Evaluating the effect of fabric type on thermal insulation properties of sports clothing

M J Abreu[1], A Catarino[1] and D Tama[1,2]

[1] University of Minho, Center for Textile Science and Technology, Campus de Azurem, Guimaraes, Portugal
[2] Ege University, Department of Textile Engineering, 35100 Bornova / Izmir, Turkey

Corresponding author: derya.tama@ege.edu.tr

Abstract. In the present study, evaluating the fabric characteristics on thermal insulation properties of garments was aimed. For that purpose, two fiber combinations and seven different knitting structures were chosen and seven long sleeve basic shirts were manufactured from these fabrics. As a water-repellent finishing treatment, all shirts were treated with 5% of a fluorocarbon-based product. A thermal manikin of PT-Teknik made in Denmark was used to measure the heat loss of the shirts and the surface of manikin was kept at a constant temperature. Afterwards, the total and effective clothing insulation values were calculated for each shirt. The comparisons of heat loss values according to the body parts, and also for the effective clothing insulations were done. Moreover, the heat flux according to the body parts were determined. In the light of these obtained data, a new shirt design was designed and proposed by combining the evaluated fabrics in order to enhance the comfort and performance of the user.

Keywords. Thermal comfort, thermal manikin, heat loss, total thermal insulation, effective clothing insulation.

1. Introduction

In active sports, the clothing is one of the key elements that affects the performance of the athlete. Slater (1985) defined comfort as "a pleasant state of physiological, psychological, neurophysiological and physical harmony between a human being and the environment" [1-3].

Depending on the exercise intensity, the human body produces energy and heat. In order to provide thermoregulation, the heat should be released to the environment. Core temperature can be smoothly raised in the range of 36–39˚C with motor activities and chemical reactions, and greater than 39˚C becomes critical for human body [4]. Therefore, maintenance of core temperature within the referred range and provide heat flux is crucial for thermo-physiological comfort.

As Bhatia and Malhotra (2016) concluded in their overview research about thermo-physiological wear comfort of clothing, heat and moisture transmission mechanism through clothing, need to be analyzed together with material properties and other influencing parameters [5]. There are also several methods for measuring heat and moisture transmission through clothing. The mostly used is measuring heat loss by using thermal manikins.

Thermal manikins provide a good estimate of the total dry heat loss from the body and the distribution of heat flow over the body surface. In a standard environment, these measures can be used to describe the thermal characteristics of clothing [6]. The operation of the thermal manikins can be set with the constant skin temperature, the constant heat flux or the thermal comfort regulation modes in the different body parts [7,8].

2. Methods

2.1. Specimens

In order to evaluate the influence of fabric characteristics on thermal insulation properties of active sportswear, two fiber combinations and seven different knitting structures were chosen. The details of the compositions and knitting structures were given in Table 1. Seven rounded-neck raglan sleeve tight-fitting shirts were manufactured from these fabrics. Since the active sport garments evaluated in this research were to be used for outdoor sports, a water-repellent finishing treatment was applied to all specimens. All shirts were treated with 5% of a fluorocarbon-based product.

Table 1. The compositions, knitting structures and the codes of shirts

Code	Composition	Knitting Structures
F1	100% Cotton	Single Jersey
F2	60% Polyamide	False Rib 1
F3	35% Polyester	False Rib 2
F4	5% Elastane	Single Jersey jacquard 1
F5	60% Polyamide	Single Jersey jacquard 2
F6	35% Polypropylene	Single Jersey jacquard 3
F7	5% Elastane	False Rib 3

2.2. Thermal Manikin

A female model thermal manikin (PT-Teknik made in Denmark) was used in this study in order to develop heat in a homogeneous distribution. The thermal manikin was installed in the research laboratory of the 2C2T- Center for Textile Science and Technology of the University of Minho in Portugal. The body shell of the thermal manikin is fiber glass armed polystyrene which is responsible for a light and strong mechanical construction and simultaneously a low thermal conductivity and thermal capacity. There are 20 independent sections, which can be controlled separately and independently. The thermal manikin was placed inside the climate chamber, placed around 0.1m above the floor with hanging arms and legs.

2.3. Experimental Procedure

The tests were carried out according to ISO 15831 standard. The trials were performed in constant skin temperature mode and the skin temperature of thermal manikin was set at 33 ±0,2°C. The specimens were dressed up to the thermal manikin and the manikin was kept in a stationary standing position. The tests were performed in a climatic chamber at constant ambient temperature of 24,5±1°C and relative humidity of 60±5%. The mean skin temperature, the heat flux of the manikin, and the room physical parameters were continuously monitored on computers. The obtained heat loss data was used to calculate the total thermal clothing insulation (IT) and the effective thermal clothing insulation (Icle).

2.4. Data analysis

In the present research, statistical analysis was performed by using PASW Statistics 18 statistical analysis package software. A repeated measures ANOVA (Analysis of variance) was conducted to compare the difference of effective clothing insulation values on structures and body parts. Post hoc least significant difference tests were also carried out by using repeated measures ANOVA and Bonferroni correction.

2.5. Garment Design

In the present study, a new shirt was proposed for active sportswear by combining the structures evaluated in this research. In order to design the shirt, the present researches about thermoregulatory responses of human body were analyzed. In the research conducted by Ouzzahra et al. (2012), the thermal sensitivity of regional body parts was analyzed by stimulating body with a 20˚C thermal probe applied onto the skin. The tests were performed in cold environment (Temperature of laboratory: 21,5±0,8˚C, Relative humidity: 44,2±4,8%) and the stimulation were applied during rest and during light exercise (30% VO2 max). The 14 male athletes participated the study and they were asked to score an 11-point cold sensation scale according to the thermal sensations [9]. The thermal sensation was lower and more homogenous during exercise (Figure 1).

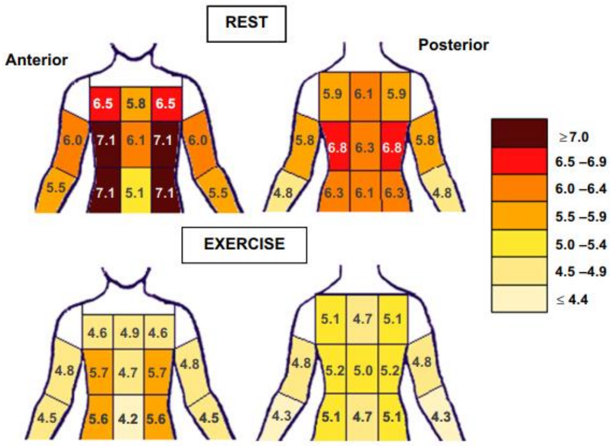

Figure 1. Body map of mean thermal sensations at rest and during exercise [9].

In another outstanding research, Fournet et al. (2013) evaluated the thermoregulatory response of males and females during 40 minutes running in the cold environment (Temp.: 10˚C, R.H.: 50%, Air Vel.: 2.8 m s−1) at 70% VO2 maximum work rate. The skin temperature was recorded by an infrared camera (Figure 2) and population-averaged body maps were developed with the obtained data [10].

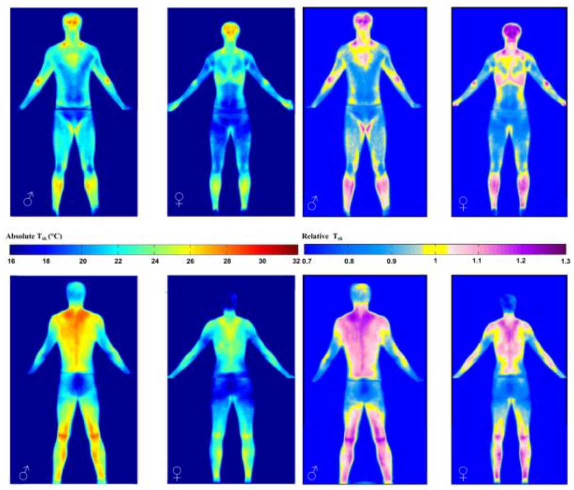

Figure 2. Group averaged body maps of absolute (left panel) and relative (right panel) skin temperature [10].

Smith and Havenith (2011), performed the research in order to develop a sweating and a thermal map of human body. All subjects completed 60 minutes treadmill run involving two exercise intensities. The laboratory were set at 25˚C and 50% RH. The regional sweating rates were measured by absorbent pads and infrared images were captured by a thermal camera. With respect to obtained data, they have developed regional temperature and regional sweat guidelines (Figure 3) in order to use garment-designing process [11].

Figure 3. Regional temperature and regional sweat guidelines for garment design [11].

3. Results

The heat loss data of each specimen were analyzed according to eight body parts namely pelvis, back, back side, chest, right upper arm, left upper arm, right forearm, left forearm (Figure 4). As heat flux decreases, heat transfer from body to the environment also decreases, therefore the microclimate temperature between the body and the garment rises. For this reason, higher heat loss values are desired for active sports' clothing. According to obtained data, F1 had the least heat loss value than other structures. This result can derive from the composition (100% cotton) and the structure (single jersey) of F1. It can be said that, at the body parts right and left forearms, the heat flux had the greatest values for F5, F6 and F7.

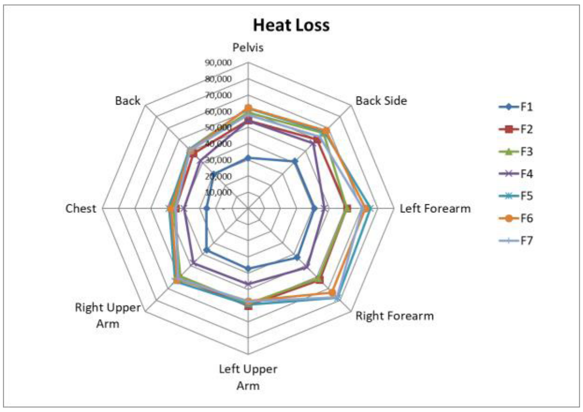

Figure 4. The heat loss values of structures according to body parts.

Figure 5 demonstrates the effective clothing values of the seven structures for eight different upper body parts. The effective clothing insulation values were higher at the back and the chest, right and left forearm had the lowest effective clothing insulation values. According to the statistical treatment (Table 2), the structure had significant difference on the effective clothing insulation properties (p=0,000). The body parts also had significant difference on the effective clothing insulation properties (p=0,000). Moreover, both the structure and body parts had a significant difference on the effective clothing insulation properties (p=0,000).

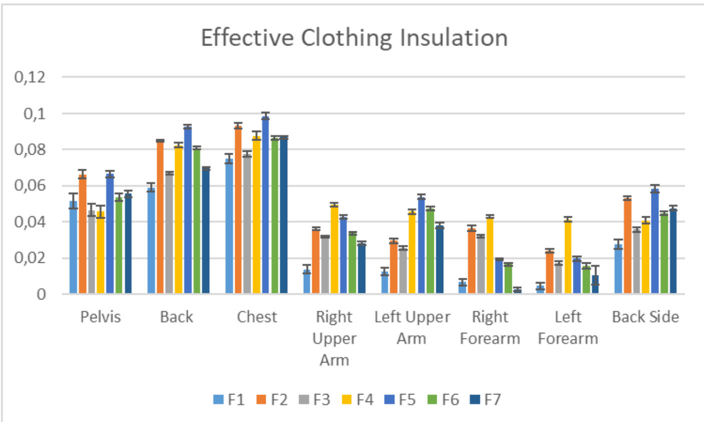

Figure 5. The effective clothing insulation values of structures according to body parts.

With respect to the pairwise test results, it can be said that the structure influences the effective clothing insulation values according with each body part. Specifically, at pelvis between F2 and F5 (p=0,699) and between F3 and F4 (p=0,135) there were no significant differences. At chest, there was no significant difference between F3 and F6 and at left upper arm, there was also no significant difference between F6 and F7.

Table 2. The repeated measures ANOVA results for effective clothing insulation values.

	Sum of squares	Degrees of freedom	Mean square	F value	Sig.
Structure	0,158	2,900	0,055	3387,729	0,000
Body Parts	1,097	2,223	0,493	16941,467	0,000
Structure * Body Parts	0,102	7,864	0,013	630,874	0,000

Considering the tests conducted in this study and the related literature review, a shirt was designed (Figure 6), two fabric constructions were suggested to use in different areas of the body with dissimilar characteristics, in order to enhance the comfort and performance of the user.

4. Conclusion

In active sports, the clothes need to cover and assist the active body and also support extreme physical and environmental performance. In order to provide this, the researches about clothing comfort of active sportswear has become an important research field for textile industry. Moreover, the necessity of considering the fabric characteristics and also human body thermoregulation in the garment design process shows up. Therefore, in the present research, thermal comfort properties of chosen fabrics were evaluated by a thermal manikin and also a literature review the thermal sensations of human body were analyzed.

As literature review indicates, during the exercise the most heated body parts for upper body are shoulders, middle chest, middle back, front sides and lateral arms. The sweating rates of upper body show that the lower and middle back are the parts that sweated most, followed by the middle chest, shoulder, neck and backsides.

Regarding to thermal behaviors of the fabrics tested in the present research and the related literature review, a rounded neck, raglan sleeve shirt for outdoor sports was designed and proposed.

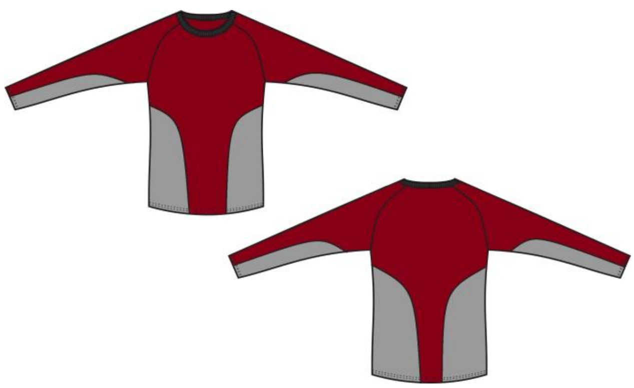

Figure 6. The developed shirt for active sports.

With respect to obtained data, F5 and F6 had the highest heat flux values almost in each body part. Additionally, F5 was the construction, which had the highest thermal insulation in pelvis, back, backside, chest and left upper arm. Moreover, F3 mostly had smaller thermal insulating. Thus, regarding to all data, it was suggested to use F3 on shoulders, front sides, armpits, middle back and lateral arms. In the remaining parts, F5 was used to manufacture the sports garment.

5. References

[1] Das, A. and Alagirusamy, R., 2010, Science in Clothing Comfort, The Textile Institute, Woodhead Publishing Limited, England, 173p.
[2] Choudhury, A.K.R., Majumdar, P. K. and Datta, C., 2011, Improving Comfort in Clothing, Chapter 1: Factors affecting comfort: human physiology and the role of clothing, The Textile Institute, Woodhead Publishing Limited, England, 459p.
[3] Li, Y. and Wong, A. S. W., 2006, Clothing Biosensory Engineering, Chapter 1: Introduction to Clothing Biosensory Engineering, The Textile Institute, Woodhead Publishing Limited, England, 381p.
[4] Balcı, G. A., Başaran, T. and Colakoglu, M., 2016, Analysing visual pattern of skin temperature during submaximal and maximal exercises, Infrared Physics & Technology 74, pp.57–62, http://dx.doi.org/10.1016/j.infrared.2015.12.002
[5] Bhatia, D. and Malhotra, U., 2016, Thermo-physiological wear comfort of clothing: an overview, J Textile Sci Eng 2016, 6:2, http://dx.doi.org/10.4172/2165-8064.1000250
[6] Abreu, M. J., 2008, Validation of the thermal comfort behavior of active wear through thermal manikin measurements, 2nd International Scientific Conference Textiles of the Future, 13-15 November 2008, Kortrijk, Belgium.
[7] Oliveira, A. V. M, Gaspar, A. R. and Quintela, D. A. (2008b) Measurements of clothing insulation with a thermal manikin operating under the thermal comfort regulation mode: comparative analysis of the calculation methods, European Journal of Applied Physiology, Vol. 104, pp. 679–688, DOI 10.1007/s00421-008-0824-5.
[8] Melikov A, 2004, Breathing thermal manikins for indoor environment assessment: Important characteristics and requirements, European Journal of Applied Physiology 92:710–713. doi:10.1007/s00421-004-1142-1
[9] Ouzzahra Y., Havenith G. and Redortier B., 2012, Regional distribution of thermal sensitivity to cold at rest and during mild exercise in males, Journal of Thermal Biology, Volume 37, Issue 7, pp. 517-523, https://doi.org/10.1016/j.jtherbio.2012.06.003.
[10] Fournet D., Ross L., Voelcker T., Redortier B. and Havenith G., 2013, Body mapping of thermoregulatory and perceptual responses of males and females running in the cold, Journal of Thermal Biology, Volume 38, Issue 6, pp. 339-344, https://doi.org/10.1016/j.jtherbio.2013.04.005.
[11] Smith C. and Havenith G., 2011, Sweat mapping in humans and applications for clothing design, The Fourth International Conference on Human-Environment System, 3-6 October, Japan.

Acknowledgment

This work was supported by FEDER funds through the Competitivity Factors Operational Program - COMPETE and by national funds through FCT – Foundation for Science and Technology within the scope of the project POCI-01-0145-FEDER-007136.