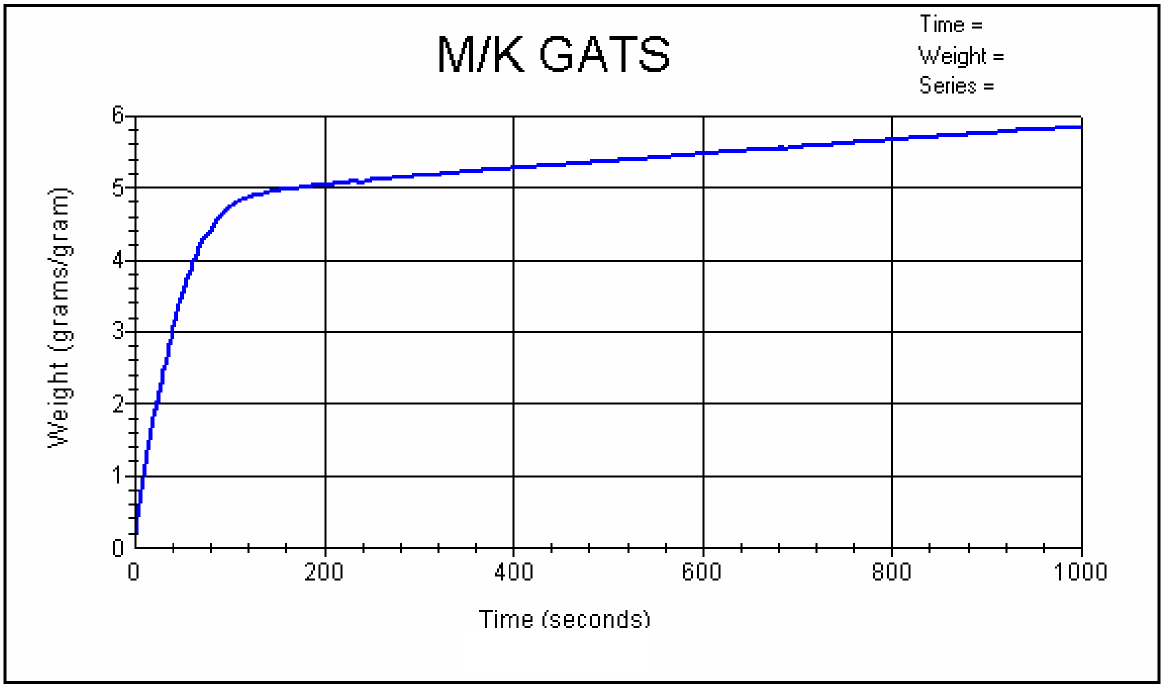

Figure A.39 – GATS Graph for Garment E Fabric

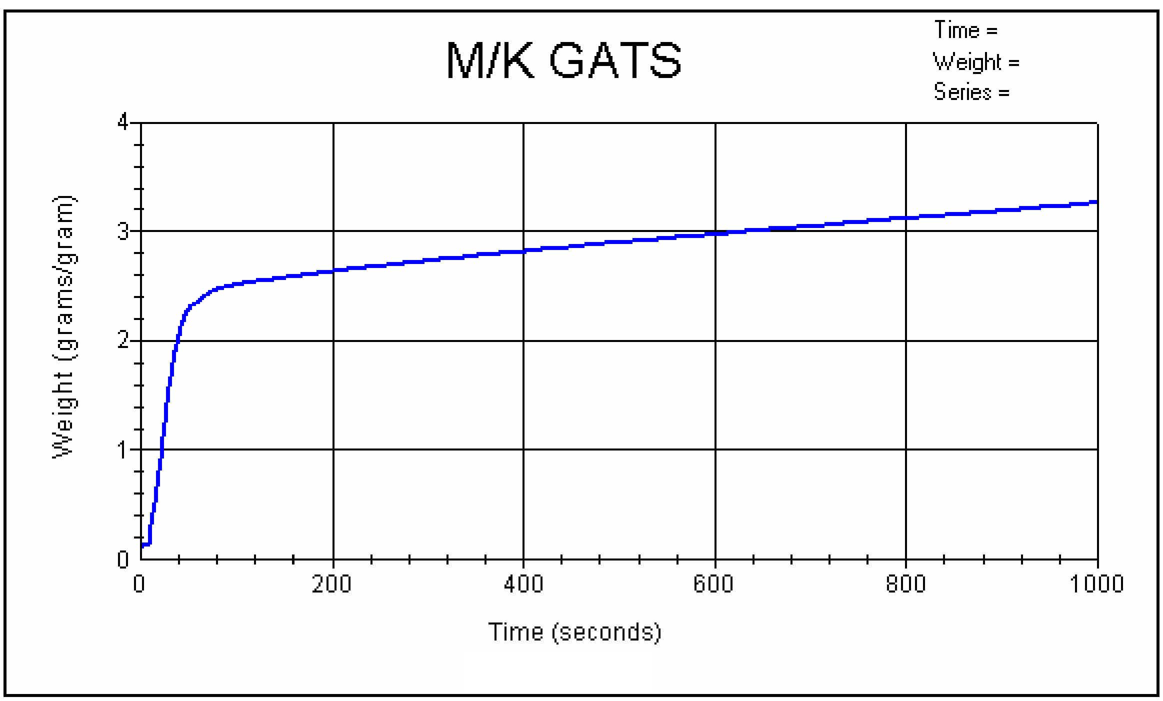

Figure A.40 – GATS Graph for Garment F Fabric

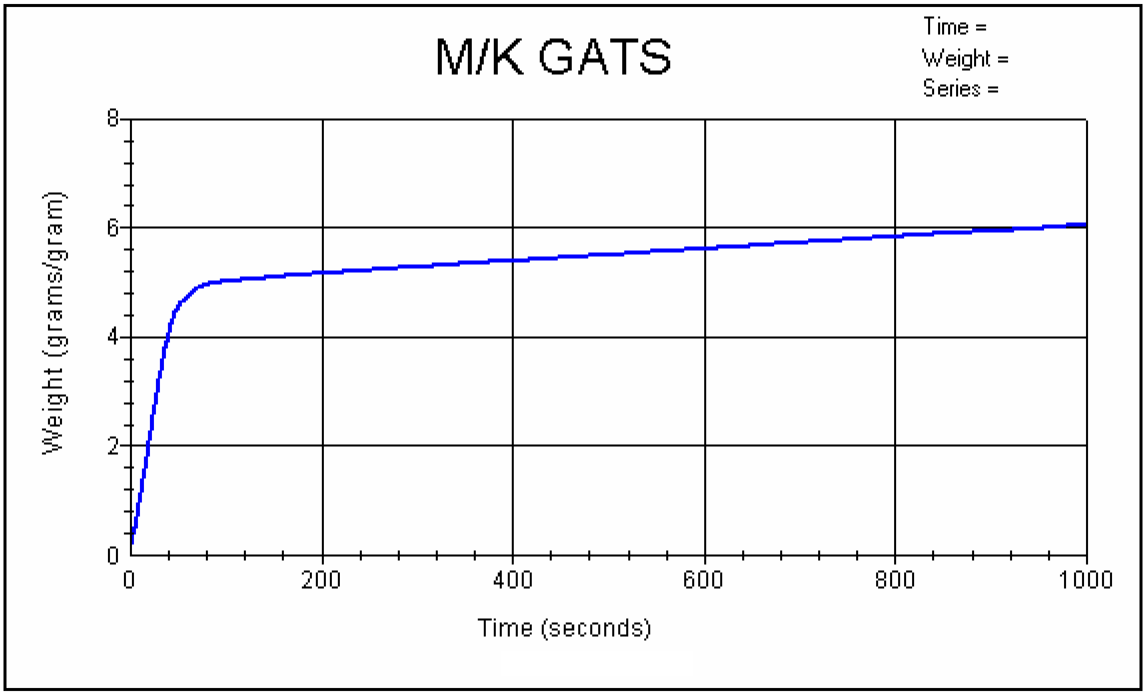

Figure A.41 – GATS Graph for Garment G Back Panel Fabric

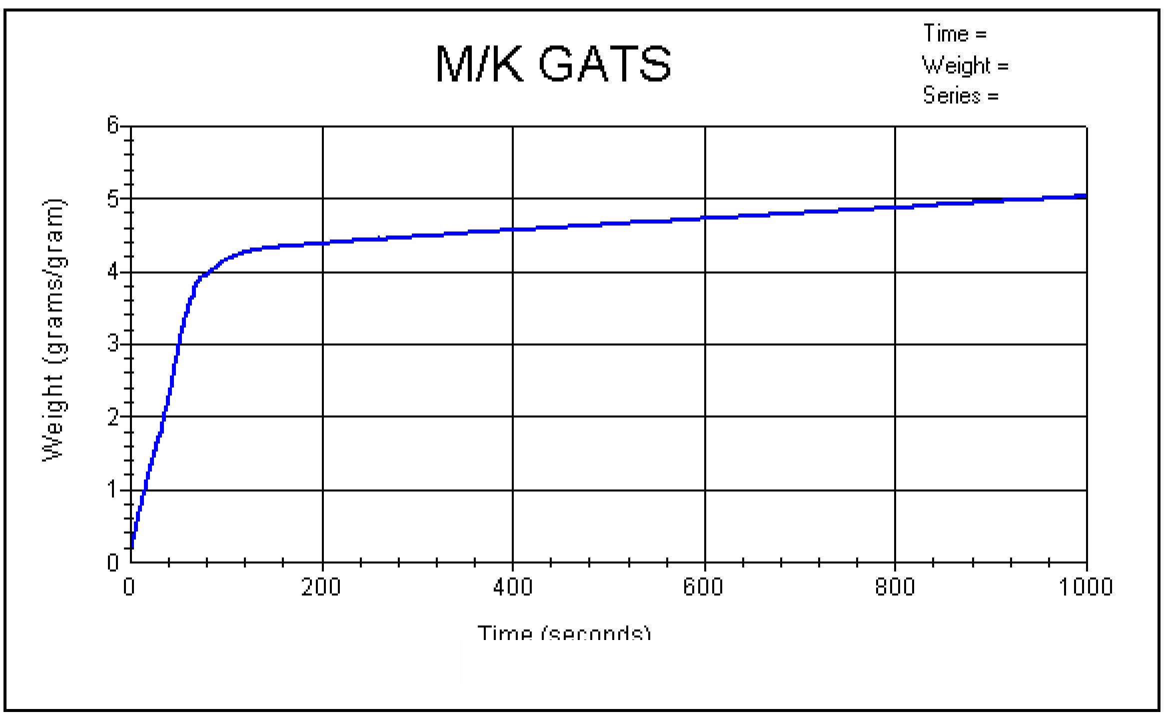

Figure A.42 – GATS Graph for Garment G Front Panel Fabric

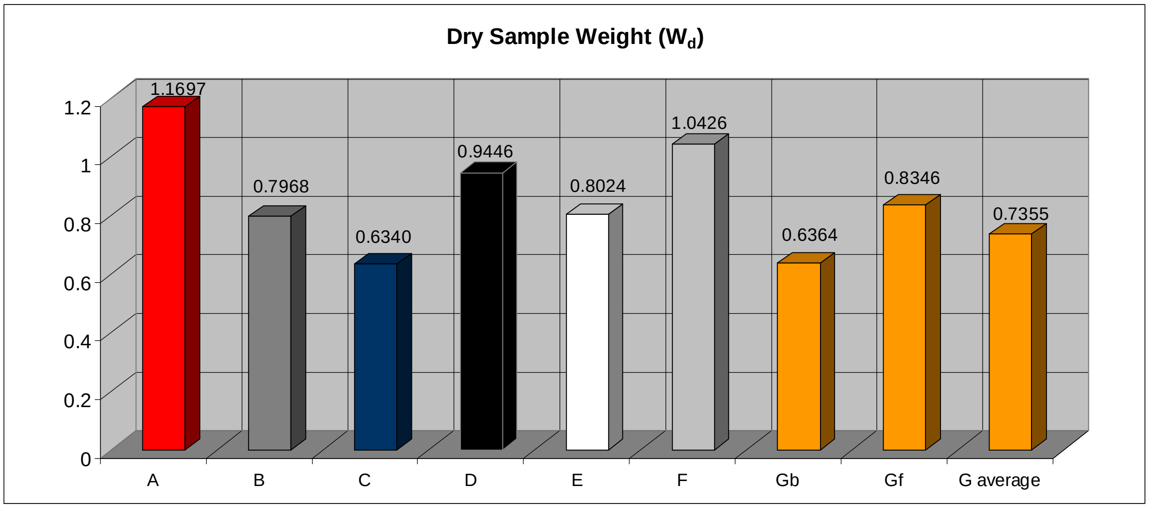

Figure A.43 – Data Average for GATS Dry Sample Weight (in grams)

Table A.62 – Analysis of Variance for GATS Dry Sample Weight

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	1.4125483	0.201793	1441.307	<.0001*
Error	34	0.0047602	0.000140		
C. Total	41	1.4173085			

Table A.63 – Tukey HSD Matrix for GATS Dry Sample Weight

Abs(Dif)-LSD

	A	F	D	Gf	E	B	Gb	C
A	-0.02041	0.10476	0.20276	0.31276	0.34496	0.35056	0.51096	0.51336
F	0.10476	-0.02415	0.07385	0.18385	0.21605	0.22165	0.38205	0.38445
D	0.20276	0.07385	-0.02415	0.08585	0.11805	0.12365	0.28405	0.28645
Gf	0.31276	0.18385	0.08585	-0.02415	0.00805	0.01365	0.17405	0.17645
E	0.34496	0.21605	0.11805	0.00805	-0.02415	-0.01855	0.14185	0.14425
B	0.35056	0.22165	0.12365	0.01365	-0.01855	-0.02415	0.13625	0.13865
Gb	0.51096	0.38205	0.28405	0.17405	0.14185	0.13625	-0.02415	-0.02175
C	0.51336	0.38445	0.28645	0.17645	0.14425	0.13865	-0.02175	-0.02415

Positive values show pairs of means that are significantly different.

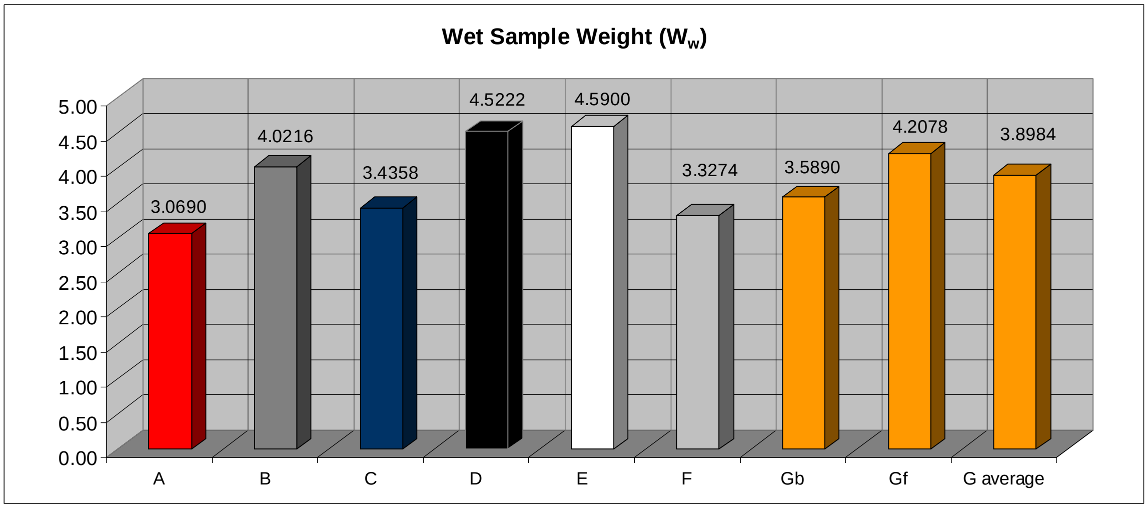

Figure A.44 – Data Average for GATS Wet Sample Weight (in grams)

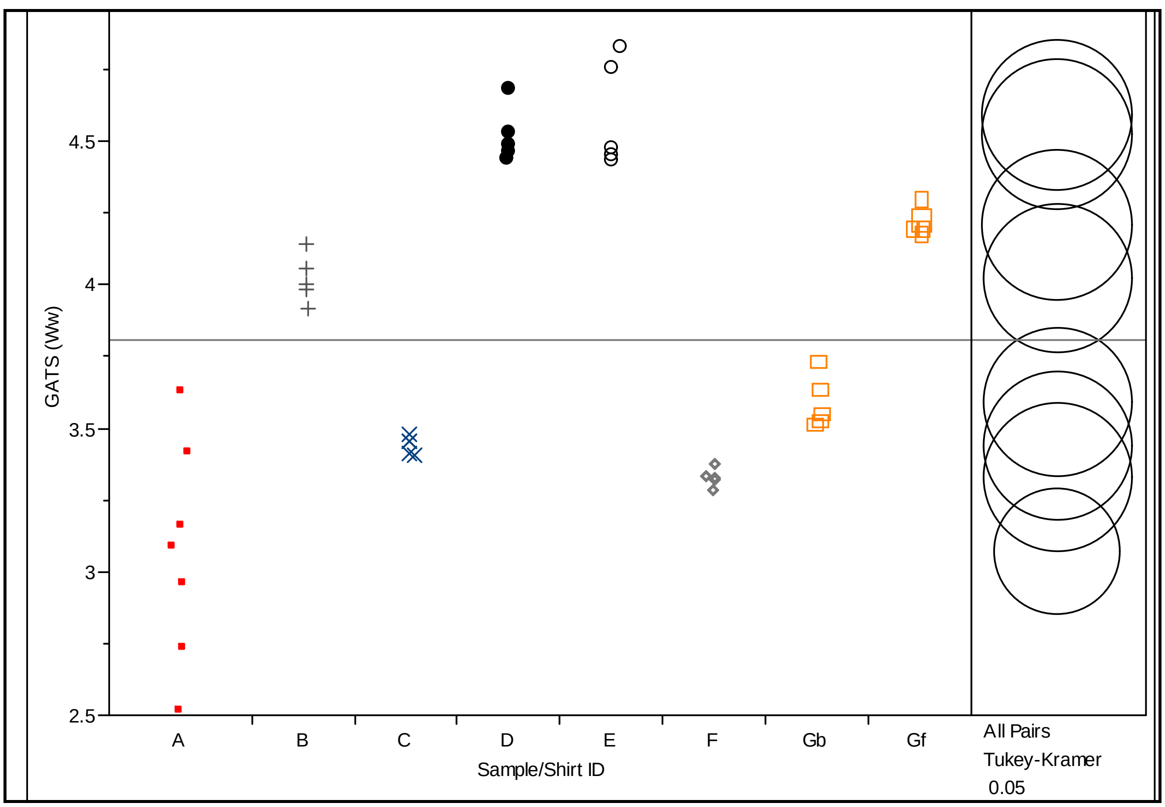

Figure A.45 – Data Points of GATS Wet Sample Weight

Table A.64 – Analysis of Variance for GATS Wet Sample Weight

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	12.545545	1.79222	53.6863	<.0001*
Error	34	1.135029	0.03338		
C. Total	41	13.680574			

Table A.65 – Tukey HSD Matrix for GATS Wet Sample Weight

Abs(Dif)-LSD

	E	D	Gf	B	Gb	C	F	A
E	-0.3729	-0.3051	0.0093	0.1955	0.6281	0.7813	0.8897	1.1758
D	-0.3051	-0.3729	-0.0585	0.1277	0.5603	0.7135	0.8219	1.1080
Gf	0.0093	-0.0585	-0.3729	-0.1867	0.2459	0.3991	0.5075	0.7936
B	0.1955	0.1277	-0.1867	-0.3729	0.0597	0.2129	0.3213	0.6074
Gb	0.6281	0.5603	0.2459	0.0597	-0.3729	-0.2197	-0.1113	0.1748
C	0.7813	0.7135	0.3991	0.2129	-0.2197	-0.3729	-0.2645	0.0216
F	0.8897	0.8219	0.5075	0.3213	-0.1113	-0.2645	-0.3729	-0.0868
A	1.1758	1.1080	0.7936	0.6074	0.1748	0.0216	-0.0868	-0.3151

Positive values show pairs of means that are significantly different.

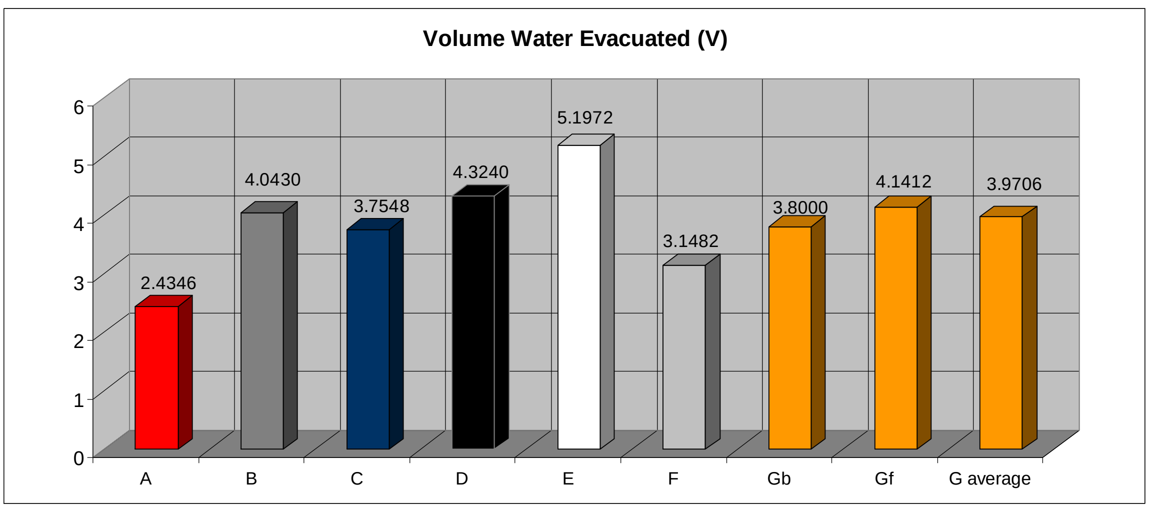

Figure A.46 – Data Average for GATS Volume Evacuated (V) – (in grams)

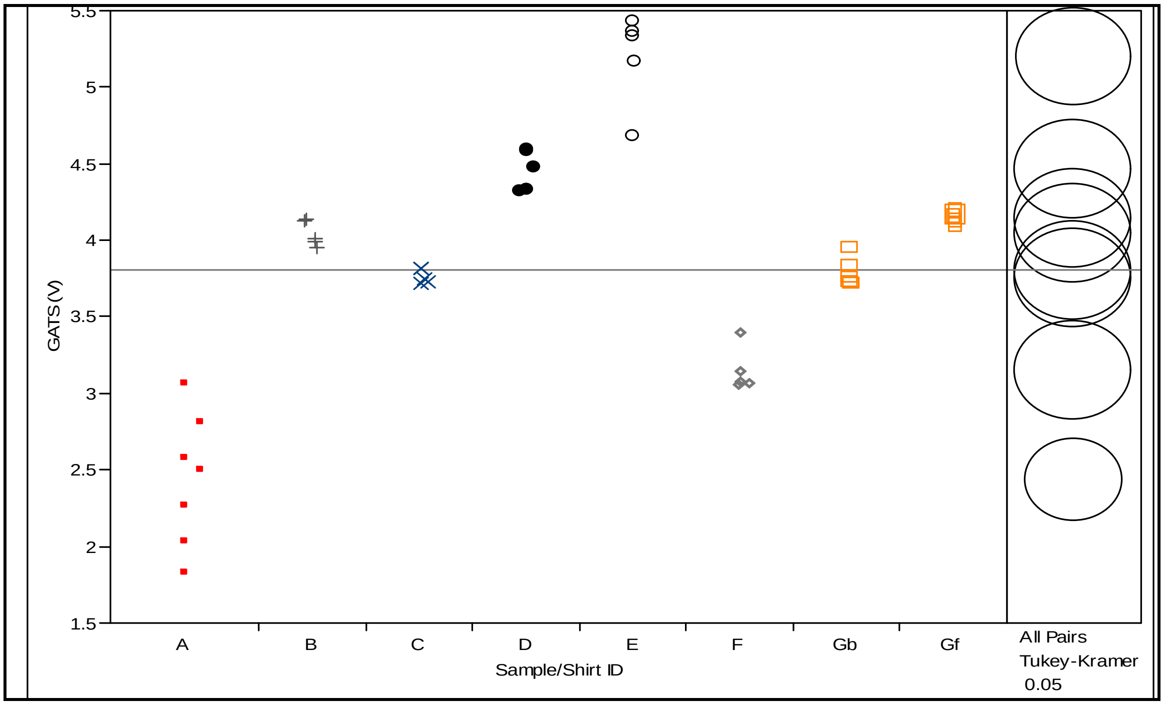

Figure A.47 – Data Points of GATS Volume Evacuated (V)

Table A.66 – Analysis of Variance for GATS Volume Evacuated (V)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	28.028362	4.00405	79.0526	<.0001*
Error	34	1.722116	0.05065		
C. Total	41	29.750478			

Table A.67 – Tukey HSD Matrix for GATS Volume Evacuated (V)

Abs(Dif)-LSD

	E	D	Gf	B	Gb	C	F	A
E	-0.4593	0.2737	0.5967	0.6949	0.9379	0.9831	1.5897	2.3374
D	0.2737	-0.4593	-0.1363	-0.0381	0.2049	0.2501	0.8567	1.6044
Gf	0.5967	-0.1363	-0.4593	-0.3611	-0.1181	-0.0729	0.5337	1.2814
B	0.6949	-0.0381	-0.3611	-0.4593	-0.2163	-0.1711	0.4355	1.1832
Gb	0.9379	0.2049	-0.1181	-0.2163	-0.4593	-0.4141	0.1925	0.9402
C	0.9831	0.2501	-0.0729	-0.1711	-0.4141	-0.4593	0.1473	0.8950
F	1.5897	0.8567	0.5337	0.4355	0.1925	0.1473	-0.4593	0.2884
A	2.3374	1.6044	1.2814	1.1832	0.9402	0.8950	0.2884	-0.3882

Positive values show pairs of means that are significantly different.

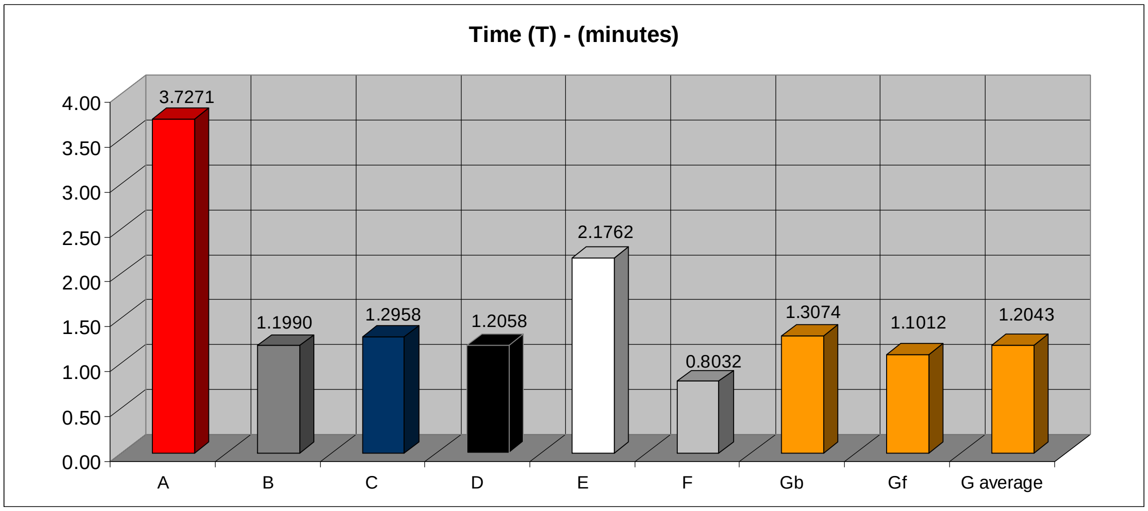

Figure A.48 – Data average for GATS Time (T) – (in seconds)

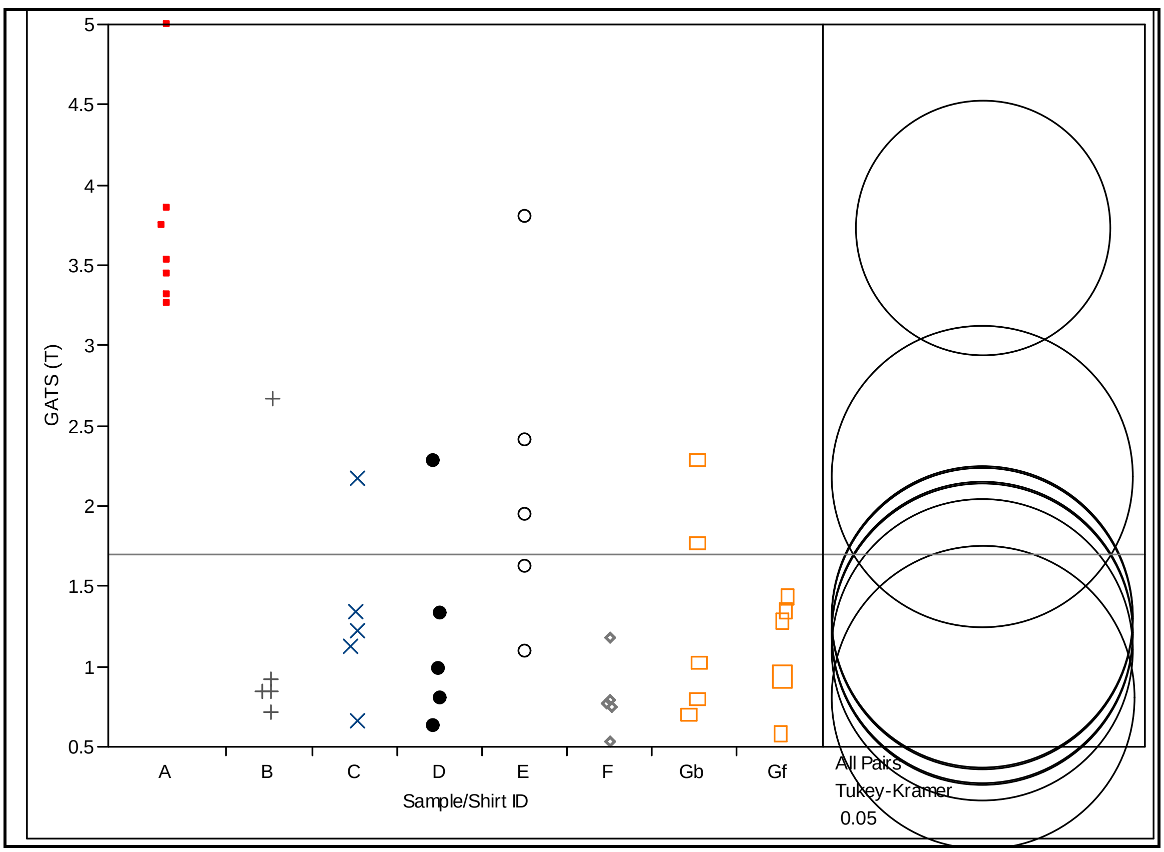

Figure A.49 – Data Points of GATS Time (T)

Table A.68 – Analysis of Variance for GATS Time (T)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	39.776362	5.68234	13.2273	<.0001*
Error	34	14.606074	0.42959		
C. Total	41	54.382436			

Table A.69 – Tukey HSD Matrix for GATS Time (T)

Abs(Dif)-LSD

	A	E	Gb	C	D	B	Gf	F
A	-1.1304	0.3126	1.1814	1.1930	1.2830	1.2898	1.3876	1.6856
E	0.3126	-1.3376	-0.4688	-0.4572	-0.3672	-0.3604	-0.2626	0.0354
Gb	1.1814	-0.4688	-1.3376	-1.3260	-1.2360	-1.2292	-1.1314	-0.8334
C	1.1930	-0.4572	-1.3260	-1.3376	-1.2476	-1.2408	-1.1430	-0.8450
D	1.2830	-0.3672	-1.2360	-1.2476	-1.3376	-1.3308	-1.2330	-0.9350
B	1.2898	-0.3604	-1.2292	-1.2408	-1.3308	-1.3376	-1.2398	-0.9418
Gf	1.3876	-0.2626	-1.1314	-1.1430	-1.2330	-1.2398	-1.3376	-1.0396
F	1.6856	0.0354	-0.8334	-0.8450	-0.9350	-0.9418	-1.0396	-1.3376

Positive values show pairs of means that are significantly different.

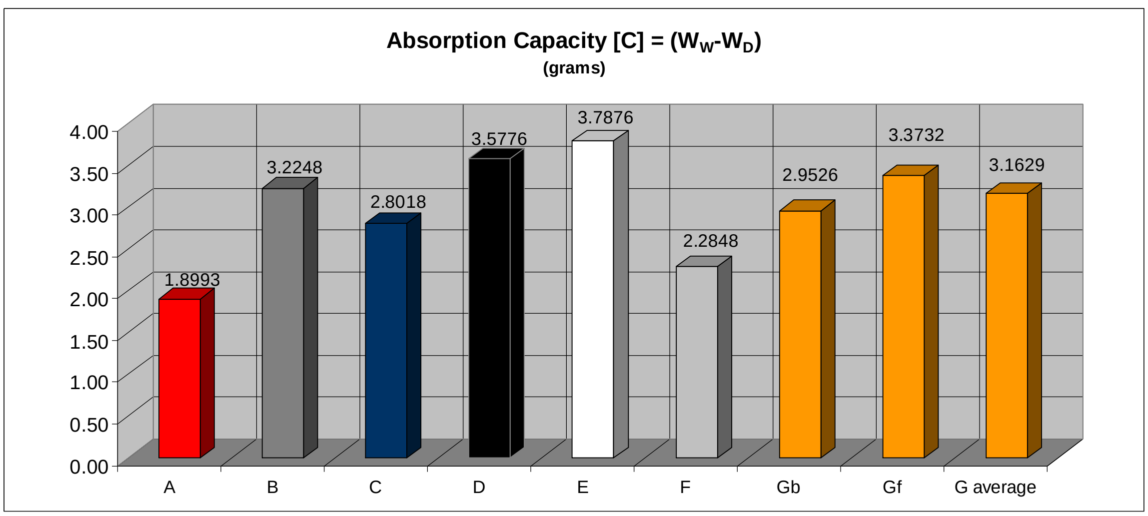

Figure A.50 – Data Average for GATS Capacity (C) – (in grams)

Table A.70 – Analysis of Variance for GATS Capacity (C)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	16.792280	2.39890	74.2368	<.0001*
Error	34	1.098680	0.03231		
C. Total	41	17.890960			

Table A.71 – Tukey HSD Matrix for GATS Capacity (C)

Abs(Dif)-LSD

	E	D	Gf	B	Gb	C	F	A
E	-0.3668	-0.1568	0.0476	0.1960	0.4682	0.6190	1.1360	1.5487
D	-0.1568	-0.3668	-0.1624	-0.0140	0.2582	0.4090	0.9260	1.3387
Gf	0.0476	-0.1624	-0.3668	-0.2184	0.0538	0.2046	0.7216	1.1343
B	0.1960	-0.0140	-0.2184	-0.3668	-0.0946	0.0562	0.5732	0.9859
Gb	0.4682	0.2582	0.0538	-0.0946	-0.3668	-0.2160	0.3010	0.7137
C	0.6190	0.4090	0.2046	0.0562	-0.2160	-0.3668	0.1502	0.5629
F	1.1360	0.9260	0.7216	0.5732	0.3010	0.1502	-0.3668	0.0459
A	1.5487	1.3387	1.1343	0.9859	0.7137	0.5629	0.0459	-0.3100

Positive values show pairs of means that are significantly different.

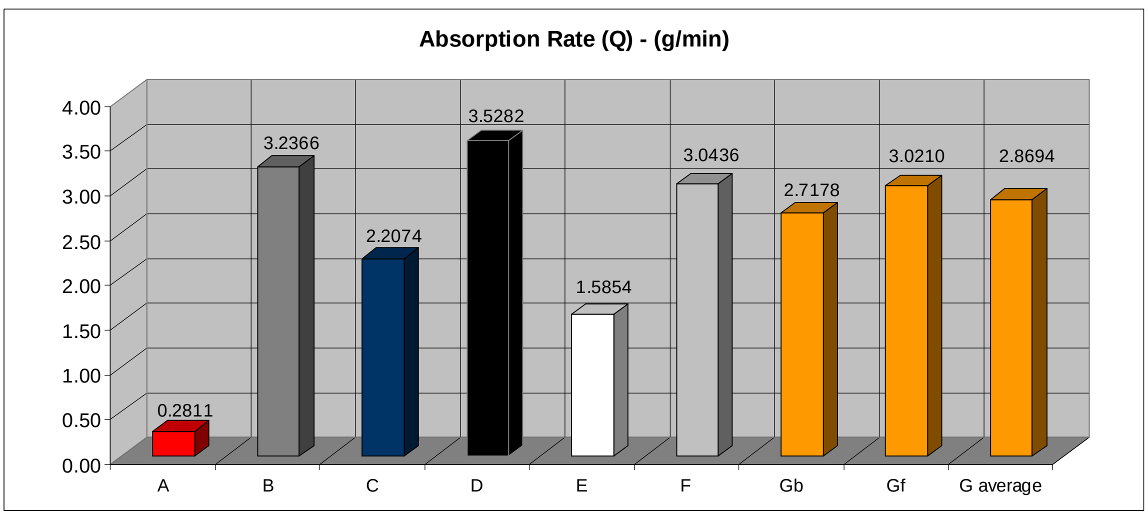

Figure A.51 – Data Average for GATS Absorption Rate (Q) – (in g/min)

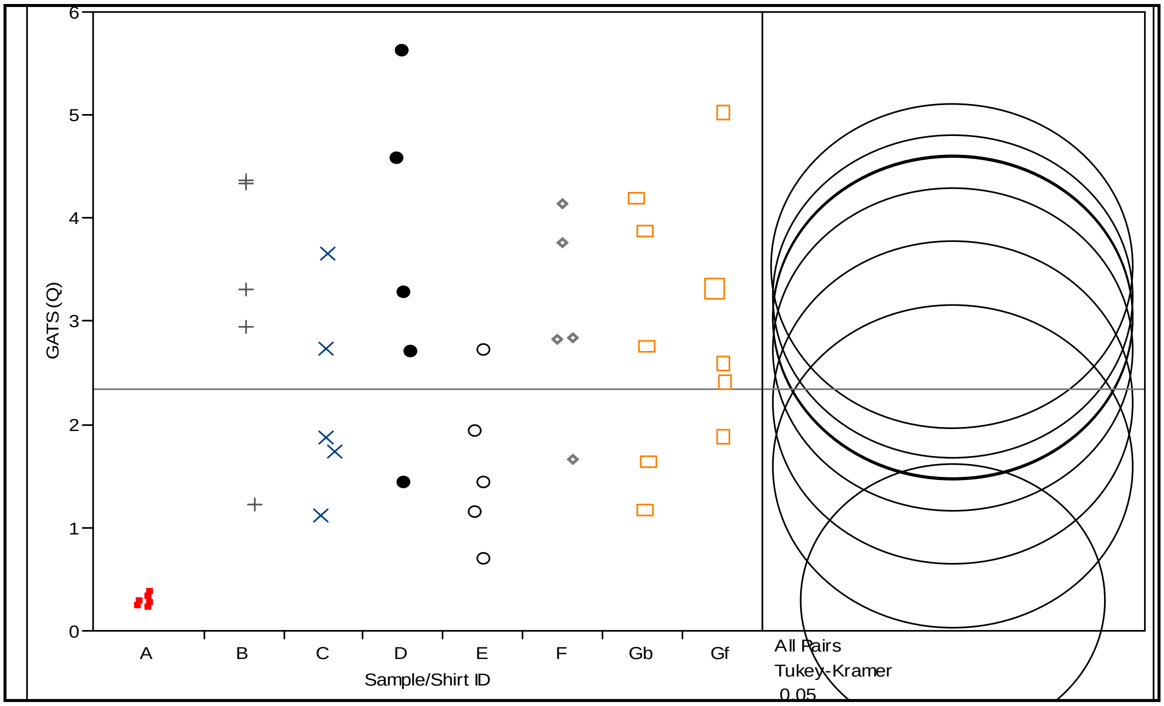

Figure A.52 – Data Points of GATS Absorption Rate (Q)

Table A.72 – Analysis of Variance for GATS Absorption Rate (Q)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	49.189972	7.02714	5.9122	0.0002*
Error	34	40.411709	1.18858		
C. Total	41	89.601682			

Table A.73 – Tukey HSD Matrix for GATS Absorption Rate (Q)

Abs(Dif)-LSD

	D	B	F	Gf	Gb	C	E	A
D	-2.2248	-1.9332	-1.7402	-1.7176	-1.4144	-0.9040	-0.2820	1.1873
B	-1.9332	-2.2248	-2.0318	-2.0092	-1.7060	-1.1956	-0.5736	0.8957
F	-1.7402	-2.0318	-2.2248	-2.2022	-1.8990	-1.3886	-0.7666	0.7027
Gf	-1.7176	-2.0092	-2.2022	-2.2248	-1.9216	-1.4112	-0.7892	0.6801
Gb	-1.4144	-1.7060	-1.8990	-1.9216	-2.2248	-1.7144	-1.0924	0.3769
C	-0.9040	-1.1956	-1.3886	-1.4112	-1.7144	-2.2248	-1.6028	-0.1335
E	-0.2820	-0.5736	-0.7666	-0.7892	-1.0924	-1.6028	-2.2248	-0.7555
A	1.1873	0.8957	0.7027	0.6801	0.3769	-0.1335	-0.7555	-1.8803

Positive values show pairs of means that are significantly different.

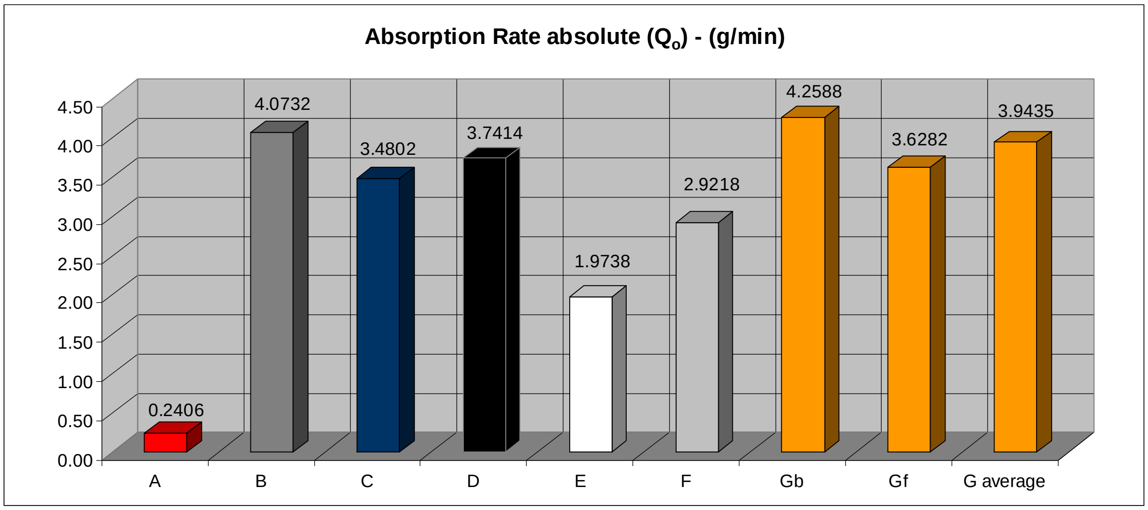

Figure A.53 – Data Average for GATS Absolute Absorption Rate (Q_o) – (in g/min)

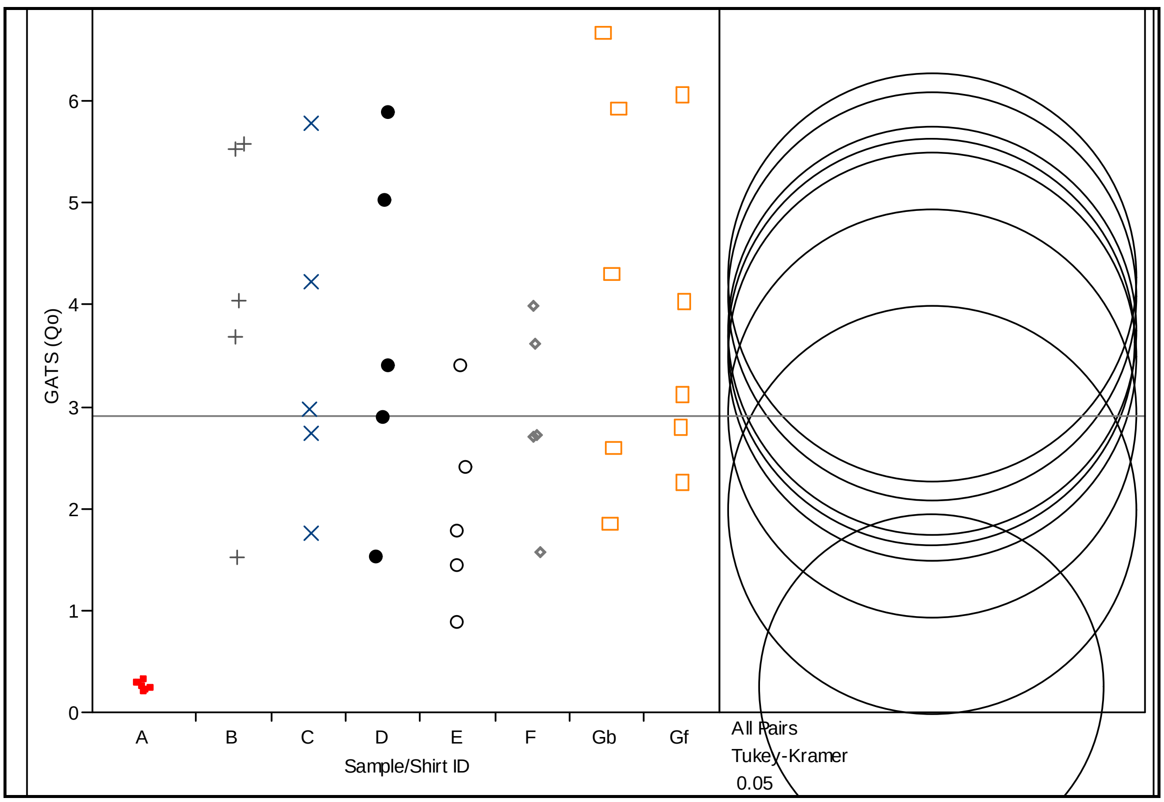

Figure A.54 – Data Points of GATS Absolute Absorption Rate (Q_o)

Table A.74 – Analysis of Variance for GATS Absolute Absorption Rate (Q_o)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	77.78577	11.1123	5.7239	0.0002*
Error	34	66.00660	1.9414		
C. Total	41	143.79236			

Table A.75 – Tukey HSD Matrix for GATS Absolute Absorption Rate (Q_o)

Abs(Dif)-LSD

	Gb	B	D	Gf	C	F	E	A
Gb	-2.8434	-2.6578	-2.3260	-2.2128	-2.0648	-1.5064	-0.5584	1.3858
B	-2.6578	-2.8434	-2.5116	-2.3984	-2.2504	-1.6920	-0.7440	1.2002
D	-2.3260	-2.5116	-2.8434	-2.7302	-2.5822	-2.0238	-1.0758	0.8684
Gf	-2.2128	-2.3984	-2.7302	-2.8434	-2.6954	-2.1370	-1.1890	0.7552
C	-2.0648	-2.2504	-2.5822	-2.6954	-2.8434	-2.2850	-1.3370	0.6072
F	-1.5064	-1.6920	-2.0238	-2.1370	-2.2850	-2.8434	-1.8954	0.0488
E	-0.5584	-0.7440	-1.0758	-1.1890	-1.3370	-1.8954	-2.8434	-0.8992
A	1.3858	1.2002	0.8684	0.7552	0.6072	0.0488	-0.8992	-2.4031

Positive values show pairs of means that are significantly different.

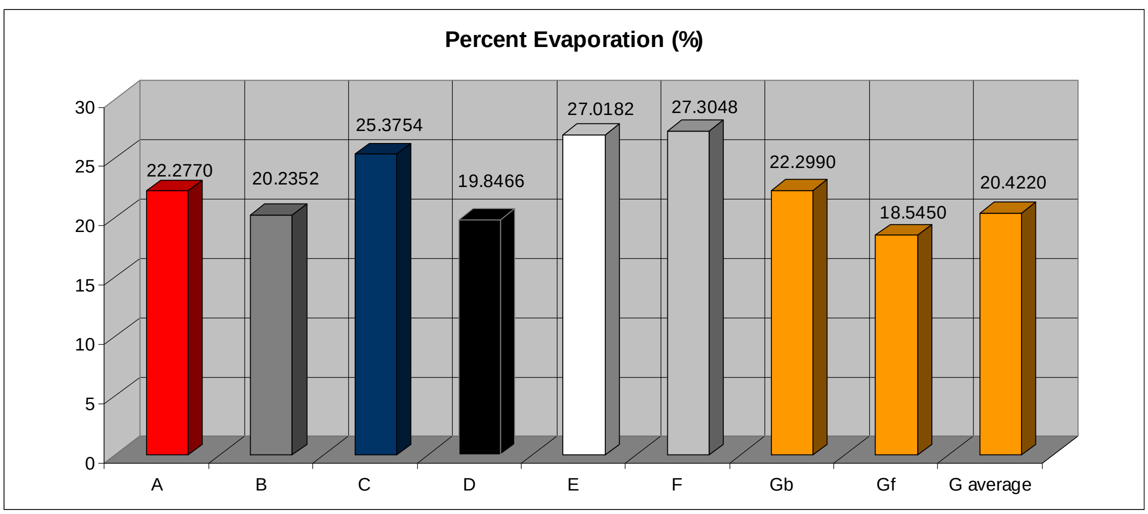

Figure A.55 – Data Average of GATS Percent Evaporation (%E)

Table A.76 – Analysis of Variance for GATS Percent Evaporation (%E)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	393.74353	56.2491	13.4480	<.0001*
Error	34	142.21197	4.1827		
C. Total	41	535.95550			

Table A.77 – Tukey HSD Matrix for GATS Percent Evaporation (%E)

Abs(Dif)-LSD

	F	E	C	Gb	A	B	D	Gf
F	-4.1736	-3.8870	-2.2442	0.8322	1.1638	2.8960	3.2846	4.5862
E	-3.8870	-4.1736	-2.5308	0.5456	0.8772	2.6094	2.9980	4.2996
C	-2.2442	-2.5308	-4.1736	-1.0972	-0.7656	0.9666	1.3552	2.6568
Gb	0.8322	0.5456	-1.0972	-4.1736	-3.8420	-2.1098	-1.7212	-0.4196
A	1.1638	0.8772	-0.7656	-3.8420	-3.5273	-1.8222	-1.4336	-0.1320
B	2.8960	2.6094	0.9666	-2.1098	-1.8222	-4.1736	-3.7850	-2.4834
D	3.2846	2.9980	1.3552	-1.7212	-1.4336	-3.7850	-4.1736	-2.8720
Gf	4.5862	4.2996	2.6568	-0.4196	-0.1320	-2.4834	-2.8720	-4.1736

Positive values show pairs of means that are significantly different.

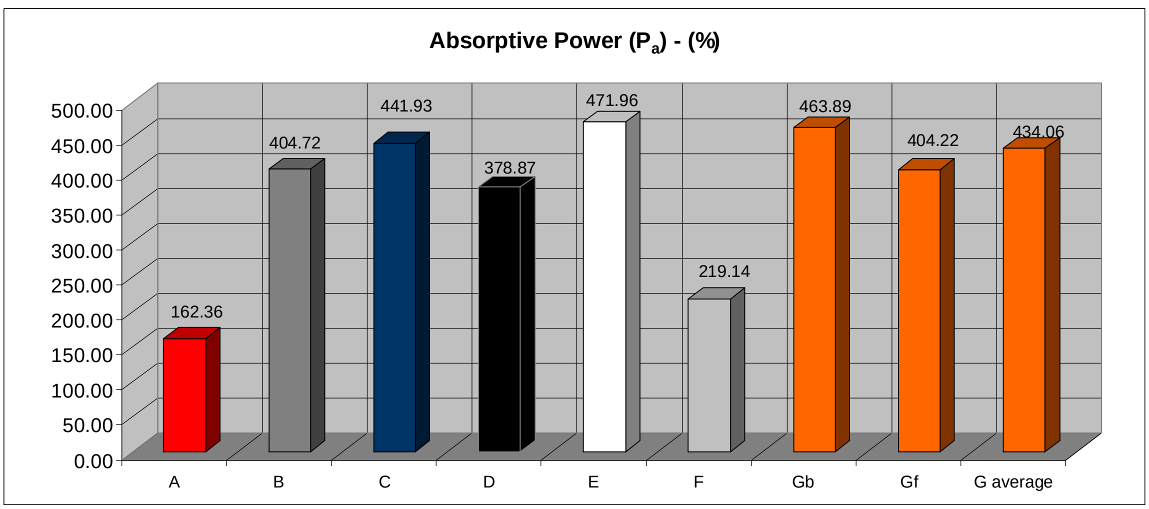

Figure A.56 – Data average for GATS Absorptive Power (P_a) – (in %)

Table A.78 – Analysis of Variance for GATS Absorptive Power (P_a)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	544304.55	77757.8	298.5010	<.0001*
Error	34	8856.81	260.5		
C. Total	41	553161.36			

Table A.79 – Tukey HSD Matrix for GATS Absorptive Power (P_a)

Abs(Dif)-LSD

	E	Gb	C	B	Gf	D	F	A
E	-32.94	-24.87	-2.91	34.32	34.80	60.15	219.88	279.10
Gb	-24.87	-32.94	-10.98	26.25	26.73	52.08	211.81	271.04
C	-2.91	-10.98	-32.94	4.29	4.77	30.12	189.86	249.08
B	34.32	26.25	4.29	-32.94	-32.45	-7.10	152.63	211.85
Gf	34.80	26.73	4.77	-32.45	-32.94	-7.59	152.14	211.37
D	60.15	52.08	30.12	-7.10	-7.59	-32.94	126.79	186.02
F	219.88	211.81	189.86	152.63	152.14	126.79	-32.94	26.29
A	279.10	271.04	249.08	211.85	211.37	186.02	26.29	-27.84

Positive values show pairs of means that are significantly different.

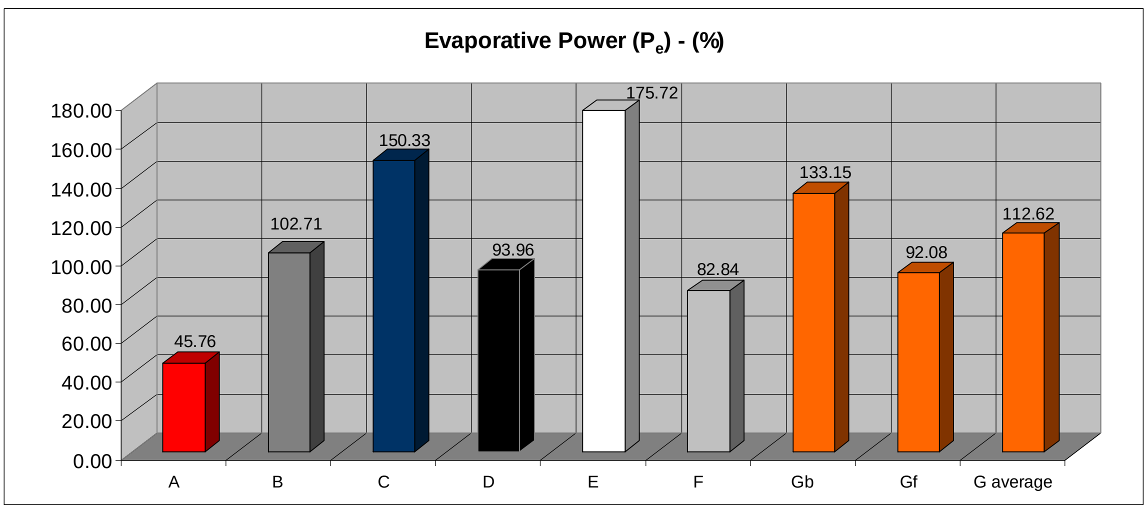

Figure A.57 – Data Average for GATS Evaporative Power (P_e) – (in %)

Table A.80 – Analysis of Variance for GATS Evaporative Power (P_e)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	67636.161	9662.31	63.1361	<.0001*
Error	34	5203.342	153.04		
C. Total	41	72839.502			

Table A.81 – Tukey HSD Matrix for GATS Evaporative Power (P_e)

Abs(Dif)-LSD

	E	C	Gb	B	D	Gf	F	A
E	-25.25	0.15	17.33	47.77	56.51	58.39	67.64	106.59
C	0.15	-25.25	-8.07	22.38	31.12	33.00	42.25	81.20
Gb	17.33	-8.07	-25.25	5.20	13.94	15.82	25.07	64.02
B	47.77	22.38	5.20	-25.25	-16.50	-14.62	-5.38	33.57
D	56.51	31.12	13.94	-16.50	-25.25	-23.37	-14.12	24.83
Gf	58.39	33.00	15.82	-14.62	-23.37	-25.25	-16.00	22.95
F	67.64	42.25	25.07	-5.38	-14.12	-16.00	-25.25	13.70
A	106.59	81.20	64.02	33.57	24.83	22.95	13.70	-21.34

Positive values show pairs of means that are significantly different.

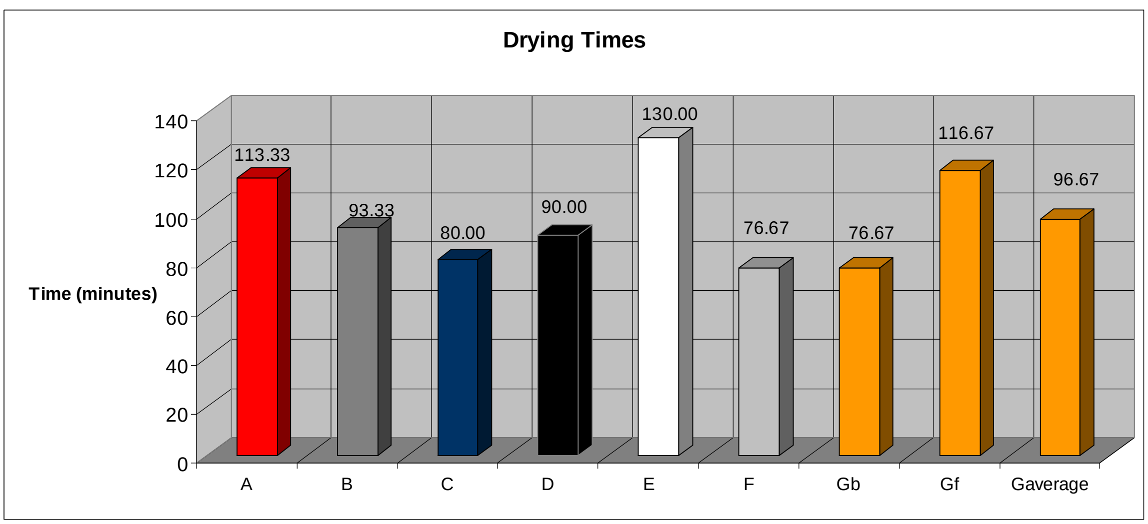

Figure A.58 – Data Average for GATS Drying Time (D) – (in minutes)

Table A.82 – Analysis of Variance for GATS Drying Time (D)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	8762.5000	1251.79	27.3117	<.0001*
Error	16	733.3333	45.83		
C. Total	23	9495.8333			

Table A.83 – Tukey HSD Matrix for GATS Drying Time (D)

Abs(Dif)-LSD

	E	Gf	A	B	D	C	Gb	F
E	-19.138	-5.804	-2.471	17.529	20.862	30.862	34.196	34.196
Gf	-5.804	-19.138	-15.804	4.196	7.529	17.529	20.862	20.862
A	-2.471	-15.804	-19.138	0.862	4.196	14.196	17.529	17.529
B	17.529	4.196	0.862	-19.138	-15.804	-5.804	-2.471	-2.471
D	20.862	7.529	4.196	-15.804	-19.138	-9.138	-5.804	-5.804
C	30.862	17.529	14.196	-5.804	-9.138	-19.138	-15.804	-15.804
Gb	34.196	20.862	17.529	-2.471	-5.804	-15.804	-19.138	-19.138
F	34.196	20.862	17.529	-2.471	-5.804	-15.804	-19.138	-19.138

Positive values show pairs of means that are significantly different.

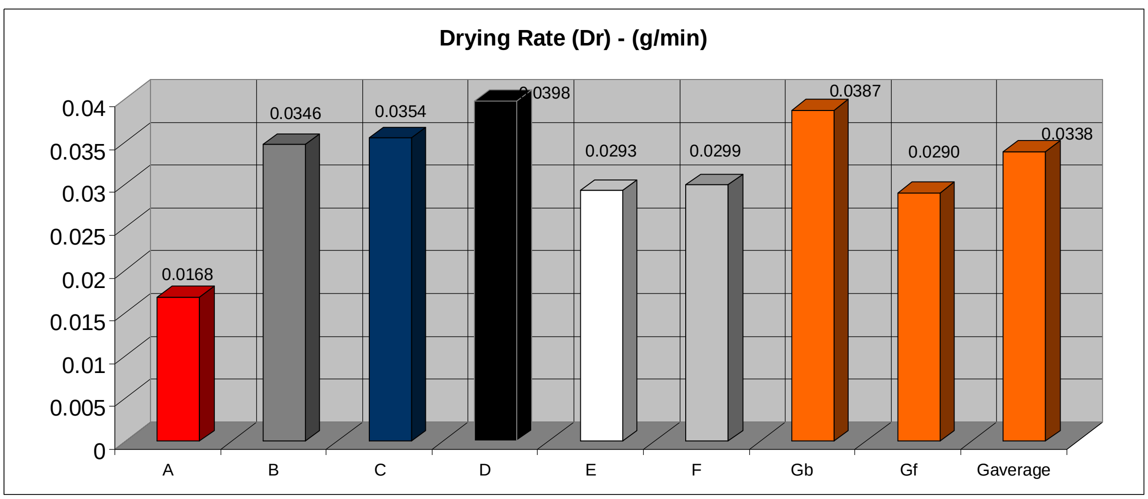

Figure A.59 – Data Average for GATS Drying Rate (D_r) – (in g/min)

Table A.84 – Analysis of Variance for GATS Drying Rate (D_r)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	7	0.00112398	0.000161	27.3681	<.0001*
Error	16	0.00009387	5.867e-6		
C. Total	23	0.00121785			

Table A.85 – Tukey HSD Matrix for GATS Drying Rate (D_r)

Abs(Dif)-LSD

	D	Gb	C	B	F	E	Gf	A
D	-0.00685	-0.00576	-0.00249	-0.00173	0.00298	0.00365	0.00394	0.01612
Gb	-0.00576	-0.00685	-0.00358	-0.00282	0.00190	0.00257	0.00286	0.01503
C	-0.00249	-0.00358	-0.00685	-0.00609	-0.00137	-0.00070	-0.00042	0.01176
B	-0.00173	-0.00282	-0.00609	-0.00685	-0.00213	-0.00146	-0.00117	0.01100
F	0.00298	0.00190	-0.00137	-0.00213	-0.00685	-0.00618	-0.00589	0.00629
E	0.00365	0.00257	-0.00070	-0.00146	-0.00618	-0.00685	-0.00656	0.00562
Gf	0.00394	0.00286	-0.00042	-0.00117	-0.00589	-0.00656	-0.00685	0.00533
A	0.01612	0.01503	0.01176	0.01100	0.00629	0.00562	0.00533	-0.00685

Positive values show pairs of means that are significantly different.

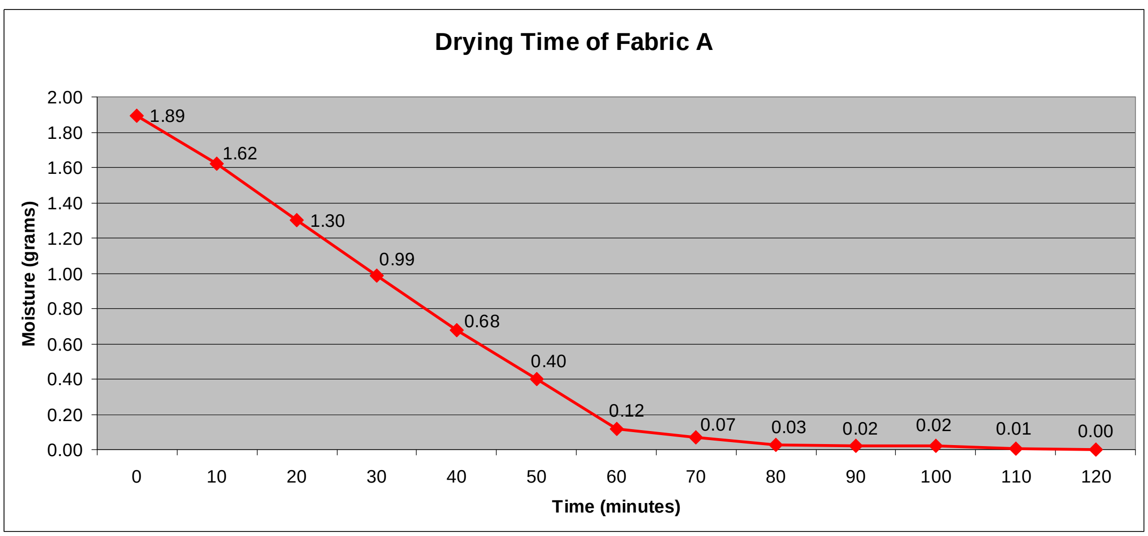

Figure A.60 – Drying Graph of 100% Cotton Fabric A

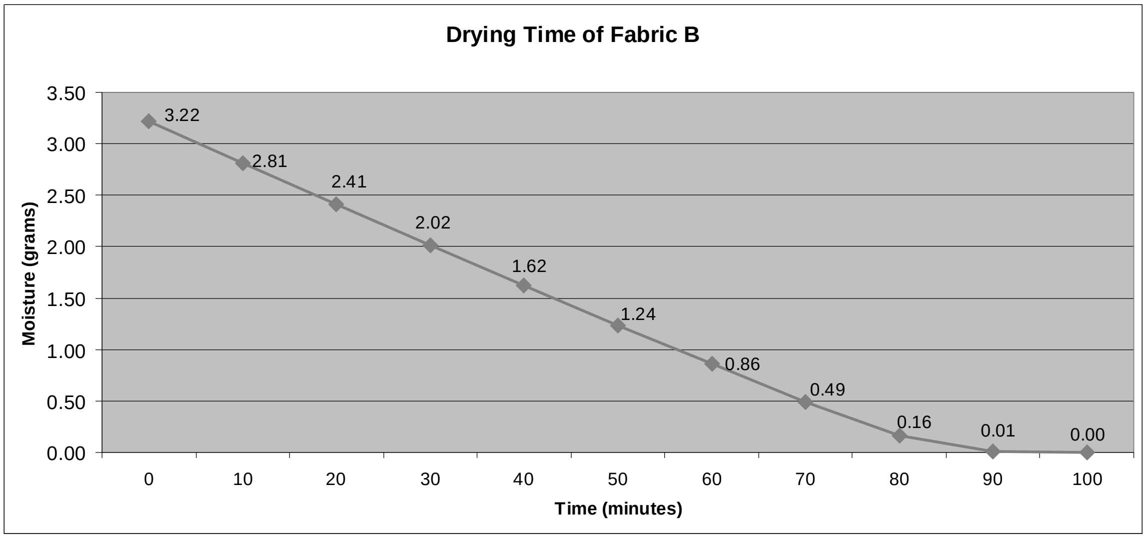

Figure A.61 – Drying Graph of Fabric B

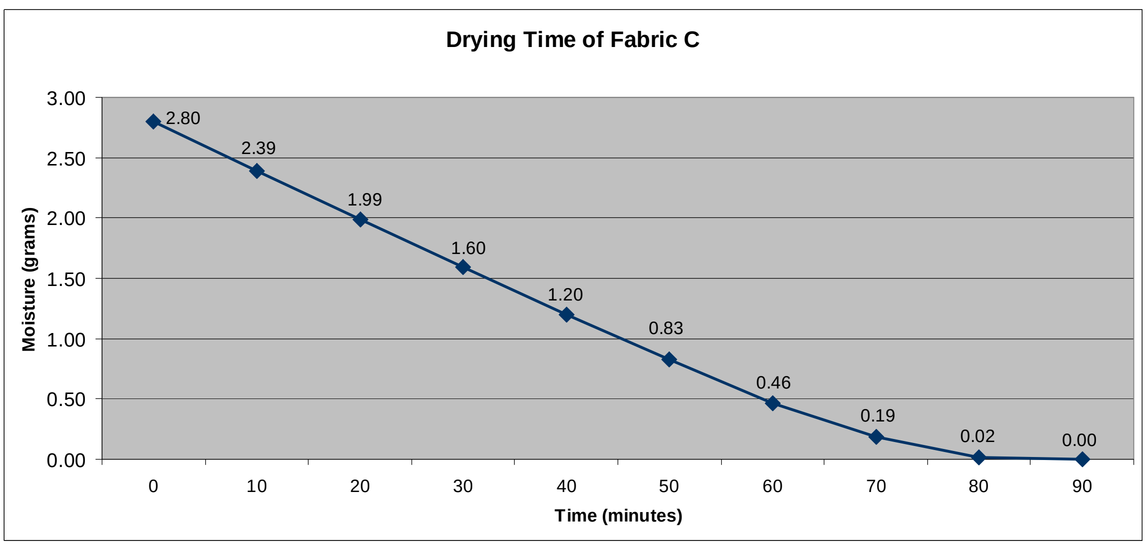

Figure A.62 – Drying Graph of Fabric C

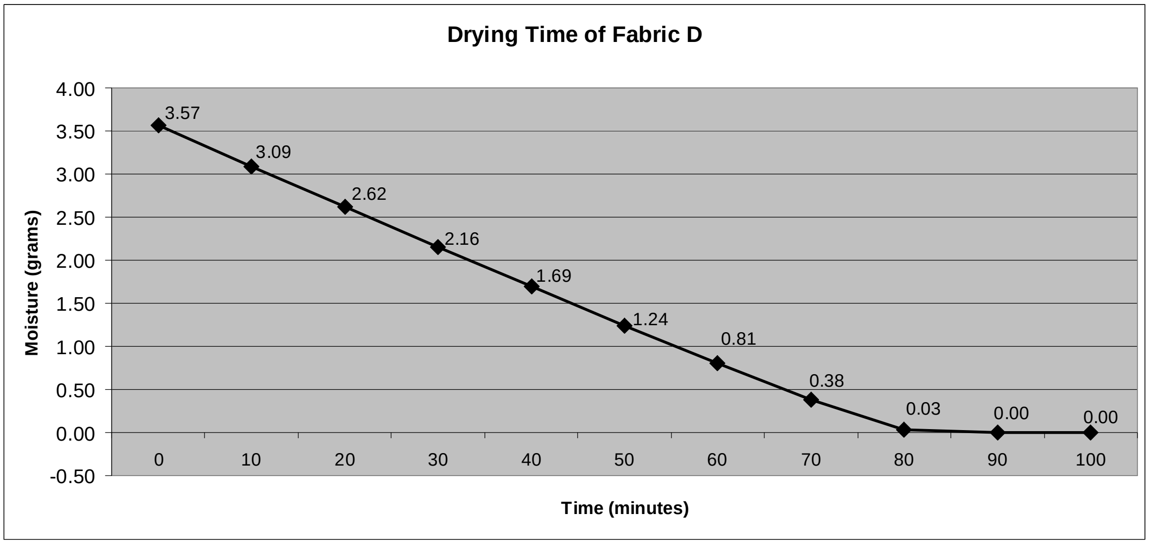

Figure A.63 – Drying Graph of Fabric D

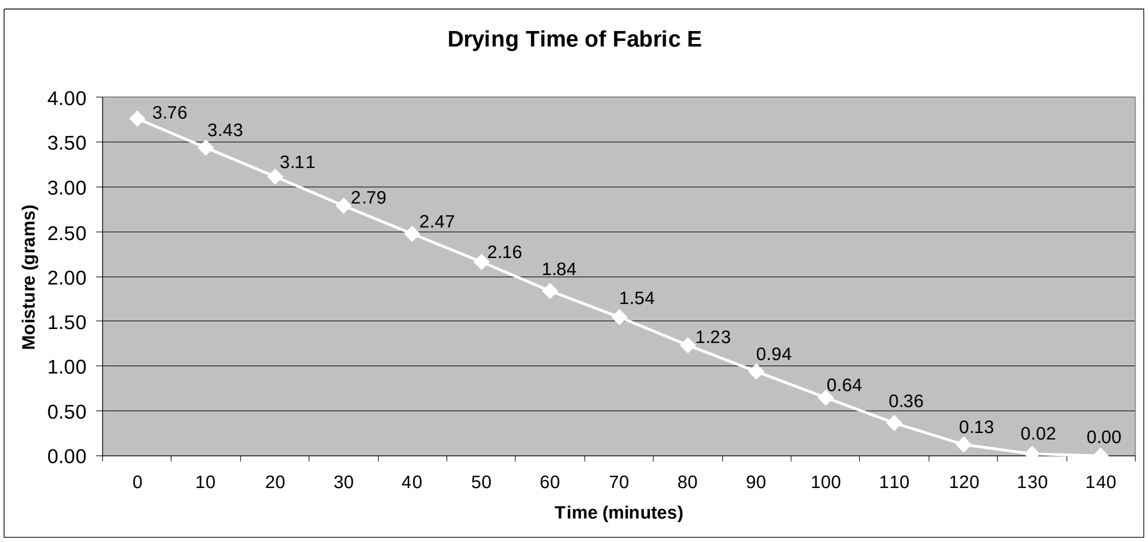

Figure A.64 – Drying Graph of Fabric E

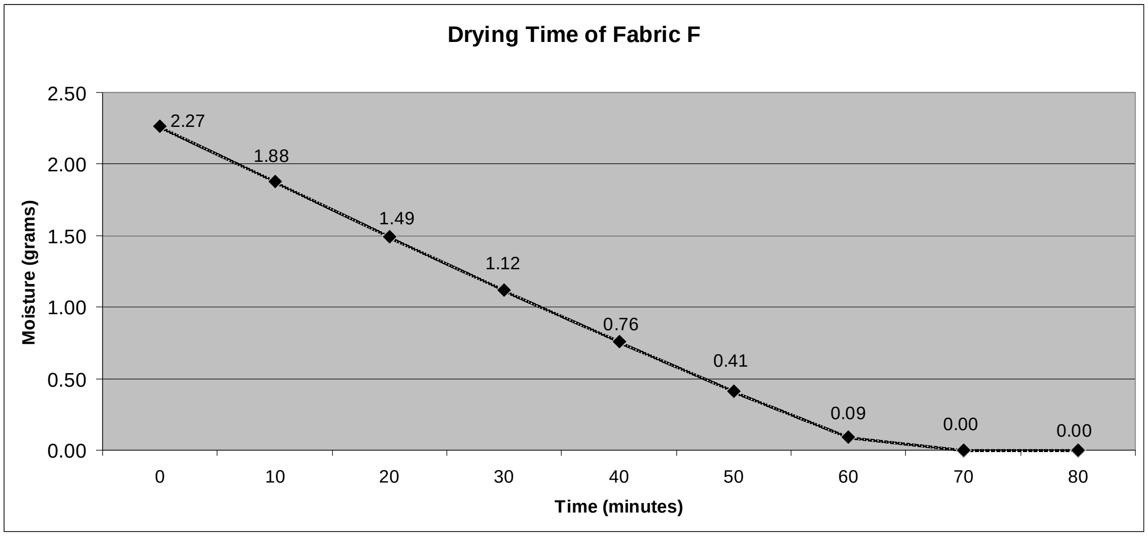

Figure A.65 – Drying Graph of Fabric F

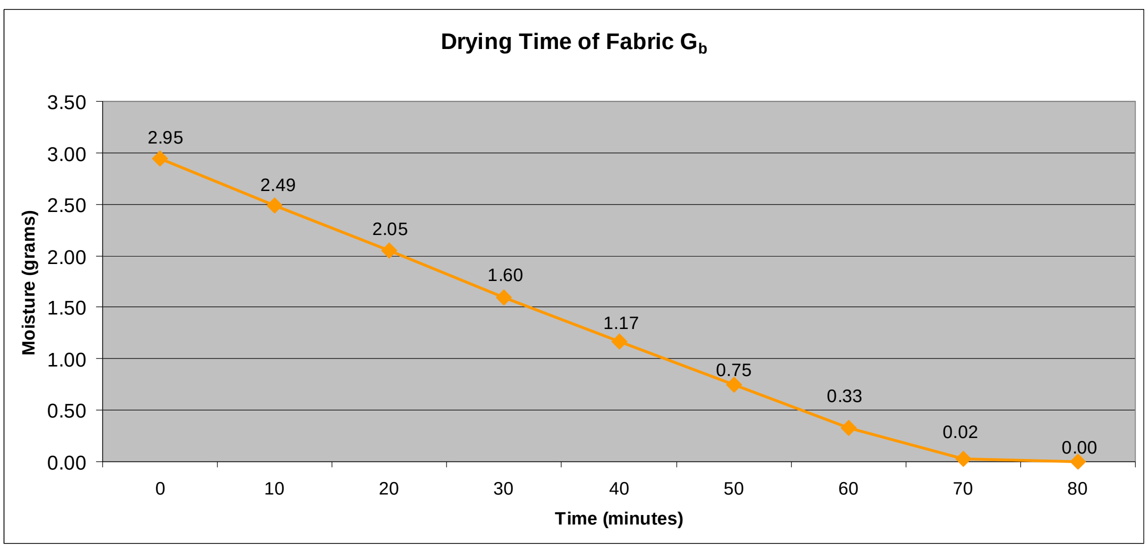

Figure A.66 – Drying Graph of Fabric G Back Panel Fabric (G_b)

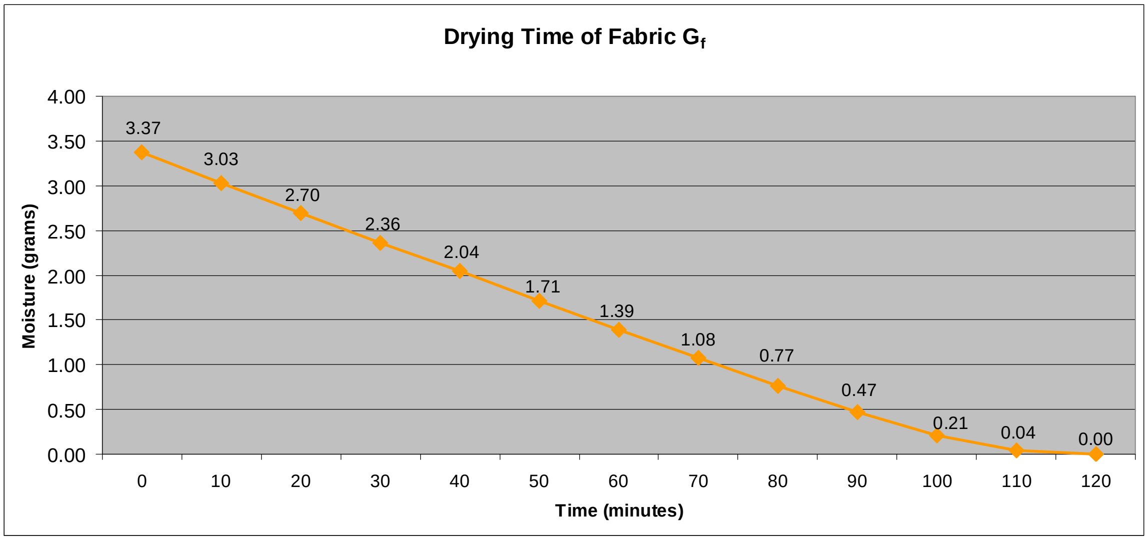

Figure A.67 – Drying Graph of Fabric G Front Panel Fabric (G_f)

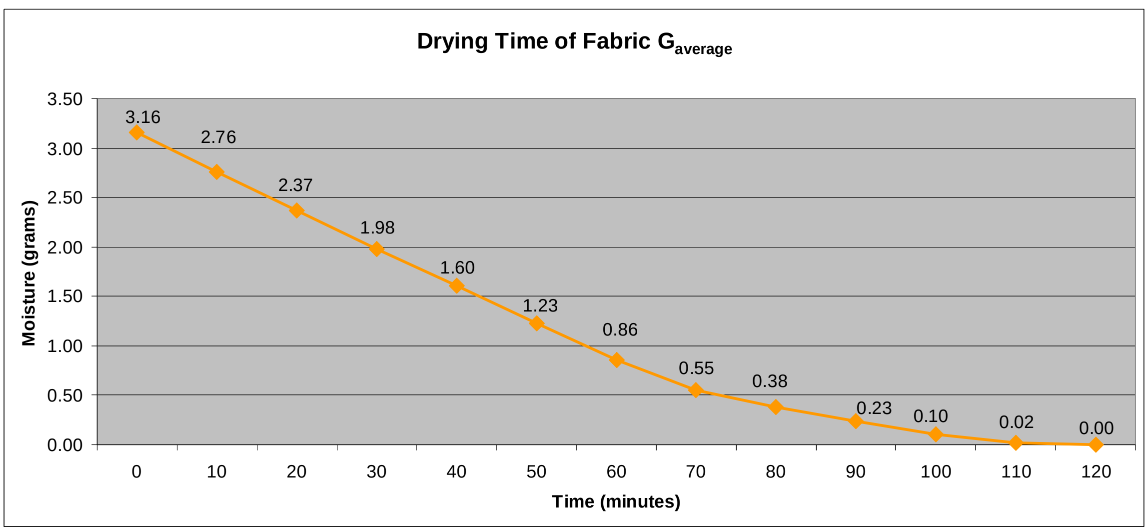

Figure A.68 – Drying Graph of Fabric G Averaged Front and Back ($G_{average}$)

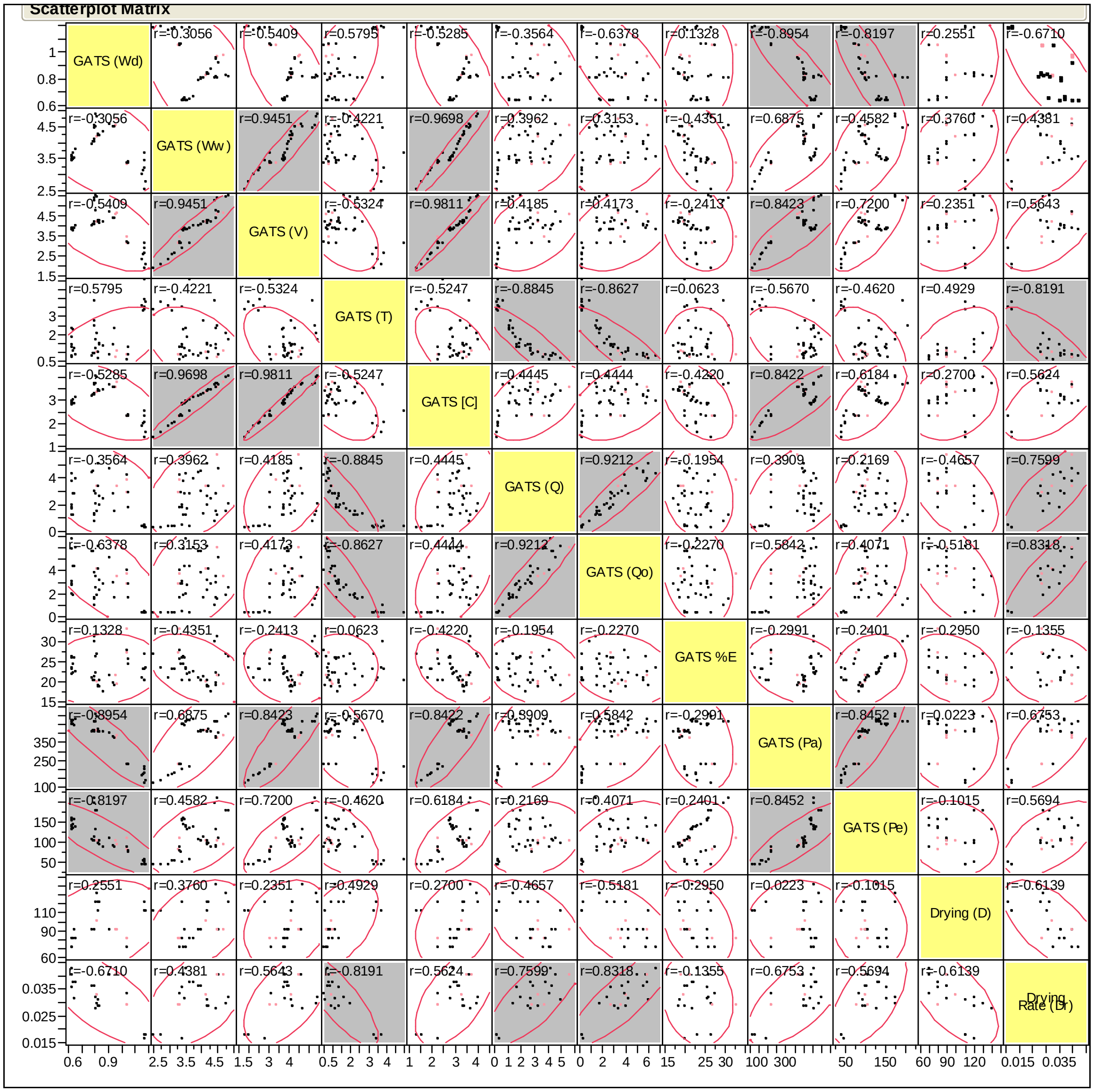

Figure A.69 – Correlation Table of all GATS and Drying Measures

A.2.4 Garment Level (Manikin) Data

This section contains bar graphs of data averages for all garment level measures, as well as statistical analysis tables for all garment level measures. Measures not covered in chapter four will have data point graphs as well. Also the graph of correlations for all manikin measures will be provided at the end of this section.

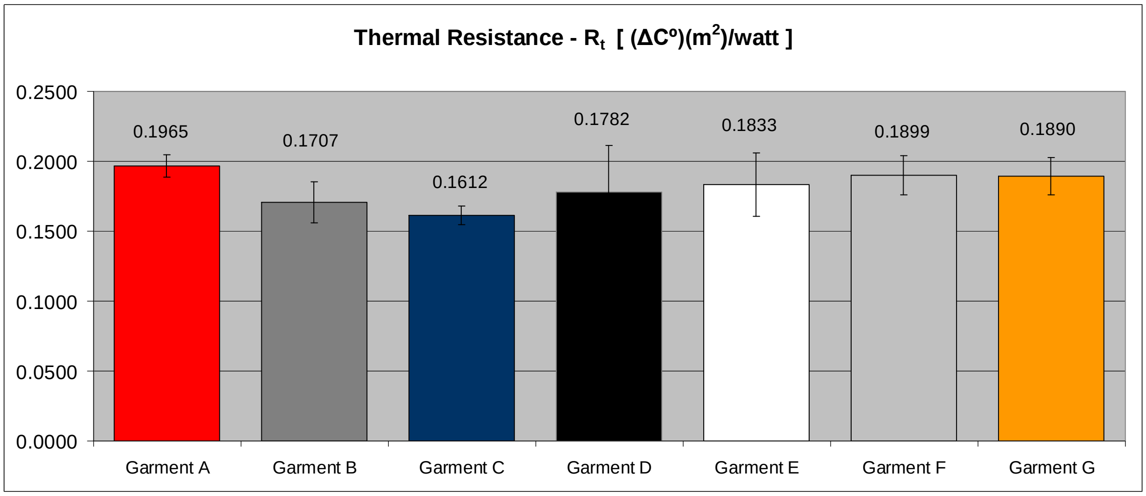

Figure A.70 – Data Average for Manikin Thermal Resistance (R_t)

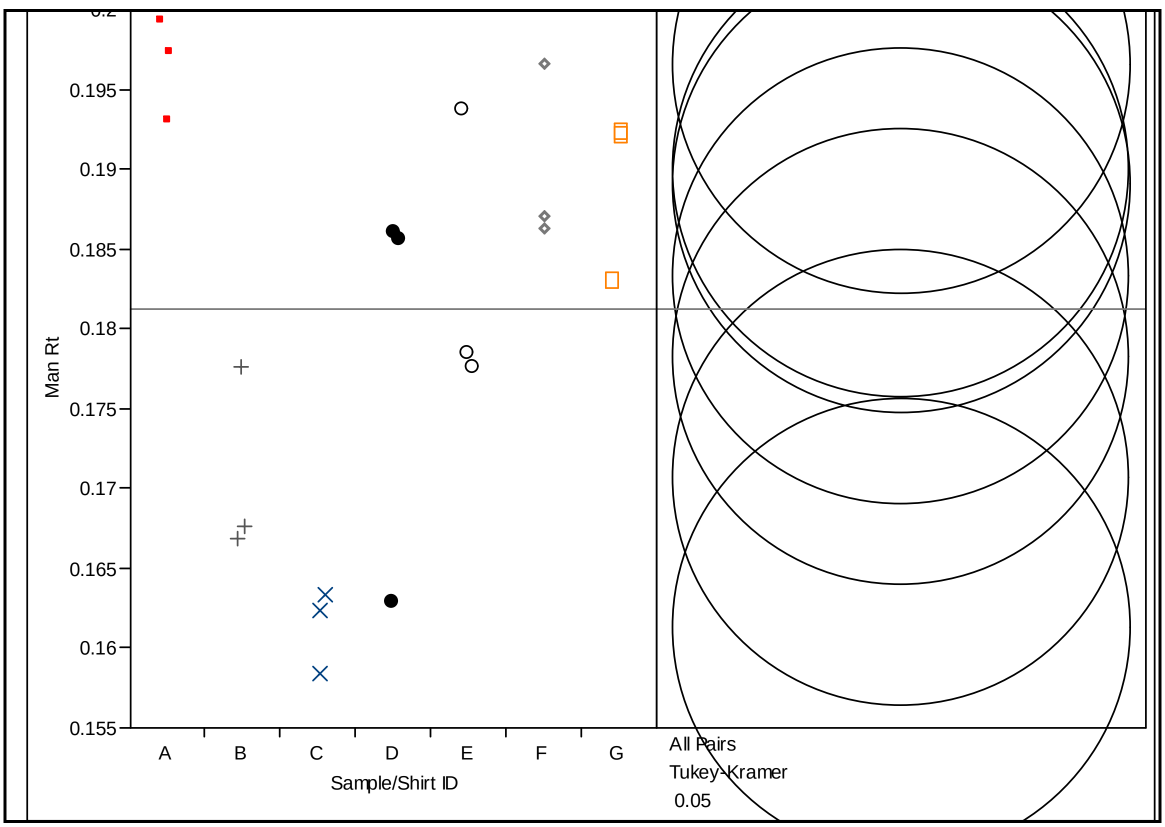

Figure A.71 – Data Points of Manikin Thermal Resistance (R_t)

Table A.86 – Analysis of Variance for Manikin Thermal Resistance (R_t)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	6	0.00267905	0.000447	8.4312	0.0005*
Error	14	0.00074143	0.000053		
C. Total	20	0.00342048			

Table A.87 – Tukey HSD Matrix for Manikin Thermal Resistance (R_t)

Abs(Dif)-LSD

	A	F	G	E	D	B	C
A	-0.02029	-0.01376	-0.01284	-0.00711	-0.00201	0.00551	0.01493
F	-0.01376	-0.02029	-0.01937	-0.01364	-0.00854	-0.00102	0.00840
G	-0.01284	-0.01937	-0.02029	-0.01456	-0.00946	-0.00193	0.00749
E	-0.00711	-0.01364	-0.01456	-0.02029	-0.01519	-0.00767	0.00175
D	-0.00201	-0.00854	-0.00946	-0.01519	-0.02029	-0.01276	-0.00335
B	0.00551	-0.00102	-0.00193	-0.00767	-0.01276	-0.02029	-0.01087
C	0.01493	0.00840	0.00749	0.00175	-0.00335	-0.01087	-0.02029

Positive values show pairs of means that are significantly different.

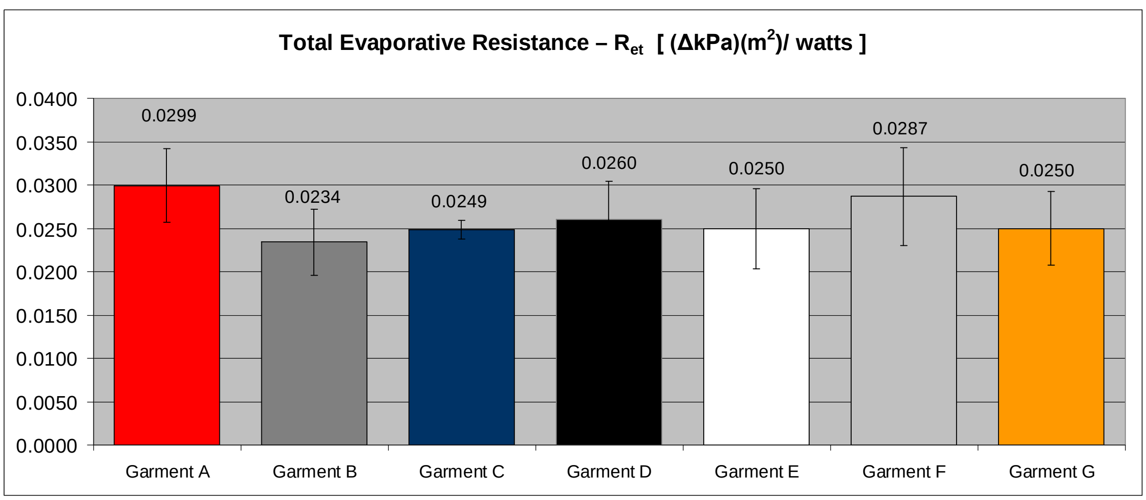

Figure A.72 – Data Average for Manikin Evaporative Resistance (R_{et})

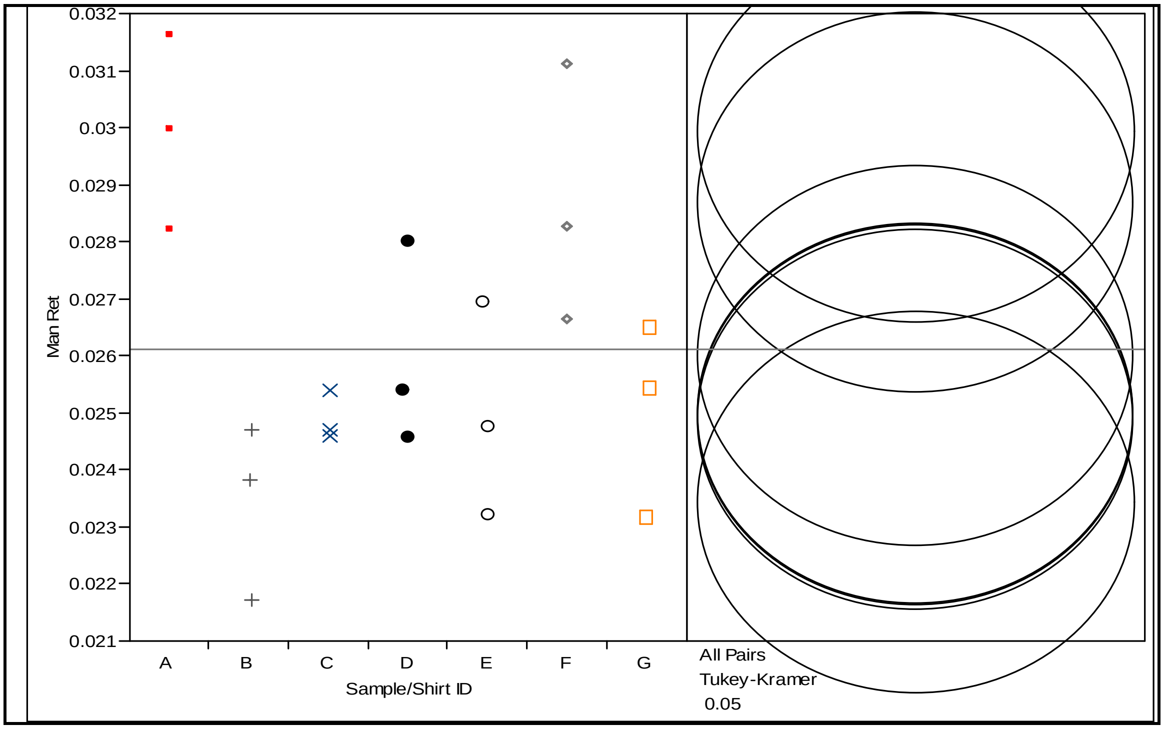

Figure A.73 – Data Points of Manikin Evaporative Resistance (R_{et})

Table A.88 – Analysis of Variance for Manikin Evaporative Resistance (R_{et})

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	6	0.00009751	0.000016	5.6307	0.0037*
Error	14	0.00004041	2.886e-6		
C. Total	20	0.00013791			

Table A.89 – Tukey HSD Matrix for Manikin Evaporative Resistance (R_{et})

Abs(Dif)-LSD

	A	F	D	G	E	C	B
A	-0.00474	-0.00350	-0.00081	0.00020	0.00023	0.00031	0.00176
F	-0.00350	-0.00474	-0.00204	-0.00104	-0.00101	-0.00093	0.00053
D	-0.00081	-0.00204	-0.00474	-0.00373	-0.00370	-0.00362	-0.00217
G	0.00020	-0.00104	-0.00373	-0.00474	-0.00471	-0.00463	-0.00317
E	0.00023	-0.00101	-0.00370	-0.00471	-0.00474	-0.00465	-0.00320
C	0.00031	-0.00093	-0.00362	-0.00463	-0.00465	-0.00474	-0.00328
B	0.00176	0.00053	-0.00217	-0.00317	-0.00320	-0.00328	-0.00474

Positive values show pairs of means that are significantly different.

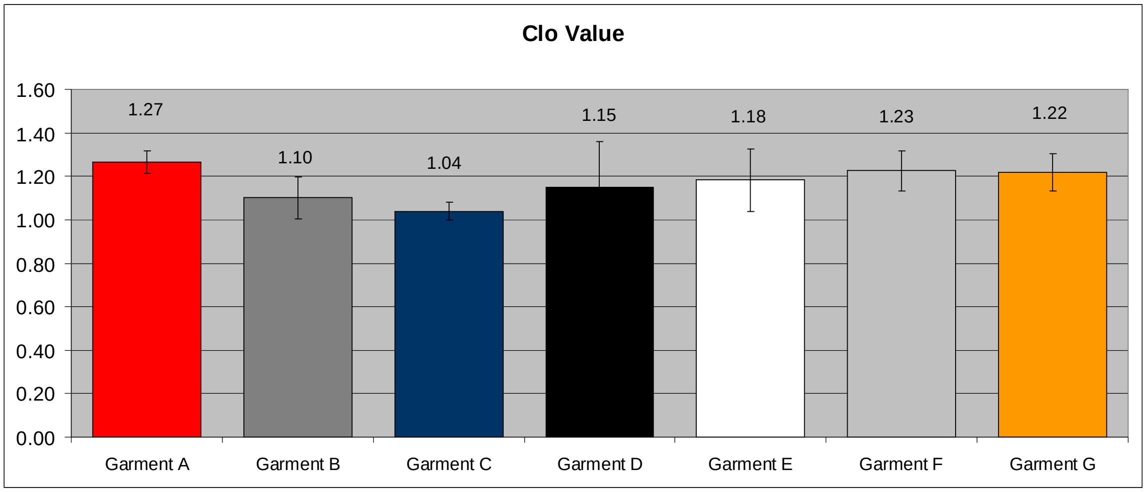

Figure A.74 – Data Average for Manikin (clo)

Table A.90 – Analysis of Variance for Manikin (clo)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	6	0.11145527	0.018576	8.4312	0.0005*
Error	14	0.03084514	0.002203		
C. Total	20	0.14230042			

Table A.91 – Tukey HSD Matrix for Manikin (clo)

Abs(Dif)-LSD

	A	F	G	E	D	B	C
A	-0.13086	-0.08875	-0.08284	-0.04587	-0.01299	0.03554	0.09630
F	-0.08875	-0.13086	-0.12495	-0.08798	-0.05510	-0.00657	0.05419
G	-0.08284	-0.12495	-0.13086	-0.09389	-0.06101	-0.01248	0.04828
E	-0.04587	-0.08798	-0.09389	-0.13086	-0.09799	-0.04945	0.01130
D	-0.01299	-0.05510	-0.06101	-0.09799	-0.13086	-0.08233	-0.02158
B	0.03554	-0.00657	-0.01248	-0.04945	-0.08233	-0.13086	-0.07011
C	0.09630	0.05419	0.04828	0.01130	-0.02158	-0.07011	-0.13086

Positive values show pairs of means that are significantly different.

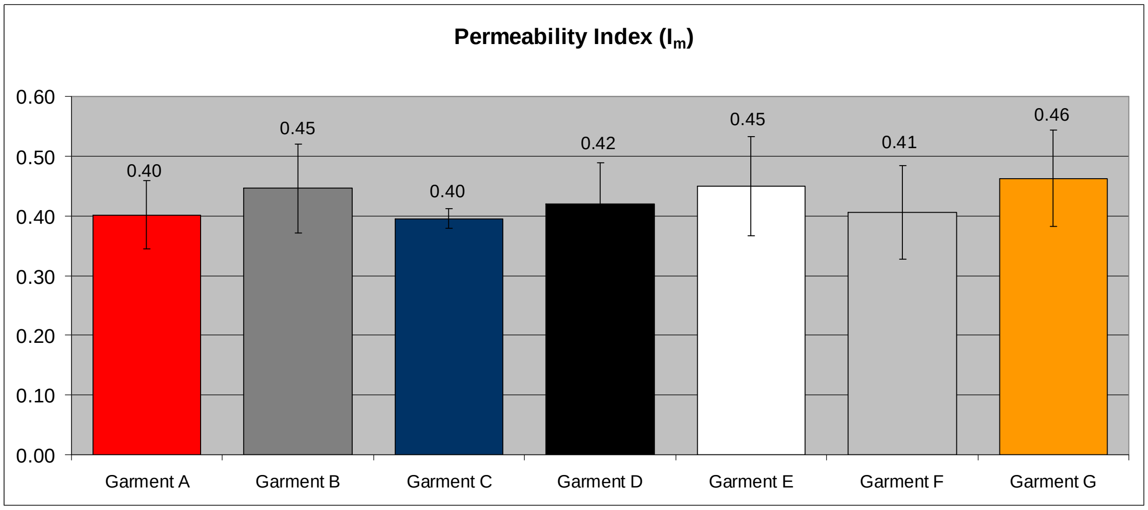

Figure A.75 – Data Average for Manikin Permeability Index (i_m)

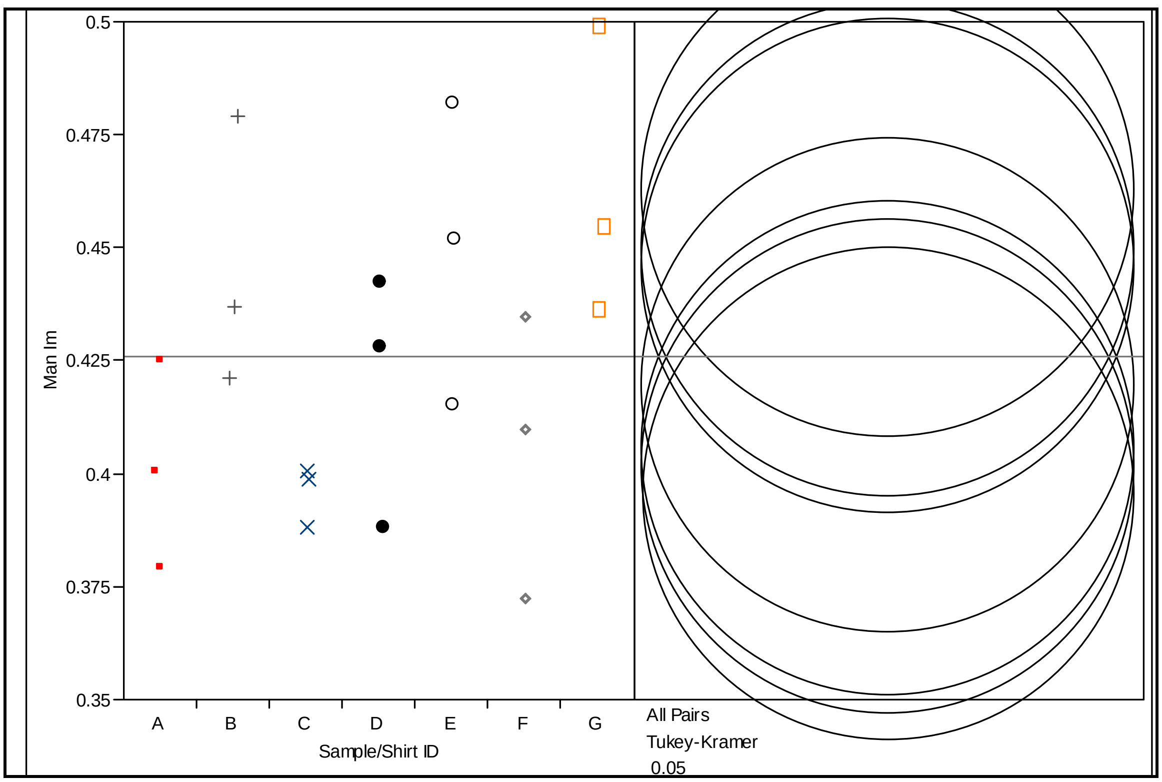

Figure A.76 – Data Points for Manikin Permeability Index (i_m)

Table A.92 – Analysis of Variance for Manikin Permeability Index (i_m)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	6	0.01292584	0.002154	2.7891	0.0534
Error	14	0.01081347	0.000772		
C. Total	20	0.02373931			

Table A.93 – Tukey HSD Matrix for Manikin Permeability Index (i_m)

Abs(Dif)-LSD

	G	E	B	D	F	A	C
G	-0.07748	-0.06420	-0.06037	-0.03407	-0.02018	-0.01596	-0.01003
E	-0.06420	-0.07748	-0.07365	-0.04735	-0.03346	-0.02925	-0.02332
B	-0.06037	-0.07365	-0.07748	-0.05118	-0.03729	-0.03308	-0.02715
D	-0.03407	-0.04735	-0.05118	-0.07748	-0.06359	-0.05938	-0.05345
F	-0.02018	-0.03346	-0.03729	-0.06359	-0.07748	-0.07327	-0.06734
A	-0.01596	-0.02925	-0.03308	-0.05938	-0.07327	-0.07748	-0.07155
C	-0.01003	-0.02332	-0.02715	-0.05345	-0.06734	-0.07155	-0.07748

Positive values show pairs of means that are significantly different.

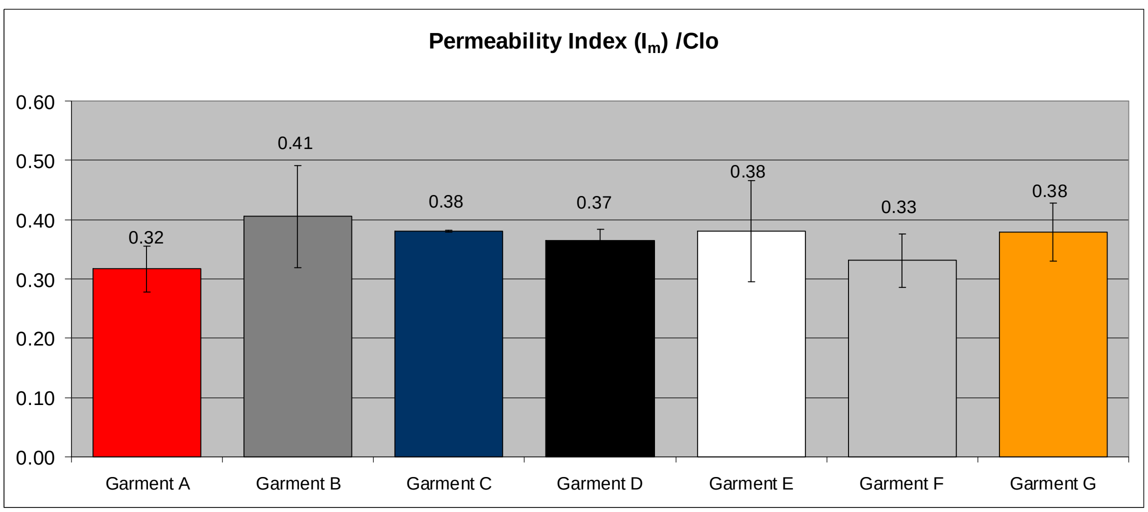

Figure A.77 – Data Average for Manikin (i_m/clo)

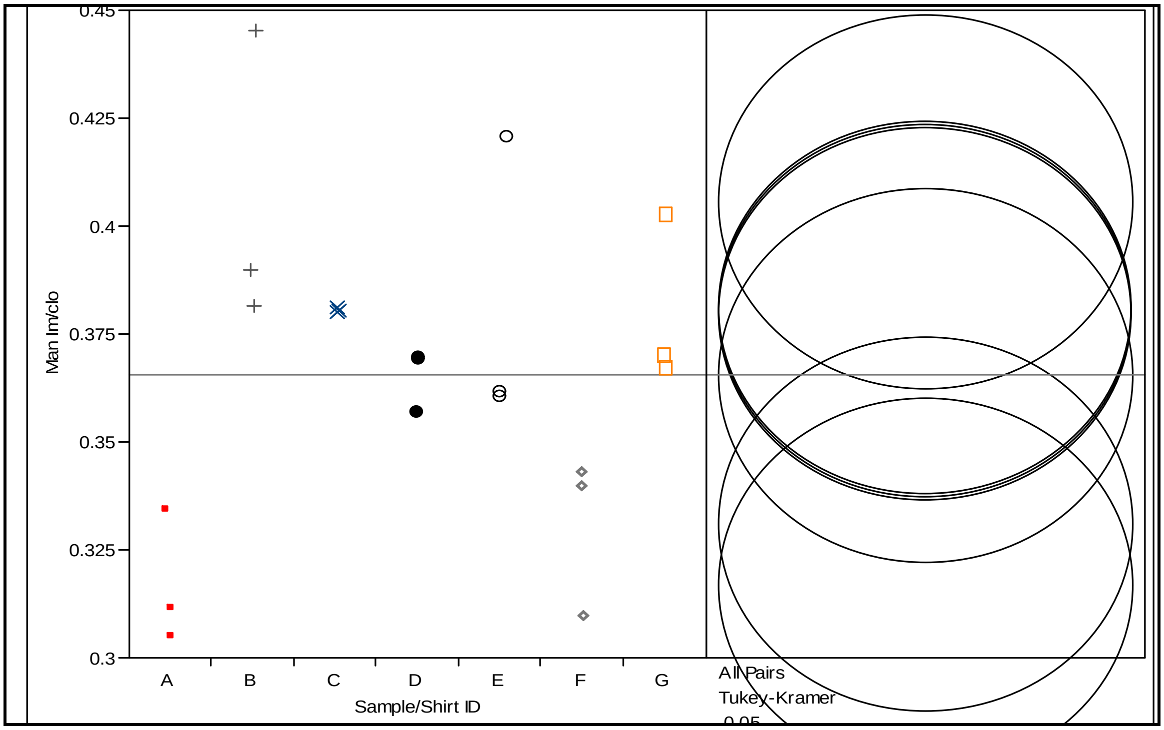

Figure A.78 – Data Points for Manikin (i_m/clo)

Table A.94 – Analysis of Variance for Manikin (i_m/clo)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	6	0.01750615	0.002918	6.0248	0.0027*
Error	14	0.00677988	0.000484		
C. Total	20	0.02428604			

Table A.95 – Tukey HSD Matrix for Manikin (i_m/clo)

Abs(Dif)-LSD

	B	E	C	G	D	F	A
B	-0.06135	-0.03677	-0.03608	-0.03537	-0.02102	0.01330	0.02747
E	-0.03677	-0.06135	-0.06066	-0.05995	-0.04560	-0.01128	0.00289
C	-0.03608	-0.06066	-0.06135	-0.06064	-0.04630	-0.01197	0.00220
G	-0.03537	-0.05995	-0.06064	-0.06135	-0.04701	-0.01268	0.00149
D	-0.02102	-0.04560	-0.04630	-0.04701	-0.06135	-0.02703	-0.01286
F	0.01330	-0.01128	-0.01197	-0.01268	-0.02703	-0.06135	-0.04718
A	0.02747	0.00289	0.00220	0.00149	-0.01286	-0.04718	-0.06135

Positive values show pairs of means that are significantly different.

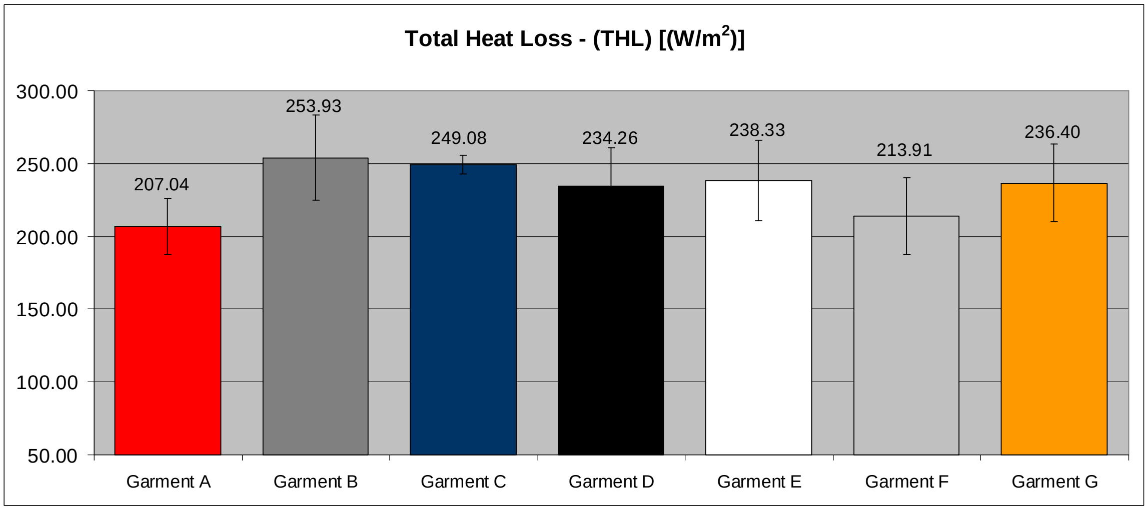

Figure A.79 – Data Average for Manikin Total Heat Loss (THL) – (in W/m^2)

Table A.96 – Analysis of Variance for Manikin Total Heat Loss (THL)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Sample/Shirt ID	6	5327.8853	887.981	9.2451	0.0003*
Error	14	1344.6890	96.049		
C. Total	20	6672.5743			

Table A.97 – Tukey HSD Matrix for Manikin Total Heat Loss (THL)

Abs(Dif)-LSD

	B	C	E	G	D	F	A
B	-27.323	-22.477	-11.730	-9.798	-7.662	12.690	19.567
C	-22.477	-27.323	-16.577	-14.644	-12.509	7.843	14.720
E	-11.730	-16.577	-27.323	-25.391	-23.255	-2.903	3.973
G	-9.798	-14.644	-25.391	-27.323	-25.188	-4.836	2.041
D	-7.662	-12.509	-23.255	-25.188	-27.323	-6.971	-0.095
F	12.690	7.843	-2.903	-4.836	-6.971	-27.323	-20.447
A	19.567	14.720	3.973	2.041	-0.095	-20.447	-27.323

Positive values show pairs of means that are significantly different.

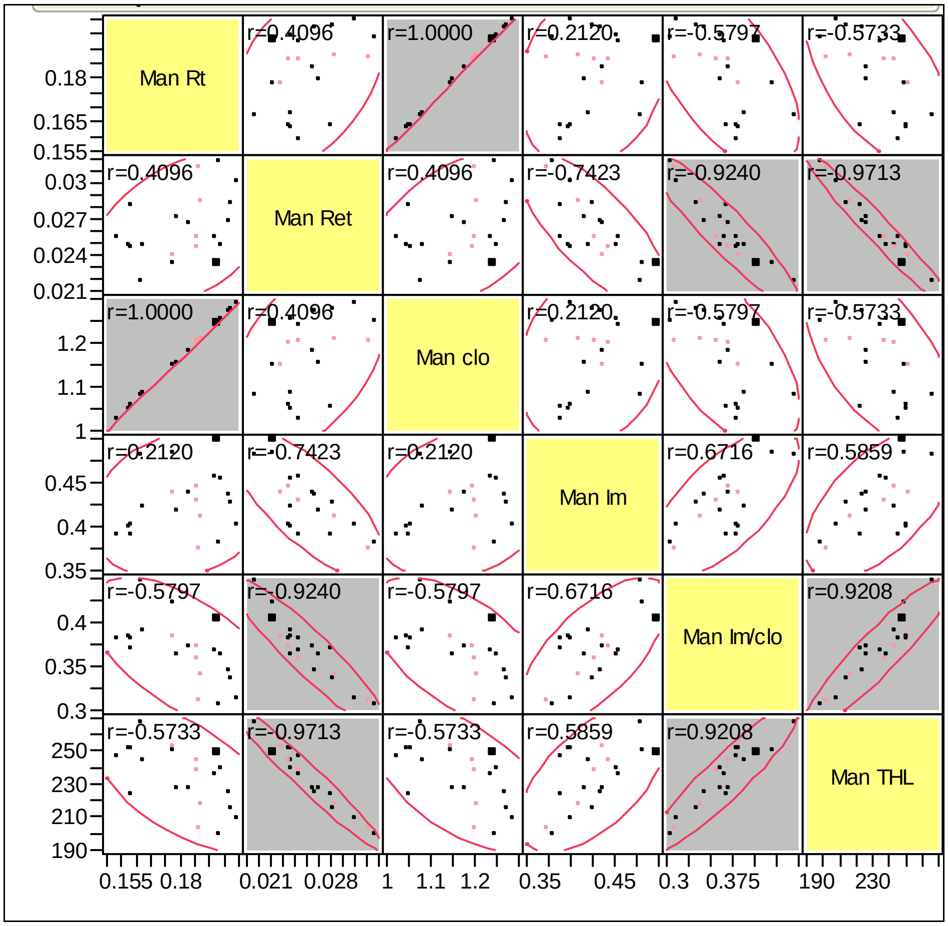

Figure A.80 – Correlation Table of all Manikin Measures

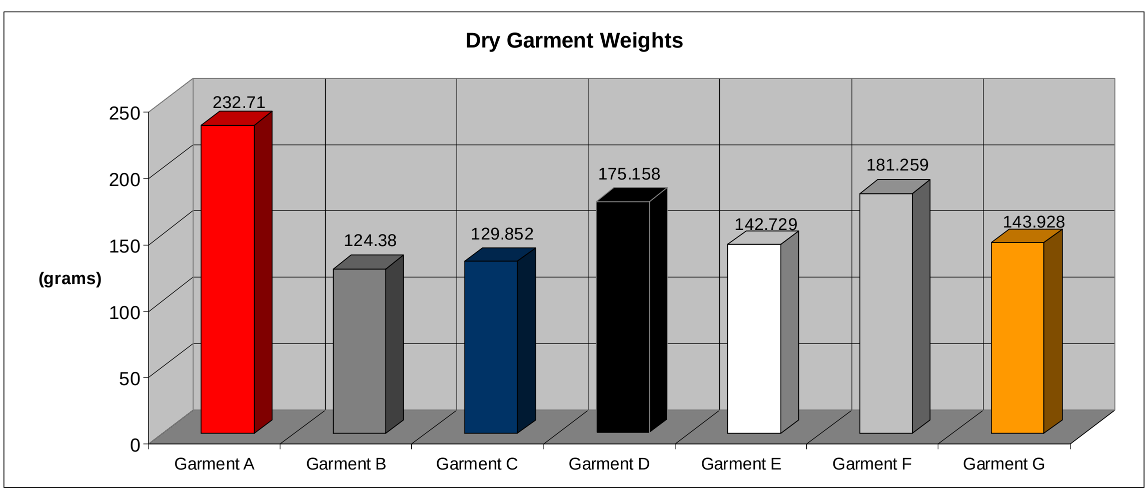

Figure A.81 – Data Average for Dry Garment Weights (grams)

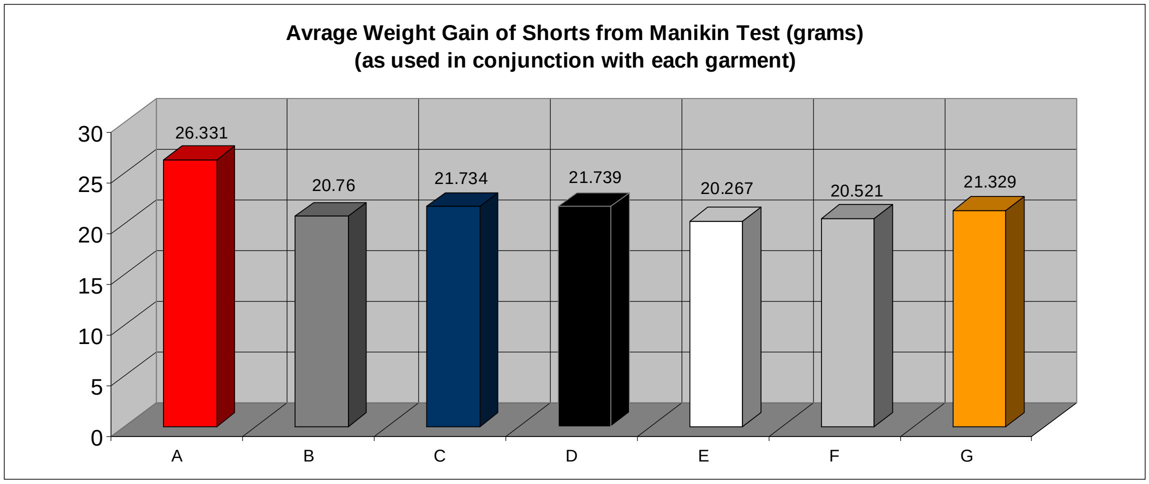

Figure A.82 – Data Average for Weight Gain of Shorts Used With Each Garment