THERMOPHYSIOLOGICAL INVESTIGATION OF COTTON FABRICS AND VISCOSE FABRICS MADE FROM BAMBOO PLANTS

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Abstract

The article deals with physiological properties of garments made of environmentally friendly materials such as viscose fibers made from bamboo plants, which are a unique biodegradable textile material. In this investigation, thermophysiological properties of knitted fabrics made from cotton and fabrics made from viscose fibers made from bamboo plants were studied. The results were discussed and presented graphically and the effect of the type of fibers on thermophysiological properties was observed for both fabrics. Although cotton fabrics are widely and commonly used in tropical weather conditions, it was found out, that the fabrics made from viscose fibers made from bamboo plants also showed enhanced thermophysiological properties.

Introduction

People wear clothing to protect their body from the environment. As clothing is being worn, the human body interacts dynamically with it and with 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].

There are specific physical textile properties that may be measured to predict the comfort performance of fabric. Basically a textile material should be evaluated in terms of the most general functional properties: thickness, weight, thermal insulation, resistance to evaporation and air penetration. There are also some properties that can be an indicator of overall thermo-physiological properties of the fabrics. For instance there are three clothing factors that relate directly to the thermal comfort. The first one is the overall thickness of the materials and air spaces between the skin and the environment. The second one is the extent to which air can penetrate the clothing by wind or wearer motion. The third one is the requirement that fabric should not restrict the evaporation of perspiration [2-4].

A special attention is focused on new greener products like bamboo; bamboo fibres are notable for their unusual ability to breath and to cool. As the cross-section of the bamboo raw material is filled with various micro-gaps and micro-hole, it has much better moisture absorption and ventilation. With this unparalleled micro-structure, bamboo raw material apparel can absorb and evaporate human sweat easily. It was important for our research to test this new material in tropical weather countries and to compare it to widely and commonly used materials like cotton, as it still not widely used there although the plant is available with a huge quantity [5-6].

1 Test methodology and materials used for the investigation

In this work different comfort properties such as the thermal effusivity *e* [W.s½/m².K], thermal diffusivity (m²/s), thermal conductivity *k* [W/m.K], thermal resistance *Rct* [m².K.w^{-1}], water vapor resistance *Ret* (m².Pa/W) and water vapor permeability index *Imt* of garments made of cotton and viscose fibers made from bamboo plants have been measured in different combination of tropical conditions to determine the comfort properties of each type and to see the effect of the humidity and temperature which really exists in tropical countries on the comfort properties of these fabrics. The thermal effusivity *e* [W.s½/m².K], thermal diffusivity [m²/s] and thermal conductivity *k* [W/m.K] were measured using TCi [7], while the thermal resistance *Rct* [m².K.w^{-1}] and water vapor resistance *Ret* [m².Pa/W] were measured using SGHP [8] while the water vapor permeability index *Imt* was calculated using the relevant standards [9].

1.1 Test samples

In this work two different types of garments made from cotton and viscose fibers made from bamboo plants with plain structure and limited variation of weight and thickness were used to investigate and compare their thermophysiological properties in the designed simulated tropical weather conditions, Table 1 shows the specification of the materials used in this research.

Tab. 1: *Specification of cotton and viscose fibers made from bamboo plants*

Sample	Cotton	Viscose fibers made from bamboo plants
Yarn count, Tex	19.6	19.74
Loop length, cm	0.253	0.34
Course count per cm	23	20
Wale count per cm	11.5	11.3
Thickness, m	0.001	0.0009
Weight, g/m^2	152.9	143.8

Source: [15]

For each of the samples, nine different test conditions were prepared by the combinations of three temperatures (15 °C, 25 °C, 35 °C) and three values of humidity (40%, 60%, 80 %) to cover all the weather combinations in a year in simulated tropical conditions which were investigated. The mean results for ten experiments were calculated and the data was graphically presented.

2 Results and discussion

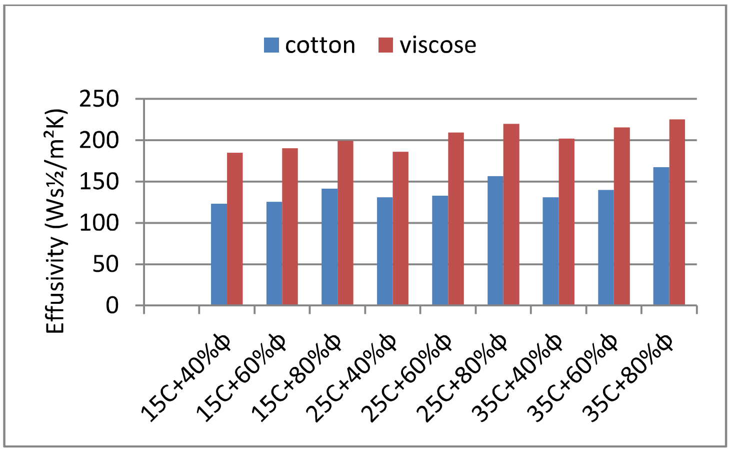
2.1 Thermal effusivity *e* [W.s½/m².K]

Effusivity combines thermal conductivity, density and heat capacity into one value

$$e = \left(kpc_p\right)^{\frac{1}{2}} = \sqrt{kpc_p} \tag{1}$$

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.

Material's thermal effusivity is a measure of its ability to exchange thermal energy with its surroundings [10].



Source: [15]

Fig. 1: *Effusivity of cotton and viscose fibers made from bamboo plants*

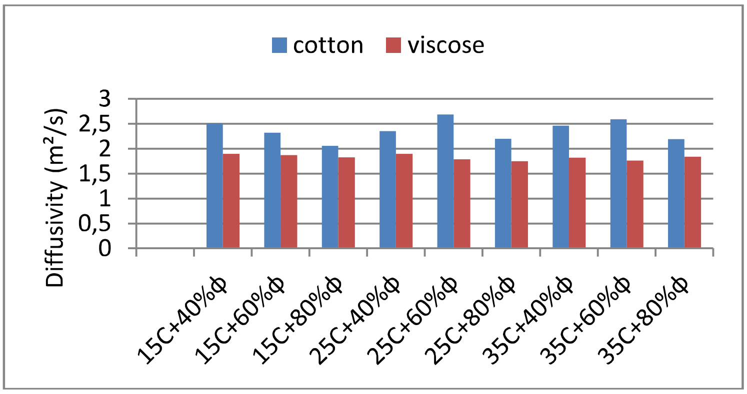
Due to the high temperature and the high humidity existing in tropical conditions, the effusivity ($Ws^{1/2}/m^2K$); which assesses the fabric's character in the aspect of its 'coolwarm' feeling, is getting higher, and we can tell that the fabrics with a low value of thermal effusivity ($Ws^{1/2}/m^2K$) give us a 'warm' feeling and vice versa, it is obvious from Figure 1 that viscose fibers made from bamboo plants give cooler feeling than cotton fabrics.

2.2 Thermal diffusivity *a* [m²/s]

Thermal diffusion is defined by the relationship

$$a = \frac{k}{pc} \tag{2}$$

where p is fabric density, c is specific heat of fabric and k is 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 [11]; it is clear from Figure 2 that viscose fibers made from bamboo plants have lower effusivity than cotton fabrics , hence it is desired for the garment worn in such a hot condition not to adjust its temperature rapidly to its surrounding, as the surrounding environment has much higher temperature. We can state that viscose fibers made from bamboo plants are much better from the thermphysiological point of view.



Source: [15]

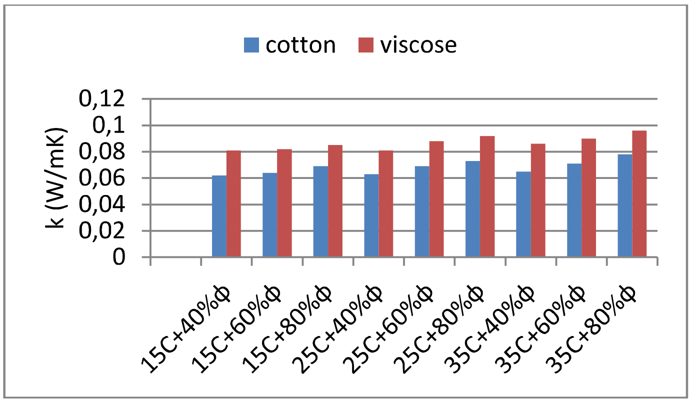
Fig. 2: *Diffusivity of cotton and viscose fibers made from bamboo plants*

2.3 Thermal conductivity *k* [W/m.K]

k is defined as thermal conductivity. The fabrics having a large thermal conductivity value are good conductors of heat; a fabric with a small thermal conductivity value is a poor heat conductor and it can be a good insulator. We were simulating the hot conditions as we need fabrics that easily release the heat from a body [12].

$$Q = kA\frac{dT}{dX} \quad (3)$$

where Q is a measure of the heat flow, A is the cross sectional area, dT/dX is the temperature / thickness gradient. Figure 3 shows that cotton fabrics have lower thermal conductivity compared to viscose fibers made from bamboo plants.



Source: [15]

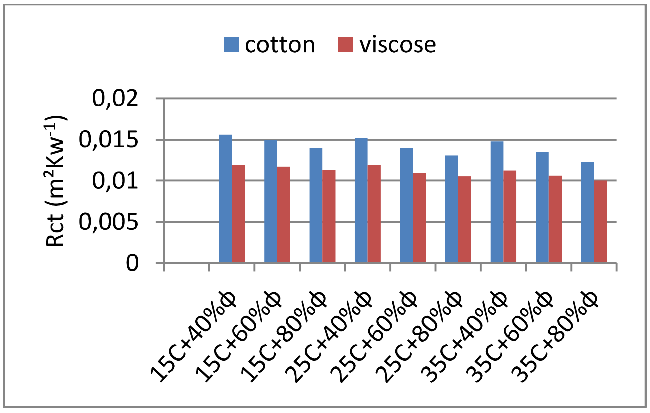
Fig. 3: *Conductivity of cotton and viscose fibers made from bamboo plants*

2.4 Thermal resistance *Rct* [m².K.W⁻¹]

Thermal resistance in connection with fabric thickness is defined by

$$Rct = \frac{\sigma}{k}\left[m^2.K.W^{-1}\right] \quad (4)$$

Where σ is fabric thickness, K is thermal conductivity [8, 13]. In such hot conditions with higher temperatures and higher humidity, it is desirable for a human being to wear something that easily releases body temperature to feel cooler. Figure 4 shows the thermal resistance of both used garments, it shows that viscose fibers made from bamboo plants have lower thermal resistance than cotton fabrics



Source: [15]

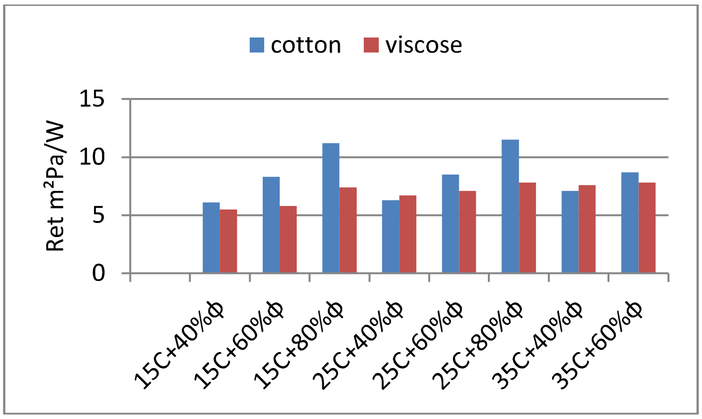
Fig. 4: *Thermal resistance of cotton and viscose fibers made from bamboo plants*

2.5 Water vapor resistance *Ret* [m².Pa/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 [8].

$$\mathrm{Re}t = \Delta P \cdot \frac{A}{H - \Delta He} \tag{5}$$

Where ΔP is the difference of partial pressure between two sides of specimen, A is the area of the measuring unit (plate) in m^2; H is the heating power supplied to the measuring unit (plate), ΔHe is a correction term. With the increase in temperature and humidity, cotton absorbs that humidity causing the fibers to swell affecting the pores ratio with in the fabric and minimizing it; and water vapor normally transfers from the areas with high water vapor pressure to others with low water vapor pressure going through the pores in the fabric. The transfer is difficult because of the reduced pores areas and also because of the higher humidity, which leads to higher water vapor resistance and lower comfort of a wearer in those tropical conditions. Figure 5 shows the water vapor resistance behavior of the garments made of cotton and viscose fibers made from bamboo plants.



Source: [15]

Fig. 5: *Water vapor resistance of cotton and viscose fibers made from bamboo plants*

2.6 Water vapor permeability index *Imt*

Imt is the ratio of the thermal resistance and the water vapor resistance in accordance with equation (6).

$$\mathrm{Im}t = S\frac{Rct}{\mathrm{Re}t} \tag{6}$$

Where S equals 60 Pa/K, Imt is dimensionless and has values between 0 and 1 [9, 14]. A value of 0 implies that the tested fabric is water vapor impermeable, so 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 is a total indicator of a wearer's comfort from the thermophysiological point of view; Figure 6 shows that viscose fibers made from bamboo plants show enhanced properties in the tropical conditions compared to cotton in most of the climatic condition combinations. It could be considered as an indicator showing that viscose fibers made from bamboo plants could be used as a good alternative to cotton fabrics which are commonly used in those conditions.

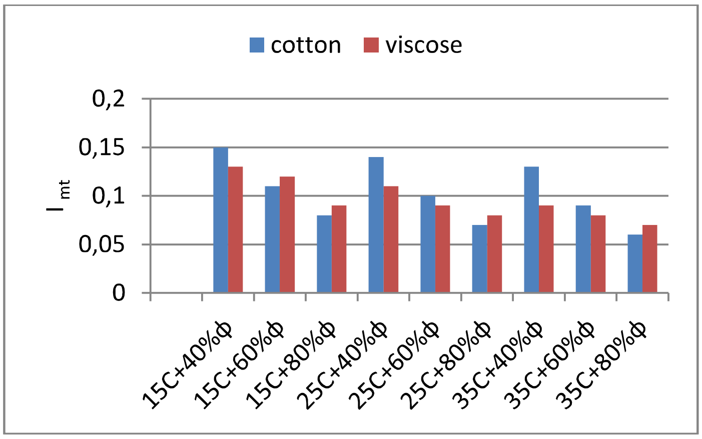


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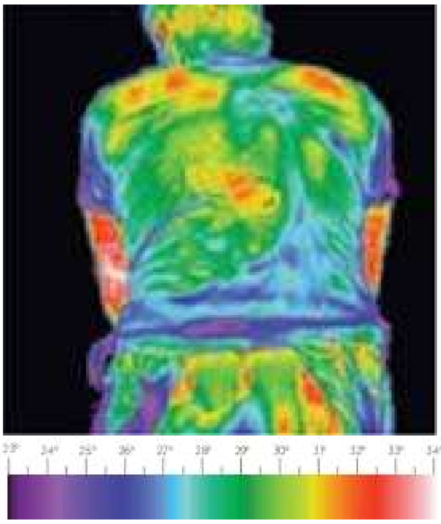
Fig. 6: *Water vapor permeability index of cotton and viscose fibers made from bamboo plants*

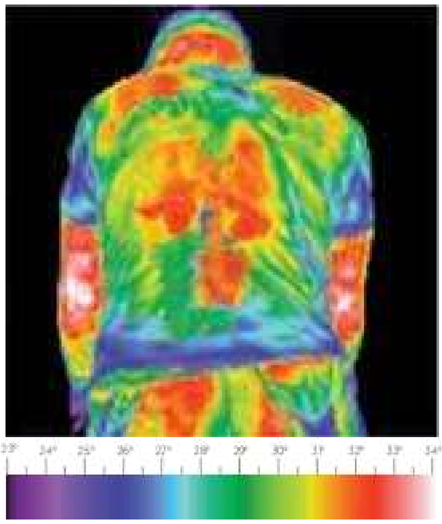
2.7 A comparative study in specific conditions

A comparative study of the tested fabrics was held at 25 °C with 40% humidity as a neutral condition related to the other conditions and wearer tests have been accomplished, the test was carried out by a healthy human being. The photos were taken with a thermal camera after forty minutes of continuous normal cycling load. Each of the trials was performed in a single day to avoid overheating of the body, and to make sure that there is no body over temperature involved in the thermal photographing. In addition, the level of effort was kept as constant as possible to see which of the fabrics will provide the best thermoregulation properties in comparison with the other samples. It is clear from Figure 7 and Figure 8 that viscose fibers made from bamboo plants maintain an enhanced thermoregulation property in the simulated tropical conditions even after physical performance for a certain amount of time. It shows that viscose fibers made from bamboo plants will be comfortable for the wearer as they provide a cooler feeling compared to cotton fabric even when the wearer made some physical effort.



Source: [15]

Fig. 7: *Thermal photo of viscose fibers made from bamboo plants*



Source: [15]

Fig. 8: *Thermal photo of cotton*

Conclusion

This research studied the thermophysiological properties for common garments used in tropical weather countries, compared them to new garments and measured the comfortability of these different materials under different conditions of temperatures and humidity that actually exist in countries with hot weather. It was found out that viscose fibers made from bamboo plants achieved most of the significant thermophysiological properties desired for materials used in such hot conditions. Cotton absorbs well sweat and humidity, but it loses its humidity worse. Moreover, that humidity when absorbed by the fibers causes that the fibers swell, leading to lower air permeability. Also, this is a dominant factor in releasing water vapor from skin to the environment and this humidity causes unpleasant feeling. The fabric sticks to the body, which leads to less comfort of the wearer. Thermograms also show that viscose fibers made from bamboo plants garment have enhanced thermoregulating properties and better transfer heat and humidity compared to cotton garments.

The measured values of thermophysiological properties of fabrics made from viscose are better than properties of cotton fabrics. We would like to emphasize that the value of water vapor resistance *Ret* [m^2.Pa/W] and thermal conductivity k [W/m.K] are better for viscose fibers than cotton fibers. The value *Ret* of viscose fibers is about 30% better and the value of thermal conductivity k is about 10-30% better than the value of cotton fibers. Therefore fibers, fabric and clothes made from viscose have better heat transfer from the body.

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VÝZKUM TERMOFYZIOLOGICKÝCH VLASTNOSTÍ PLOŠNÝCH TEXTILIÍ Z BAVLNY A VISKÓZY ZÍSKANÝCH Z BAMBUSOVÝCH ROSTLIN

Předložený příspěvek se zabývá fyziologickými vlastnostmi oděvů vyrobených z ekologicky šetrných materiálů, jako jsou viskózová vlákna vyrobená z bambusových rostlin, která představují unikátní textilní materiál. V tomto výzkumu byly studovány termofyziologické vlastnosti pletenin z bavlny a viskózy, která byla vyrobená z bambusových rostlin. Uvedené výsledky výzkumu jsou diskutovány a prezentovány graficky a byl zjišťován vliv typu vláken na vlastnosti ovlivňující fyziologický komfort oděvů. Ačkoliv jsou bavlněné textilie běžně používány na oděvy pro horké – tropické počasí, bylo zjištěno, že textilie vyrobené z viskózových vláken mají některé termofyziologické vlastnosti, které jsou lepší než u textilií vyrobených z klasických přírodních vláken.

UNTERSUCHUNG DER THERMOPHYSIOLOGISCHEN EIGENSCHAFTEN VON GESTRICKWAREN AUS BAUMWOLLE UND VISKOSE, DIE AUS BAMBUSPFLANZEN GEWONNEN WERDEN

Dieser Artikel befasst sich mit den physiologischen Eigenschaften der Kleidung, die aus umweltfreundlichen Materialen, wie Viskosefasern aus Bambus-Pflanze, die ein einzigartiges Textilmaterial darstellen, hergestellt ist. In diesem Forschungsprojekt wurden thermophysiologische Eigenschaften von Gestrickwaren aus Baumwolle und Viskose, die aus Bambus Pflanzen hergestellt wurden, untersucht. Die Forschungsergebnisse werden diskutiert und graphisch präsentiert und wurde den Einfluss von Faser-art auf die Eigenschaften, die den physiologischen Komfort der Kleidung beeinflussen, untersucht. Obwohl das Baumwollgewebe häufig für Kleidung für heißes bis tropisches Wetter verwendet ist, wurde festgestellt, dass das von Viskosefasern hergestellte Gewebe einige thermophysiologische Eigenschaften hat, die besser als bei von klassischen Naturfasern hergestellten Textilien sind.

BADANIA TERMO FIZJOLOGICZNE WŁAŚCIWOŚCI TKANIN Z BAWEŁNY I WISKOZY Z BAMBUSA ROŚLIN UZYSKANYCH

Niniejszy artykuł zajmuje się fizjologicznymi właściwościami odzieży wytworzonej z produktów przyjaznych dla środowiska np. takich jak wiskozowe włókna wykonane z bambusa, które stanowią unikalny materiał włókienniczy. W niniejszej pracy badano termofizjologiczne właściwości dzianin wykonanych z bawełny i wiskozy. Wiskoza została wykonana z bambusa. Wyniki badań zostały omówione i przedstawione graficznie. W pracy analizowano wpływ rodzaju włókien na właściwości wykonanych z nich ubrań z punktu widzenia fizjologicznego komfortu. Bawełniane tkaniny są powszechnie stosowane przy wytwarzaniu odzieży używanej w środowiskach tropikalnych. Z przeprowadzonych analiz można wnioskować, że tkaniny wykonane z włókien wiskozowych charakteryzują się niektórymi lepszymi właściwościami termofizjologicznymi w porównaniu z tradycyjnymi tkaninami wykonanymi z włókien naturalnych.