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FAKULTA TEXTILNÍ

Factors affecting garment's thermophysiological properties in tropical weather countries

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AUTOREFERÁT DISERTAČNÍ PRÁCE

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1. Aim of the work

This research work aims mainly to investigate the comfort properties of classic underwear and outer wear made from classical cotton, and comparing these fabrics with new functional materials for example polypropylene, polyester cool max, viscose fibers made from bamboo plants and Merino wool, and it aims to find the best and optimal wear for the conditions in hot weather countries.

Also it aims to measure the comfortability of these different materials under different conditions of temperatures and humidity that actually exists in countries with hot weather like Egypt all around the year, and monitoring the factors that affects the comfortability of the garments used in that tropical weather.

It is well know that cotton for example is a very good material for absorbing humidity , but when it absorbs this humidity it is not that easy to lose this humidity , so when using this material in practicing sports for example , it will be useful in the beginning because it will absorb sweat , but after a while it becomes saturated with this maximum amount of sweat it could absorb , it will not be comfortable anymore because it will not get rid of this sweat easily and it will lead to discomfort for the wearer , so the only way to be comfortable is to change this garment with another one , so what about using new functional clothes from new materials like polyester cool max or Marino wool in these tropical weather? Will it be comfortable under these circumstances? And what about using these new functional materials and analyzing the heat, moisture loss, heat and moisture transport through these fabrics under this hot condition which could reach to about 35 Celsius degrees and 80 % relative humidity.

Although a lot of studies have been done concerning the comfort properties of garments and a lot of mathematical models have been established to predict and to study the comfort properties, but a real study and a real application is needed to actually determine factors which affect the comfort properties in real conditions, this is the main aim for the research, to exercise and examine different materials with different structures and finishes under variation of heat , humidity and combination of heat and humidity which actually exists all around the year in countries with tropical weather and here the climate condition of Egypt is actually being achieved varying from summer to winter time as well as the humidity; to study the comfort properties of garments which could be used to achieve the maximum comfort properties ,and this will allow us to understand the factors which affect the comfort properties in these conditions, leading us to develop garment properties that could be applied to enhance these properties.

2. Over view of thermophysiological properties of fabrics

People wear clothing to protect their body from environment. As clothing is being worn, the human body interacts dynamically with it and the surrounding environment. There are four processes occurring interactively that determine the comfort status of the wearer. The processes are: physical processes in clothing and surrounding environments, physiological processes in the body, neurophysiological and psychological processes [1].

These four types of processes occur concurrently. The laws of physics are followed by the physical processes in the environment and clothing, which determine the physical conditions for the survival and comfort of the body. The laws of physiology are followed by the thermoregulatory responses of the body and the sensory responses of skin nerve endings. The thermoregulatory and sensory systems react to the physical stimuli from clothing and the environment to create certain appropriate physiological conditions for the survival of the body and to inform the brain of various physical conditions that influence comfort status.

The psychological processes are the most complicated, the brain needs to formulate subjective perceptions from the sensory signals from the nerve endings in order to evaluate and weigh these sensory perceptions against past experiences, internal desires and external influences. Through these processes, the brain formulates a subjective perception of overall comfort status, judgments and preferences. Alternatively, the psychological power of the brain can influence the physiological status of the body through various means such as sweating, blood-flow justification and shivering. These physiological changes will alter the physical processes in the clothing and external environment [1].

On the basis of integration of all of these physical, physiological, neurophysiological and psychological processes and factors, the comfort status as the subjective perception and judgment of the wearer is determined.

3. Used methods

In this work the different comfort properties like the thermal effusivity (e) (Ws½/m²K), thermal conductivity (K) (W/mK), thermal resistance (Rct) (m^2Kw^{-1}), thermal diffusivity (m²/s), air permeability (m/sec), water vapor resistance (Ret) (m²Pa/W) and water vapor permeability index (I_{mt}) for these garments have been measured under the mentioned different conditions to determine the comfort properties of each type and to see the effect of each of the humidity and the temperature which actually exists in tropical countries on the comfort properties of these fabrics.

3.1. Thermal effusivity (e) (Ws½/m²K)

Thermal effusivity is a heat transfer property present in all materials in all formats – solid, liquid, pastes, powder and gas. Effusivity is the property that dictates the interfacial temperature when two semi-infinite objects at different temperature touch. Effusivity combines thermal conductivity, density and heat capacity into one value

$$e = (k\rho c_p)^{\frac{1}{2}} \qquad (1)$$

Where k is the thermal conductivity, ρ is the density and c_p is the specific heat capacity. The product of ρ and c_p is known as the volumetric heat capacity. A material's thermal effusivity is a measure of its ability to exchange thermal energy with its surroundings [2]. If two semi-infinite bodies initially at temperatures T1 and T2 are brought in perfect thermal contact, the temperature at the contact surface Tm will be given by their relative effusivities.

$$Tm = T1 + (T2 - T1)\frac{e2}{(e2+e1)} \qquad (2)$$

Thermal effusivity is a surface property [3], and therefore the finishing processes can change it. This parameter allows assessment of the fabric’s character in the aspect of it’s ‘coolwarm’’ feeling. Fabrics with a low value of thermal effusivity give us a ‘‘warm’’ feeling, in this investigation the thermal effusivity was measured by TCI apparatus [4], and the mean of 10 experiments was taken.

3.2. Thermal conductivity (K) (W/mK)

Thermal conductivity K, is a physical property of a material that characterizes the ability of that substance to transfer heat [3]. The value of thermal conductivity determines the quantity of heat passing per unit of time per unit area at a temperature drop of 1 degree ^{o} C per unit length. In the limit of infinitesimal thickness and difference in temperature, the fundamental law of heat conduction is:

$$Q = K\,A\,{}^{dT}/_{dX} \qquad (3)$$

Where: Q Is a measure of the heat flow, A Is the cross sectional area, ${}^{dT}/_{dX}$ Is the temperature / thickness gradient. K is defined as the thermal conductivity. Materials having a large thermal conductivity value are good conductors of heat; one with a small thermal conductivity value is a poor heat conductor i.e. good insulator. Hence, knowledge of the thermal conductivity value (W/mK) allows for quantitative comparisons to be made between the thermal insulation efficiencies of different materials, in this investigation the thermal conductivity was measured by TCI apparatus [4] and the mean of 10 experiments was taken.

3.3. Thermal resistance (Rct) (m^2Kw^{-1})

Thermal resistance is a very important parameter from the point of view of thermal insulation [5], and is proportional to the fabric structure. In this investigation the thermal resistance was measured by the Sweat Guarded Hot Plate system and the mean of 10 experiments was taken. Clothing insulation can be described in terms of its Clo value. The Clo value is a numerical representation of a clothing ensemble's thermal resistance. Thermal resistance is connected with fabric thickness by the relationship:

$$R = \frac{\sigma}{K} \quad , m^2KW^{-1} \qquad (4)$$

Where: σ : fabric thickness, K: thermal conductivity

3.4. Thermal diffusivity (m^2/s)

Thermal diffusion is defined by the relationship:

$$a = \frac{k}{pc} \qquad (5)$$

Where: p Fabric density, c Specific heat of fabric, K Thermal conductivity. Thermal diffusion is an ability related to the heat flow through the fabric structure. Substances with high thermal diffusivity rapidly adjust their temperature to that of their surroundings because they conduct heat quickly in comparison to their volumetric heat capacity or 'thermal bulk' and they generally do not require much energy from their surroundings to reach thermal equilibrium [6, 7]. In this investigation the thermal diffusivity was measured by TCI apparatus [4], and the mean of 10 experiments was taken.

3.5. Air permeability (m/sec)

Air permeability is defined as the volume of air in milliliters, which is passed in one second through l00 mm^2 of the fabric at a pressure difference of 10 mm head of water. In the British Standard test, the airflow through a given area of fabric is measured at a constant pressure drop across the fabric of 10 mm head of water. The specimen is clamped over the air inlet of the apparatus with the use of rubber gaskets and air is sucked through it by means of a pump. The air valve is adjusted to give a pressure drop across the fabric of 10 mm head of water and the airflow is then measured using a flow meter. [8, 9] In this investigation the air permeability was measured by SDL M0215 according to the relevant standards [10] and the mean of 10 experiments was taken after leaving each of the samples in every climatic condition for 48 hours.

3.6. Water vapor resistance (Ret) (m^2Pa/W)

Water vapor resistance (Ret) is water-vapor pressure difference between the two sides of specimen divided by the resultant evaporative heat flux per unit area in the direction of the gradient. In this work the Water vapor resistance was measured by Sweating Guarded Hot Plate system [5], and the mean of 10 experiments was taken. Water-Vapor Resistance [m^2 pa/w] is calculated as:

$$Ret = \Delta P \frac{A}{H - \Delta He} \qquad (6)$$

Where: Δ p difference of partial pressure between two sides of specimen, A area of the measuring unit (plate), m^2; H heating power supplied to the measuring unit (plate), W; Δ He correction term, W.

3.7. Water vapor permeability index (I_{mt})

I_{mt} is the ratio of thermal resistance and the water vapor resistance in accordance with this equation:

$$i_{mt} = S \frac{R_{ct}}{R_{et}} \qquad (7)$$

Where S equals 60 Pa/K, I_{mt} is dimensionless and has values between 0 and 1. A value of 0 implies that the tested fabric is water vapor impermeable, that is, it has infinite water vapor resistance, and a material that has a value of 1 has both the water vapor resistance and the thermal resistance of an air layer with the same thickness. The water vapor permeability index was measured according to the relevant standards [11].

3.8 Materials used

In this work eight different types of garments with plain structure and very limited variation of weight and thickness were used varying from classical cotton with core yarn with different spandex ratios and new functional materials like polypropylene, polyester cool max, polyester thermolite, viscose fiber made from bamboo plants and Merino wool. Cotton is being commonly used in Egypt , but the new functional material are not in common use , it is well known that the cotton is very good in absorbing moisture but in the same time it is not that easy to get rid of it , so after a short while of wearing it will be wet and in this case it will cause uncomfortable and unpleasant feeling for the wearer , so the new materials are being investigated to notice the behavior of these material in such conditions, Table 1; shows the specification of the used materials.

Table 1 Specification of materials under investigation

No	Sample	Yarn count, Tex	Loop length, cm	Course count per cm	Wale count per cm	Thickness, m	Weight, g/m^2
1	96%Cotton 4%Lycra	19.6	0.253	23	11.5	0.00109	152.9
2	94%Cotton 6%Lycra	19. 6	0.29	24	11.6	0.00113	155.78
3	92%Cotton 8%Lycra	19.6	0.246	24	12.1	0.00115	161.38
4	Polypropylene	19.82	0.274	22	12.3	0.00102	148.72
5	Merino wool	19.78	0.38	22	12.2	0.00097	146.22
6	95%Viscose fiber made from bamboo plants, 5%Lycra	19.74	0.34	20	11.3	0.00093	143.8
7	62%PE Coolmax 32%PE micro 6%Lycra	19.81	0.275	22	11.6	0.00094	144.72
8	94%PE 6%Lycra	19.75	0.268	23	11.4	0.00103	150.48

3.9. Climatic conditions used in investigating the thermophysiological properties:

Nine different test conditions were held for each of the samples varying between 15 °C then 25 °C then 35 °C with combination with the humidity from 40% then 60% and then 80 % to actually represent all the weather combinations conditions in the tropical condition under investigation. Table 3 shows the design of experiments used to achieve the different climatic conditions under investigation.

3.10. Image analysis for material under investigation:

In this research, image analysis was used in two phases, the first one is to calculate the pore percentage of each material, where photos were captured after leaving each of the samples in each of the climatic conditions for 48 hours then the pictures were taken then processed within the Matlab system to get the pore ratio. The measurement system was constructed on the basis of a computer and a camera. The image was processed by transferring it to a digital image which is composed of pixels which can be thought of as small dots on the screen.

A digital image is a way of how to color each pixel, the image was transferred into a grey scale on and then to a binary image. The output image replaces all pixels in the input image with luminance greater than level with the value 1 (white) and replaces all other pixels with the value 0 (black). Where level in the range (0,1) were specified. This range is relative to the signal levels possible for the image's class. Therefore, a level value of 0.5 is midway between black and white, regardless of class. So the areas which contain yarns was presented as black dots, while areas that presented pore spaces was presented as white dots, and grey values are areas within between. Following that, area of pores was calculated as a percentage comparing to areas that contain yarns. The second phase was to calculate the yarn diameter, which was used in the theoretical model; it was measured as well within the same procedure using Image analysis system [12]. Twenty-five measurements were taken on each of the samples in every condition. The system consists of microscope, monitor and image processing system. The image analysis system was calibrated using special graph grade. The image of the fabric was displayed on a monitor. The fabric was placed under the microscope and it was adjusted to display the portion of the yarn on which the diameter measurements were to be carried out. The diameter of that portion of the yarn was read directly from the calibrated scale on the screen. This was done 25 times on several loops from different locations on each fabric to assure that we get the average reading which refers to nearly the whole fabric.

3.11. Wearer trials and thermal photos:

In this stage the 25 °C with 40% humidity was taken as the neutral condition related to the other conditions and wearer trial have been accomplished, a trial was done by a healthy human being and photos with thermal camera were taken after forty minutes of continuous normal cycling, this was to see which of the fabric will maintain the best thermoregulation properties compared with the other samples.

4. Results

A comparative study of the tested fabrics was held in 25 ^{o}C with 40% humidity as a neutral condition related to the other conditions and wearer trial have been accomplished, a trial was done by a healthy human being and photos with thermal camera were taken after forty minutes of continuous normal cycling, each of the trials was done in a single day to avoid over heating of the body ,also to make sure that there is no body over temperature involved in the thermal photographing, and to maintain the same body effort level as constant as possible, this was to see which of the fabrics will maintain the best thermoregulation properties compared with the other samples (Figures 1- 7) show the difference of the thermophysiological properties of the tested garments in the selected condition .

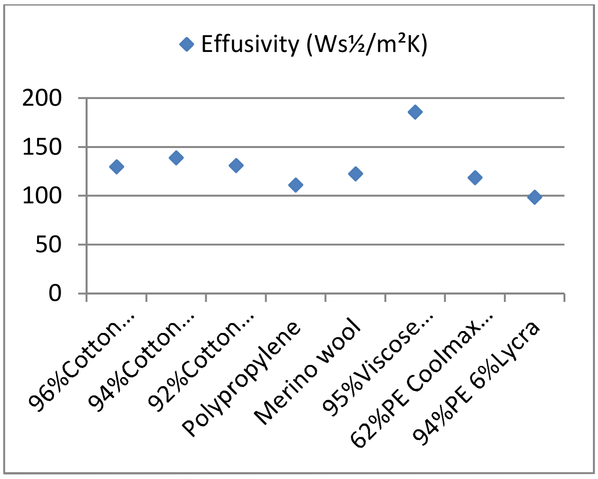

Figure 1 The Effusivity (Ws½/m²K) of the tested materials in the selected condition

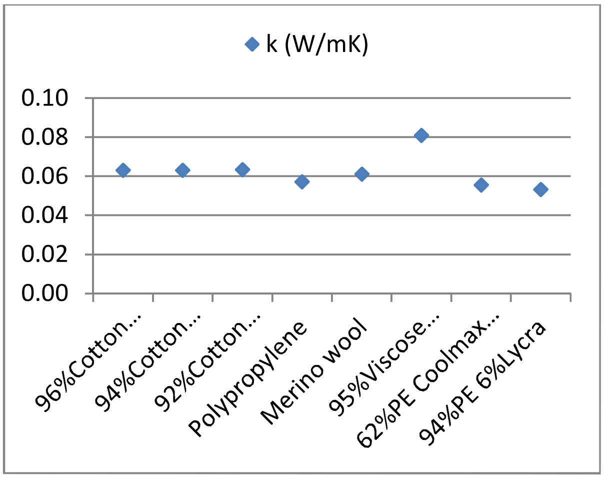

Figure 2 The Conductivity (W/mK) of the tested materials in the selected condition.

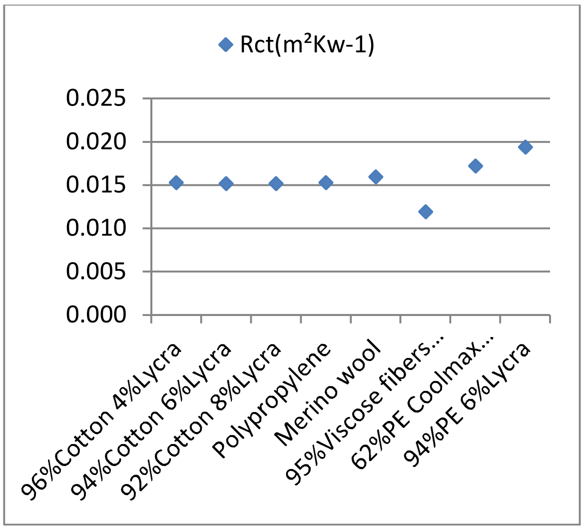

Figure 3 Thermal resistance (m^2Kw-1) of the tested materials in the selected condition

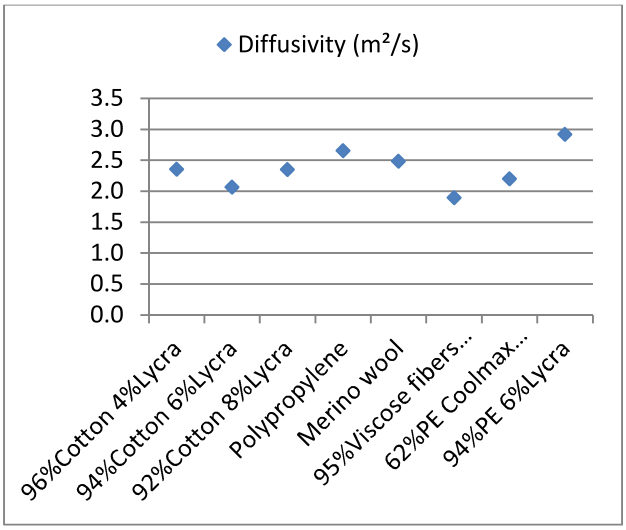

Figure 4 Thermal diffusivity (m^2/s) of the tested materials in the selected condition.

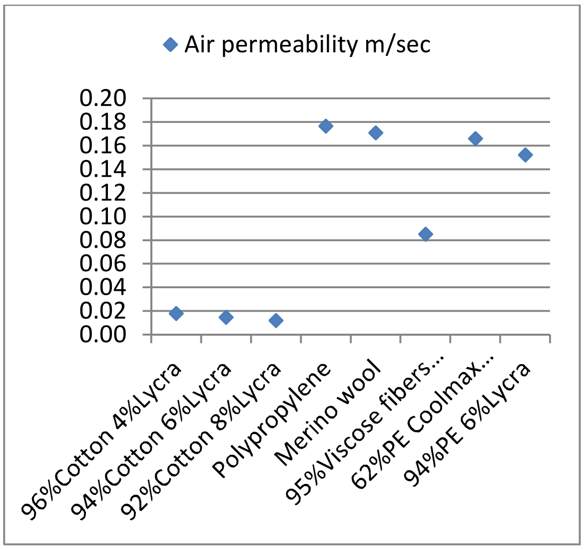

Figure 5 Air permeability (m/s) of the tested materials in the selected condition

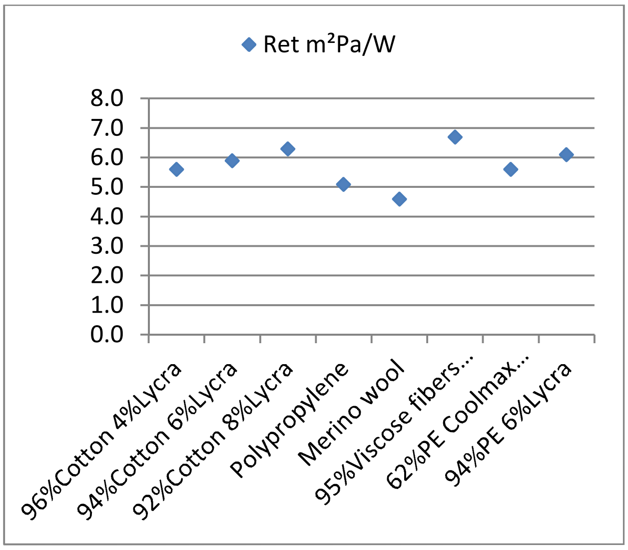

Figure 6 Water vapor resistance (m^2Pa/W) of the tested materials in the selected condition

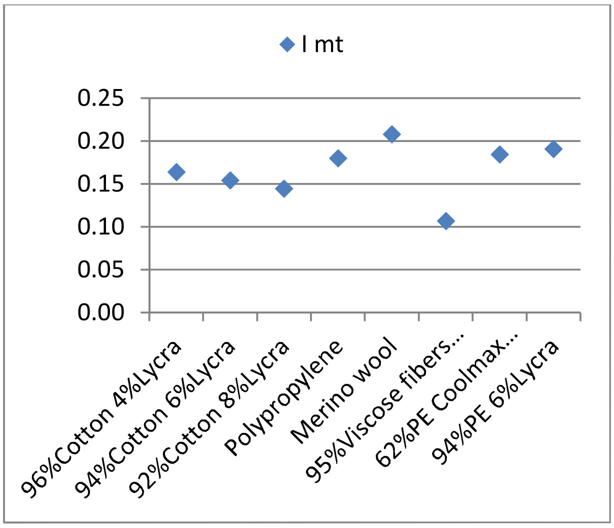

Figure 7 Water vapor permeability index for the tested materials in the selected condition

The previous figures show the thermophysiological properties of the tested fabrics, and as we are studying here the hot condition, special properties are recommended, concerning the Effusivity, as mentioned before the lower the Effusivity the warmer the feeling, but here we need the cooler feeling, we can find this feeling is achieved with the 95%Viscose fiber made from bamboo plants, 5%Lycra.

About the conductivity, it is clear that; here as most of the times in that hot condition, the temperature of the environment is much higher that the human being and as the heat normally transfers from regions with higher temperature to others with lower one, it is desired here to have a material with lower heat conductivity so that the heat will not transfer rapidly from the environment through the clothing material to the wearer, and we can see that it is achieved with using 94%PE 6%Lycra, but it is the only property that is achieved with in that material , so it is not desired to use it in the hot condition.

Concerning the thermal resistance, in such a hot condition, insulation is not desired as we need the body to release heat easily if overheated, and we can see that this condition is achieved by using 95%Viscose fiber made from bamboo plants, 5%Lycra, and here we can tell that is the second desired thermophysiologiacl property achieved by using 95%Viscose fiber made from bamboo plants, 5%Lycra.

Material that rapidly adjust its temperature with its surrounding has high thermal Diffusivity, and here it is desired to have a material that doesn't, as it is not desired to wear a material that quickly adjust its temperature with that higher temperature environment , it will cause the body to feel the surrounding heat even without doing any effort yet, and it is clear here also that 95%Viscose fiber made from bamboo plants, 5%Lycra achieves this requirement, which is here the third desired thermophysiological property existing in this material.

Polypropylene achieves only the highest air permeability , but it doesn't achieve any of the other desired thermophysiological properties comparing to the other materials , so it is not desired for use with in that hot condition . Thermal photos (Figure 8) show the thermal behavior of the garments after wearer trial in the selected condition.

while Merino wool achieves two of the most significant thermophysiological properties desired for materials used in such a hot condition, which are; the lowest water vapor resistance , and in that case it allows the ease of water vapor transfer in the form of sweat to the outer environment , and the other property is the highest water vapor permeability index, as mentioned before that its value is normally between 0 and 1 , where 0 indicates that the material is water vapor impermeable and 1 indicates that the material have both a thermal resistance and water vapor resistance as an air layer, so here the higher is the better in such hot conditions. While merino wool achieves these two properties, we can find also that these two properties are accepted by using 95%Viscose fiber made from bamboo plants, 5%Lycra.

Cotton is widely used in such hot conditions, although cotton garments provide a good combination of softness and comfort. However, cotton absorbs too much sweat when used in base layer clothing because of its tendency to absorb and retain moisture. When wet, cotton garments cling to the skin, causing discomfort; it also becomes heavy when wet. The slow-to-dry and cold-when-wet characteristics of cotton make this material unsuitable in conditions in which there are high levels of moisture-either perspiration or precipitation. Moisture handling properties of textiles during intense physical activities have been regarded as major factor in the comfort performance. Actually the comfort perceptions of clothing are influenced by the wetness or dryness of the fabric and thermal feelings resulting from the interactions of fabric moisture and heat transfer related properties. For the garment that is worn next to skin should have, good sweat absorption, sweat releasing property to the atmosphere, and fast drying property for getting more tactile comfort. It has been found that frictional force required for fabric to move against sweating skin (resulting from physical activities, high temperature and humidity of surroundings) is much higher than that for movement against dry skin. Which means, the wet fabric, due to its clinging tendency, will give an additional stress to the wearer. On the other side, we can see that 95%Viscose fiber made from bamboo plants, 5%Lycra and merino wool which are not commonly used within that conditions, are more comfort concerning the thermal behavior, and they are highly recommended to be used in that tropical condition, especially Bamboo because it is available in such regions.

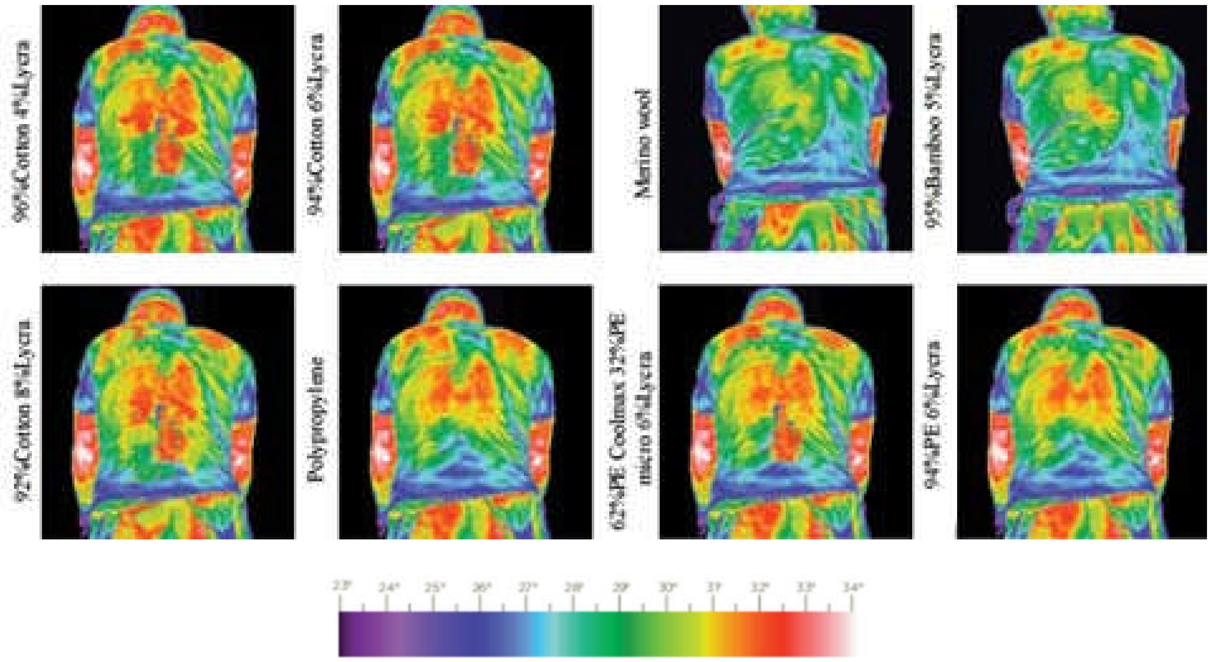

Figure 8 Thermal photos showing the thermal behavior of the garments after wearer trial in the selected condition

4.1. Comfort Index for Fabrics under investigation:

Evaluation of physiological Index of Comfort IC is a complex combination of individual fabrics properties connected with physiological comfort [13]. Thermal comfort is generally connected with sensations of hot, cold or dampness in clothes and is usually associated with environmental factors, such as moisture transport, thermal conductivity and air permeability. Here all the dominant factors that affect the thermophysiological properties are combined together to create a unique comfort code.

The procedure for evaluation physiological Index of Comfort IC starts with specification of K properties R_1 ,...,R_K characterizing comfort (e.g. thermal resistivity, air permeability, areal weight). Based on the direct or indirect measurements it is possible to obtain some comfort characteristics x_1,...,x_k. These characteristics represent comfort properties. Functional transformation of these characteristics leads to partial comfort functions.

$$U_i = f(x_i ,L ,H) \qquad (8)$$

Where L is value of characteristic for just non acceptable value (smallest U_i usually = 0) and H is value of characteristic for just fully acceptable product (U_i equal to highest value = 1). Physiological Index of Comfort IC is weighted average of U_i with weights bi

$$IC = ave\ (u_i ,b_i) \qquad (9)$$

Weight b_i corresponds to the importance of given comfort property [13]. The weighted geometric mean used as average has following advantages: For zero value of U_i is also IC = 0. This means that non acceptable comfort property cannot be replaced by combinations of other comfort properties. Geometric mean is for not constant U_i always lower that arithmetic mean. This reflects evaluation based on the concept that the values of comfort properties close to unsatisfactory fabric are more important for expressing the IC than those close to optimum fabric. For the case of thermophysiological comfort, selected properties and weights were extracted from properties characterizing utility value of clothing [14]. For practical expression of IC it is sufficient to replace standardization and nonlinear transformation to the partial comfort functions by the piecewise linear transformation [13]. For one side bounded properties the partial comfort function is monotone increasing or decreasing function of quality characteristic x The piecewise linear transformation of partial comfort function is here composed from three pieces (two are constant and the linearly increasing or decreasing dependence is placed between them). For two side bounded comfort properties is partial comfort function monotone decreasing on both sides from optimal (constant) region and the piecewise linear transformation has form shown in the (Figure 9).

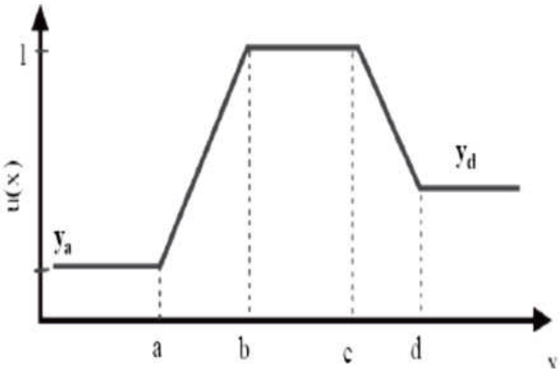

Figure 9 Transformation into to partial comfort functions

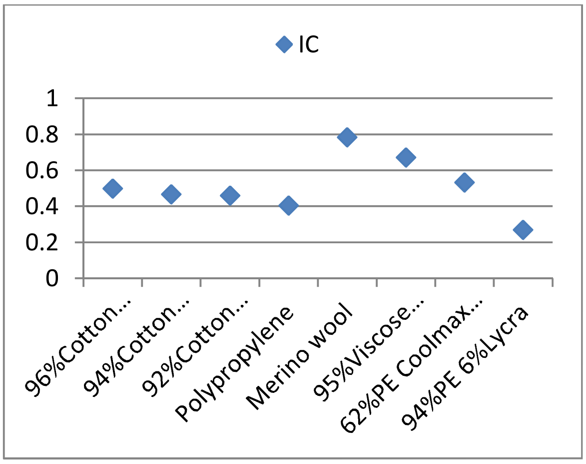

Figure 10 Index of comfort for the tested materials used in the selected tropical condition

Physiological Index of Comfort IC is then weighted geometrical average simply calculated from the relation [13]:

$$IC = \exp(\sum_{j=1}^{k} b_j \ln(u_j)) \qquad (10)$$

Where a, b, c, d and b_j were previously calculated and experimentally concluded [13], and the value of u_j was calculated from (figure 9), when forming the aggregating function IC from experimentally determined values of individual comfort properties, the statistical character of the x_j quantities can be considered and the corresponding variance can be determined as well [15], (Figure 10) shows the index of comfort for the tested materials used in the selected tropical condition and it clearly explains the previous concluded results.

5. Evaluation of the results

This research studied the thermophysiological properties for garments used in tropical weather countries as well as measuring the comfortability of these different materials under different conditions of temperatures and humidity that actually exists in countries with hot weather like Egypt all around the year, and monitoring the factors that affects the thermal behavior of the garments used in this tropical weather.

It is well known that cotton is a very good material for absorbing humidity and it is widely used in that tropical condition, but is it really the best material to be used.

The results show the thermophysiological properties of the tested fabrics, and as we are studying here the hot condition, special properties are recommended, the cooler feeling was achieved by using Viscose fiber made from bamboo plants. About the conductivity, it is clear that; here as most of the times in that hot condition, the temperature of the environment is much higher that the human being and as the heat normally transfers from regions with higher temperature to others with lower one, it is desired here to have a material with lower heat conductivity so that the heat will not transfer rapidly from the environment through the clothing material to the wearer, and we can see that it is achieved with using 94%PE 6%Lycra, but it is the only property that is achieved with in that material , so it is not desired to use it in the hot condition. Insulation is not desired in material used here as we need the body to release heat easily if overheated, and we can see that this condition is achieved by using Viscose fiber made from bamboo plants, and here we can tell that is the second desired thermophysiologiacl property achieved by using Viscose fiber made from bamboo plants.

It is desired to have a material that doesn’t adjust its temperature with the environment quickly as it will get heated quickly from the high temperature surrounding, as it will cause the body to feel the surrounding heat even without doing any effort, and it was found also that Viscose fiber made from bamboo plants achieves this requirement, which is here the third desired thermophysiological property existing in that material. While it was found that Polypropylene is not desired as it achieves only the highest air permeability , but it doesn’t achieve any of the other desired thermophysiological properties, Merino wool achieves two of the most significant thermophysiological properties desired for materials used in such a hot condition, which are; the lowest water vapor resistance , and the highest water vapor permeability index, but while it achieves these two properties, we can find also that these two properties are accepted by using Viscose fiber made from bamboo plants. Cotton is widely used in such hot conditions, but as we can see that Viscose fiber made from bamboo plants and merino wool which are not commonly used within that conditions, are more comfortable concerning the thermal behavior , and they are highly recommended to be used in that tropical condition , especially Bamboo because it is available in such regions and it is also naturally anti-bacterial which is good to wear in that conditions where the human being releases a lot of sweat, where it is a good media for bacteria to grow . It is naturally antibacterial, antifungal and anti-static because it has a unique anti-bacteria and bacteriostasis bio-agent named "bamboo kun" which bonds tightly with bamboo cellulose molecules during the normal process of bamboo fiber growth. It is also UV protective and we can tell how important is this when it comes to that hot condition with long time of exposure to sun during long summer days, it is also green and biodegradable which means that it is safe to get rid of it without having any effect on the environment. It is also breathable , cool, strong, flexible, soft and has a luxurious shiny appearance, we can tell it is good to use viscose fiber made from bamboo plants instead of cotton not only because of its advantages but also may be because the cotton is good in absorbing sweat and humidity, but it is not that good when it comes to loosing that humidity , and in the same time that humidity when absorbed by the fibers causes the fibers to swell , leading to less air permeability , which is also a dominant factor in releasing the water vapor from the skin to the environment, also this humidity causes unpleasant feeling when wearing as it sticks to the body , leading to less comfort to the wearer. It was also concluded that the total water vapor permeability becomes fewer as the water vapor resistance gets higher, leading to less comfort.

A theoretical model was used and tested, results obtained is representing and clarifying the experimental results held for the different materials in the different experimental conditions (figures 11-18).

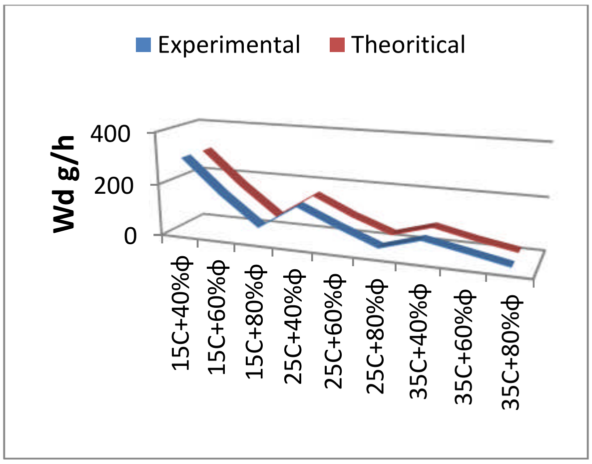

Figure 11 96%Cotton 4%Lycra Total water vapor permeability in the different tropical conditions

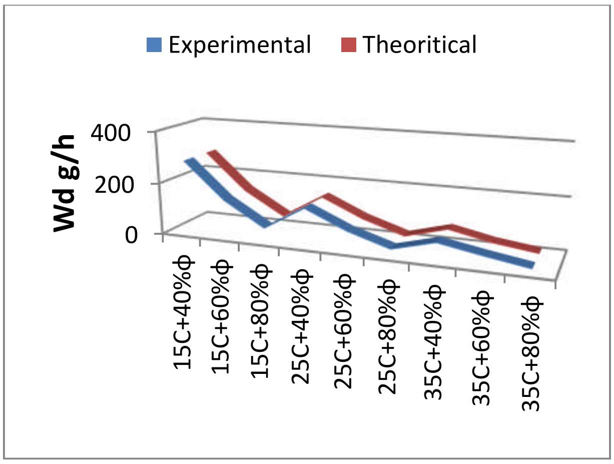

Figure 12 94%Cotton 6%Lycra Total water vapor permeability in the different tropical conditions

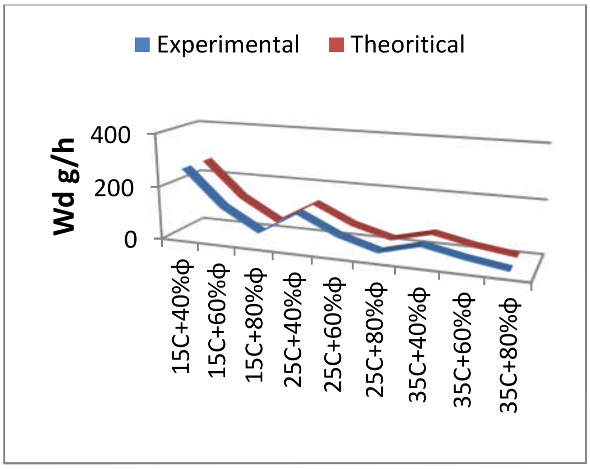

Figure 13 92%Cotton 8%Lycra Total water vapor permeability in the different tropical conditions

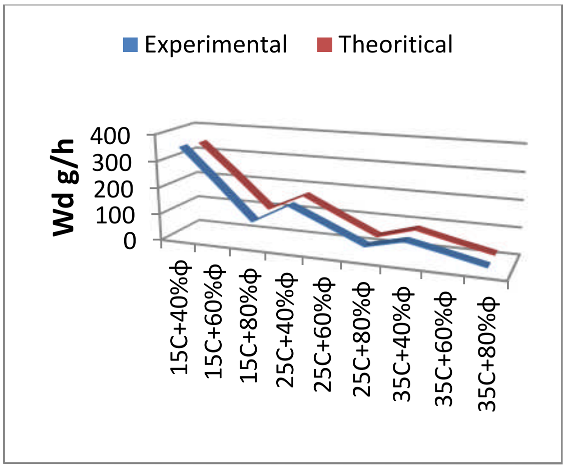

Figure 14 Polypropylene Total water vapor permeability in the different tropical conditions

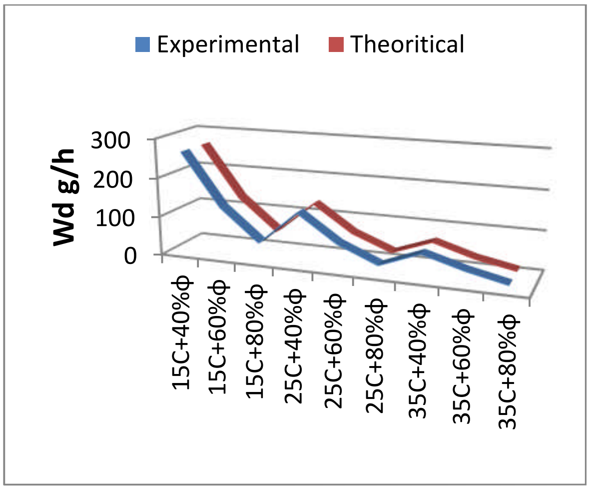

Figure 15 Merino wool Total water vapor permeability in the different tropical conditions

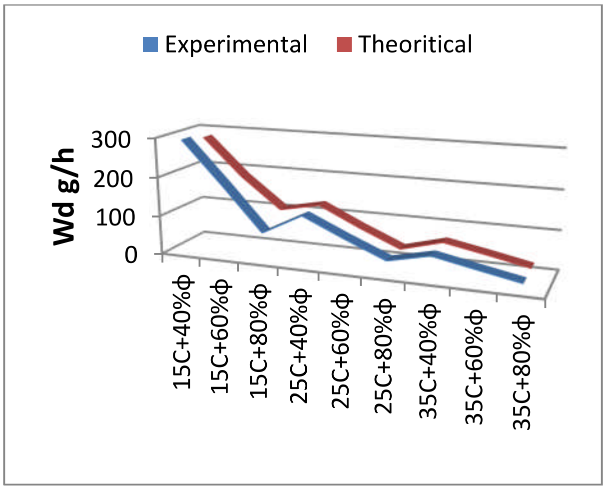

Figure 16 95%Viscose fiber made from bamboo plants, 5%Lycra Total water vapor permeability in the different tropical conditions

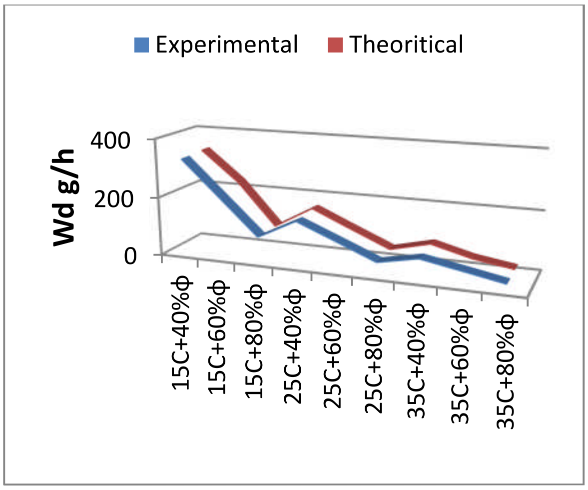

Figure 17 62%PE Coolmax 32%PE micro 6%Lycra Total water vapor permeability in the different tropical conditions

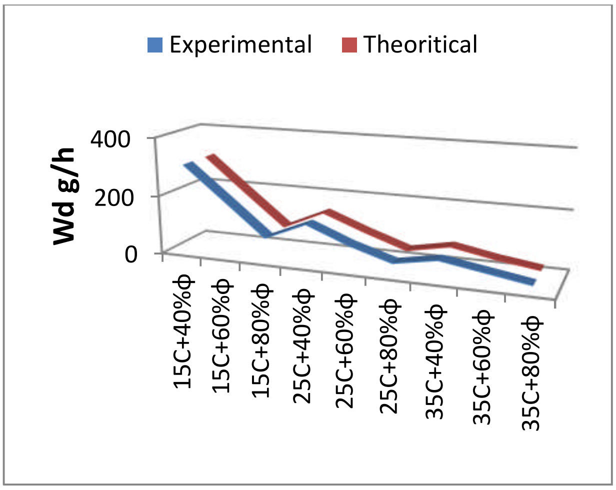

Figure 18 94%PE 6%Lycra Total water vapor permeability in the different tropical conditions

Total water vapor permeability through garments could be predicted depending on the fabric parameters and construction, and this information is very useful when it comes to designing a special functional garment for special use, where we could estimate the thermal behavior of the designed fabric. It is recommended for upcoming studies, to investigate the mass and heat transfer process through macro and micro structure of yarns and fabrics to help in more understanding for the thermal behavior as well as the heat and mass transfer through designed garments, and this will allow us to understand the factors which affect the comfort properties in the required conditions, leading us to develop garment properties that could be applied to enhance comfort properties.

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3. Motawe, M., Havelka, A., Kůs, Z. Measuring Fabrics Thermophysiological Properties: A New Approach. Under publication. **Fibres & Textiles in Eastern Europe.**

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6. Motawe, M., Havelka, A., Kůs, Z. Knitted fabrics thermal resistance in different tropical conditions. **STRUTEX 2011 December, 18th International Conference, Faculty of Textile Engineering**, Technical University of Liberec, 2011, s. 397-400, ISBN 978-80-7372-786-4.

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8. Summary

This research was concerned with thermophysiological behavior analysis of garments made of classical cotton, and new functional materials like polypropylene, polyester cool max, viscose fiber made from bamboo plants and Merino wool, it aimed to find the best and optimal wear for the conditions in hot weather countries under different conditions of temperatures and humidity that actually exists in countries with hot weather like Egypt all around the year, and monitoring the factors that affects the comfortability of the garments used in that tropical weather. It is well know that cotton is a very good material for absorbing humidity and it is commonly used in tropical countries, but is it really the best material to be used?, what about using new functional materials like polyester cool max ,viscose fiber made from bamboo plants or Marino wool in these tropical weather? Will it be comfortable under these circumstances? And what about analyzing heat and moisture transport through these materials under these conditions which could reach to about 35 Celsius degrees and 80 % relative humidity. Answering these questions could lead us to achieve the maximum comfort properties, allowing us to understand the factors affecting the comfort properties in these conditions, leading us to develop garment properties that could be applied to enhance these properties.

The results show that viscose fiber made from bamboo plants garments achieved most of the special recommended thermophysiological properties. It is was found that viscose fiber made from bamboo plants doesn’t adjust its temperature with the environment quickly as it will get heated quickly from the high temperature surrounding, as it will cause the body to feel the surrounding heat even without doing any effort and it has also acceptable water vapor resistance, water vapor permeability index and most of the desired required thermophysiological properties. Bamboo is available in such regions and it is also naturally anti-bacterial which is good to wear in those conditions where the human being releases a lot of sweat, where it is a good media for bacteria to grow. It is also UV protective and we can tell how important is this when it comes to that hot condition with long time of exposure to sun during long summer days, it is also green and biodegradable. The theoretical model shows that the total water vapor permeability becomes fewer as the water vapor resistance gets higher, leading to less comfort, and we can tell that the theoretical model used represents and clarifies the experimental results held for the different materials in the different experimental conditions, which will help in predicting the comfortability of the designed materials depending on the material specification.

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