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Changes in thermal comfort properties of sports wear and underwear due to their wetting

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In this investigation, a study of indexes characterizing thermal comfort of garments have been outlined and a new so called wet comfort index (WCI) of sport dresses and underwear at real conditions of their use is presented. The experimental study includes determination of thermal resistance and water vapour permeability of 12 sport dresses in dry and wet states, and these values are then used for the calculation of WCI, which ranges from 0 to 1. The maximum value 1 indicates the best thermophysiological comfort level in wet state. Wetting of the dresses is achieved by training of a sportsman on a running simulator. It is found that for the best sport dresses consisting of special polyester and polypropylene surface grooved fibres, the WCI does not exceed 0.2. This surprisingly low level demonstrates the importance of testing of thermal comfort properties of fabrics in wet state by means of special instruments.

Keywords: Sport dresses, Thermophysiological comfort, Underwear, Wet comfort index, Wet state

1 Introduction

Achievement of optimum level of thermal comfort belongs to the most important functions of clothing. Thermal comfort of clothing for a long duration results from thermal balance between body heat production and body thermal losses when the clothing or garment is worn. Depending on the level of physical activity human body can produce heat in the range from 80W (sleeping) to more than 1000W (very intensive effort)[1]. In many cases, the body activity is accompanied by sweating, which leads to moistening of the garment fabrics and consequently changes in fabric heat and moisture transfer properties. However, these changes in most cases would affect the thermophysiological comfort in the negative way. Thermal insulation of most of the garments decreases with their increasing moisture, and simultaneously the garment water vapor permeability decreases. All these lead to disruption of thermal balance of the body.

It is known that comfort is a complex property and when the new functional garment is designed, then thermal comfort as a part of total comfort plays a substantial role. Therefore, a major effort is focused on the prediction of total comfort or its parts by means of a set of measurable properties and characterizing it by using some parameters or indexes. During last decades several indexes were proposed for characterization of comfort or its part, e.g. thermal comfort, physiological comfort, etc. Generally, it is possible to divide the indexes into two main groups:

(i) the indexes, based only on inherent properties of textile fabric, and
(ii) the indexes, which also include the properties of environment.

Two indexes proposed by Hes[2] can be included to the first group. The first index, called index of quality (IQ) characterizes protection and wear comfort of winter jackets. Their thermal resistance, water vapour permeability and minimum thermal comfort levels create this IQ index. The second index is more complex. The proposal of comfort evaluation system (CES) consists of nine comfort parameters, where three parameters are related to thermal comfort, other three are related to sensorial comfort and the last three reflect the handle. Another complex solution was presented by Umbach[3]. His indicator of thermophysiological comfort (WC_T) consists of five properties, such as thermal resistance, moisture regulation index, sweat buffering, sweat transport and water retention. Together with sensorial comfort (WC_S) having relation to the sensitivity of skin to mechanical and moisture irritations, the WC_T creates the total wear comfort. Physiological comfort index

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(IC) was introduced by Militký and Matusiak[4]. Their procedure consists of four steps, and unacceptable and fully acceptable values of properties representing physiological comfort are determined. Matusiak[1] also proposed thermal comfort index. For this index, thermal resistance, thermal absorbtivity, water vapor resistance and air permeability were used for prediction of thermophysiological comfort of the different textile materials. As in this index the extreme levels of single fabric properties are not defined, it is impossible to make decision on the ability of the studied fabric to provide thermal comfort under specific ambient conditions[5]. This disadvantage was corrected later by introduction of minimum and maximum levels of particular parameters into the formula and thus the relative thermal comfort index was set[5]. Raj and Sreenivasan[6] introduced the total wear comfort indexes for winter ($TWCI_w$) and summer ($TWCI_s$) wear. Along with the characteristics relating into thermophysiological comfort (thermal and flow resistance and moisture transport rate) in these indexes, the total hand value (THV) representing tactile comfort was also used. Thus, both indexes are believed to characterize the overall quality of the apparel fabric. For evaluation of mechanical comfort of linen fabrics, Taieb *et al.*[7] proposed two indexes namely tactile mechanical comfort index (TMCI) and clothing mechanical comfort index (CMCI). Higher values of both indexes mean the better mechanical comfort of a fabric. Selection of the suitable mechanical properties is given by the area of the fabric used. Thermal comfort equation developed by Fanger[8] comprises six parameters, namely metabolic rate, cloth index, air velocity, mean radiant temperature, ambient air temperature and ambient water vapor pressure, which characterize the state of the environment. Based on the Fanger's parameters, Ma *et al.*[9] presented prediction model of thermal comfort index using combination of neural network and genetic algorithm.

However, none of the presented indexes show how the thermal comfort of clothes is changed when the fabric is moistened or sweated.

Thermophysiological comfort of clothes, for simplicity called as thermal comfort of clothes, is fully characterized by their thermal resistance and water vapor permeability (or evaporation resistance) when the steady-state parameters are only considered[10]. Nevertheless, besides their steady–state properties, their dynamic (transient) properties are also important, like their thermal contact feeling, expressed in terms of thermal absorbtivity[2]. Both the mentioned groups of the fabric properties are generally determined on dry fabrics. Both outerwear and particularly underwear fabrics (T–shirts, next-to-skin textiles, dresses) are frequently used in wet state, caused by the sweat condensation and absorption.

As the difference in water vapour permeability and thermal resistance of textiles in dry and wet state exists, the simple index showing the changes in the thermal comfort based on the changes of mentioned properties in their dry and wet states is introduced in this paper.

2 Materials and Methods

Twelve different vareity of sports dressess were used for the study (Table 1). Vapor permeabilities of 12 sports dresses in dry and wet states were determined, and all these values were used for the calculation of dimensionless wet comfort index (WCI) which ranges from 0 to 1. The maximum value 1 indicates the smallest changes in thermophysiological comfort level in wet state. Wetting of the dresses was achieved during the medium effort training of a sportsman on the running simulator. The conditions in the testing laboratory were temperature 21°C and relative humidity (RH) 40%. Thermal resistance and water vapor permeability of dry and wet dresses were determined by means of non-destructive fast testing instruments PERMETEST and ALAMBETA[11,12].

In the beginning of the experiment, all dresses were washed twice so that possible non-permanent finishes were removed, and then their thermal properties and relative water vapor permeability (RWVP) under standard (dry state) conditions were determined. RWVP is the ratio between the cooling heat flow passing through the studied fabric inserted in the PERMETEST instrument and the cooling heat flow passing through the measuring head of this instrument without any fabric covering on the measuring surface[13-15].

Before the training, the dresses were dried at 110°C and weighed. Then the sportsman, wearing the test dresses one by one, performed training under same or very similar climatic conditions (22°C, 36% RH) and with the same or similar effort (running velocity 2.8 m/s, time 20 min). After the training, dresses were hermetically closed in boxes and weighed.

The effective relative water vapour permeability (ERWVP) of wet fabrics was also determined. The total relative cooling flow ($q_{tot,fab,w}$) transferred through the boundary layer of the wet fabric surface is given by the sum of relative heat (cooling) flow passing from the skin through the permeable fabric ($q_{fab,w}$) and relative heat flow ($q_{fab,surf}$) caused by temperature gradient between skin and fabric surface, which is cooled by evaporation of water from the fabric surface as shown below:

$$q_{tot,\ fab\ ,w} = q_{fab,\ w} + q_{fab,\ surf} \quad \dots (1)$$

Hence

$$q_{fab,\ w} = q_{tot,\ fab,\ w} + q_{fab,\ surf} \quad \dots (2)$$

It should be understood that all the above quantities are related to the heat flow passing through the free wet porous surface of the measuring head (q_o), which simulates the sweating of human skin. That is why we have used the word "relative". Relative water vapour permeability of dry fabric (RWVP) is then defined as

$$RWWP = 100\, q_{fab} / q_0 \quad \dots (3)$$

where (q_{fab}) is the heat flow measured by the PERMETEST, when the measuring head is covered by a dry fabric. From the above definition, it is observed that the water vapour permeability of dry fabric (RWVP) is in fact the relative cooling flow passing through the dry fabric multiplied by 100. Similarly, the effective relative water vapor permeability (ERWVP) is defined as 100 times the relative heat flow passing from the skin through the permeable fabric ($q_{fab,w}$) [Eq. (1)].

In order to determine the ERWVP by means of the PERMETEST instrument, it is necessary to execute two different measurements on the same wet sample. In the first step, the relative cooling heat flow ($q_{tot,\ fab,w}$) [Eq. (1)] passing through the wet sample and also the cooling flow generated by the wet sample surface are measured.

In the second step, the measuring head of PERMETEST instrument is covered by an impermeable foil[5], which stops the effective relative cooling flow ($q_{fab,w}$) through the wet fabric. Thus, in the second step, we measure the relative cooling flow ($q_{fab,surf}$) from the wet fabric surface only. The difference between both the mentioned measurements yields the required relative cooling flow ($q_{fab\ ,w}$), which after multiplying by 100 also presents the ERWVP as shown below:

$$ERWVP = 100\, q_{fab,\ w} = 100\,(q_{tot,\ fab w} - q_{fab,\, surf}) \quad \dots (4)$$

Thermal resistance (R) and thermal absorbtivity (b) of the dresses in dry (index d) state and wet (index w) state (R_w. R_d, b_w, b_d) were determined by the ALAMBETA instrument at 200 Pa pressure. The wet dresses were measured in such places, which were subject to intensive sweating during the training. The most uniform sweating takes place in the back part of the body along the backbone.

3 Results and Discussion

Figures 1 and 2 show that the ERWVP of the wet dresses exhibit very low values. Should the wet dress not be in the direct contact with skin, the cooling flow resulting from the water evaporation from the wet fabric surface may not contribute to the skin cooling, and most of the cooling effect gets lost.

As regards thermal resistance of the dresses which got wet during the training, this important parameter drops to 30 – 70% of the original (dry) values (Fig. 3a). Thermal absorbtivity of the studied dresses (Fig. 3b), due to their wetting, is increased by 30-190%, where the last value indicates quite unpleasant and cold feeling.

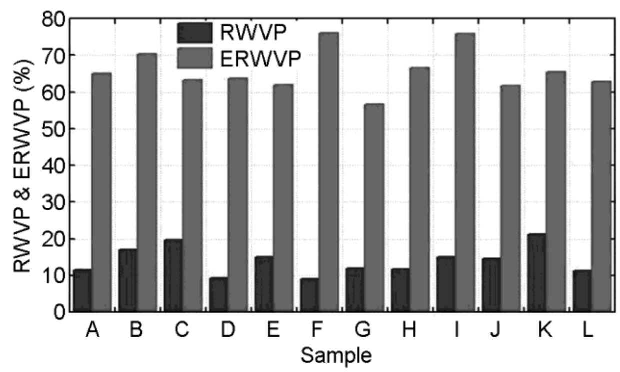

Fig. 1—RWVP of the samples in dry state and ERWVP of the samples after wetting during the training

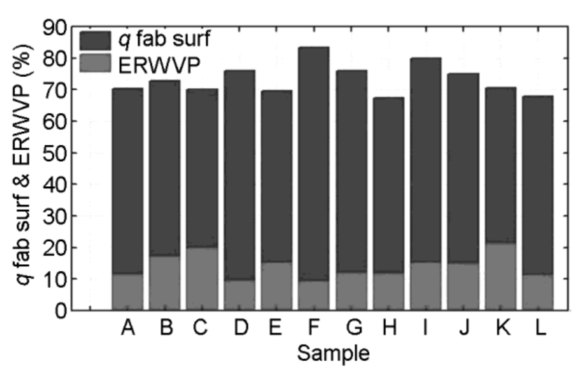

Fig. 2—ERWVP of the dresses in wet state (light) and relative cooling heat flow ($q_{fab\ surf}$) from the wet fabric surface (dark)

Table 1—Description of samples wetted by running on the simulator

Code	Fabric composition	Fabric structure	Fabric weight g/m^2	Wetting level %	Thickness mm
A	PE 62% / PA32% / EL 6%	Weft single jersey with ribs	185	7.0	1.26
B	PE 92% / EL 8%	Weft single jersey	218	5.0	1.00
C	PE 100% - chemically modified	Weft double jersey +single rib (3:2)	160	6.2	1.21
D	CO 100%	Weft single jersey	192	16.2	0.86
E	CO 55% / PA 45%	Weft interlock (smooth)	184	15.5	1.01
F	PE 54% / PE Cooldry 46%	Weft single jersey with loops	174	7.1	0,63
G	PA 56% / PP 39 % / EL 5%	Weft single jersey	203	5.5	0.89
H	PP 100% physically modified	Weft double jersey with loops	95	16.5	1.28
I	PE 51% / PE 49% mineral filled	Weft interlock knit	129	12.2	0.57
J	PE 50% / CO 50%	Weft double jersey (smooth)	150	12.5	1.02
K	PE 79% /PA 12% / EL 9%	Weft single jersey	168	11.5	1.11
L	PA micro 55% / PE 40% / EL 5%	Weft double jersey with ribs	214	6.3	1.29

PE – Polyester, PA – Polyamide, PP – Polypropylene, EL – Elastane, and CO – Cotton.

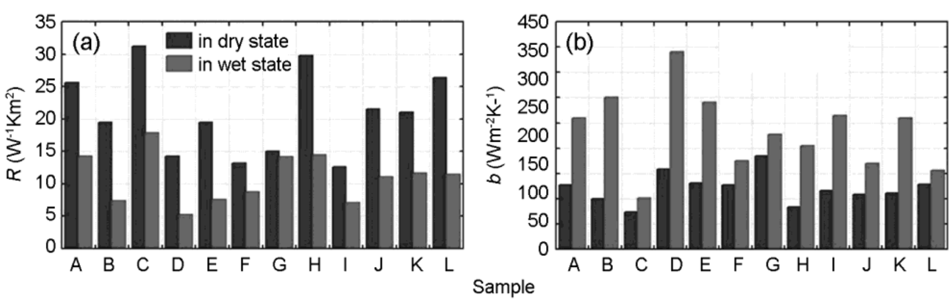

Fig. 3—(a) Thermal resistance (*R*), and (b) thermal absorbtivity (*b*) of dresses in dry state and after their wetting during training

The results confirm that both ERWVP and thermal resistance of dresses, which got wet during the real sport activity, decrease substantively. This decrease is specific for dresses of various composition and structure. The best dresses exhibit, in wet state, the highest values of the mentioned ERVWP and thermal resistance (or $RWVP_w$ and R_w). To characterize the effect of moisture on thermophysiological comfort of underwear and sport dresses, a new so called wet comfort index (WCI) is introduced, as shown below:

$$WCI = \frac{ERWVP\ ,\ R_w}{RWWP_d\ ,\ R_d} \quad \ldots (5)$$

This index level ranges from 0 to 1. WCI of the best underwear and sport dresses will approximate to the 1 value. The WCI level of the dresses studied is shown in Fig. 4.

The WCI dependence on fabric weight (*w*), thickness (*t*), fabric density (*d*) and fabric porosity (*P*) are presented in Fig 5. The mentioned fabric density and porosity were calculated from the fabric square weight (g.m^{-2}), fabric thickness (m) and fibre density (kg.m^{-3})[16]. No dependence among the investigated properties and WCI is found. It indicates that the fabric structure and fibre physical properties (such as hydrophobicity, capillary forces and moisture

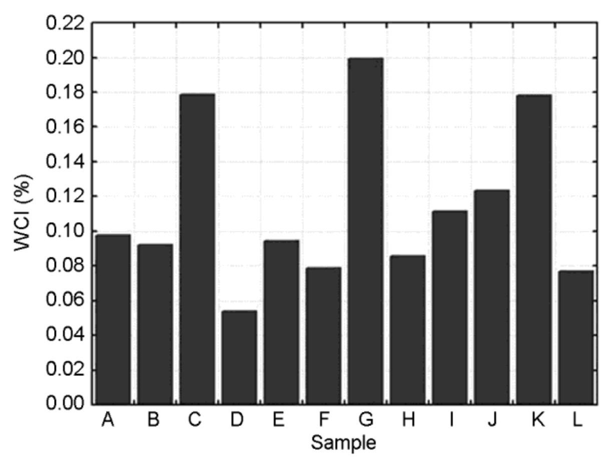

Fig. 4—Wet comfort index of the dresses wetted during training

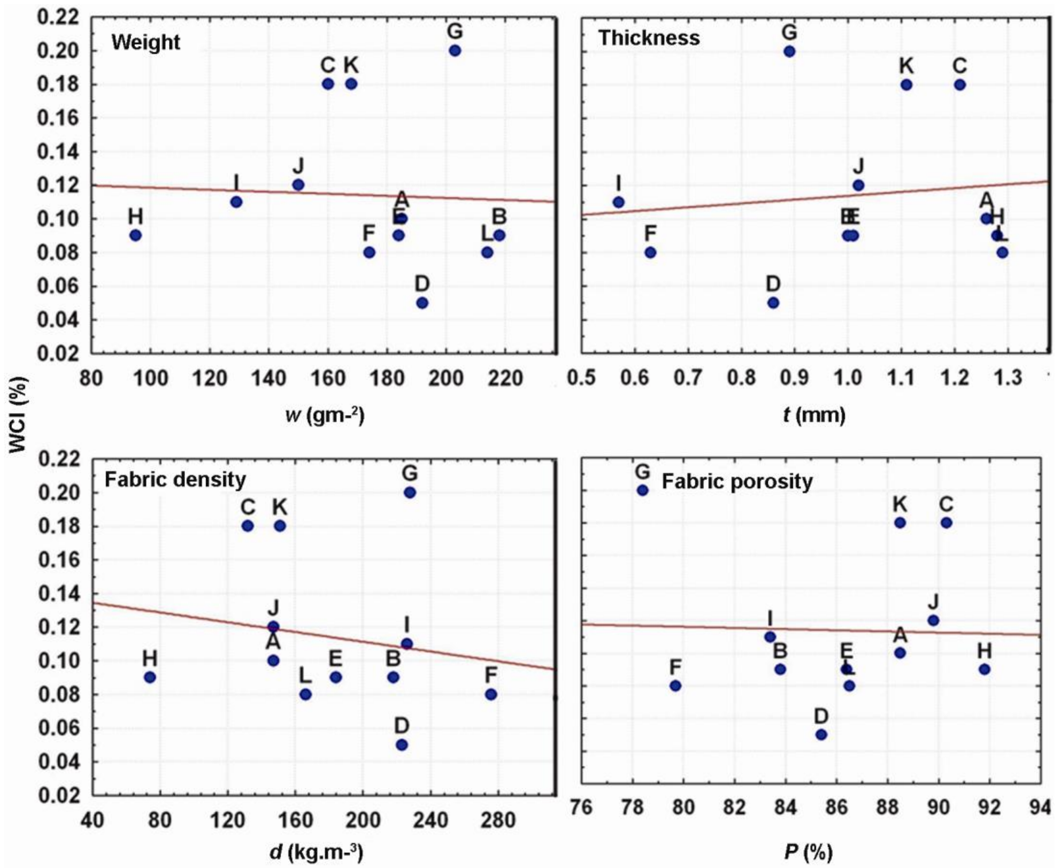

Fig. 5—WCI dependence on fabric weight (*w*), thickness (*t*), fabric density (*d*) and fabric porosity (*P*)

absorbtivity) play most important role in changes of thermophysiological comfort of fabrics caused by sweating.

The results show that values of WCI for specified samples lie in the range from 0.05 (sample D, 100% cotton) to 0.2 (sample G, PA 56% / PP 39 % / EL 5%). It indicates that after sweating the thermal comfort is changed dramatically, 5 times for the best material and 20 times for the worst material. It is evident that the use of this index to characterize thermal comfort of sport dresses and underwear in wet state can be very helpful for the dress or underwear users.

4 Conclusion

The best level of WCI is observed for the dress G (56% polyamide, 39% polypropylene, 5% elastane) followed by the dress C (100% chemically modified polyester) and K (79% polyester, 12% polyamide, 9% elastane). The worst properties in wet state are found for the dress D (100% cotton), and then for dresses L (55% micro nylon, 40% micro polyester, 5% spandex) and F (54% polyester, 46% polyester Cooldry). From this study it follows that thermophysiological comfort properties of underwear or dresses in dry state can be substantially higher than their comfort properties in real conditions during their use due to the absorbed sweat. This surprising observation emphasizes the importance of testing of thermal comfort properties of fabrics in wet state by means of special instruments.

References

1 Matusiak M, *Fibres Text Eastern Eur*, 79(2) (2010) 45.
2 Hes L, *Proceedings, 3rd European Conference on Protective Clothing* (CIOP-PIB, Warszawa Gdynia), 2006.
3 Umbach K H, *Melliand Textilber* 85 (10) (2004) 802.
4 Militky J & Matusiak M, *Proceedings, 3rd International Textile, Clothing & Design Conference*, edited by Z Dragsevic (TU Zagreb, Dubrovnik), 2006.
5 Matusiak M & Sikorski K, *Fibres Text Eastern Eur*, 89(2) (2011) 94.
6 Raj S & Sreenivasan S, *J Eng Fibers Fabrics*, 4 (4) (2009) 29.
7 Taieb A H, Msahli S & Sakli F, *J Natutal Fibres*, 7 (4) (2010) 251.
8 Fanger P O, *Thermal Comfort* (inpolish), Arkady, Warsaw, 1974.
9 Ma B, Shu J & Wang Y, *Proceedings, Seventh International Conference on Natural Computation*, edited by J K Hao, (University of Hawaii, Shangai), 2011, 771.

10 Gibson P W, *Text Res J*, 63(12) (1993) 749.
11 Hes L & Araujo M, *Text Res J*, 80 (14) (2010) 1488.
12 Hes L & Lizak P, *Proceedings, Fiber Society Spring Conference*, edited by R Hufenus (EMPA St. Gallen), 2012, 30-40.
13 Hes L, Bajzik V & Dolezal I, *Proceedings*, *ICETT Conference* (NIST, Jalandhar), 2014.
14 Bogusławska-Bączek M & Hes L, *Fibres Text Eastern Eur*, 21(1) (2013) 67.
15 Hes L & Dolezal I, *Proceedings, AUTEX 2009 World Textile Confoerence*, edited by E Kumbasar (EGE University, Izmir) 2009, 714.
16 Mangat M M, Hes L & Bajzik V, *Text Res J*, 85 (2) (2015) 200.