TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

Thermo-physiological comfort analysis of traditional indian clothing (Sarees)

Master Thesis

Study programme: N3106 Textile Engineering
Study branch: Clothing and Textile Engineering

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Master Thesis Assignment Form

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Rules for Elaboration:

1. Elaboration of research on physiological clothing and testing possibilities.
2. Collection of samples, minimum 5 samples of Sarees with different fiber properties. The experimentation involves thermos physiological comfort properties of Sarees and following devices according to define standards will be used.
3. Evaluation (Comparison) of the test results: To identify the quality and comfort level of sarees worn by the masses on daily basis in India.
4. Outcome and Results: The research work will identify the comfort level of Sarees and will also provide information if the Sarees (a loose fit garment) can be tested on the thermal manikin or not.

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- BHATIA, D., MALHOTRA, U. Thermophysiological Wear Comfort of Clothing: An Overview. J Textile Sci Eng, 2016, 6, 250. doi:10.4172/2165-8064.1000250.
- LEI, Z. Review of application of thermal manikin in evaluation on thermal and moisture comfort of clothing. Journal of Engineered Fibers and Fabrics. 2019, 14. doi: 10.1177/1558925019841548.
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- RANAVAADE, V. P. A semiotic study of the Indian sari. Clothing and Textile [online]. June 2017. [Accessed 9 January 2020]. Available from: http://hdl.handle.net/10603/189648.

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ABSTRACT

The traditional Indian clothing holds a market share of more than 30% in the Indian Fashion industry and projected to grow stronger by 2023 despite the westernization of the Indian population. The purchasing power and the community of India ensure that traditional Indian clothing will be one of the most prevailing segments in global fashion. Despite the emergence of Indo – western garments in Indian attire, Sarees remains the most authentic and well-identified form of traditional Indian clothing.

This research aims to explore the suitable combination of fabrics variables for engineering Sarees with good thermophysiological properties. Thermophysiological properties of textile greatly determine the transport of heat, moisture vapor, and liquid moisture from the skin to the environment through clothing and, therefore, crucial to provide comfortable microclimate to the wearer. The study plans to collect five contemporary designs of Sarees draped in the most contemporary style from different parts of India with different fiber properties and test them for various identified parameters of thermophysiological comfort. The certified tests like ASTM F2370-05, EN ISO9237, and ISO 11092 will be carried out in a controlled environment replicating the hot and humid climatic conditions in India to achieve accurate results for measuring physiological comfort factors such as heat and mass transfer, air permeability and water vapor permeability.

The study will have significant implications in the academia by elaborating on the testing possibilities in traditional clothing verifying whether Sarees (a loose fit garment) can be tested on the thermal manikin or not. It can further help to lay the groundwork for physiological comfort testing of traditional clothing from other parts of the world. The research also has empirical benefits to the industry practitioners in the Indian Ethnic wear by presenting a comparative analysis of the quality and comfort level of different types of sarees worn by the masses in India daily.

Keywords: Sarees, Thermophysiological comfort, Air permeability, Water vapor permeability, Thermal resistance, thermal manikin, Clothing comfort

ABSTRACT

Podíl tradičního indického oblečení na indickém oděvním trhu je více než 30%, a předpokládá se, že toto procento poroste do roku 2023. Stále se rozrůstající indická populace a její kupní síla zajištují zvyšující se poptávku po tradičních indických oděvech i navzdory vlivu západní civilizace. Dle předpokladů bude tradiční indický oděv významnou částí světového oděvního trhu. I přes vznik indo-západního oděvu zůstává klasické Sárí nejautentičtějším tradičním indickým oděvem.

Cílem tohoto výzkumu bylo prozkoumat vhodnou kombinaci proměnných parametrů pro výrobu Sárí s dobrými termofyziologickými vlastnostmi. Termofyziologické vlastnosti textilu do značné míry určují přenos tepla, vlhkosti a kapalné vlhkosti z pokožky do okolního prostředí pomocí oděvů, a jsou zásadní pro poskytnutí pohodlného mikroklimatu uživatele. Studie shromáždila pět současných návrhů Sárí v nejmodernějším stylu z různých částí Indie s různými vlákennými vlastnostmi. Vzorky byly zkoušeny na rozličné identifikované parametry termofyziologického pohodlí. Byly prováděny certifikované zkoušky jako ASTM F2370-05, EN ISO9237 a ISO 11092 v kontrolovaném prostředí napodobujícím teplé a vlhké klimatické podmínky v Indii. Záměrem bylo dosažení přesných výsledků přenosu tepla, hmoty a propustnosti vodní páry a vzduchu, které určují měření fyziologického pohodlí.

Studie má významnou hodnotu pro vědeckou činnost. Zabývá se možnostmi testování tradičního indického oděvu Sárí (volně padnoucího oděvu) a jeho možnostmi testování na tepelné figuríně. Tato studie položila základy pro testování fyziologického pohodlí tradičního oděvu z různých částí světa. Významnou částí studie jsou srovnávací analýzy kvality a pohodlí různých etnických typů Sárí, které jsou nošeny početnou indickou populací každý den.

Klíčová slova: Sárí, Termofyziologický komfort, Propustnost vzduchu, Propustnost pro vodní páru, Tepelný odpor, Tepelná figurína, Oděvní komfort

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CHAPTER 1: LITERATURE REVIEW

1.1 INTRODUCTION

Clothing, foods, and shelter are the three most widely accepted basic needs of human beings. Food nourishes the body for proper functioning, and shelter gives protection from the natural elements present on this planet like sun, rain, pollutants. [1] Clothing comes with a broader sense, gives immediate protection, and covers the whole body and even caters to social responsibilities. Clothing further divided into garments, footwear, and other accessories. Enhancing or imparting aesthetic appeal is one of the primary responsibilities that catered by clothing. From the point of the functions, garments provide a suitable environment for the human body to maintain the comforts. [2]

Over a period, clothing has evolved from the basic to extravagant, from traditional to modern. Now clothing gives an identity to the individual and reflects the social, cultural, and economic background of a person. [3] This research focuses on such garments that have traveled a long way maintaining its traditional identity and yet appealing to modern outlook- SAREE of India, the traditional woman wears widely accepted and respected by a modern Indian woman.

1.2 INDIAN TRADITIONAL WOMAN WEAR

1.2.1 Reasons for traditional wear

An essential factor that determines clothing over time is typically correlated with factors like geographic location, climate, and history. This can also apply to economic, social, and religious status. It is said that in ancient times the Aryan invaders from Central Asia traveled through the Hindukush mountains, brought with them the use of leather and animal skin used as protection against the elements. However, the tropical climate of the Indian subcontinent had to give up the use of leathers regularly in favor of cotton and linen, most notably in the Indo-Gangetic plains, due to their abundance and the comfort of use.

The land of diversity is the definition for India, each state has their unique weaving, dyeing, and fabric printing style, be it the Mundum Neriyathum, the traditional, off white golden bordered Saree from Kerela, Langa Voni and Kalamkari from Andhra Pradesh, Kanjivaram from Tamil Nadu, Lugda sarees from Maharashtra or the Mekhela Chadar from Assam. Saree gives them a root, and they are in their way very similar to the traditional saree and different. [4]

The material used in the different garments vary from cotton to the different types of silks depending on the availability in that area, case in point being Muga silk was the most widely used material for the weaving of Mekhela Chadar in Assam during earlier times because cotton was scarce there. However, now with the availability of cotton freely, Muga has become a luxury item instead of cotton.

The occasion also determines the color and material of the saree, like red is considered to color for celebration, that is why one can find the brides wearing red silk, yellow is the color for hope and prosperity, which is why people tend to wear sarees in religious functions. [5]

1.2.2 History and culture of Saree

The saree is one of the oldest pieces of garment that has been in use. There are records as far back as the Indus Valley Civilization that depicts a kind of saree being used by women at that time, which makes it one of the oldest pieces of the garment in human history, rivaled only by perhaps the loincloth and trouser. [6]

It is believed that the saree emerged from a three-piece ensemble consisting of unstitched fabric one-piece draped over the lower torso, a chest band, and another segment of fabric as a covering one's shoulder or head. [6] Today, the most widely accepted and used form of saree consists of a long piece of unstitched fabric, ranging from 4 yards to 9 yards, that is draped around the lower torso and then pleated across the upper torso to cover the bust and shoulder and occasionally the head. According to legends, it is stated that stitching a fabric makes it impure, that is the reason that it is worn unstitched even today. [6]

The Aryans brought with them the word 'Vastra.' Traveling from the cold North, they adopted the style of draping the cloth around the waist as they moved toward the Southern part of India, shedding their leather ensembles in the process. The process of dyeing with vegetables and floral sources seems to have developed during this period. [7]

Every succeeding entry of a new culture into the milieu of India introduced something new into the way people dress, the Greeks and Persians were no different, and they brought their aesthetics with them. The Greeks used to wear a belt, cummerbund, at the waist, and the

Persians women wore their garments tied to their neck and belted to their waists. The Persians are said to have been the first to introduce the art of stitching to India, and during this time, the style of wearing tight-fitting blouses, called 'Cholis' first started. The Persians also introduced the elegant art of encrusting pearl and other precious stones into fabrics. [7]

During the Mughal reign, India experienced yet another significant change in sarees. The Mughals were fond of luxurious clothes and extravagant designs, and this can be seen in their choice of fabrics and the embellishment. They learned the art of sewing and were fascinated by silk clothes. During this time, the modern style of the draping sarees worn with a petticoat and blouse, called the Nivi style, also emerged [7].

The next stage of development of the saree came in the British Raj, who brought with them their methods of mechanized production and woven designs. During this era, the saree began to be prized all over the world as a piece of art rather than just a simple piece of fabric. Merchants and Noblemen from Europe commissioned great pieces in luxurious fabrics and intricate designs [8].

1.2.3 Reasons for wearing the Saree

Sarees have always been important to Indian culture, and its popularity can be gauged from the fact that it is worn on almost all occasions, whether on special occasions and as a daily attire, granted the material used for making it will change, and the amount embellishment will vary. However, there is a commonality in the wardrobe of an Indian woman, among thousands of other things there would at least be a saree in her wardrobe, be it a borrowed one for a special occasion or one passed on from her mother or grandmother.

Sarees have long come to be associated with womanhood in Indian culture, that is the reason, traditionally girls have gifted their first sarees after they reach puberty, which signifies their first steps in womanhood. In Indian weddings, one is most likely to find the bride dressed up beautifully in a red saree or lehenga, which is, in a way start of a different phase in her journey.

1.2.4 Present circumstances of the Saree

Since the late 1990s, most sarees worn by workers were made from synthetic and blended materials. While the yarn is mostly spun in major mills, the weaving process can vary from the handloom to the large mills to the power-loom sector in between the two extremes. [9]

The reason for the popularity of synthetic materials is that the cost is substantially less as compared to natural fibers and that synthetics are easier to maintain on a day-to-day basis.

Today one can find Sarees on the ramps of major fashion shows in India and the world. Designers like Prabal Gurung have showcased saree inspired garments on the runway of the New York Fashion Week, and one can regularly find Indian invitees to significant events like the Cannes Festival wearing sarees, which has allowed the humble saree transcend the Indian subcontinent and into prominence around the fashion world. [10] Saree trends have changed according to the times, be it the heavily embellished sarees during the Raj era to the minimalistic saree of the last decade and the return to the root resurgence of handloom sarees in the last couple of years. [9] It is said that the only thing constant is change, and we will find that saree will also evolve with the changing times, with more use of eco-friendly production techniques and more emphasis being given to the comfort of the wearer.

1.2.5 Saree as an attire

Saree is a single piece of unstitched strip of cloth. Only women wear sarees mostly in South Asia and in other places across the globe. It is used since millennia, circa 3000 BC. Indian women mostly used traditional ensembles at work [11]. Unlike western wear the saree is worn as an ensemble and not as different pieces of garments assembled together.

Data on Indian traditional ensembles are not fully represented in the present building standards [12]. More over detailed comfort analysis requires segmental level information on clothing insulation to understand local discomfort of occupants [13]. Being a ‘one-size-fits – all’ ensemble, it lends itself to a high degree of customization and acclimatization at wearer’s level. However, the present codes and published information on saree and similar ensembles do not address the importance of drapes on clothing insulation [14].

As reported earlier on the versatility of the saree in climate adaptation using different drapes. [15]. Extending this work, we report the segmental level and whole-body insulation of 41 different saree ensembles in this paper. In addition, we also present these values for eleven different traditional ensembles for both the genders.

The ensemble

This ensemble has three pieces of garments essentially: a saree, a short blouse or bodice and a petticoat. Saree measures 5.0 – 8.1 m in length and 1.15 to 1.25 m in width. The length usually depends on the draping style. The most common type of saree measures 5.0 - 6.0 m, width being the same, used in this study. A strip of underlining (2 -2.5 m long and 75 – 100 mm wide) is usually attached at the bottom boarder of the saree to improve the drape and durability of the saree.

India has rich and varied textile tradition and sarees can be found in very diverse fabrics, designs and embellishments. In this study we used sarees in silk, silk chiffon, handloom and milled cotton and polyester and nylon fabrics, common to the normal saree stock.

A bodice or blouse as is referred to in India is a stitched tight fitting garment few inches above the navel. It is usually made in fine cotton or in the same fabric as that of the saree. Some bodices have cotton underlining. The necklines and shoulder lengths are a matter of fashion and user's choice. In this study we tested the blouses with deep and medium depth necklines and short and medium shoulder lengths. The blouse fabrics are cotton, silk, polyester in this study, with the non-cotton blouses being provided with thin cotton interlining.

A petticoat is a conical shaped, drawstring ankle length skirt worn under the saree. Stitched in cotton, polyester or satin, it holds the saree in place, provides fullness and mobility to the wearer. We used cotton, polyester and satin petticoats in this study. Indraganti et al. [15] described the articles used in the typical saree ensemble in greater detail.

The drapes

The saree can be draped in over a hundred different ways, the most common one being the '*nivi*' style of draping. In this study we used the *nivi* style of draping for all the ensembles. This essentially has the saree wrapped around the petticoat in two layers. The second layer has frills or folds at the center front, which gives the attire fullness. The second layer also covers the belly and the chest in a diagonal manner, the other end of which is the *pullu*. A detailed pictorial description of draping of saree can be found in Boulanger [16].

1.3 CLOTHING COMFORT

The aim of modern consumers is mostly focused on comfort, aesthetic appeal, and ethics [17,18]. Comfortable clothing comprises characteristics like natural body movement, thermal comfort, fittings, suitability, and other physiological factors [19-23]. There are four main categories to define the function of clothing: Protection, adornment, modesty, and status. [24] According to Slater [25], comfort is defined as "*a pleasant state of physiological, psychological, and physical harmony between human beings and the environment.*"

These are classified into three categories:

1. **Physiological comfort**- Capability to sustain life.
2. **Psychological comfort**- With the help of external factor satisfies the functioning of the mind.
3. **Physical comfort**- Outside environment impact.

According to Fris [26], garment comfort is a subsequent result of the heat exchange phenomena between the outside environment of wearers' body and garment. The primary concern implies the ability of the clothing to provide and maintain appropriate micro-climate. Since garments protect the human body from sudden or frequent changes in temperature (thermal shock) and transfer heat and moisture to the environment from the skin. Clothing is regarded as the first layer of protection from the surrounding and create a comfortable microclimate. Metabolism of the human body or the external environmental condition may also generate heat [27-28]. According to Hatch [29], comfort is defined as *"freedom from pain and discomfort as a natural state."*

To keep the human body thermally comfortable, the garment must protect the user from inadvertent heat loss because of lower external temperature and must retain metabolic heat and stop the influx of heat in response to higher external temperature. Several factors affect metabolic heat in humans viz., dietary habits, amount of physical activities, or the lack of it and BMI. Clothing ensembles' performance in regards to the thermal physiology of the human body varies greatly depending on the material used to craft it, the design of the ensemble, and the construction. Therefore, the assessment of clothes on the metric of thermal comfort is very significant in understanding the comfort of users [30].

1.3.1 Thermal comfort

A person's physical and mental performance is greatly affected by its response to the external environment. Moreover, clothes provide an effective way for the body to achieve a modicum of comfort irrespective of the external factors.

As mentioned above, clothing's thermal comfort simply refers to the ability of the clothing to help maintain the body's temperature within a specific limit. In cases of excessive cold or very high temperatures, the body's internal mechanism for thermal-comfort regulation will fail, which is when it becomes necessary for the person to wear clothing that supports his/her body to resist or facilitate the metabolic exchange heat with the environment [31]. Case in point being in an extremely cold climate, the ideal garment would be one, which does not let body heat to outflow and therefore maintain a comfortable cocoon for the body. [32].

The ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) defines thermal comfort as being "the condition of the mind in which satisfaction is expressed with the thermal environment" [33]. Clothing thermal comfort is the ability of clothing to help the human body to maintain a state of thermal comfort through its performance [2]. The interaction between the factors of clothing, ambient climate, and level of physical activity defines the level of thermal comfort [17].

Thermal comfort is primarily associated with the process of thermoregulation, which means that the body needs to sustain a required temperature of approximately 37° C by either dissipating heat or by conserving it [34]. Any change in this temperature can increase the feeling of discomfort in the body in response to the effects of warm or cold sensations [35]. The standard temperature for human physiology is 37± 0.5° C [35], and prolonged exposure to temperatures significantly beyond the comfort zone can lead to illness. In cases when someone exposed to extreme climatic conditions and the body is unable to thermo-regulate owing to the destabilization of core body temperature, it can even lead to death, such as in case of hypothermia or heat-stroke. Hot environments demand garments that facilitate the release of heat from the human body to the environment [36].

Heat balance

Heat balance is the measure of the rate of heat production heat loss to maintain a balance in the human body. The human body will be in a state of thermal equilibrium when the rate of loss of heat to the environment is the same as the rate of heat gain [37]. The blood circulatory system regulates the temperature of the body as it circulates from the internal organs to the skin where evaporation, convection, and radiation dissipate the body heat [38]. Thus, the primary function of clothing is to protect the body from external elements and aid in the function of thermal control when the body is working under a certain parameter of environment and physical activity [39]. If we are to explain the concept of the heat balance of the human body as a mathematical equation, it can be thus, Equation 1.1 [40]:

$$M - W = C + R + E_{sk} + C_k + (C_{res} + E_{res}) \quad \textit{Equation 1.1}$$

where,

M is the metabolic rate (internal energy production W/m2)

W is the external work (W/m^2)

C is the heat loss by convection (W/m^2)

R is the heat loss by thermal radiation (W/m^2)

E_{sk} *is the heat loss by evaporation from the skin* (W/m^2)

Cres is the sensible heat loss due to respiration (W/m^2)

Eres is the evaporative heat loss due to respiration (W/m^2) *and*

C_k *is the heat loss by thermal conduction* (W/m^2).

1.3.2 The process of heat and moisture transfer through clothing

Heat transfer is the movement of heat from one material to another. The 2nd Law of Thermodynamics states that whenever there is a difference between the temperature of two systems, there will a transfer of heat till the time when the two systems achieve a state of thermal equilibrium [41]. This heat transfer takes place by two processes: sensible heat transfer and latent heat transfer. Sensible heat transfer happens by the method of conduction, convection, and radiation, and changes some macroscopic aspects of the system or body but leaves other aspects such as volume and pressure unchanged. Latent heat results in a change of state of the matter from solid to liquid or liquid to gaseous. The latent heat vaporization is the amount of energy required to change the state of a liquid to a gaseous state, and the latent heat of fusion is the amount required to induce a change from solid to liquid state [42]. Human perspiration can be classified into two types:

(a) **Insensible perspiration:** Insensible perspiration means loss of moisture from the skin without it forming any perspiration.

(b) **Active sweating:** Active sweating is induced in humans in response to heat, mental stimuli such a stress, and carbon dioxide [43].

Clothing serves as insulation between the external environment and the body [44]. There are two ways for the transference of heat from the clothing system to the environment: (a) dry heat loss (which occurs through transmission through fibers and air, radiation and convection) and (b) evaporative heat loss [45].

Conduction

Conduction is defined as the process of transferring heat between systems when they are in contact with each other [37]. In static substances, the conduction of heat is initiated by the interaction of liquid, gas molecules, solids, and free electrons, which leads to the flow of heat from the system at the higher temperature to a system of lower temperature [46]. Direct physical contact between the elements is necessary for heat transfer to occur. In other words, the higher temperature object must be in contact with the lower temperature object for heat transfer to take place. Conversely more the area of contact more is the amount of heat transfer [28]. The conductive heat transferring rate is directly proportional to temperature differential and inversely proportional to the distance over which conduction occurs [47].

Each fiber type conducts heat differently, but this difference becomes irrelevant when the fibers are converted into garments. Garments trap air and have considerably lower thermal conductivity than the fiber itself. Thus, the thermal conductivity of the garment is determined by the amount of air the garment traps [29].

Convection

Convection occurs when the molecules of gas or liquid around a heated object vibrate and transfer heat. Convection occurs by two means: (a) forced, in response to an external catalyst, such as a fan, or (b) naturally because of buoyancy and density differentials [37]. The motion of the fluid and temperature gradient are the elements that affect the rate of convection [42]. Changes in buoyancy forces because of temperature differences, such as the movement of warm air towards the upper reaches of the system, is one of the factors for natural convection

[31]. Heat exchange in a mixed system of liquid or gases takes place at a higher rate than in a homogenous system. In a clothing system, convection is achieved because of differences in air density in spaces between the body and the garment, external wind conditions, and bodily motion. Ventilation is an essential aspect of convective transfer of heat through clothing; it is the process of passing warm and moist air within the clothing system in exchange for cooler-dry air from the external environment without passing through fabric layers. A person walking in a well-ventilated area, ventilation can result in the passing of a significant amount of heat to the environment from the body [49].

Radiation

Radiation, the spread of heat in the form of electromagnetic waves with no need for intervening matter. All objects above the absolute zero, i.e., 0 K emit electromagnetic radiation, and Planck's Law gives the energy distribution of energy from all matter. The temperature of the surface to body determines the wavelength of waves emitted, with increase in temperature decreases the wavelength.in case the temperature around of the body is higher than the surrounding than the waves move away from the body and vice versa. The clothing warmer than the surroundings transmits heat to all surfaces that are cooler than it. As a person can step out of the heat of the sun by moving into the shadow of the tree, also placing a curtain before the window in winter can stop the loss of heat from a room.

Under any condition the infrared energy received by a surface can either be transmitted, scattered or absorbed. When it is absorbed, the energy raises the surface temperature of the recipient [37]. Wavelengths spectrum emits from the sun, where the temperature of the object determines the maximum wavelength, and ranges from the ultraviolet to the infrared regions passing through the visible region. The human body and its ambient surroundings, because of it relatively low temperature, can only emit infrared radiation. The fibers of our clothing scatter or absorb the heat from the sun, after it only travels a couple of millimeters. The fiber absorption and emission properties of fibers are based on the indirect radiant heat transfer taking place between any clothed body and the surroundings [48]. Air pockets in clothes allow radiant heat to move freely from the skin to the surroundings, as well as between the clothing materials themselves.

Evaporation

Evaporation takes place when water moves from liquid form into gaseous form. It is a fundamental thermoregulatory mechanism, and the liquid (sweat and perspiration) dissipates the heat from the body surface by this process [50]. Air volume, bodily movement, and low relative humidity (RH) of the surroundings cause moisture to evaporate from the body. When the evaporation of perspiration takes place from the surface of the skin, the human body loses the heat at the rate of approximately 450 calories, or 0.00188 MJ per gram of water, which is required for evaporation; as a result, cooling the body [44]. A person perspires when he is thermal, physiological and psychological stress and perspiration can be classified into sensible and insensible. The sensible sweat is sweat produced when body is under hot and energetic conditions while insensible is when sweat evaporates from the skin and released as vapor without it coming into a liquid form [44].

1.3.2.1 Dry heat transfer through clothing

Determination of different methods of transferring dry heat (mainly conduction, convection and radiation) can be done by determining the difference between temperatures of skin and environment. The equation (Equation 1.2) given below depicts the transfer of dry heat through clothing system [51].

$$Lt = A.\ (T_s - T_a)/\ R_t \qquad \textit{Equation 1.2}$$

where,

Lt is the dry heat transfer through the clothing system by conduction, convection or radiation

A is the surface area (m^2)

$(T_s - T_a)$ *is temperature difference between skin and environment (˚C)*

R_t *is the total thermal resistance of the clothing and the air layer outside the clothing surface; generally expressed in ˚C/W (ISO unit).*

To get a clothed person's body temperature cooled off, transfer of dry heat is insufficient during high activity levels or under high surrounding temperature. Therefore, in such case, perspiration evaporation is required from skin for the reduction of body heat [36, 37].

1.3.2.2 Evaporative heat transfer through clothing

To obtain temperature of the body surface, loss of evaporation is dependent upon ratio of air humidity and mass transfer coefficient. Unfelt or intangible heat loss due to skin diffusion combined with heat loss due to regular sweating creates evaporation-based heat loss. The processes of radiation, conduction and convection helps a human body in gaining heat or losing it whereas sweat evaporation is a cooling process in its entirety [37]. Evaporation performance can be better guaranteed by high ambient temperature and low relative humidity. Expression of sweat evaporation energy from skin can be seen in the below equation (Equation 1.3):

$$L_e = A.\ (P_s - P_a)/\ R_e \qquad \textit{Equation 1.3}$$

where,

L_e is the heat transfer by evaporation through clothing A is the surface area (m^2)

P_s is partial water vapor pressure at skin temperature (m^2Pa)/W

P_a is the partial water vapor pressure at ambient temperature (Pa); and

R_e is the total resistance to water vapor transfer through clothing and air outside the clothing surface (Pa. m^2/W) [50].

The human body during exercise, it produces sweat due to increase in body heat (in an assumed hot and dry environment). The body releases heat through dry and evaporative transfer and sweat will change into vapor through evaporation [50]. Thus, the total heat transfer (*L*) can be described by Equation 1.4.

$$L = L_t + L_e = A.\ (T_s - T_a)/\ R_t + A.\ (P_s - P_a)/R_e \qquad \textit{Equation 1.4}$$

Where,

L_t is the dry heat transfer through the clothing system by conduction, convection or radiation

L_e is the heat transfers by evaporation through clothing A is the surface area (m^2)

($T_s - T_a$) is temperature difference between skin and environment (°C)

R_t is the total thermal resistance of the clothing and the air layer outside the clothing surface and it is generally expressed in ° C/W (ISO unit)

Ps is the partial water vapor pressure at skin temperature (m^2.Pa)/W Pa is the partial water vapor pressure at ambient temperature (Pa); and

Re is the total resistance to water vapor transfer through clothing and air outside the clothing surface (Pa. m^2/W).

To keep the wearer comfortable, the garment must be able to facilitate moisture transfer with the environment, this can happen through diffusion, sorption or wicking [48]. Evaporation helps to remove moisture from both the skin as well as the surface of a textile fabric.

Diffusion

Diffusion is the primary process of moisture transference. Water vapor concentration in the external environment determines the rate of vapor transfer. Pockets of air spaces in between fibers and yarns provide paths of access for the moisture diffusion to occur. However, the thickness and porosity of fabric determine the effectiveness of diffusion process. A loose construction of the fabric enables greater diffusion of moisture and vice versa [36, 48].

Sorption

Sorption can be divided into three stages: adsorption, absorption and desorption. Adsorption is when the surface takes up the moisture and stores it. When the material diffuses molecular moisture, it can be said as absorption. In desorption, the material releases the absorbed and adsorbed moisture [36].

When the fibers of the fabric act as capillaries and the moisture is taken up and transferred, **wicking** takes place. For wicking to be effective, wettability of the fiber surface and the structure of yarn and fabric play an important part [48]. The greatest amount of wicking takes place when moisture regain is low. Wicking is in direct contrast to dispersion, where is directly proportional to absorbance [52].

The design and type of fabric used to make a garment needs to be considered when designing a garment to achieve comfort and produce a functional design [46]. The next sections will review the factors that affect thermal transfer in garments (fabrics) and the current methods used in the measurement of the same.

1.3.3 Factors related to heat transfer through clothing

External factors like ambient relative humidity, temperature and wind speed affect the transfer of heat through clothing. Andersson [53] has listed three factors related to thermal comfort, they are:

The material's thickness and air space between the skin and garment, which is a direct result of drape of the fabric.

The ability of air to permeate through the clothing both inherently and because of the wearer's motion or wind.

The ability of fabric to aid in the evaporation of perspiration and not block it.

Predicting the performance of a fabric in comfort parameters can be achieved through measurement of physical properties such as mass per unit area, thickness, evaporative resistance, thermal insulation, moisture management and air permeability [54-58]. These properties are briefly described below.

1.3.3.1 Air permeability

The air permeability of a fabric is the rate of airflow passing through a fabric per unit surface area at a differential pressure (EN ISO 9237: 1995). The factor of air passage plays a big role in evaluation and comparison of the 'breathability' of fabrics (coated and uncoated). This particularly significant in determining suitability of fabrics to be utilized in manufacture of raincoats, tents, uniform shirting, parachutes, industrial filter fabrics, sail cloth and covering fabrics such as pillows and duvets [59, 60].

Resistance to water vapor transmission has an indirectly correlation to air permeability of clothing materials. Therefore, fabrics with low air permeability materials are not preferred for making next-to-skin garments, as the factor of high latent heat transfer is essential for thermal comfort. Conversely, fabrics that have low air permeability are used in the manufacture of garments that will be worn in windy conditions, to reduce heat loss caused by air penetration [2].

The fiber type influences the air permeability of fabrics greatly (surface characteristics and fineness) along with yarn structure (geometry, count and hairiness), and the fabric construction (loop or stitch length, tightness factor, fabric thickness, density, and cover factor) [58, 61-65]. Cover factor is extent to which the area of a fabric is covered by one set of threads in relation to the total surface area. Having a high cover factor will result in low air permeability [66]. Ishtiaque et al. [67] indicated that yarn deformation properties within the fabric is an additional factor. In woven fabrics, Ogulata [60] highlighted a direct correlation between air permeability and the porosity rate, which is the ratio of free space to the area covered by yarns in a given volume of fabric [68]. Conversely, the air permeability of a woven fabric is inversely proportional to the number of warp yarns per centimeter. When Ogulata and Mavruz [69] evaluated plain knitted fabrics on the metrics of porosity and air permeability, they found the highest values of air permeability in fabric that had the lowest courses per cm and yarn count in tex. Longer loop length produces a loose fabric and which in turn increases air permeability.

Marmarali et al. [70] on comparison of the dimensional and physical properties (including air permeability) of single jersey fabrics made from cotton alone and cotton/spandex blends; found that fabrics that were made from spandex blends exhibited lower air permeability. Sundaramoorthy et al. [71] had advanced a model aimed at connecting the number of layers with the structural parameters of a single fabric and the air permeability of a multilayered woven fabric system, which indicated a hyperbolical decrease of air permeability with an increase in the number of layers.

The air permeability of the fabric will always play a significant role in the transport of moisture vapor from the skin to the outer environment. Karaguzel [68] identified the diffusion mechanism as the transfer of vapor in the air through fabric pores from one side of the fabric to the other. Jun et al. [72] investigated the microclimate inside caps and the effect of textile properties on the subjective wearing sensations of the wearer in stable environmental conditions. They found that because of a because of the formation of a stationary dense air layer of hair between the skin and the cap, water vapor could not transfer easily to the outside environment.

1.3.3.2 Evaporative resistance

The clothing materials usually obstruct the flow of heat and moisture from the skin to the outer environment. [73]. Salmon [74] identified SGHP as the most precise procedure for determination of thermal conductivity of insulation materials. Thermal resistance of a fabric is an important in the evaluation of the fabric's efficiency in providing a thermal barrier to the wearer [75].

People have investigated the thermal properties of different knitted and woven fabrics to understand the impact of materials and fabric construction [76]. Yoo and Kim [77] examined fiber type (cotton broadcloth and polyester (PET) broadcloth, and cotton canvas), air layer thickness, fiber type and garment openings to determine their effect on vapor pressure changes in the microclimate based on the vertical sweating skin model.

Greyson [78] and Havenith [79] noted that as material thickness increases and more air is trapped in the fabric, there is an increased resistance of heat and water vapor. Dhinakaran et al. [80] reported that the structure, weight, moisture absorption, types of raw materials used, heat transmission and skin perception are the main factors that affect the comfort characteristics of fabrics. Ozdel et al. [81] identified that an increase in yarn twist and count as well as water vapor permeability values decrease thermal resistance values. Karaca et al. [82] tried to find the correlation between thermal comfort of polyester fibres when produced in two different weave patterns (plain and twill) with different cross-sectional shapes (round, hollow round, trilobal and hollow trilobal). They found that fabrics made from hollow polyester fibers exhibit the highest thermal conductivity and thermal absorption values on one hand, and lower water vapor, thermal resistance and air permeability values on the other hand when compared to others. Moreover, the lowest thermal conductivity and thermal absorption level was found in the twill fabrics made from trilobal fibers but with the highest thermal resistance, water vapor and air permeability.

Kakvan et al. [18] examined the thermal comfort properties of Kermel© (polyamide-imide), cotton/nylon and cotton/nylon-blended Kermel©-woven fabrics. The results show that with an increase in the Kermel© fiber blend ratio, the fabric porosity, air permeability and thermal resistance are increased.

1.3.3.3 Clothing insulation using thermal manikin

In 1940s, the US Army developed the first thermal manikin comprising of a one-segment copper manikin with electrical circuits which provided uniform surface heating. These thermal manikins were created initially to investigate the thermal interaction between the human body and its environment, particularly in the design and fabrication of clothing due to its intrinsic thermal properties. The early versions of manikin however could not simulate human phenomenon of sweating and body movement [83, 84]. There is broad interest in utilizing the thermal manikins in research and measurement standards [84].

In the present scenario, manikins mostly incorporate mobility characteristics such as being movable and are equipped with more than fifteen body segments [84]. These manikins are created from variety of materials which provide a reliable, relevant and accurate heat loss measurements. The experiments comprise of not only flat 12 x 12 sets of layered fabrics, but also of three-dimensional garment ensembles [23]. Thermal manikins are put through extreme scenarios and experimental conditions which could prove be fatal to humans. Recently thermal or sweating manikins have helped to create more real-life simulations of thermal interaction with the environment incorporating methods which are quick, regulated and repeatable [83].

Thermal manikins are used to research broadly two significant areas, one is to assess the characteristics of heat transfer, and second is to check the influence of thermal environments such as clothing, sleeping bags, interiors, cars, and chairs on the human body [85, 86]. The following clothing factors can be varied to perform experiments with modern manikins [83, 85]:

- Amount of exposed skin and the amount of body surface area covered by textiles
- The non-uniform distribution of air and textile layers over the surface of the body
- Tightness or looseness of fit.
- Due to the fabric around skin, the heat loss surface area (i.e. clothing area factor)
- The effect of the product design
- The adjustments made for feature of garments like fasteners open, hood up.
- The temperature variations and heat flux on the different body parts.
- The variation in different body postures and position like standing, lying down.
- The variations while body is motion like walking, jumping, cycling.

Researchers have utilized manikins and explored the above features to objectively investigate clothing insulation and the thermal comfort properties of garments [86]. Manikins help assess the heat flow and heat loss from various parts of the body surface. Data collected is useful in estimating the body's performance of thermal and evaporative resistance ratio in various clothing and climatic conditions [45, 85, 87-91].

One of the measurement technologies of the Newtons model is sweating manikin that accommodates ISO 9920 and ASTM F-1291-05, ASTM 2370-05 standards. The model is widely used to evaluate environmental heat loss and garment. The manikins created with this model have isolated sections from individual sweating, temperature measuring and heating systems. Sweat control takes place by even spread of fluid over the whole surface, where it can be controlled by the sweating rate [92, 93]. The Newton manikin system gave more analytical results compared to human trial methods reported by the Blood [94].

1.3.3.4 Effect of garment fit and body movement

Garment's design and fit are essential because the openings in clothing and the wearer's movement and position allow air, heat and moisture transfer to circulate appropriately [95]. It is essential to produce air gaps between fabrics layers and openings around the body and therefore fashioning fabrics into clothing to wear on the body allows design and fit to be varied to introduce the gaps. About 75% of total body heat can be transported to the environment through openings in areas like the neck, waist, wrists and ankles during body movements in windy conditions is reported by McCullough [88]. Size and fabric properties (stiffness or extensibility) also contribute to the looseness or tightness of fit. Body motion and body posture can help clothing to transfer heat by changing the effective surface area, the entrapped air layers and the geometry of the clothing. According to Olesen et al. [96] and McCullough [88] measurements on thermal manikins found that a standing person has higher clothing thermal insulation than a sitting or moving person. However, the values of evaporative resistance for a sitting person is more and it decreases when a person is walking. Walking creates relative air movement and air motion, which affects the thermal insulation and vapor resistance of the clothing layer [97].

1.3.3.5 Liquid moisture management

Moisture management is the process of transferring sweat through fabric away from the body to keep the wearer dry and comfortable [98]. The liquid moisture management properties of knitted and woven fabrics' can be tested by an instrument called moisture management tester (MMT) which is operated according to AATCC TM 195-2009. There are various factors affecting the fabrics' moisture management properties such as water resistance, water absorption, water repellence, and wicking within the fibers and yarns, [59].

The MMT is a reasonably new instrument that objectively helps in determining the spread of moisture and the transfer properties on and between fabric surfaces [99]. Hu et al. [100] researched on the measuring principles and design adopted for of the MMT apparatus. The findings confirmed the relation between the definition and values of performance indices and subjective perceptions of moisture sensations in sweating, such as ''clammy'' and ''damp''. Yao et al. [101] further focused on the improvement of the test method and the evaluation of indices of liquid moisture management properties, grading and classification methods, data processing and the expression of test results for industrial applications.

As Öner et al. [102], performed a comparison between polyester fabrics and cellulose-based fabrics found out that polyester fabrics had higher overall moisture management capacity (OMMC) values than those of the cellulose-based fabrics. Namlıgöz et al. [103] observed that woven fabrics fashioned from cellulosic/polyester blended fibers were able to transfer liquid more efficiently than both 100% cotton and 100% polyester fabrics. Ozkan and Meric [104] measured the moisture management and thermal properties of six different types of polyester knitted fabrics (warp and weft) used in the production of summer cycling clothes. They found that warp knitted fabric made from 100% polyester can be positioned as a better summer cycling material due to its good air permeability, and low thermal and water vapor resistance values.

As Prakash et al. [105, 106] studied the thermal comfort properties of knitted bamboo fabrics in terms of blend ratio, loop length and yarn linear density. It was observed that it is the bamboo fiber content in the fabric and the linear density of the constituent yarns that determines the thermal conductivity, thermal resistance, air permeability and relative water vapor permeability values of the fabrics. Troynikov and Wardiningsih [107] showed that blended materials made of wool/polyester or wool/bamboo have better moisture management properties as compared to fabrics of 100% wool and 100% bamboo. They also examined the moisture-transport characteristics of knitted fabrics produced from regenerated bamboo with different cover factors, and concluded that overall moisture management capacity decreases with the increase in fabric cover factor [107].

As Fangueiroa et al. [108] used blends of wool and moisture management fibers such as Coolmax® and Finecool® to produce innovative yarns and knitted fabrics. Coolmax® polyester showed better moisture transport results and Finecool® polyester showed better performance in drying rate. Sampath et al. [109] analyzed the thermal behavior of moisture management finish (MMF) fabrics to learn about the thermal comfort characteristics of selected knitted fabrics for different climatic conditions. The knitted fabrics made from yarns of micro-denier polyester filament, spun polyester, polyester/cotton, filament polyester, and 100% cotton were used for this purpose. Their test results indicated that the knitted fabrics produced from different yarns nature more considerable influence on thermal characteristics. There was a significant effect of MMF treatment on the thermal behavior of micro-denier polyester knitted fabrics with respect to thermal conductivity, water vapor permeability, thermal absorptivity and water vapor resistance.

As Guo et al. [110] investigated the impact of fabric moisture transport properties (MTP) on physiological responses when one is wearing protective clothing. Bedek et al. [54] analyzed the relations between the thermal comfort of six knitted types of underwear and their textile properties. The fabrics used were made from cotton/polyester/rayon blend simple rib, cotton, cotton/viscose blend, polyamide 1×1 interlock and polyester double rib. The findings indicated that the highest water vapor transmission rate and most significant moisture management capability were found in the fabric with the lowest porosity and thickness values.

The moisture management properties in double-face fabrics was examined by Supuren et al. [111]. The yarns selected for face and back sides were cotton/cotton, cotton/polypropylene, polypropylene/cotton and polypropylene/ polypropylene. The polypropylene (inner)-cotton (outer) fabric proved to have better moisture management properties and provide right amount of comfort and therefore preferred for summer active and sportswear.

1.3.4 Subjective Method

To evaluate the thermal comfort of textile and clothing, earlier subjective methods were practiced like survey or wearer trials. These methods can be combined and used individually with the above-mentioned subjective methods to achieve the closest result.

1.3.4.1 Wearers trials

Wearer trial method Is done by gathering a set of people or one person who tries the clothing which needs to be evaluated and then exposing the test subject into different kinds of real-life simulation. For example, test subjects are made to do number of outdoor and indoor activities to analyze the clothing. According to Kim it al [112] the only method to achieve comprehensive and realistic result of clothing performance, wearer trials or test are the best way.

This method has some limitations such as:

- Evaluation of/for masses is not achievable.
- Very time consuming.
- All real-life situations cannot achieve by simulation.
- Possibilities of error and bias are high.

1.3.4.2 Survey method

Survey method is a method that depends on the opinion-oriented answers collected from a comparatively large number of participants, which is then analyzed and evaluated [113]. Most common and popular survey methods are evaluating comforts are:

- **Interview survey method** – It is the method where personal one to one interview or survey is conducted. Multiple choice responses or open-ended response are addressed and conducted to evaluate or analyzed. [114]
- **Questionnaire survey method** – it is the method where a set of objective and subjective questions are prepared and shared or circulated among large group of people and responses from them are collected after a fixed period or after the set number of responses. The questions in the questionnaire are designed to gather the required information according to the target audience. [115]

The limitations of the survey method are very similar to the wearer trial method but it can cater large number of participants to participate and requires shorter period to valuate

1.4 RESEARCH GAPS

Over the past few decades Sarees have gained a global recognition and widely excepted in modern day lifestyle and have achieves the stature of fashion garments as well despite this fact there have not been much of the study done about the comfort, thermal and other properties of Sarees as the garment.

1.5 RESEARCH PURPOSE AND PLAN OF WORK

1.5.1 Aim

To explore the suitable combination of fabrics variables for engineering Sarees with good thermophysiological properties of Traditional Indian clothing (Sarees)

1.5.2 Purpose

The thermophysiological properties of textiles significantly influence the transportation of heat, moisture vapor and liquid moisture from the skin to the environment by clothing and thus essential to the wearer's comfortable microclimate. In this research, the selected Sarees will be evaluated for comfort of thermophysiological properties

Focusing on the Indian environmental conditions and the socio-culture of traditional wear, tests will be carried out under moderate climatic conditions to reach the desired conclusion.

1.5.3 Plan of work

Elaboration of research on physiological clothing and testing possibilities,

Conduct a survey to analyze most widely used materials, style drape and other influencing factors.

Based on survey, selection of minimum 5 samples of Sarees with different fiber properties. The experimentation involves thermophysiological comfort properties of Sarees and following devices according to define standards will be used,

- ASTM F2370-05 for thermal manikin testing of heat and mass transfer through selected Sarees.

- Air permeability using standard EN ISO9237
- Water-vapor permeability using standard ISO 11092

Evaluation (Comparison) of the test results: To identify the quality and comfort level of sarees worn by the masses on daily basis in India.

Outcome and Results: The research work will identify the comfort level of Sarees and will also provide information if the Sarees (a loose fit garment) can be tested on the thermal manikin or not.

CHAPTER 2: UNDERSTANDING THE SAREE BY SURVEY METHOD

2.1 INTRODUCTION

The sense of comfort is one of the critical aspects. It is very subjective and measuring any subjective element has always been difficult. The survey based on the questionnaire designed in this chapter is one way of determining this problematic element. The aim of this survey was to obtain the 5 most commonly, widely used the Sarees in the one most draping style to be tested for thermal comfort. The obtained results were evaluated and analyzed to get 5 best samples for the testing.

2.2 SURVEY ADMINISTRATION AND DESIGN OF THE QUESTIONNAIRE

This research obeyed the general ethical guidelines. The invitations of the survey briefly described the goal of this research instructions and time investment for filling the Survey *[Appendix A]*.

The research used a detailed questionnaire for the better result. The questionnaire was written in English language, to facilitate the understanding of the participants. The questionnaire was designed in a manner so that women who wear sarees on daily basis or occasionally could receive information on the comfort of current trends of sarees as far as the fabric and designs are concerned.

2.3 COLLECTION OF DATA

2.3.1 Sample Size

The participants were invited by means of social networking platforms like WhatsApp and Facebook messenger. More than one hundred women volunteered to participate in the survey and gave their valuable inputs.

The survey was self-explanatory to the volunteers and all the queries were personally addressed by the researcher of this project. The participants who needed help to understand the question were addressed personally over the telephonic conversations. Participants were given time to fill the form at their convenient time.

2.3.2 Preparation and distribution of questionnaire

The questionnaire consisted 25 question including subjective and objective types. First 3 questions were personal information. 22 questions were considered for the evaluation which were divided into five sections.

- **General demographic Information:** (3 question) – This section collected information about the country you are wearing the sarees, the age group and profession to determine the working environment
- **Information on the current idea about Sarees**: (5 questions)- This section provided the idea on how sarees are perceived in the masses including the style, design and purchase behaviors.
- **Information about Comfort level while wearing saree:** (9 question)- This section collected the most important information from the participant which demonstrate the comfort level of the wearer.
- **Technical understanding of the widely accepted saree material:** (4 questions)
- **Description about the best style of saree participant preferred to wear or any other related suggestion:** (1 question)- It was generic subjective question to understand the sentiments of the participants towards the Sarees and suggestion for the betterment of the comfort.

The survey was completed by a total of 114 participants. Out of 114, fourteen forms were either incomplete or had some discrepancies because of which they were discarded. Therefore, the data analysis consisted of a total of 100 available survey forms.

2.3.3 Data analysis

The collected data were analyzed and then evaluated by using the statistical tools of Ms office excel for mac. The descriptive observation and requirements were summarized on the saree like materials, style, design, functions and most importantly, comfort.

2.4 RESULT AND DISCUSSION

Each section of the questionnaire is summarized and evaluated based on the participants' responses.

2.4.1 General demographic information

This section collected information about the country participants are wearing the sarees, the age group and profession to determine the working environment

Table 1: Demographic Information

Demographic	**Response**
Country	
Canada	1
Czech Republic	5
France	2
India	86
Nepal	2
Singapore	1
United Arab Emirates	1
United States of America	2
Age group	
18-25	20
26-40	56
41-55	13
More than 55	11
Profession	
Student	57
Employee/ Self-Employed	23
Homemaker	18
Unemployed	2

Conclusion can be draw from the Table 1 that Saree is such a garment that is worn by people from all social groups irrespective of profession and age. As analyzed highest numbers of participants are from India, so it would be prudent to base this research according to the Indian climatic condition.

2.4.2 Information on the current idea about Sarees

This section provided the idea on how sarees are perceived in the masses including the style, design and purchase behaviors.

Table 2: Responses on current idea about saree

Information on	Responses
Reason of wearing	
Religious	5
Traditional	50
Fashionable	27
Others	18
Style of Draping	
Backside pleated/open fall (Pallu)	67
Front pleated/open fall (Pallu)	27
Regional style	4
Others	2
Purchase of sarees in a year	
1~2 nos.	17
3~5 nos.	17
More than 5	22
Occasionally	44
Preferred way of buying	
Market place/Shops(offline)	87
Online	8
Both	5
Kind of design preferred as daily wear	
Plain with or without border	48
Printed	31
Embroidery	4
Others	17

From Table 2 it is analyzed that majority of the population consider sarees as traditional attire with modern outlook of minimalism in terms of draping style and design. Most common style of draping the saree now a days is contemporary style i.e. back side fall (pallu).

2.4.3 Information about Comfort level while wearing saree

This section collected the most important information from the participant which demonstrate the comfort level of the wearer.

Table 3: Responses on comfort level while wearing saree

Information	Response
Comfort level at Hot and Humid climate/weather	
Easy	12
Normal	52
Difficult	35
Others	1
Comfort level at Cold climate/weather	
Easy	20
Normal	58
Difficult	21
Others	1
Comfortable temperature *(Multiple answers were given by the participants)*	
From 15 to 20	14
From 15 to 20; From 21 to 25	8
From 15 to 20; From 21 to 25; From 26 to 30	6
From 15 to 20; From 21 to 25; From 26 to 30; From 31 to 35	2
From 15 to 20; From 21 to 25; More than 36	1
From 21 to 25	24
From 21 to 25; From 26 to 30	19
From 21 to 25; From 26 to 30; From 31 to 35	4
From 21 to 25; From 26 to 30; From 31 to 35; More than 36	1
From 26 to 30	11
From 26 to 30; From 31 to 35	7
From 26 to 30; More than 36	1
From 31 to 35	1
From 31 to 35; More than 36	1
Uncomfortable temperature *(Multiple answers were given by the participants)*	
From 15 to 20	3
From 15 to 20; From 21 to 25	1
From 15 to 20; From 21 to 25; From 31 to 35; More than 36	1
From 15 to 20; From 21 to 25; More than 36	1
From 15 to 20; From 26 to 30; From 31 to 35; More than 36	1
From 15 to 20; From 31 to 35; More than 36	3
From 15 to 20; More than 36	7
From 21 to 25; From 26 to 30	1
From 21 to 25; From 26 to 30; From 31 to 35; More than 36	2
From 26 to 30	8
From 26 to 30; From 31 to 35	2
From 26 to 30; From 31 to 35; More than 36	7
From 26 to 30; More than 36	1
From 31 to 35	10
From 31 to 35; More than 36	21
More than 36	31
Duration of a saree worn on an average	
0-1 hours	7
1-2 hours	6
2-4 hours	35
More than 4 hours	52
Effect Multilayer clothing underneath the saree (blouse, petticoat, bra, under-pants)?	
Yes	48
No	21
Maybe	14
Depends on the occasion	17

The comfort level of saree as a daily wear attire	
Uncomfortable Comfortable Very comfortable Depends on the profession	33 24 4 39
Area in the body, stress/distress is felt	
Shoulder with fall (pallu) Waist where saree is tucked Both A and B Others	14 57 22 7
Part of the body with most heat stress	
Upper part (blouse side) Lower part (petticoat side) Middle part (waist)	35 19 46

Interesting observation made from this section which portrays sarees as an all-season garment because of the result obtained from Table 3. The level of discomfort is not as a correlation to the season but to the style it is worn. It is uncomfortable in extreme environments i.e. extreme heat or extreme cold, but apart from that it can be worn in all seasons with right kind of outwears or innerwear.

2.4.4 Technical understanding of the widely accepted saree material

Table 4: Technical understanding of the widely accepted saree material

Information	**Responses**
Kind of material do you preferred	
Natural fibers such as cotton, silk, bamboo, etc. Synthetic fibers such as polyester & nylon Fiber blends Favorite	87 3 6 2
Kind of blouse and petticoat preferred	
Blouse attached to saree + cotton petticoat Attached blouse with any kind of petticoat Different fabric blouse + cotton petticoat different fabric blouse different fabric petticoat	35 8 43 14
Type of fabric preferred in terms of thickness	
Thin Medium Thick	37 63 0
Type of fabric preferred in terms of fabric weight	
Light Medium	65 32

Heavy	3

As studied in the Chapter 1 sarees are unstitched long fabric which needs to be draped, and majority of wearers want sarees to be easy to handle, which depends on the material, thickness and weight of the fabric.

From Table 4 analysis drawn that women want light to medium weight sarees made from natural fabrics as it is easy to drape and handle.

2.5 CONCLUSION

From the above analysis, the following conclusions can be drawn towards the selection of the sarees for further lab testing. These samples further tested for their thermal comfort and performance. It is concluded that 87% of the participants preferred the sarees made from natural fibers with medium thickness and light to medium overall saree weight. Participants majorly responded that saree with the fall or pallu falling to the back of the shoulder is more preferred than any other style.

The 5 (five) selected samples of sarees are made of natural fibers for all the testing and back side fall (pallu) draping style is selected for the testing on thermal manikin. Technical details of the selected sarees are discussed in the Chapter 3.

CHAPTER 3: EXPERIMENTAL METHODOLOGY

3.1 INTRODUCTION

This chapter provides the details on the experimental methods and procedures used along with the detail on the, fabrics and instruments used during the study.

3.2 RESEARCH DESIGN

The study was carried to bring out the three prime objectives which are as follows:

- Identifying the suitable material used for studies according to Indian climatic condition based on its performance.
- Understanding the common factors that influence the thermophysiological comfort property of the Saree.
- Identifying the factors that influence thermophysiological properties and way to improve them. Figure 1 gives the experimental outlining of the research

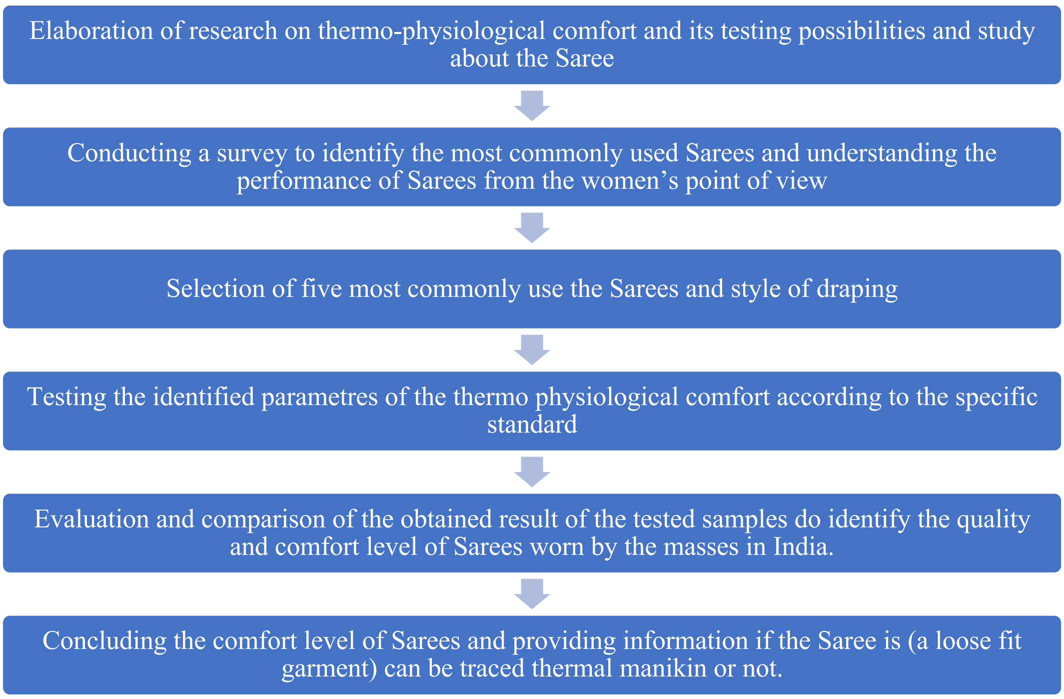


Figure 1: Experimental outlining of research

3.3 SELECTION OF MATERIALS FOR LAB TESTING

3.3.1 Selection of saree fabrics

As mentioned in Chapter 2, a survey was carried out to identify Sarees according to popularity amongst masses which comprised of 5 types of woven fabric (Table 5).

Table 5: Basic Details of Selected Saree Fabrics

Sample name	**SARI 1**	**SARI 2**	**SARI 3**	**SARI 4**	**SARI 5**
					
Fabric	Khadi silk	Linen cotton	Linen	Cotton	Cotton Silk
Length (in cms)	600	550	550	600	550
Width (in cms)	115	115	115	150	120
Surface	Printed	Printed	Printed	Zari work	Zari work
Weave	Plain	Plain	Plain	Plain with jacquard boarder	Plain with jacquard boarder
Base Colour	Beige	Grey	Khakhi	Off-white	Off-white
Wash care	Hand wash or Dry clean	Hand Wash only	Dry clean only	Hand Wash only	Dry clean only

3.4 FABRIC EVALUATION

The testing was carried out after conditioning of the samples for minimum of 24 hours under standard parameters provided by **ASTM F2370-0, EN ISO9237 and ISO 11092** standards.

3.5 PHYSICAL PROPERTIES

Physical properties of the fabrics which mainly affect the comfort were tested such as material type, fabric construction (like weave and ends/picks per inch) and mass per unit area.

3.5.1 Fabric mass per unit area

To determine fabric mass ČSN 80 0845 standard was followed. Specimens from each fabric sample were prepared and weighed using a Denver Instrument, to determine the weight indicator with 0.0001 g accuracy. Mass per unit area was calculated using Equation 3.1:

$$M_{ua} = \frac{m}{a} \qquad \textit{Equation 3.1}$$

where,

M_{ua} in g/m^2 (mass per unit area of the fabric)

m in g (mass of the specimen)

a in m^2 (area of the specimen)

3.5.2 Fabric count

Fabric count is defined as the total number of yarns per unit of length along warp direction, keeping in mind the fabric count and width of the yarn. A device comprising of a magnifying lens and a pointer that is movable also called as Pick Glass was used in counting the yarns. The result summary showed an average count of five in each warp direction. Only evenly spaced positions across the fabric were selected and not the selvedges.

3.6 FABRIC COMFORT PROPERTIES

The thermal resistance, water vapor permeability and air permeability are the most important parameters affecting thermophysiological comfort of garments.

3.6.1 Air permeability

Standard: ISO (International organization for standard)

Method: **EN ISO9237 (European Standard)**

Tittle: Determination of the permeability of fabrics to air

3.6.1.1 Principal

Rate of flow of air passing perpendicularly through a given area of fabric is measured at a given pressure difference across the fabric test area over a given time-period.

3.6.1.2 Sample preparation

As sarees are a draped attire so it not uniformly spread all over the body. It has pleats on the shoulder and at waist line. To accommodate all possible factors the two sets of samples were prepared and per-conditioned as per testing standards. Sample size should be minimum 10 cm x10 cm to cover the required circular area of the instrument.

1. Set 1: 2 Layer of each fabric tested together
2. Set 2: 10 layers of each fabric tested together

3.6.1.3 Instrument: AIR PERMEABILITY TESTER

Air permeability was measured using the **air permeability tester** (Figure 2) by SDL ATLAS Ltd where air was drawn through the specimen using a vacuum pump. For a specific pressure drop, airflow was measured using a flowmeter (1 of 4) indicated via manometer tube. The unit of the results was defined as air permeability in mL/cm²/s at a given specified pressure. The instrument comprises of four flowmeters which can be selected by switches provided in front of the machine. The flowmeter covers the airflow range from 5mL/min to 25L/min. The flow of the air through selected flowmeter and the specimen was regulated using the Valves. Flow readings were captured when the manometers showed the specified pressure drop. Across the samples the air permeability was measured within certain pressure differences.

Figure 2: Air permeability Tester

3.6.1.4 Experiment Method

The findings are not influenced by the orientation of the fabric because the measured area is in circular form. The pressure difference (Pa) and the clamping area (cm^2) are the test conditions five measuring the air permeability. According to EN ISO9237 (European standard) calculation is done. The air is blown in a perpendicular direction through fabric and the rate of airflow is adjusted according to pressure difference between two fabric surfaces. The pressure drop is 100 Pa for apparel fabrics.

3.6.1.5 Calculation Method

The Air permeability (R) is calculated in mm/second as:

$$R = \frac{Q_v}{A} * 167 \qquad \textit{Equation 3.2}$$

Where,

Q_v in litre per minute is the rate of airflow, and

A in cm^2 is area

Readings to be calculated for final evaluation: Area A =20 cm^2

Table 6: Readings to be calculated for final evaluation

	Q [ml/s]				
Sample No.	**2 layers**		**10 layers**	**10 layers**	
	1 Pa		**1Pa**	**20 Pa**	
SARI 1	130	130	15	160	160
SARI 2	210	190	24	290	290
SARI 3	280	320	28	270	300
SARI 4	160	200	20	270	270
SARI 5	130	160	5	50	50

3.6.2 Water vapor permeability

Standard: ISO

Method: **ISO11092:1993(E)**

Tittle: Determination of the permeability of fabrics to water -vapor

3.6.2.1 Principal

Basic principle depends on the dimensions and construction of the apparatus used.

3.6.2.2 Sample preparation:

As sarees are a draped attire so it not uniformly spread all over the body. It has pleats on the shoulder and at waist line. To accommodate all possible factors the two set of samples were prepared as per the size of rim of the cup. Pre-conditions as per testing standard

1. Set 1: 2 Layers combined of each fabric
2. Set 2: 10 layers combined of each for every

3.6.2.3 Instruments: TEXTEST FX 3180 CUPMASTER

Cup method is useful to determine the weight loss using the evaporation time (24h) of water in a cup covered by cover ring. The test fabric in this method is placed on top of the cup in an airtight manner. The reference fabric is placed in a similar airtight manner in another cup. Two sets of sample fabric and reference fabrics are organized in the cups as stated above to carry out the experiment in duplicate. ISO11092:1993(E)testing standard are followed for the testing.

3.6.2.4 Experiment Method

The water vapor permeability of the samples is determined by using the cup method according to the test standard [73]. This method is easy to perform, that determines weight loss [73], with evaporation time (24 h) of water stored in the cup, the top of which is concealed by the covering ring. In this process, the test fabric is put in the airtight condition above the top of the cup. Each cup contains the reference fabric sealed in the same airtight manner and the experiment is carried out in duplicate, so that two cups with sample fabric and two cups with reference fabric are checked. The size of the cup was measured to provide a 10 mm deep layer of air in between surface of water and bottom of the sample. The technique compares the rate of transfer of the water mass through the fabric from cups, along with the reference fabric and the test samples. The weight of the cups was measured first at the start of the test and then regularly at a certain time interval, with a resolution of 0.01 g, to determine how much water was lost from each cup. The difference in water loss between the cup covered by the normal fabric and the cup covered by the test fabric makes it possible to study the relative humidity movements through the test fabrics so that the humidity vapor permeability of the test specimen can be calculated.

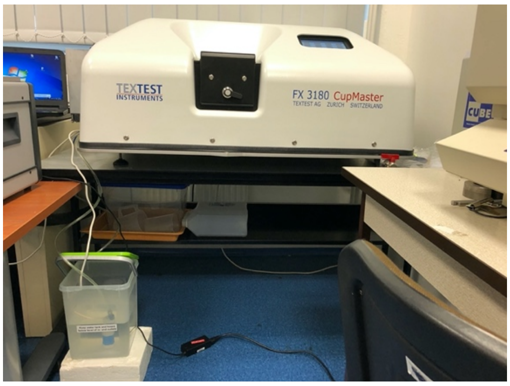


Figure 3: TEXTEST FX 3180 CUPMASTER

3.6.2.5 Calculation Method

The results of measurement are noted in water vapor permeability index units which is calculated as percentage of water vapor permeability (WVP) of the fabric to the WVP in $g/m^2/24h$ of reference fabric, as shown below:

$$WVP = \frac{24*M}{A*T} \ g/m^2/24h \qquad \textit{Equation 3.2}$$

Where,

M is loss in mass (g)

T is time interval (h)

The water vapor permeability index (I) can be calculated by the water vapor permeability (WVP) of the fabric as a percentage of the WVP of reference, as shown below:

$$I = \frac{(WVP)}{(WVP)_r} * 100 \qquad \textit{Equation 3.3}$$

Readings [*Appendix B(B1 to B10)]*

3.6.3 Dry Thermal Resistance and Intrinsic Evaporative Resistance

Standard: ASTM (American Society for testing & material)

Method: **ASTM F2370-05**

Tittle: Measuring the Thermal and Evaporative Resistance of Clothing

3.6.3.1 Principal

It describes the measurement of the resistance to evaporative heat transfer in a relatively calm environment. It specifies the configuration of sweating thermal manikin, test protocol, and test conditions.

3.6.3.2 Sample preparation

The research was performed mainly to measure the thermal insulation properties using thermal manikins draped with sarees of a selected draping style. Heated manikins were used to test specified range of sarees. These experiments were performed in dry conditions. For the dry tests the ambient air temperature was maintained at 23ºC and Relative Humidity kept as 50% and average mean skin temperatures kept at 35ºC. The results concluded that the type of woven fabric affects the performance of the thermal insulation.

3.6.3.3 Instrument: CHILD THERMAL MANIKIN

The design of child thermal is equipped with providing thermal resistance measurements of garments with high precision and repeatability under steady-state conditions. Thermetrics® designed the thermal manikin system to accurately evaluate the thermal resistance (R_{ct}) properties of the clothing ensembles [116].

Data collection and calculations were performed on the ThermDAC software, which enables the operator to obtain test results along with a data file comprising the data of the test reports. Any changes to the test settings can be modified in the operator interface in ThermDAC.

System Specifications

Manikin system and its major components are depicted in the Figure 9 below. Standard Equipment:

- Thermal Manikin
- Ambient Sensor J-Box

- Ambient Sensors
- Power Supply Enclosure
- ThermDAC Control Software

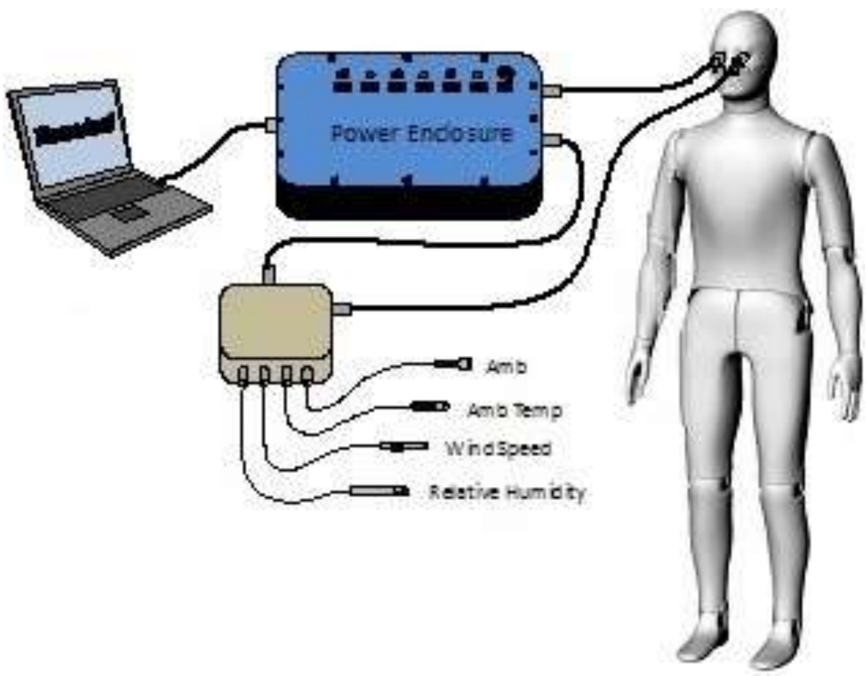


Figure 4: Thermal Manikin System Block Diagram [116]

Table 7: Standards for Thermal Manikin System

Operational Temperature Range	-20 to 50° C
Operational Humidity Range (limited by dewpoint temperature)	0 to 100% RH (including condensation)
Operational Wind Speed Range	0 to 2.5 m/s
Heater Voltage	48 volts
Nominal maximum heat flux	$800W/m^2$
Weight	~40 lb (18kb)

3.6.3.4 Experiment Method

ThermDAC Version: v8.4.3.18

Experiment Type: Dry Nude Test

Duration: 60 minutes

- The manikin is dressed as per the test requirements followed by the calibration of temperature and humidity conditions of the environmental chamber or area under test to attain desired values.
- In the ThermDAC main screen, select Run from the tool bar. An appropriate test is selected from the list of the available tests or Test Parameters is selected to create a new test.
- This will open a Test Parameters window. If necessary, modify the test parameters for a new test or add comments. Additionally, logging intervals, temperature set points, desired steady state conditions can be adjusted as well.
- After ensuring all the above steps, the test is started.
- A specified file name is given when prompted.
- This will begin the test. By enabling the steady-state detection, automatic termination of the test is achieved when accurate measurement of thermal resistance is possible. Manual generation of steady state reports can be done by using the save report option in the experimental screen.

Running Dry Test:

To perform dry tests, the manikin can either be clothed or nude. The procedure will remain the same in both conditions, however with certain exceptions. While performing clothing tests, it is necessary to understand that the manikin measurement corresponds to total resistance R_{ct}. Intrinsic resistance R_{cf} can be obtained by applying nude resistance R_{ct0} and clothing factor F_{cl}.

Care must be taken to ensure the active heater operation on all zones before beginning every test day.

- Garment ensemble is installed on the manikin. (Nude R_{ct0} values are obtained by performing the procedure without dressing the manikin.)
- In the main ThermDAC screen, Run is selected from the top tool bar followed by selecting one of the test files corresponding to dry test. This opens the window containing the test parameters.
- To begin the test with a garment, Load reference button is selected in the test parameters window and fixing the reference type to Nude Dry. A file from a previous dry nude manikin test is selected by clicking Add.

- Before starting the test, ensure the correct set points and ambient while entering any desired user comments.
- Furthermore, enter the desired file name and storage location in the Log File Location window.

This will begin the test, however, frequent check on the test parameters and operation conditions is advised to ensure the test is operating within the tolerances. Typical tests last for about 60 minutes.

The obtained results from Thermal Manikin system consists of air boundary layer resistance. Care must be taken to enter the right nude value R_{ct0} and clothing factor F_{cl} to acquire the intrinsic fabric resistance $R_{cf.}$

3.6.3.5 Calculation and Readings

Dry Thermal Resistance (R_{ct}): As per ASTM F1291-10- standard test method, the thermal resistance (R_{ct}) was measured using a heated manikin. Total thermal resistance (insulation) was calculated via parallel method using Equation 3.4, which included the insulation of the clothing and the surface air layer:

$$R_{ct} = (T_{skin}-T_{amb}).Q/A \qquad \textit{Equation 3.4}$$

Where,

R_{ct} is total thermal resistance of the clothing ensemble and surface air layer ($m^2.^oC/W$),

T_{skin} is Zone average temperature (^oC),

T_{amb} is Ambient temperature (^oC) and,

Q/A = Area weighted Heat Flux (W/m^2)

The intrinsic clothing insulation (R_{cf}) which is defined as the insulation from the skin surface to the clothing surface, can be deducted from the measured (R_{ct}) value by Equation 3.5:

$$R_{cf} = R_{ct} - (R_{ct0} / f_{cl}) \qquad \textit{Equation 3.5}$$

Where,

R_{cf} is intrinsic evaporative resistance of the clothing ($m^2.^oC/W$),

R_{ct0} is thermal resistance of air layer in naked condition ($m^2.°C/W$),

F_{cl} is clothing area factor (ratio of outer surface area of clothed body to surface area of nude body) estimated according to ISO - 9920

Table 8: Average Ambient Sensors readings for each sample

Sample No.		**SARI 1**	**SARI 2**	**SARI 3**	**SARI 4**	**SARI 5**
Ambient Sensor	Units					
Avg.Amb Temp	degC	20,52	20,42	20,41	20,58	20,45
Amb 1	degC	20,56	20,42	20,42	20,62	20,53
Amb 2	degC	20,47	20,42	20,38	20,54	20,38
RH	%RH	54	54,5	54,1	54	54,1
Windspeed	m/sec	0,047	0,037	0,034	0,043	0,04
Water Temp		31,26	34,39	31,73	33,56	33,094

Individual readings of each saree samples are added as [*Appendix C*]

Figure 5: SARI 1 draped on Child Thermal Manikin

Figure 6: SARI 2 draped on Child Thermal Manikin

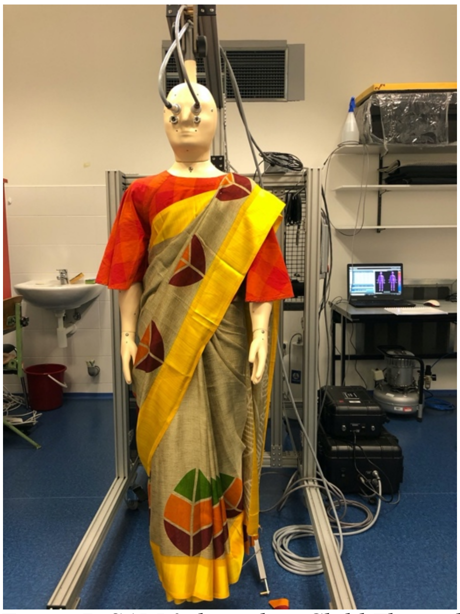


Figure 7: SARI 3 draped on Child Thermal Manikin

Figure 8: SARI 4 draped on Child Thermal Manikin

Figure 9: SARI 5 draped on Child Thermal Manikin

3.7 SUMMARY

All the sections above broadly outline the experiments that were carried out for this thesis. All the materials of the fabrics used have been provided above. Standard tests are outlined that have been carried out for evaluating the physical and thermal properties. Procedures and equipment used have been listed. Details of the further experiments will be discussed and the detailed results and analysis will be provided in the following chapters.

CHAPTER 4: DATA ANALYSIS & DISCUSSION

The most important parameters effecting thermophysiological comfort of Sarees are thermal resistance, water vapor permeability and air permeability.

In this chapter the thermophysiological properties of selected saree samples were analyzed to determine the comfort level based on material, physical properties and fabric comfort properties.

4.1 INTRODUCTION

Several studies and statistics revels that 79.5 % of women who wear saree on daily or occasionally [117]. Researched in this field have studied and worked towards the improvement of comfort performance of the clothing [21, 36]. However, the research related to thermophysiological comfort of sarees, are very limited. Therefore, this research project is a contribution to the fill the void.

4.2 EXPERIMENTAL DESIGN

4.2.1 Materials

Five kind of commercially available fabrics selected for the testing which were described the Section 3.3.1. These were the most popular saree materials. They were:

- Khadi Silk [SARI 1]
- Linen Cotton [SARI 2]
- Linen [SARI 3]
- Cotton [SARI 4]
- Cotton Silk [SARI 5]

A fabric made from natural fiber has been often used in recent years to produce wear with high hygiene requirements and to protect against low temperatures. The fabrics made of natural fiber also has high breathable and low thermal conductivity, so it is an ideal material for summer and winter wear. It also prevents skin from heat during the summers and maintains body warmth during the winters [118].

4.2.2 Physical properties

The selected physical properties that affects the comfort properties were determined. These were described in the Section 3.4. The evaluated properties were:

- Fabric weight (GSM= gram per meter square)
- Thread count (EPI = Ends per inch; PPI= Picks per inch)

4.2.3 Thermophysiological comfort properties

The parameters to test the comfort properties (described in the Section 3.5.) were determined to evaluate were:

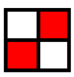
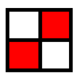
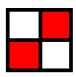
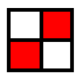
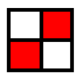
- Air permeability
- Water vapor permeability
- Dry thermal and evaporative resistance

4.3 RESULTS AND DISCUSSION

4.3.1 Evaluation of materials and physical properties of Saree fabrics

Final Readings: Fabric Specification and evaluation (Table 9).

Table 9: Details of the selected saree fabrics studied

Sample code	**SARI 1**	**SARI 2**	**SARI 3**	**SARI4**	**SARI 5**
Fabric composition	Khadi silk	Linen Cotton	Linen	Cotton	Cotton silk
Weave structure	Plain weave	Plain weave	Plain weave	Plain weave	Plain weave
Weave diagram					
Length (m)	6,0	5,5	5,5	6,0	5,5
Width(m)	1,15	1,15	1,15	1,5	1,2
Fabric mass (g/m^2)	54	57	59	63	52
Ends/inch	54	56	51	60	54
Picks/inch	86	96	63	74	92

The results in Table 9 show that selected fabrics may have wide range of properties. As concluded by the survey method in Chapter 2, women are more inclined towards sarees made from natural fibers. Natural fiber comes with their own advantages over synthetic fibers. Garments made from natural fibers are breathable, mostly chemical free and most importantly harmless to the wearer's skin. In recent years, there are many concerns about the environmental degradation and natural fiber clothing is a beneficial for the environmental point of view and it should be more encouraged [119]. Today, textile industries have discovered large variety of natural sources of fibers [119]. They feel and looks good on the wearer's body. The construction of the fibers is closely woven and yet they are extremely breathable and soft to touch [b]. Natural fibers do not cling to the surface of the body and drape of saree looks extremely neat. Mostly they are processed naturally and toxin free. They are light weight and still able to provide proper protection and comfortable microclimate to the wearer's body. Most importantly they are biodegradable.

The thread count also plays a vital role in defining the structure of the fabric. As shown in the Table 9 the selected fabrics have GSM ranging between 50gsm and 60gsm. Fabric weight is one of the vital factors while purchasing a saree [120].

Based on the evaluation done for physical properties, fabric with low GSM is best. Figure 10 below shows the comparison between the selected sample.

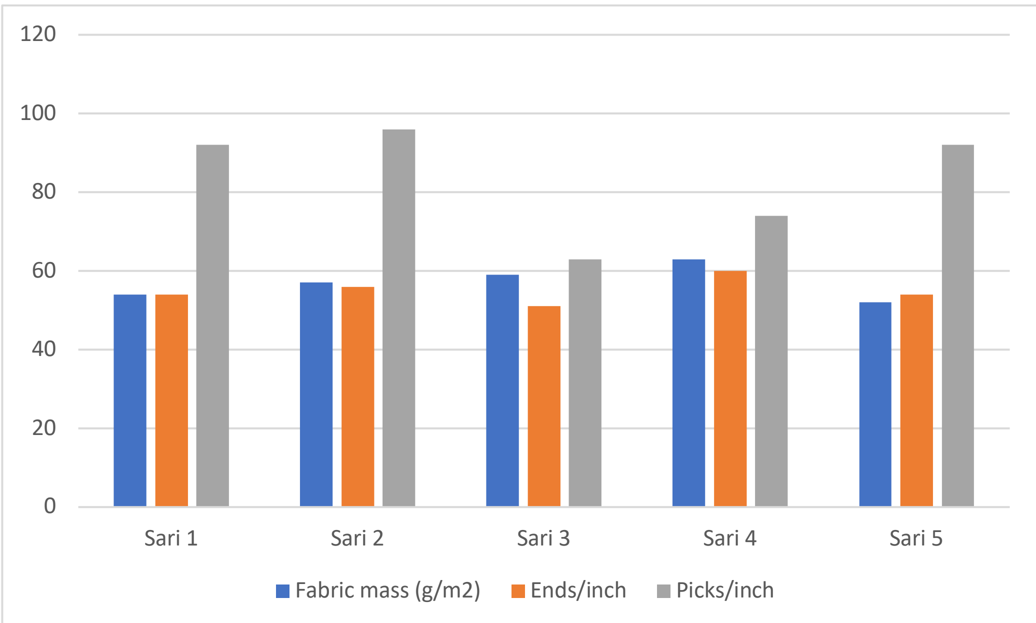


Figure 10: Comparison between evaluated physical properties.

4.3.2 Air permeability

Final Readings: As mentioned in Section 3.5.1.2 two different sets of one fabric was prepared:

4.3.2.1 **Set 1:** Average of the evaluated readings for 2 layers of fabric (1Pascal) are shown in Table 10

Table 10: evaluated readings for 2 layers of fabric for Air permeability

With Area= 20cm²	**2 Layers (1 Pa)**	**2 layers (1 Pa)**	**Air Permeability**
Unit	ml/s	l/min	mm/s
Sample No.			
SARI 1	130	7,8	65,13
SARI 2	200	12	100,2
SARI 3	300	18	150,3
SARI 4	180	10,8	90,18
SARI 5	145	8,7	72,645

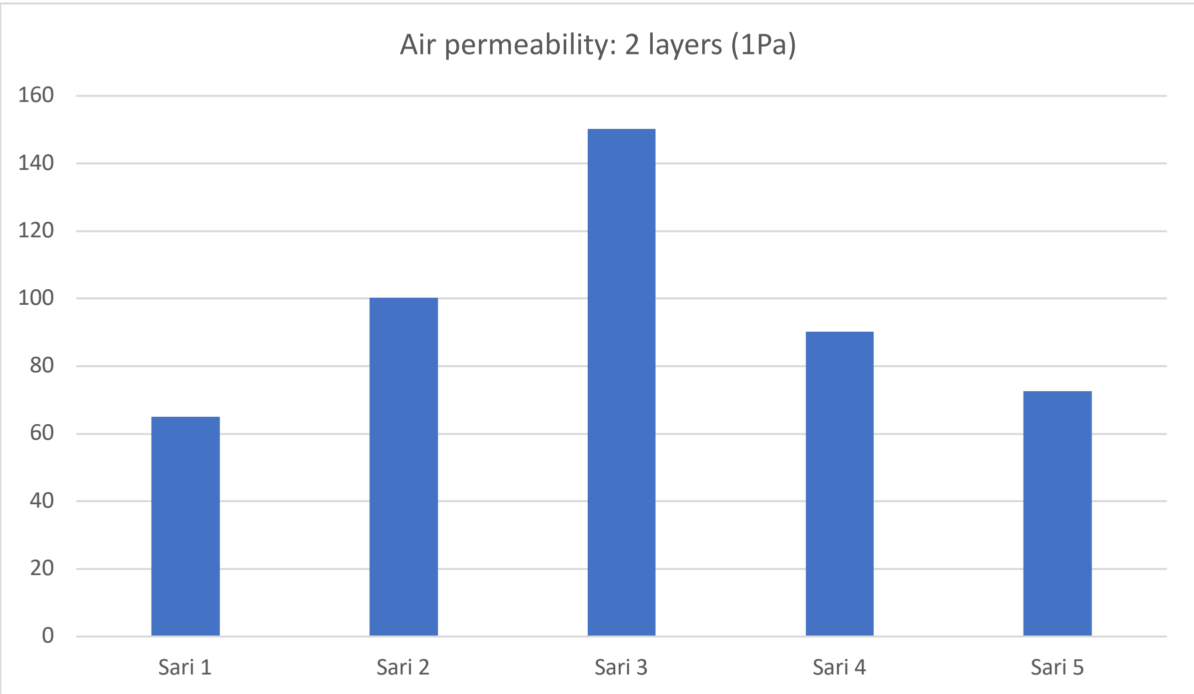


Figure 11: Comparison between the air permeability of 2 layers of fabric (1pa)

4.3.2.2 Set 2: Average of the evaluated readings for 10 layers of fabrics (20 pascals) are shown in Table 12

Table 11: Evaluated readings for 10 layers (20Pa) of fabric for Air permeability

With Area= 20cm²	**10 layer (20 Pa)**	**10 layer (20 Pa)**	**Air permeability**
Units	ml/s	l/min	mm/s
Samples No.			
SARI 1	160	9,6	80,16
SARI 2	290	17,4	145,29
SARI 3	285	17,1	142,78
SARI 4	270	16,2	135,27

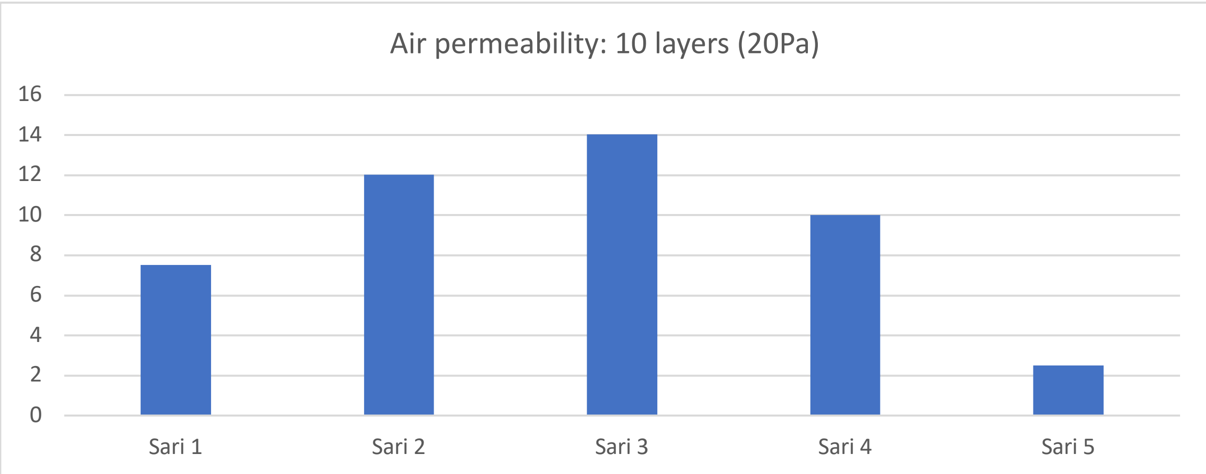


Figure 12: Comparison between the air permeability of 10 layers of fabric (20pa)

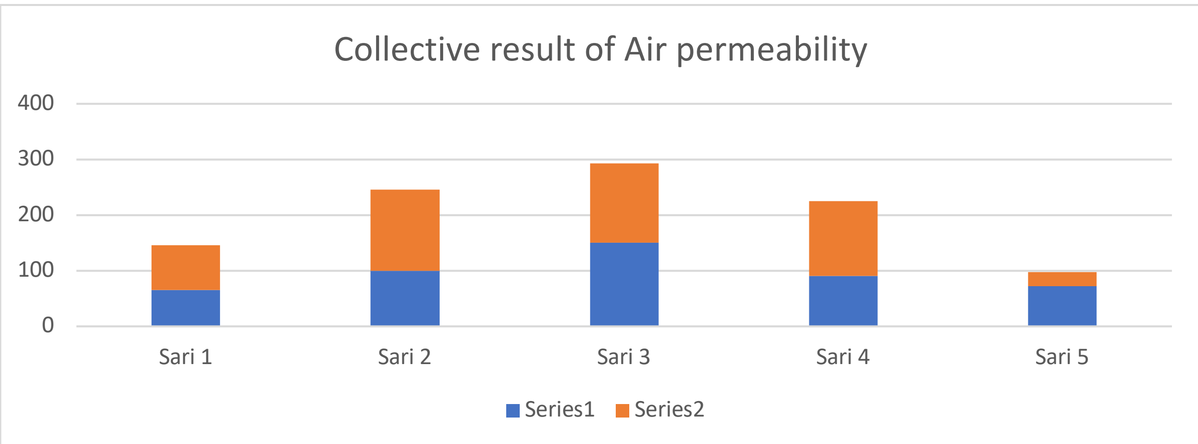


Figure 13: Comparison between air permeability by putting 2Layers and 10 layers together

The resistance of air permeability of fabric majorly depends on the fabric construction. The difference in the physical properties of the affects the permeability behaviors under the same environmental condition.

Table10 and Table 11 demonstrates that all the tested fabrics were highly air permeable. In fact, fabrics when tested with single layer were immeasurable and could not able to support the standard (EN ISO 9237:1995). As mention in the section 3.6.1.2 two sets of samples were prepared for each fabric. From figure 13 SARI 3 made of linen yarn with minimum yarn cout of 51 EPI had the highest air permeability value. The weave structure and yarn count may have been responsible for its higher air permeability. Although SARI 5 had lower fabric weight (Table 9), showed lowest air permeability. This was mainly due to different fabric construction used for the fabrics on the loom. This result disagrees with the findings made by Backer and Kaynak [121, 122] that is, the plain weave fabrics typically exhibit lower air permeability than satin or twill weaves. From the point of view of weave compactness, weave structure with lower EPI numbers have higher air permeability values. Since long-float weaves have better mobility for yarns in their construction, the gaps between these yarns increase so that air can circulate more easily than in other forms of structures [163]. Air permeability has the most important role in the transfer of water-vapor to the outer atmosphere from the skin. It is assumed that moisture passes by diffusion of air from one side of the fabric to the other, primarily through the porosity of the fabric [68]. In hot climates (hot dry deserts or humid tropics), higher air permeability enables more air to circulate around the skin, encourages the removal of moist air and decreases perspiration discomfort [24].

4.3.3 Evaluation of Water vapor resistance (Ret)

Final Readings: As mentioned in Section 3.6.2.2 two different sets of one fabric were prepared:

4.3.3.1 Set 1: Average of the evaluated readings for 2 layers of fabric are shown in Table 12

Table 12: Evaluated readings for 2 layers of fabric for Water vapour permeability

Sample No.	**WVTR [g/m²/d]**	**WVTR [gr/ft²/h]**
	2 layers	2 layers

SARI 1	4098,5	365,3
SARI 2	5274,65	315,08
SARI 3	7312,7	436,85
SARI 4	4304,59	257,17
SARI 5	4190,24	250,32

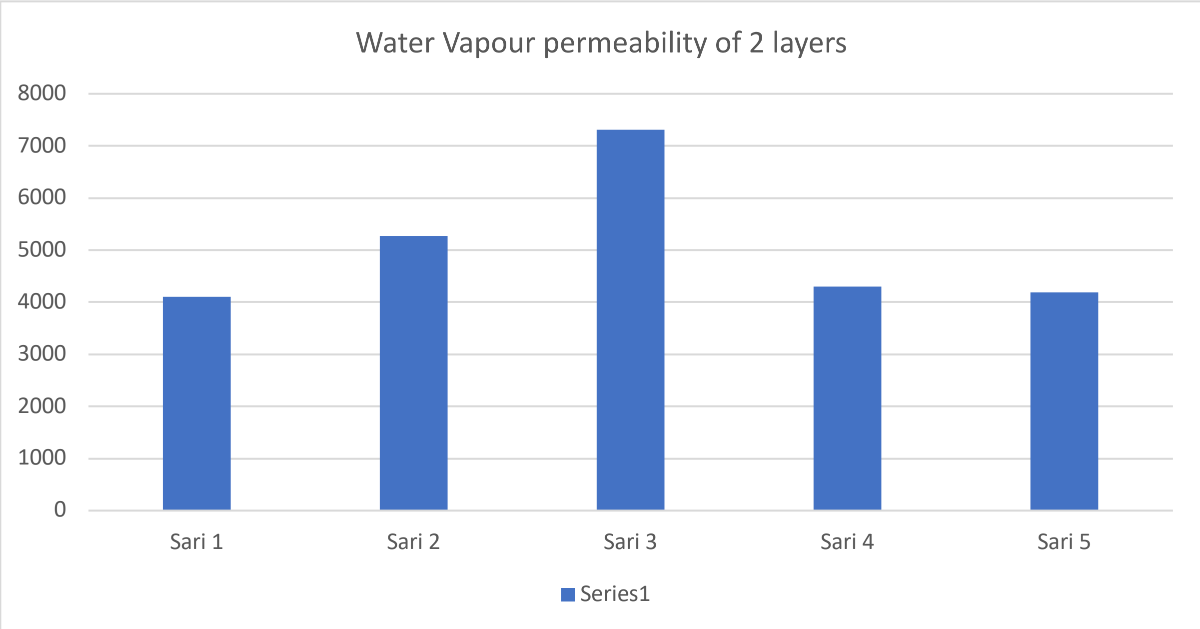


Figure 14: Comparison between water vapor permeability of 2 layers of fabric

4.3.4.2 Set 2 readings: Average of the evaluated readings for 2 layers of fabric are shown in Table13.

Table 13: Evaluated readings for 10 layers of fabric for Water vapour permeability

Sample No.	**WVTR [g/m²/d]**	**WVTR [gr/ft²/h]**
	10 layers	10 layers
SARI 1	2723,5	164,43
SARI 2	2723,4	162,7
SARI 3	2833,4	169,27
SARI 4	2999	179,15
SARI 5	2981,62	178,12

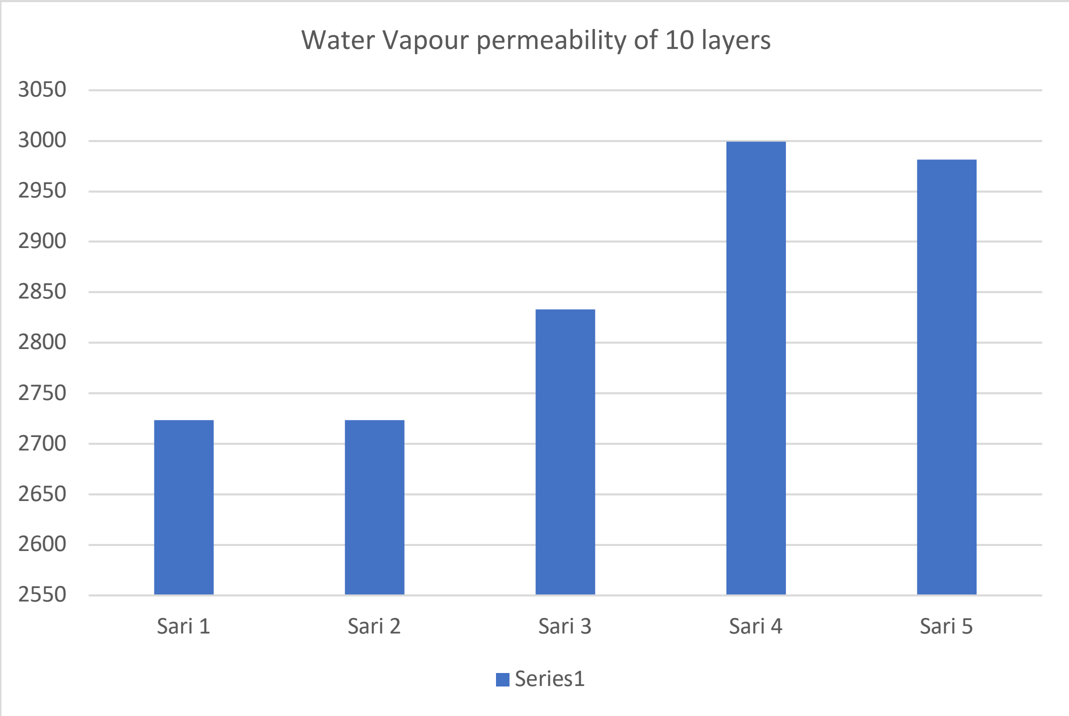


Figure 15: Comparison between water vapor permeability of 10 layers of fabric

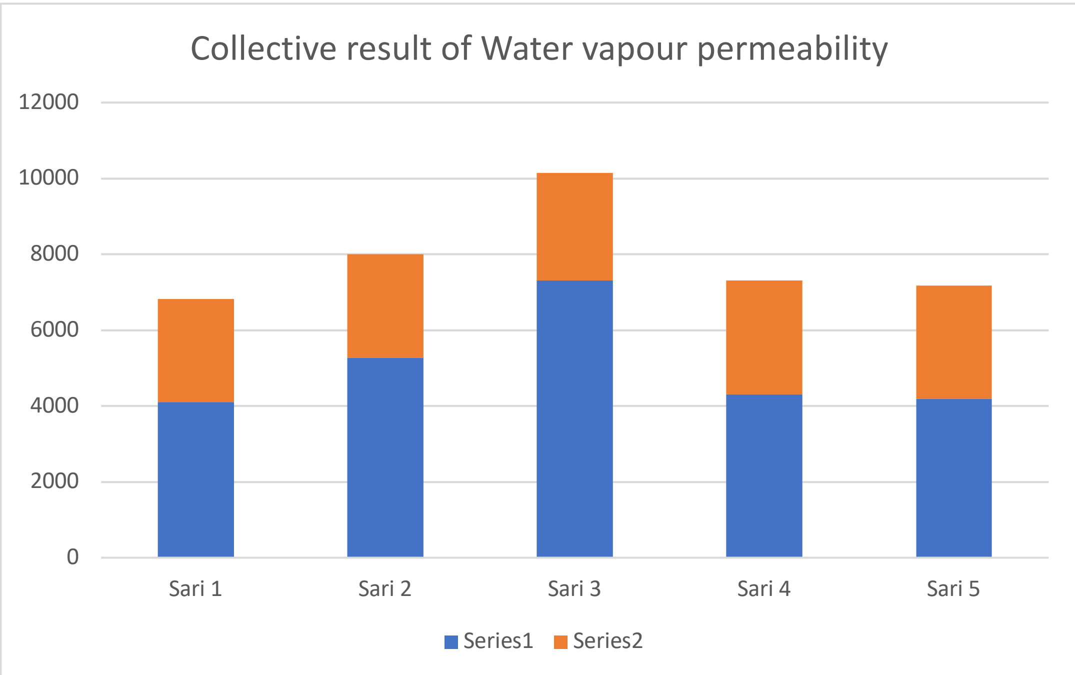


Figure 16: Comparison between WVTR by putting 2Layers and 10 layers together

The conditions within which the experiment was conducted have a significant impact on the result. The temperature and humidity gradients across the sample were measured, monitored and reported with the test. The international unit for moisture vapor transmission rate (MTVR) is g / m2 / day.

The permeability of water vapor in fabrics depends directly on the properties of thermal comfort of the garments [45]. Higher permeability means more moisture permeability of clothing and therefore heat transfer and thermal comfort are desirable. The WVTR value does not provide a value for clothing because external environmental parameters affect it. The permeability index is affected by air stored within and between fibers and clothing layers was stated by Davis and Bishop [123]. This is the case in several layers of clothing, where the permeability index is increased because of the amount of stagnant air stored between and within the clothing layers.

The WVP values of the fabrics are given in Table 12 and Table 13. From the Figure 16 and Table 9, it is observed that WVP decreases as fabric cover increases, irrespective of the thread count. Another observation seen from Figure 16 that WVP of SARI 3 with 51EPI is higher than the SARI 4 with 60EPI. Table 9 shows that SARI 4 is thinner than the SARI 3. Therefore, SARI 3 show higher WVP than SARI 4, irrespective of fabric construction.

Table 12, Table 13, and Appendix B shows the change in WVP value measured by cup method with time for fabrics. It is observed that the water vapor transmission rate decreases as the time increases. According to Morton and Hearle [8] and Nordon et al.[9], the decrease in the rate of diffusion is due to the swelling phenomenon of the hygroscopic material, as the absorption of moisture leads to blockage of the pores. Swelling phenomenon affects the transmission of vapor through diffusion as time increases; which results in the decrease of the permeability index when time increases.

Appendix B shows the effect of a long-term method (cup method) derived from wind velocity on WVP. The SARI 4 shows lower transmission of moisture through fabrics at all wind speeds as compared to the SARI 3. It is observed that under windy condition, diffusion of water vapor throught the fabrics occur along with air circulation across the surface, because which the water vapor slowly evaporates by the process of convection. This is because the relatively dry air is moving above the surface of fabric as wind speed increases, thus increasing the transmission of water vapor.

4.3.4 Thermal resistance (R_{ct}) and Intrinsic evaporative resistance (R_{cf})

4.3.4.1 Dry Thermal Resistance

Table 14: Evaluation of R_{ct}

Manikin Zones	RCT Average readings				
	SARI 1	**SARI 2**	**SARI 3**	**SARI 4**	**SARI 5**
Face	0,084	0,084	0,084	0,082	0,084
Head	0,11	0,11	0,11	0,11	0,11
R Upper Arm	0,27	0,27	0,27	0,27	0,27
L Upper Arm	0,29	0,34	0,32	0,26	0,25
R Forearm	0,09	0,10	0,09	0,09	0,10
L Forearm	0,13	0,13	0,13	0,13	0,13
R Hand	0,09	0,09	0,09	0,09	0,09
L Hand	0,08	0,08	0,08	0,08	0,08
Chest	0,26	0,31	0,28	0,28	0,28
Back	0,26	0,26	0,26	0,26	0,25
R Thigh	0,47	0,56	0,41	0,47	0,46
L Thigh	0,35	0,42	0,36	0,32	0,39
R Calf	0,16	0,16	0,16	0,15	0,16
L Calf	0,17	0,17	0,16	0,16	0,16
R Foot	0,09	0,09	0,11	0,09	0,09
L Foot	0,11	0,11	0,11	0,11	0,101

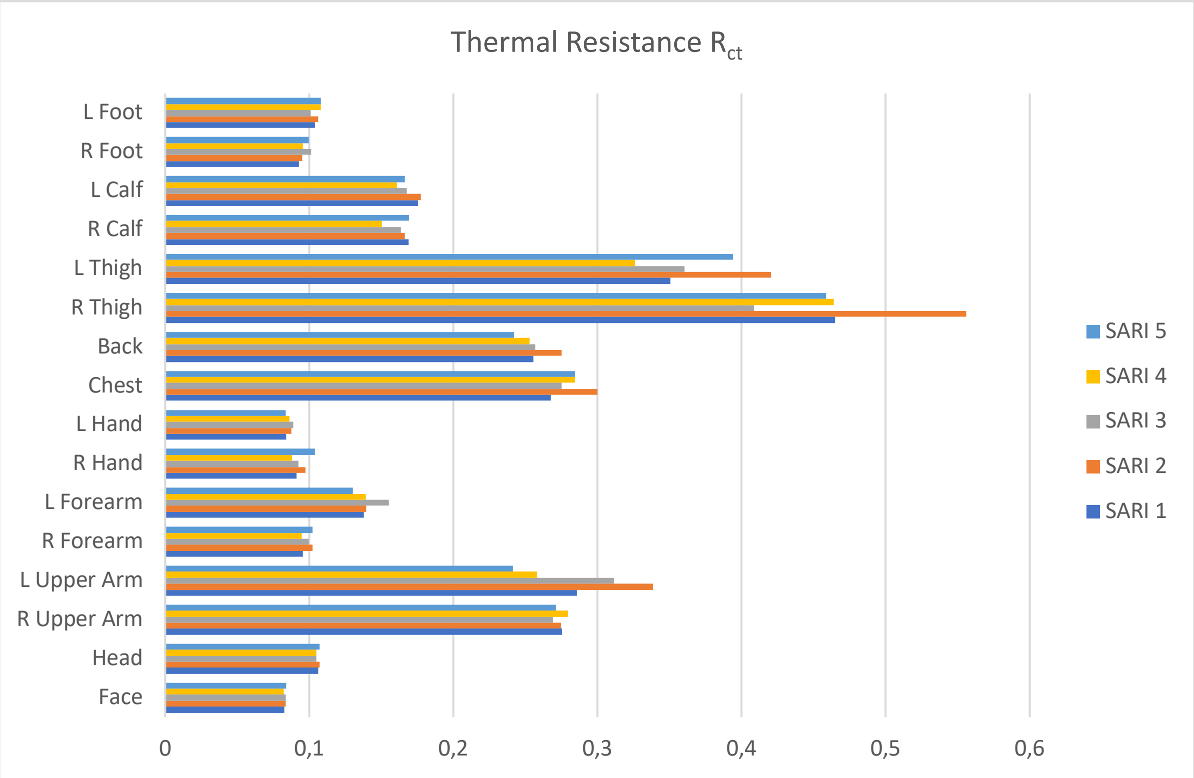


Figure 17: Comparison of Thermal Resistance of all samples (bar graph)

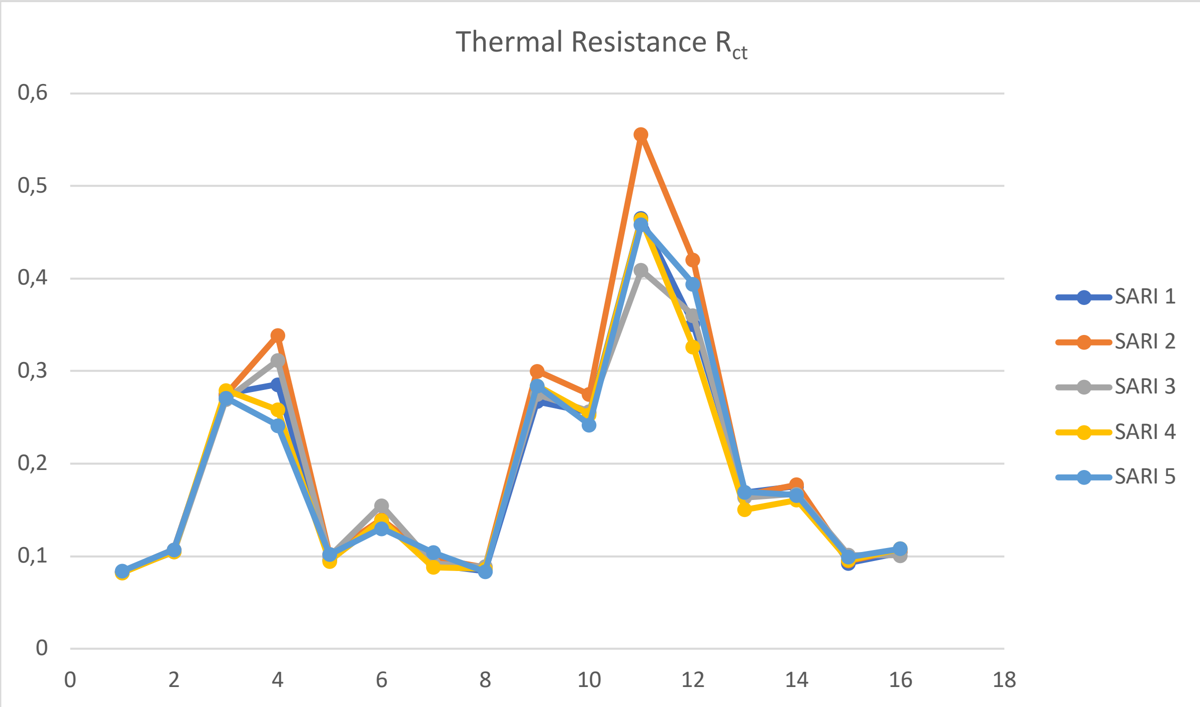


Figure 18: Comparison of Thermal Resistance of all samples (line graph)

4.3.4.2 Intrinsic Evaporative resistance

Table 15: Readings of Intrinsic evaporitic resistance

Manikin Zones	R_{ef} Average Readings				
	SARI 1	**SARI 2**	**SARI 3**	**SARI 4**	**SARI 5**
Face	-0,01	-0,01	-0,01	-0,01	-0,01
Head	-0,01	-0,01	-0,01	-0,01	-0,01
R Upper Arm	0,15	0,14	0,14	0,15	0,14
L Upper Arm	0,19	0,24	0,21	0,16	0,14
R Forearm	0,02	0,03	0,02	0,02	0,03
L Forearm	0,05	0,05	0,07	0,05	0,04
R Hand	0,01	0,01	0,01	0	0,02
L Hand	0,01	0,01	0,01	0,01	0
Chest	0,16	0,19	0,168	0,18	0,18
Back	0,15	0,17	0,15	0,14	0,13
R Thigh	0,38	0,47	0,32	0,38	0,37
L Thigh	0,27	0,34	0,27	0,24	0,31
R Calf	0,08	0,08	0,08	0,06	0,08
L Calf	0,09	0,09	0,08	0,08	0,08
R Foot	0,01	0,01	0,02	0,01	0,02
L Foot	0,02	0,02	0,019	0,026	0,026

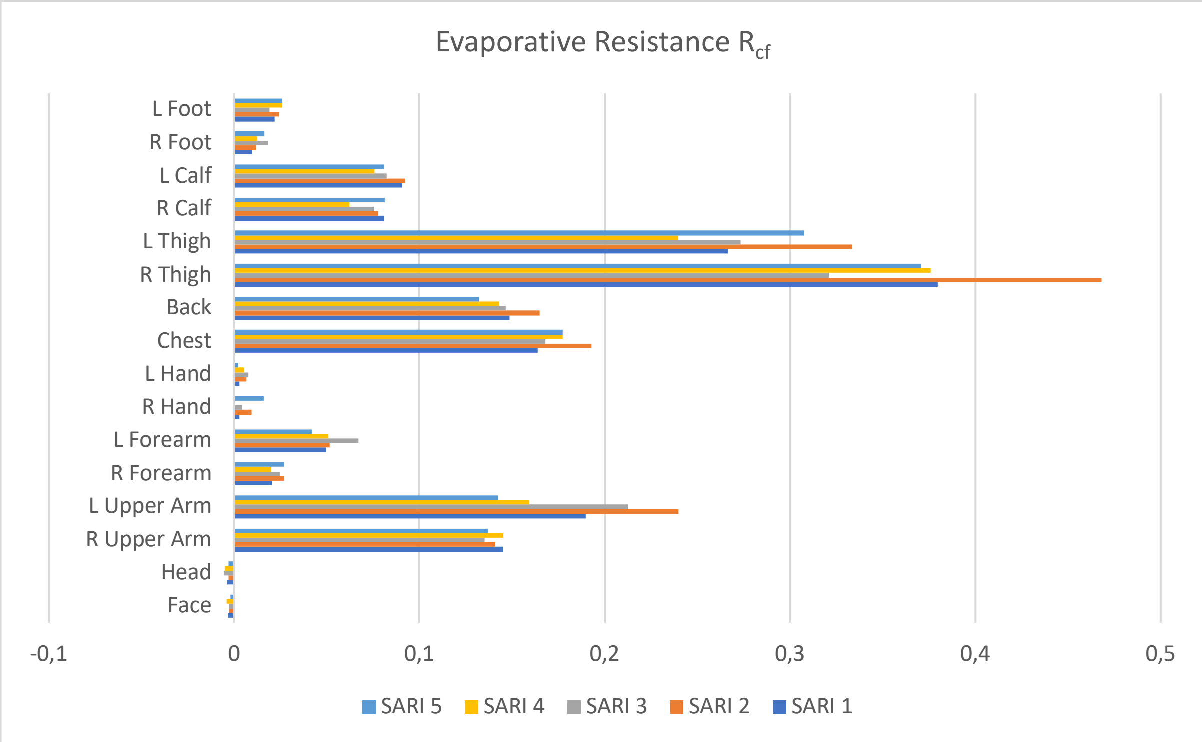


Figure 19: Comparison of Evaporative Resistance of all samples (bar graph)

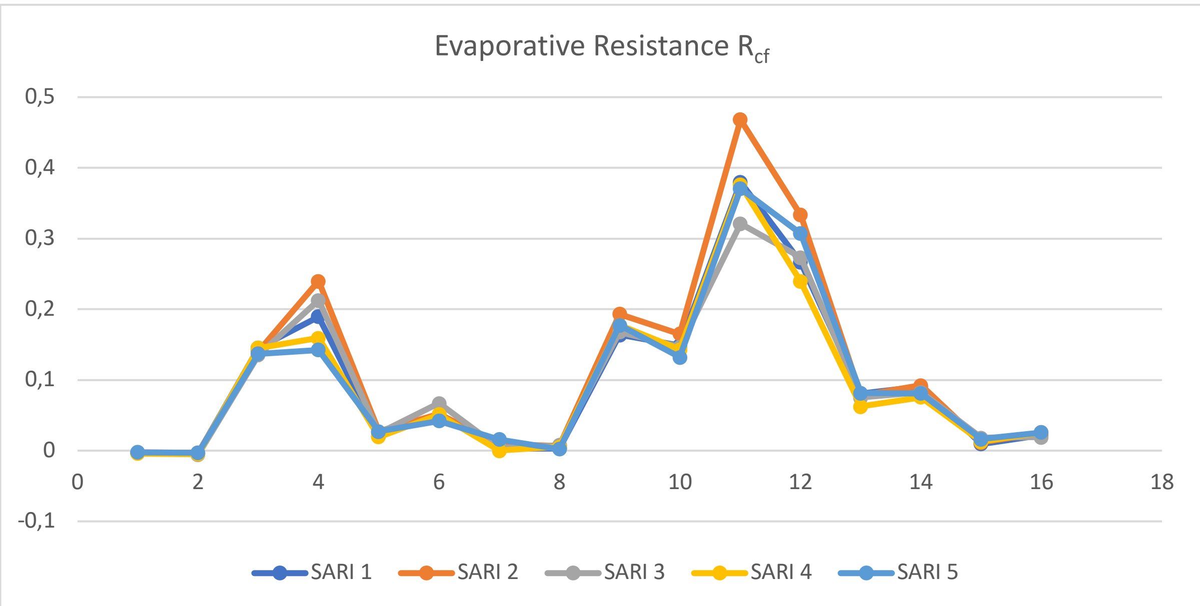


Figure 20: Comparison of Evaporative Resistance of all samples (line graph)

The Rct from a fabric reflects how good the fabric is providing a thermal barrier to the wearer with a quantitative evaluation [124]. The R_{ct} of SARI 4 shows the lowest value from the results in Figure 20. It was because of SARI 4 being thin and lightweight. To remove heat and reduce the R_{ct} value higher air permeability will be helpful. Considering its physical properties SARI 2 still showed the highest value of the R_{ct}. It can be explained by a process that lower the fiber proportion to the air, higher will be the resistance to the heat flow of the cloth [125]. It could be a result of Cotton fiber having a higher rct value (0.0126 m2. ° C/W) with a lower thermal conductivity (0.029 W/mK) [63] when compared to polyester filament (0.14 W/mK) or viscose (0.29 W/mK) [126-128]. Lower R_{ct} value is required in a warm environment to allow the heat from the body to disperse in the environment [129]. Sari 4 showed the lowest R_{ct} from the tested fabrics. So, it is the best fabric among the selected samples.

Nevertheless, in the case of a given sari, blouse, the petticoat ensemble drape in the upper body alone had a significant effect on the clothing insulation value of the total ensemble. The variation due to drape in a combination of garments was observed to vary from 7.7% to 40.1%. Understandably, the lower variability was in light saris, usually used in summer.

Comparison with other's results

The insulation of clothing offered by a garment is directly related to the surface area of the body covered. This area is known as a body surface area covered (BSAC) [130]. This BSAC varied from 65% to 81% while the clo value varied between 0.71 clo to 1.20 clo.

For instance, the clo value varied from 0.71 clo to 0.91 clo for the summer (light sarees), giving a difference of 28%. The recorded value, from winter viewpoint (heavy sarees), increased the clo from 0,72 clo to 1,26 clo (67% variation).

This variation can be achieved by the wearers without adding a new piece of garments to the ensemble. The variation of sari ensemble in few segments of the body, couldn't be tested by the observation due to logistic constraints.

4.4 SUMMARY

This chapter was mainly focused on understanding the fabrics for saree and to analyze their comfort properties. Five different types of commercial fabrics had been studied. From the result it was found that Saree fabrics have woven structures. It implies that fabric weave structure, fiber composition and other properties significantly influences fabrics comfort performance.

CHAPTER 5: CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

5.1 INTRODUCTION

This research aimed to investigate the Saree, a traditional Indian women's attire. The emphasis was on getting an overview of the saree, its implementation, and functionality. Objective assessments are reported regarding the thermophysiological comfort properties of the sarees.

The research started with a survey aimed at selecting the fabric for evaluation and recognizing the factors that affect the properties of thermophysiological comfort. The survey identified the textile materials typically used by the participants for the saree worn. The findings from the survey provided the basis for forensic research. Important properties associated with thermophysiological comfort are air permeability, water vapor permeability, and thermal resistance were studied during the research. This research used of sophisticated equipment such as SDL ATLAS Air Permeability Tester, TEXTEXT FX3180 Cupmaster, and Child Thermal Manikin.

5.2 CONCLUSION

5.2.1 Survey outcomes

This study was about recognizing the saree in terms of its comfort from the customers ' point of view. This expresses the view of a small female community about the comfort of the Saree they were wearing. The survey provided an insight and showed that the degree of comfort depended on the kind of saree fabric and style

The survey identified the women's broadly accepted preference for sarees. Based on the survey findings, the fabrics investigated in this research were chosen for further analysis.

5.2.2 Fabric physical properties

This research selected 5 Sarees made of natural fiber, commercially used for Sarees. Woven fabric studies have confirmed that the fabric structure, fiber quality and other fabric properties have greatly influenced the comfort performance. A fabric made of natural fiber also finds its use in the production of work wear with high hygienic specifications and for protection against low temperatures over the last years. Fabric made from natural fiber also has very good breathable properties. It has low thermal conductivity; thus, it is an ideal material for both summer and winter clothing, in summer it stops the skin from getting heated and in winter it keeps the body dry and warm.

The selected sarees made of natural fibers Natural fiber has its own advantages over synthetic fibers. Garments made of natural fibers are breathable, often chemically free and most of all harmless to the skin of the wearer. Based on the assessment performed for physical properties, fabric with low GSM can be one of the most important criteria in buying the saree.

5.2.3 Thermophysiological comfort properties

Based on the testing done for air permeability the resistance of air permeability of fabric majorly depends on the fabric construction. The difference in the physical properties of the affects the permeability behaviors under the same environmental condition.

The weave of the fabric and the thread count are responsible for their greater air permeability. It has been found that weave variants with lower EPI numbers have higher air permeability values. Since long-float weaves make yarns more flexible in their structure, the spaces between these yarns are wider for air to flow more freely.

The transition rate of water vapor from fabrics with natural fibers with different physical properties were tested. From the analysis it is credited that evident water vapor permeability of fabrics decreases as the fabric cover and solid fabric volume increases, independent of weft count. Under high winds environment the cycle of convection plays a major role in the transmission of water vapor through fabrics, and the rate of transmission of moisture vapor increases with wind speed.

The values obtained in this study are a valuable addition to the sources for clothing insulation. Incorporating the appropriate clothing insulation values in the design ensures higher thermal resistance acceptability and reduced energy usage. The basic information collected in the study therefore assumes great importance.

It has been established that Sarees can be referred as all-season clothing. Suitable for Indian climatic conditions and selected fabrics has excellent thermophysiological comfort properties.

It is also concluded that the Sarees (a loose fit garment) can be easily tested on the thermal manikin

5.3 SUGGESTIONS FOR FUTURE WORK

After conducting the work presented here and reviewing the literature available in the public domain, the following areas have been identified for future work:

- The current survey was conducted with only 118 participants; by increasing the size of the sample, we can collect broader information and a global perspective.
- This important study was conducted under standard conditions. Further analysis in simulated or natural environments at high and low temperatures is therefore recommended. This would help to understand the process for preserving thermal comfort at extreme environmental temperatures.
- This research was done with sarees with natural fiber. In future more, variations of saree fabrics like synthetic materials and the pricing of fabrics can be also be included.
- Child manikin gave the basic understanding but testing on women thermal manikin will illustrate the better results and findings.

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APPENDIX A

SURVEY FORM

Understanding the thermal comfort performance of Saree

You are kindly invited to participate in a research project Understanding the thermal comfort performance of Saree being conducted by a student at the Technical University of Liberec, Czech Republic. Please read this information sheet carefully and be confident that you understand its contents before deciding whether to participate or not. If you have any questions about the project, please ask the investigators at deepali.dhruvanshi@tul.cz.

This survey aims to study and understand thermo-physiological comfort of traditional Indian womenswear-Saree, as well as to investigate ways to improve the microclimate condition between the saree and the skin.

This survey will take approximately 10 to 15 minutes of your time. Most questions have multiple-choices. Some may ask you to provide a brief response, but long answers are not required. Note that the results of the questionnaire will be used only for scientific research. The results of this study will contribute to improving the design and comfort aspects of the fabric and Saree. Your opinion and additional comments are welcome.

Name: ____

Email Id (optional): ____

Please upload your photo wearing saree (optional)

A. General demographic Information:

a. Country: ________________________
b. Age group:
    i. 18-25
    ii. 26-40
    iii. 41-55
    iv. More than 55.
c. Profession:
    i. Student
    ii. Employee/ Self-Employed
    iii. Homemaker
    iv. Unemployed

B. Information on the current idea about Sarees:

a. Why do you wear saree? (Because it is _)
    i. Religious
    ii. Traditional
    iii. Fashionable
    iv. Others (Please specify) ____
b. What type of style do you usually like draping:
    i. Backside pleated/open fall (Pallu)
    ii. Front pleated/open fall (Pallu)
    iii. Dhoti style
    iv. Others (Please specify) ____
c. How many sarees do you buy in a year:
    i. 1~2 nos.
    ii. 3~5 nos.

iii. More than 5
iv. Occasionally

d. Where and how do you prefer buying saree and why?
   i. Market place/Shops(offline)
   ii. Online

e. What kind of design do you prefer for daily wear?
   i. Plain with or without border
   ii. Printed
   iii. Embroidery
   iv. Others (Please specify) ____________________

C. Comfort level while wearing saree:

a. Hot and Humid climate/weather: [average country's climatic condition]
   i. Easy
   ii. Normal
   iii. Difficult
   iv. Others (Please specify) ____________________

b. Cold climate/weather: [average country's climatic condition]
   i. Easy
   ii. Normal
   iii. Difficult
   iv. Others (Please specify) ____________________

c. At what environmental temperature (in degree Celsius) do you feel comfortable:
   i. From 15 to 20
   ii. From 21 to 25
   iii. From 26 to 30
   iv. From 31 to 35
   v. More than 36

d. At what environmental temperature (in degree Celsius) do you feel uncomfortable:
   i. From 15 to 20
   ii. From 21 to 25
   iii. From 26 to 30
   iv. From 31 to 35
   v. More than 36

e. For how long do you wear saree on an average:
   i. More than 4 hours
   ii. 2-4 hours
   iii. 1-2 hours
   iv. 0-1 hours

f. Do you think multilayer clothing underneath affects the level of comfort (blouse, petticoat, bra, under-pants)?
   i. Yes
   ii. No
   iii. Maybe
   iv. Depends on the occasion

g. Describe the comfort level of saree as a daily wear attire.
   i. Uncomfortable
   ii. Comfortable
   iii. Very comfortable
   iv. Depends on the profession

h. What area in the body do you feel stress/distress while wearing saree: -
   i. Shoulder with fall (pallu)
   ii. Waist where saree is tucked
   iii. Both A and B
   iv. Other (specify)____________________

i. In which part of the body do you feel more heat stress:
   i. Upper part (blouse side)
   ii. Lower part (petticoat side)
   iii. Middle part (waist)

D. Technical understanding of saree material:

a. What kind of material do you prefer for daily wear?
   i. Natural fibers such as cotton, silk, bamboo, etc.
   ii. Synthetic fibers such as polyester & nylon
   iii. Fiber blends
   iv. Please mention your favorite____

b. What kind of blouse and petticoat do you prefer:
   i. Blouse attached to saree + cotton petticoat
   ii. Attached blouse with any kind of petticoat
   iii. Different fabric blouse + cotton petticoat
   iv. different fabric blouse different fabric petticoat

c. What type of fabric do you prefer in terms of thickness:
   i. Thin
   ii. Medium
   iii. Thick

d. What type of fabric do you prefer in terms of fabric weight
   i. Light
   ii. Medium
   iii. Heavy

E. Describe the best style of saree you prefer to wear or any other related suggestion:

____

____

APPENDIX B

LAB TEST READINGS FOR WATER VAPOUR PERMEABILITY FROM **TEXTEST FX3180 CUPMASTER:**

SARI 1

TEST READING OF 2 LAYERS OF SAMPLE FABRIC						
Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-29, 11:31:18	0.000	146.0459	0.0000	0	0
1	2020-04-29, 12:30:51	0.000	145.3917	-0.6542	3164	189
2	2020-04-29, 13:31:19	0.000	144.5203	-0.8714	4150	247,9
3	2020-04-29, 14:31:06	0.000	143.5901	-0.9302	4481	2677
4	2020-04-29, 15:31:04	0.000	142.6377	-0.9524	4574	273,2
5	2020-04-29, 16:31:06	0.000	141.6818	-0.9559	4586	273,9
6	2020-04-29, 17:31:06	0.000	140.7249	-0.9569	4593	274,4
7	2020-04-29, 18:31:18	0.000	139.7741	-0.9508	4549	271,7
8	2020-04-29, 19:31:04	0.000	138.8349	-0.9392	4526	270,4
9	2020-04-29, 20:31:04	0.000	137.8982	-0.9367	4496	268,6
10	2020-04-29, 21:31:05	0.000	136.9709	-0.9273	4450	265,8
11	2020-04-29, 22:31:17	0.000	136.0521	-0.9188	4396	262,6
12	2020-04-29, 23:31:10	0.000	135.1482	-0.9039	4347	259,7
13	2020-04-30, 00:31:20	0.000	134.2469	-0.9013	4314	257,7
14	2020-04-30, 01:31:17	0.000	133.3504	-0.8965	4307	257,3
15	2020-04-30, 02:31:18	0.000	132.4584	-0.8920	4280	255,7
16	2020-04-30, 03:31:08	0.000	131.5759	-0.8825	4248	253,8
17	2020-04-30, 04:31:22	0.000	130.6927	-0.8832	4223	252,3
18	2020-04-30, 05:31:22	0.000	129.8261	-0.8666	4160	248,5
19	2020-04-30, 06:31:24	0.000	128.9661	-0.8600	4126	246,5
				Average	4098,5	365,3

TEST READING OF 10 LAYERS OF SAMPLE FABRIC						
Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-29, 11:32:43	0.000	149.7177	0.0000	0	0
1	2020-04-29, 12:32:49	0.000	149.2884	-0.4293	2057	122,9
2	2020-04-29, 13:32:44	0.000	148.7278	-0.5606	2695	161
3	2020-04-29, 14:32:42	0.000	148.1234	-0.6044	2903	173,4
4	2020-04-29, 15:32:42	0.000	147.5029	-0.6205	2978	177,9
5	2020-04-29, 16:32:46	0.000	146.8774	-0.6255	2999	179,2
6	2020-04-29, 17:32:42	0.000	146.2490	-0.6284	3020	180,4
7	2020-04-29, 18:32:40	0.000	145.6211	-0.6279	3016	180,1

8	2020-04-29, 19:32:46	0.000	144.9943	-0.6268	3004	179,4
9	2020-04-29, 20:32:46	0.000	144.3692	-0.6251	3000	179,2
10	2020-04-29, 21:32:47	0.000	143.7481	-0.6211	2980	178
11	2020-04-29, 22:32:39	0.000	143.1332	-0.6149	2958	176,7
12	2020-04-29, 23:32:41	0.000	142.5211	-0.6121	2936	175,4
13	2020-04-30, 00:32:42	0.000	141.9093	-0.6118	2936	175,4
14	2020-04-30, 01:32:44	0.000	141.2927	-0.6166	2958	176,7
15	2020-04-30, 02:32:43	0.000	140.6782	-0.6145	2950	176,3
16	2020-04-30, 03:32:47	0.000	140.0649	-0.6133	2941	175,7
17	2020-04-30, 04:32:42	0.000	139.4555	-0.6094	2929	175
18	2020-04-30, 05:32:42	0.000	138.8503	-0.6052	2905	173,5
19	2020-04-30, 06:32:42	0.000	138.2493	-0.6010	2885	172,3
				Average	2752,5	164,425

SARI 2

TEST READING OF 2 LAYERS OF SAMPLE FABRIC

Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-29, 11:30:07	0.0000	144.9933	0.0000	0	0
1	2020-04-29, 12:30:19	0.0000	144.1336	-0.8597	4113	245,7
2	2020-04-29, 13:30:05	0.0000	142.9968	-1.1368	5478	327,2
3	2020-04-29, 14:30:04	0.0000	141.7661	-1.2307	5909	353
4	2020-04-29, 15:30:05	0.0000	140.5136	-1.2525	6010	359
5	2020-04-29, 16:30:02	0.0000	139.2598	-1.2538	6023	359,8
6	2020-04-29, 17:30:01	0.0000	138.0070	-1.2528	6015	359,3
7	2020-04-29, 18:30:07	0.0000	136.7734	-1.2336	5911	353,1
8	2020-04-29, 19:30:04	0.0000	135.5533	-1.2201	5861	350,1
9	2020-04-29, 20:30:02	0.0000	134.3416	-1.2117	5819	347,6
10	2020-04-29, 21:30:02	0.0000	133.1467	-1.1949	5736	342,6
11	2020-04-29, 22:30:07	0.0000	131.9715	-1.1752	5633	336,5
12	2020-04-29, 23:30:03	0.0000	130.8145	-1.1570	5560	332,1
13	2020-04-30, 00:30:06	0.0000	129.6681	-1.1464	5498	328,4
14	2020-04-30, 01:30:05	0.0000	128.5271	-1.1410	5478	327,3
15	2020-04-30, 02:30:07	0.0000	127.3973	-1.1298	5420	323,8
16	2020-04-30, 03:30:00	0.0000	126.2837	-1.1136	5356	319,9
17	2020-04-30, 04:30:09	0.0000	125.1741	-1.1096	5313	317,4
18	2020-04-30, 05:30:06	0.0000	124.0890	-1.0851	5213	311,4
19	2020-04-30, 06:30:08	0.0000	123.0161	-1.0729	5147	307,5
				Average	5274,65	315,085

TEST READING OF 10 LAYERS OF SAMPLE FABRIC						
Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-29, 11:28:57	0.0000	149.9628	0.0000	0	0
1	2020-04-29, 12:29:03	0.0000	149.5489	-0.4139	1983	118,5
2	2020-04-29, 13:28:57	0.0000	148.9995	-0.5494	2642	157,8
3	2020-04-29, 14:28:52	0.0000	148.4021	-0.5974	2872	171,5
4	2020-04-29, 15:28:53	0.0000	147.7880	-0.6141	2947	176
5	2020-04-29, 16:28:57	0.0000	147.1678	-0.6202	2974	177,6
6	2020-04-29, 17:28:55	0.0000	146.5452	-0.6226	2990	178,6
7	2020-04-29, 18:28:58	0.0000	145.9242	-0.6210	2978	177,9
8	2020-04-29, 19:28:53	0.0000	145.3048	-0.6194	2977	177,9
9	2020-04-29, 20:28:54	0.0000	144.6867	-0.6181	2966	177,2
10	2020-04-29, 21:28:59	0.0000	144.0701	-0.6166	2956	176,6
11	2020-04-29, 22:28:55	0.0000	143.4609	-0.6092	2927	174,9
12	2020-04-29, 23:28:56	0.0000	142.8549	-0.6060	2908	173,7
13	2020-04-30, 00:28:59	0.0000	142.2489	-0.6060	2906	173,6
14	2020-04-30, 01:28:52	0.0000	141.6402	-0.6087	2927	174,9
15	2020-04-30, 02:28:51	0.0000	141.0315	-0.6087	2923	174,6
16	2020-04-30, 03:28:53	0.0000	140.4241	-0.6074	2914	174,1
17	2020-04-30, 04:28:57	0.0000	139.8167	-0.6074	2912	174
18	2020-04-30, 05:28:55	0.0000	139.2148	-0.6019	2891	172,7
19	2020-04-30, 06:28:49	0.0000	138.6169	-0.5979	2875	171,7
				Average	2723,4	162,69

SARI 3

TEST READING OF 2 LAYERS OF SAMPLE FABRIC						
Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-29, 11:28:39	0.0000	145.5217	0.0000	0	0
1	2020-04-29, 12:28:44	0.0000	143.4775	-2.0442	9799	585,3
2	2020-04-29, 13:28:40	0.0000	140.9029	-2.5746	12372	739,1
3	2020-04-29, 14:28:39	0.0000	138.1712	-2.7317	13116	783,5
4	2020-04-29, 15:28:39	0.0000	135.3994	-2.7718	13305	794,8
5	2020-04-29, 16:28:38	0.0000	132.6210	-2.7784	13340	796,9
6	2020-04-29, 17:28:37	0.0000	131.0464	-1.5746	7560	451,6
7	2020-04-29, 18:28:39	0.0000	129.7520	-1.2944	6210	371
8	2020-04-29, 19:28:35	0.0000	128.4788	-1.2732	6118	365,5
9	2020-04-29, 20:28:36	0.0000	127.2164	-1.2624	6058	361,9
10	2020-04-29, 21:28:42	0.0000	125.9673	-1.2491	5986	357,6

11	2020-04-29, 22:28:38	0.0000	124.7401	-1.2272	5897	352,3
12	2020-04-29, 23:28:43	0.0000	123.5273	-1.2128	5813	347,3
13	2020-04-30, 00:28:37	0.0000	122.3123	-1.2150	5842	349
14	2020-04-30, 01:28:35	0.0000	121.0794	-1.2329	5921	353,7
15	2020-04-30, 02:28:33	0.0000	119.8570	-1.2224	5871	350,7
16	2020-04-30, 03:28:35	0.0000	118.6432	-1.2138	5823	347,9
17	2020-04-30, 04:28:43	0.0000	117.4323	-1.2109	5799	346,4
18	2020-04-30, 05:28:35	0.0000	116.2400	-1.1923	5736	342,6
19	2020-04-30, 06:28:35	0.0000	115.0549	-1.1851	5688	339,8
				Average	7312,7	436,845

TEST READING OF 10 LAYERS OF SAMPLE FABRIC

Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-29, 11:28:09	0.0000	151.4974	0.0000	0	0
1	2020-04-29, 12:28:06	0.0000	151.0797	-0.4177	2007	119,9
2	2020-04-29, 13:28:01	0.0000	150.5173	-0.5624	2703	161,5
3	2020-04-29, 14:28:00	0.0000	149.9062	-0.6111	2934	175,3
4	2020-04-29, 15:28:05	0.0000	149.2755	-0.6307	3023	180,6
5	2020-04-29, 16:28:04	0.0000	148.6401	-0.6354	3051	182,2
6	2020-04-29, 17:28:07	0.0000	147.9994	-0.6407	3073	183,6
7	2020-04-29, 18:28:05	0.0000	147.3602	-0.6392	3070	183,4
8	2020-04-29, 19:28:04	0.0000	146.7211	-0.6391	3069	183,3
9	2020-04-29, 20:28:02	0.0000	146.0826	-0.6385	3067	183,2
10	2020-04-29, 21:28:06	0.0000	145.4467	-0.6359	3049	182,1
11	2020-04-29, 22:28:03	0.0000	144.8187	-0.6280	3017	180,2
12	2020-04-29, 23:28:04	0.0000	144.1952	-0.6235	2992	178,7
13	2020-04-30, 00:28:05	0.0000	143.5615	-0.6337	3041	181,7
14	2020-04-30, 01:28:00	0.0000	142.9118	-0.6497	3123	186,6
15	2020-04-30, 02:28:04	0.0000	142.2615	-0.6503	3118	186,3
16	2020-04-30, 03:28:06	0.0000	141.6143	-0.6472	3105	185,5
17	2020-04-30, 04:28:06	0.0000	140.9677	-0.6466	3104	185,4
18	2020-04-30, 05:28:03	0.0000	140.3288	-0.6389	3069	183,4
19	2020-04-30, 06:28:05	0.0000	139.6925	-0.6363	3053	182,4
				Average	2833,4	169,265

SARI 4

TEST READING OF 2 LAYERS OF SAMPLE FABRIC

Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]

0	2020-04-27, 13:52:42	0.0000	147.0963	0.0000	0	0
1	2020-04-27, 14:52:24	0.0000	146.4639	-0.6324	3051	182,2
2	2020-04-27, 15:52:38	0.0000	145.5858	-0.8781	4199	250,8
3	2020-04-27, 16:52:40	0.0000	144.6238	-0.9620	4615	275,7
4	2020-04-27, 17:52:40	0.0000	143.6312	-0.9926	4764	284,6
5	2020-04-27, 18:52:39	0.0000	142.6293	-1.0019	4810	287,4
6	2020-04-27, 19:52:38	0.0000	141.6266	-1.0027	4814	287,6
7	2020-04-27, 20:52:40	0.0000	140.6293	-0.9973	4784	285,8
8	2020-04-27, 21:52:39	0.0000	139.6410	-0.9883	4745	283,5
9	2020-04-27, 22:52:39	0.0000	138.6586	-0.9824	4716	281,7
10	2020-04-27, 23:52:38	0.0000	137.6775	-0.9811	4711	281,4
11	2020-04-28, 00:52:29	0.0000	136.7043	-0.9732	4683	279,8
12	2020-04-28, 01:52:35	0.0000	135.7377	-0.9666	4632	276,7
13	2020-04-28, 02:52:35	0.0000	134.7802	-0.9575	4596	274,6
14	2020-04-28, 03:52:37	0.0000	133.8323	-0.9479	4547	271,7
15	2020-04-28, 04:52:39	0.0000	132.8846	-0.9477	4546	271,6
16	2020-04-28, 05:52:25	0.0000	131.9523	-0.9323	4493	268,4
17	2020-04-28, 06:52:29	0.0000	131.0200	-0.9323	4470	267
18	2020-04-28, 07:52:35	0.0000	130.0955	-0.9245	4430	264,7
19	2020-04-28, 08:52:40	0.0000	129.1785	-0.9170	4395	262,6
20	2020-04-28, 09:52:39	0.0000	128.2631	-0.9154	4395	262,6
				Average	4304,571429	257,1619048

TEST READING OF 10 LAYERS OF SAMPLE FABRIC

Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-27, 13:53:59	0.0000	149.1847	0.0000	0	0
1	2020-04-27, 14:53:36	0.0000	148.7330	-0.4517	2182	130,4
2	2020-04-27, 15:54:02	0.0000	148.1168	-0.6162	2937	175,4
3	2020-04-27, 16:54:01	0.0000	147.4554	-0.6614	3176	189,7
4	2020-04-27, 17:54:01	0.0000	146.7735	-0.6819	3273	195,5
5	2020-04-27, 18:54:00	0.0000	146.0871	-0.6864	3296	196,9
6	2020-04-27, 19:54:03	0.0000	145.3978	-0.6893	3306	197,5
7	2020-04-27, 20:53:57	0.0000	144.7132	-0.6846	3292	196,6
8	2020-04-27, 21:53:57	0.0000	144.0295	-0.6837	3282	196
9	2020-04-27, 22:53:59	0.0000	143.3472	-0.6823	3273	195,5
10	2020-04-27, 23:53:59	0.0000	142.6643	-0.6829	3278	195,8
11	2020-04-28, 00:53:35	0.0000	141.9908	-0.6735	3254	194,4
12	2020-04-28, 01:53:38	0.0000	141.3178	-0.6730	3228	192,8
13	2020-04-28, 02:53:35	0.0000	140.6487	-0.6691	3214	192
14	2020-04-28, 03:54:00	0.0000	139.9798	-0.6689	3189	190,5

15	2020-04-28, 04:53:56	0.0000	139.3177	-0.6621	3182	190,1
16	2020-04-28, 05:53:37	0.0000	138.6628	-0.6549	3160	188,8
17	2020-04-28, 06:53:38	0.0000	138.0097	-0.6531	3134	187,2
18	2020-04-28, 07:53:40	0.0000	137.3591	-0.6506	3121	186,5
19	2020-04-28, 08:54:00	0.0000	136.7086	-0.6505	3105	185,5
20	2020-04-28, 09:53:57	0.0000	136.0639	-0.6447	3097	185
				Average	2999	179,147619

SARI 5

TEST READING OF 2 LAYERS OF SAMPLE FABRIC

Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-27, 13:50:32	0.0000	146.5821	0.0000	0	0
1	2020-04-27, 14:50:28	0.0000	145.9485	-0.6336	3045	181,9
2	2020-04-27, 15:50:23	0.0000	145.0836	-0.8649	4157	248,3
3	2020-04-27, 16:50:29	0.0000	144.1311	-0.9525	4564	272,7
4	2020-04-27, 17:50:25	0.0000	143.1550	-0.9761	4690	280,2
5	2020-04-27, 18:50:28	0.0000	142.1714	-0.9836	4717	281,8
6	2020-04-27, 19:50:27	0.0000	141.1903	-0.9811	4711	281,4
7	2020-04-27, 20:50:29	0.0000	140.2111	-0.9792	4698	280,6
8	2020-04-27, 21:50:25	0.0000	139.2461	-0.9650	4637	277
9	2020-04-27, 22:50:20	0.0000	138.2878	-0.9583	4606	275,2
10	2020-04-27, 23:50:25	0.0000	137.3292	-0.9586	4595	274,5
11	2020-04-28, 00:50:26	0.0000	136.3762	-0.9530	4573	273,2
12	2020-04-28, 01:50:28	0.0000	135.4380	-0.9382	4501	268,9
13	2020-04-28, 02:50:25	0.0000	134.5125	-0.9255	4446	265,6
14	2020-04-28, 03:50:33	0.0000	133.5896	-0.9229	4420	264
15	2020-04-28, 04:50:34	0.0000	132.6742	-0.9154	4393	262,4
16	2020-04-28, 05:50:23	0.0000	131.7753	-0.8989	4328	258,5
17	2020-04-28, 06:50:27	0.0000	130.8784	-0.8969	4300	256,9
18	2020-04-28, 07:50:27	0.0000	129.9950	-0.8834	4240	253,3
19	2020-04-28, 08:50:29	0.0000	129.1206	-0.8744	4195	250,6
20	2020-04-28, 09:50:29	0.0000	128.2500	-0.8706	4179	249,6
				Average	4190,238095	250,3142857

TEST READING OF 10 LAYERS OF SAMPLE FABRIC

Pos.	Time (YYYY-MM-DD, HH:MM:SS)	Tare (g)	Weight (g) compensated	Weight alteration (g)	WVTR [g/m²/d]	WVTR [gr/ft²/h]
0	2020-04-27, 13:51:30	0.0000	150.8882	0.0000	0	0
1	2020-04-27, 14:51:21	0.0000	150.4445	-0.4437	2135	127,5

2	2020-04-27, 15:51:27	0.0000	149.8433	-0.6012	2881	172,1
3	2020-04-27, 16:51:26	0.0000	149.1859	-0.6574	3156	188,6
4	2020-04-27, 17:51:25	0.0000	148.5084	-0.6775	3253	194,3
5	2020-04-27, 18:51:25	0.0000	147.8251	-0.6833	3280	195,9
6	2020-04-27, 19:51:25	0.0000	147.1405	-0.6846	3286	196,3
7	2020-04-27, 20:51:30	0.0000	146.4543	-0.6862	3289	196,5
8	2020-04-27, 21:51:25	0.0000	145.7750	-0.6793	3265	195,1
9	2020-04-27, 22:51:24	0.0000	145.0965	-0.6785	3258	194,6
10	2020-04-27, 23:51:25	0.0000	144.4149	-0.6816	3271	195,4
11	2020-04-28, 00:51:21	0.0000	143.7375	-0.6774	3255	194,5
12	2020-04-28, 01:51:25	0.0000	143.0653	-0.6722	3223	192,5
13	2020-04-28, 02:51:25	0.0000	142.3993	-0.6660	3197	191
14	2020-04-28, 03:51:29	0.0000	141.7361	-0.6632	3180	190
15	2020-04-28, 04:51:27	0.0000	141.0752	-0.6609	3174	189,6
16	2020-04-28, 05:51:20	0.0000	140.4229	-0.6523	3137	187,4
17	2020-04-28, 06:51:24	0.0000	139.7714	-0.6515	3124	186,6
18	2020-04-28, 07:51:29	0.0000	139.1254	-0.6460	3096	185
19	2020-04-28, 08:51:29	0.0000	138.4843	-0.6411	3077	183,8
20	2020-04-28, 09:51:26	0.0000	137.8437	-0.6406	3077	183,8
				Average	2981,619048	178,1190476

APPENDIX C

LAB TEST READINGS FOR THERMAL RESISTANCE FROM **CHILD THERMAL MANIKIN- THERMDAC VERSION-V8.4.3.18**

SARI 1

Ambient Sensors					**AVERAGE**
Ambient	Units	Avg	Avg	Avg	
Avg Amb Temp	degC	20,69	20,21	20,64	20,5133333
Amb 1	degC	20,67	20,24	20,75	20,5533333
Amb 2	degC	20,71	20,18	20,52	20,47
RH	%RH	53,5	55,8	52,7	54
Windspeed	m/sec	0,06	0,05	0,03	0,04666667
Water Temp	^{o}C	30,49	29,73	33,57	31,2633333

Manikin Zones		**RCT**			
Manikin Zones		**Average**			
Face		0,082	0,083	0,083	0,08266667
Head		0,105	0,106	0,108	0,10633333
R Upper Arm		0,278	0,272	0,276	0,27533333
L Upper Arm		0,263	0,28	0,314	0,28566667
R Forearm		0,091	0,093	0,103	0,09566667
L Forearm		0,136	0,138	0,139	0,13766667
R Hand		0,082	0,083	0,108	0,091
L Hand		0,085	0,084	0,083	0,084
Chest		0,291	0,243	0,268	0,26733333
Back		0,275	0,226	0,265	0,25533333
R Thigh		0,502	0,433	0,46	0,465
L Thigh		0,329	0,357	0,366	0,35066667
R Calf		0,171	0,172	0,164	0,169
L Calf		0,184	0,178	0,165	0,17566667
R Foot		0,093	0,091	0,094	0,09266667
L Foot		0,11	0,099	0,103	0,104
Manikin Zones		**RCF**			
Manikin Zones		**Average**			
Face		-0,004	-0,003	-0,003	-0,0033333
Head		-0,005	-0,004	-0,002	-0,0036667
R Upper Arm		0,156	0,138	0,142	0,14533333
L Upper Arm		0,173	0,181	0,215	0,18966667
R Forearm		0,016	0,018	0,028	0,02066667
L Forearm		0,048	0,05	0,051	0,04966667
R Hand		-0,006	-0,005	0,02	0,003
L Hand		0,004	0,003	0,002	0,003

Chest		0,194	0,136	0,161	0,16366667
Back		0,175	0,116	0,155	0,14866667
R Thigh		0,422	0,345	0,372	0,37966667
L Thigh		0,25	0,27	0,279	0,26633333
R Calf		0,083	0,084	0,076	0,081
L Calf		0,099	0,093	0,08	0,09066667
R Foot		0,01	0,008	0,011	0,00966667
L Foot		0,028	0,017	0,021	0,022
Manikin Zones		**Heat Flux Generated**			
Manikin Zones		**Average**			
Face		175,7	178,5	173,2	175,8
Head		136	140,5	133,1	136,533333
R Upper Arm		51,6	54,5	52,1	52,7333333
L Upper Arm		54,6	53	45,7	51,1
R Forearm		158	159,4	140,2	152,533333
L Forearm		106,3	108	104,1	106,133333
R Hand		175,1	179,9	133,2	162,733333
L Hand		171,7	178,9	174,7	175,1
Chest		49,6	61,2	53,9	54,9
Back		52	65,7	54,2	57,3
R Thigh		28,6	34,2	31,3	31,3666667
L Thigh		43,7	41,6	39,3	41,5333333
R Calf		83,9	86,2	87,9	86
L Calf		78	83,3	87,4	82,9
R Foot		154,7	163,3	153,8	157,266667
L Foot		131,2	150,9	139,9	140,666667

SARI 2

Ambient Sensors					**Average**
Ambient	Units	Avg	Avg	Avg	
Avg Amb Temp	degC	20,6	20,47	20,18	20,4166667
Amb 1	degC	20,57	20,53	20,16	20,42
Amb 2	degC	20,63	20,4	20,21	20,4133333
RH	%RH	53,7	53,9	55,9	54,5
Windspeed	m/sec	0,05	0,05	0,01	0,03666667
Water Temp	ºC	33,76	34,51	34,91	34,3933333

Manikin Zones	**RCT**				
Manikin Zones	**Average**				
Face		0,081	0,084	0,085	0,08333333
Head		0,106	0,107	0,108	0,107
R Upper Arm		0,27	0,264	0,29	0,27466667
L Upper Arm		0,36	0,328	0,328	0,33866667

R Forearm		0,102	0,102	0,102	0,102
L Forearm		0,139	0,135	0,145	0,13966667
R Hand		0,097	0,1	0,095	0,09733333
L Hand		0,086	0,088	0,089	0,08766667
Chest		0,299	0,303	0,298	0,3
Back		0,279	0,273	0,273	0,275
R Thigh		0,499	0,497	0,672	0,556
L Thigh		0,434	0,38	0,447	0,42033333
R Calf		0,175	0,166	0,157	0,166
L Calf		0,174	0,181	0,177	0,17733333
R Foot		0,102	0,089	0,094	0,095
L Foot		0,104	0,117	0,098	0,10633333
Manikin Zones	**RCF**				
Manikin Zones	**Average**				
Face		-0,005	-0,002	-0,001	-0,0026667
Head		-0,004	-0,003	-0,002	-0,003
R Upper Arm		0,136	0,13	0,156	0,14066667
L Upper Arm		0,261	0,229	0,229	0,23966667
R Forearm		0,027	0,027	0,027	0,027
L Forearm		0,051	0,047	0,057	0,05166667
R Hand		0,009	0,012	0,007	0,00933333
L Hand		0,005	0,007	0,008	0,00666667
Chest		0,192	0,196	0,191	0,193
Back		0,169	0,163	0,163	0,165
R Thigh		0,411	0,409	0,584	0,468
L Thigh		0,347	0,293	0,36	0,33333333
R Calf		0,087	0,078	0,069	0,078
L Calf		0,089	0,096	0,092	0,09233333
R Foot		0,019	0,006	0,011	0,012
L Foot		0,022	0,035	0,016	0,02433333
Manikin Zones	**Heat Flux Generated**				
Manikin Zones	**Average**				
Face		177,8	174,7	175,2	175,9
Head		135,6	136,4	137,7	136,566667
R Upper Arm		53,3	55	51,1	53,1333333
L Upper Arm		40,1	44,4	45,2	43,2333333
R Forearm		141,7	143,1	145,5	143,433333
L Forearm		105	108,5	102,9	105,466667
R Hand		149,2	146,5	157,2	150,966667
L Hand		170,8	166,2	168,3	168,433333
Chest		48,5	48,3	50	48,9333333
Back		51,6	53,2	54,3	53,0333333
R Thigh		28,9	29,3	22,1	26,7666667
L Thigh		33,3	38,3	33,3	34,9666667
R Calf		82,3	87,7	94,4	88,1333333
L Calf		83,2	80,4	83,8	82,4666667

R Foot		141,8	164	158,8	154,866667
L Foot		139	124,3	152,2	138,5

SARI 3

Ambient Sensors					**Average**
Ambient	Units	Avg	Avg	Avg	
Avg Amb Temp	degC	20,48	20,22	20,51	20,4033333
Amb 1	degC	20,48	20,21	20,58	20,4233333
Amb 2	degC	20,47	20,22	20,44	20,3766667
RH	%RH	53,7	55,1	53,5	54,1
Windspeed	m/sec	0,05	0,03	0,02	0,03333333
Water Temp	°C	30,66	29,31	35,21	31,7266667

Manikin Zones	**RCT**				
Manikin Zones	**Average**				
Face		0,081	0,085	0,084	0,08333333
Head		0,103	0,104	0,107	0,10466667
R Upper Arm		0,274	0,267	0,267	0,26933333
L Upper Arm		0,302	0,253	0,38	0,31166667
R Forearm		0,086	0,119	0,094	0,09966667
L Forearm		0,157	0,149	0,159	0,155
R Hand		0,078	0,106	0,093	0,09233333
L Hand		0,089	0,093	0,084	0,08866667
Chest		0,286	0,279	0,26	0,275
Back		0,254	0,241	0,275	0,25666667
R Thigh		0,386	0,383	0,458	0,409
L Thigh		0,307	0,364	0,41	0,36033333
R Calf		0,161	0,159	0,17	0,16333333
L Calf		0,174	0,155	0,173	0,16733333
R Foot		0,098	0,096	0,11	0,10133333
L Foot		0,102	0,097	0,104	0,101
Manikin Zones	**RCF**				
Manikin Zones	**Average**				
Face		-0,005	-0,001	-0,002	-0,0026667
Head		-0,007	-0,006	-0,003	-0,0053333
R Upper Arm		0,14	0,133	0,133	0,13533333
L Upper Arm		0,203	0,154	0,281	0,21266667
R Forearm		0,011	0,044	0,019	0,02466667
L Forearm		0,069	0,061	0,071	0,067
R Hand		-0,01	0,018	0,005	0,00433333
L Hand		0,008	0,012	0,003	0,00766667
Chest		0,179	0,172	0,153	0,168
Back		0,144	0,131	0,165	0,14666667

R Thigh		0,298	0,295	0,37	0,321
L Thigh		0,22	0,277	0,323	0,27333333
R Calf		0,073	0,071	0,082	0,07533333
L Calf		0,089	0,07	0,088	0,08233333
R Foot		0,015	0,013	0,027	0,01833333
L Foot		0,02	0,015	0,022	0,019
Manikin Zones	**Heat Flux Generated**				
Manikin Zones	**Average**				
Face		180,9	174,9	173,5	176,433333
Head		141,6	141,7	135,7	139,666667
R Upper Arm		53	55,5	54,3	54,2666667
L Upper Arm		48,2	58,6	38,2	48,3333333
R Forearm		169,4	124,4	154,9	149,566667
L Forearm		93,2	99,8	91,3	94,7666667
R Hand		187,7	140,1	157,3	161,7
L Hand		164,9	159,9	174,7	166,5
Chest		51	53,2	55,9	53,3666667
Back		57,3	61,4	52,7	57,1333333
R Thigh		37,7	38,6	31,6	35,9666667
L Thigh		47,4	40,6	35,4	41,1333333
R Calf		90,5	93,1	85,3	89,6333333
L Calf		83,7	95,8	83,8	87,7666667
R Foot		148,9	154,4	132,3	145,2
L Foot		142,4	152,4	140,3	145,033333

SARI 4

Ambient Sensors					**Average**
Ambient	Units	Avg	Avg	Avg	
Avg Amb Temp	degC	20,74	20,53	20,47	20,58
Amb 1	degC	20,78	20,52	20,54	20,6133333
Amb 2	degC	20,69	20,53	20,39	20,5366667
RH	%RH	53,3	55	53,7	54
Windspeed	m/sec	0,05	0,05	0,03	0,04333333
Water Temp	°C	34,51	35,17	30,99	33,5566667

Manikin Zones	**RCT**				
Manikin Zones	**Average**				
Face		0,081	0,081	0,084	0,082
Head		0,106	0,106	0,103	0,105
R Upper Arm		0,264	0,309	0,265	0,27933333
L Upper Arm		0,315	0,334	0,126	0,25833333
R Forearm		0,096	0,093	0,095	0,09466667
L Forearm		0,127	0,135	0,155	0,139

R Hand		0,104	0,08	0,08	0,088
L Hand		0,084	0,084	0,091	0,08633333
Chest		0,287	0,312	0,254	0,28433333
Back		0,266	0,264	0,229	0,253
R Thigh		0,56	0,458	0,374	0,464
L Thigh		0,338	0,306	0,335	0,32633333
R Calf		0,157	0,156	0,138	0,15033333
L Calf		0,165	0,164	0,153	0,16066667
R Foot		0,097	0,102	0,088	0,09566667
L Foot		0,109	0,119	0,096	0,108
Manikin Zones	**RCF**				
Manikin Zones	**Average**				
Face		-0,005	-0,005	-0,002	-0,004
Head		-0,004	-0,004	-0,007	-0,005
R Upper Arm		0,13	0,175	0,131	0,14533333
L Upper Arm		0,216	0,235	0,027	0,15933333
R Forearm		0,021	0,018	0,02	0,01966667
L Forearm		0,039	0,047	0,067	0,051
R Hand		0,016	-0,008	-0,008	0
L Hand		0,003	0,003	0,01	0,00533333
Chest		0,18	0,205	0,147	0,17733333
Back		0,156	0,154	0,119	0,143
R Thigh		0,472	0,37	0,286	0,376
L Thigh		0,251	0,219	0,248	0,23933333
R Calf		0,069	0,068	0,05	0,06233333
L Calf		0,08	0,079	0,068	0,07566667
R Foot		0,014	0,019	0,005	0,01266667
L Foot		0,027	0,037	0,014	0,026
Manikin Zones	**Heat Flux Generated**				
Manikin Zones	**Average**				
Face		176,3	179,1	173,5	176,3
Head		135	136,5	141,6	137,7
R Upper Arm		54,2	46,8	55	52
L Upper Arm		45,5	43,5	115,8	68,2666667
R Forearm		150,4	156,9	153,5	153,6
L Forearm		113,4	108,9	95,2	105,833333
R Hand		137,7	182,2	183,6	167,833333
L Hand		171,8	176,1	161,8	169,9
Chest		50	46,8	57,4	51,4
Back		53,7	54,8	63,5	57,3333333
R Thigh		25,5	31,7	38,9	32,0333333
L Thigh		42,5	47,4	43,4	44,4333333
R Calf		90,9	92,7	105,9	96,5
L Calf		86,6	88,8	95,2	90,2
R Foot		146,9	141,6	165,7	151,4
L Foot		131,8	122,1	151,3	135,066667

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Ambient Sensors					Average
Ambient	Units	Avg	Avg	Avg	
Avg Amb Temp	degC	20,59	20,34	20,42	20,45
Amb 1	degC	20,67	20,36	20,56	20,53
Amb 2	degC	20,51	20,33	20,28	20,3733333
RH	%RH	52,6	53,4	56,3	54,1
Windspeed	m/sec	0,05	0,05	0,02	0,04
Water Temp		32,16	33,94	33,18	33,0933333

Manikin Zones	RCT				
Manikin Zones	Average				
Face		0,082	0,083	0,087	0,084
Head		0,105	0,108	0,108	0,107
R Upper Arm		0,274	0,292	0,247	0,271
L Upper Arm		0,302	0,288	0,134	0,24133333
R Forearm		0,106	0,108	0,092	0,102
L Forearm		0,12	0,117	0,153	0,13
R Hand		0,102	0,1	0,11	0,104
L Hand		0,083	0,08	0,087	0,08333333
Chest		0,251	0,326	0,276	0,28433333
Back		0,236	0,256	0,234	0,242
R Thigh		0,443	0,484	0,449	0,45866667
L Thigh		0,396	0,385	0,402	0,39433333
R Calf		0,173	0,173	0,162	0,16933333
L Calf		0,165	0,17	0,163	0,166
R Foot		0,108	0,101	0,089	0,09933333
L Foot		0,116	0,115	0,093	0,108
Manikin Zones	RCF				
Manikin Zones	Average				
Face		-0,004	-0,003	0,001	-0,002
Head		-0,005	-0,002	-0,002	-0,003
R Upper Arm		0,14	0,158	0,113	0,137
L Upper Arm		0,203	0,189	0,035	0,14233333
R Forearm		0,031	0,033	0,017	0,027
L Forearm		0,032	0,029	0,065	0,042
R Hand		0,014	0,012	0,022	0,016
L Hand		0,002	-0,001	0,006	0,00233333
Chest		0,144	0,219	0,169	0,17733333
Back		0,126	0,146	0,124	0,132
R Thigh		0,355	0,396	0,361	0,37066667
L Thigh		0,309	0,298	0,315	0,30733333

R Calf		0,085	0,085	0,074	0,08133333
L Calf		0,08	0,085	0,078	0,081
R Foot		0,025	0,018	0,006	0,01633333
L Foot		0,034	0,033	0,011	0,026
Manikin Zones	**Heat Flux Generated**				
Manikin Zones	**Average**				
Face		177,1	177,9	167,3	174,1
Head		137,1	135,7	135,4	136,066667
R Upper Arm		52,7	50,3	59,2	54,0666667
L Upper Arm		47,9	51	108,7	69,2
R Forearm		136,5	136,6	159,5	144,2
L Forearm		121,3	127	95,8	114,7
R Hand		142,4	147,6	132,9	140,966667
L Hand		175,9	187,1	168,9	177,3
Chest		57,6	45,2	53	51,9333333
Back		61	57,4	62,3	60,2333333
R Thigh		32,6	30,3	32,5	31,8
L Thigh		36,4	38,2	36,4	37
R Calf		83,5	84,6	89,9	86
L Calf		87,5	86,6	90	88,0333333
R Foot		133,5	145,2	165,2	147,966667
L Foot		124,8	128,1	158,7	137,2