

Heat and Moisture transport of socks

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Abstract. Investigating the liquid moisture transport and thermal properties is essential for understanding physiological comfort of clothes. This study reports on an experimental investigation of moisture management transport and thermal transport on the physiological comfort of commercially available socks. There are subjective evaluation and objective measurements. Subjective evaluation of the physiological comfort of socks is based on individual sensory perception of probands during and after physical exertion. Objective measurements were performed according to standardized methods using Moisture Management tester for measuring the humidity parameters and C-term TCi analyzer for thermal conductivity and thermal effusivity. The obtained values of liquid moisture transport and thermal properties were related to the material composition and structure of the tested socks. In summary, these results show that objective measurement corresponds with probands feelings.

1. Introduction

The most important feature of functional clothing is to create a stable microclimate next to the skin in order to support body's thermoregulatory system, even if the external environment and physical activity change completely [1, 2]. Socks belong to group of first layer clothing products that should protect skin in warm or cold weather conditions and should safe good thermo-physiological comfort. Till date, a lot of research work has been devoted to comfort of socks. Van Amber et al. analysed effect of fabric thickness on thermal and moisture transfer properties of socks [3]. The study was aimed to determine the relative effects of fiber type, yarn type, and fabric structure on thermal resistance, water vapour resistance, thermal conductance, water vapour permeability, liquid absorption capacity, and regain of sock fabrics. In study of Čiukas the influence of different fibres of the socks on the thermal conductivity coefficient of plain knits and plated plane knits with textured polyamide or elastane wrapped with textured polyamide thread was investigated [4]. Bedek et al. found that the thermal comfort in steady state is mainly influenced by the relative porosity and moisture regain which affect the first thermal contact feeling and their thermal conductivities [5]. In the past few years, different advanced experimental techniques have been used to characterize liquid water transport and thermal transport in fabrics or socks. Leisen et al. applied magnetic resonance to study the moisture transport in different textiles [6]. Neutron radiography was used for measurement measurements of moisture distribution in multilayer clothing systems by Weder [7]. Rossi used X-ray tomography to analyse the transplanar and in-plane water transport in different sock materials when two defined pressures were applied [8]. This method enables quantify the three-dimensional water transport properties in textile structures, which is especially relevant for fabrics with asymmetrical capillary transport properties like the sock materials. Researchers have reached the conclusion that fibre type,



yarn properties, fabric structure, finishing treatments and clothing conditions are the main factors affecting thermo-physiological comfort of socks wearing. But, it is very difficult to uncover how to set afore mentioned parameters of socks material to production suitable socks for winter or summer conditions. Till date, performance of socks was mainly determined by objective measurement. Therefore, our study is focus on analysation of results from both objective and subjective evaluation of physiological properties of socks.

2. Materials

Commercially available sport and everyday wear socks differing in fiber content, structure, weight and thickness were selected for this research. (Table 1). Socks were divided in three characteristic classes according to material composition. Basic series comprises the socks from the nearly one hundred-percent share of raw materials. Classic series includes socks for leisure activities from blended materials with nearly the same share of basic raw materials – cotton. And functional series is designed for sports activities and is made from yarns with functional properties.

Table 1. Specification of tested socks.

Sample code	Fiber content	Pattern	Wearing purpose (by producer)
Basic series			
B1	100% cotton	Welt: turned welt with inlaid rubber thread, Leg: plain jersey	Everyday wearing, No special treatment
B2	100% polypropylene	Welt: turned welt, Leg: plain jersey Foot: float fabric, single jersey jacquard Heel, toe: plating fabric	Everyday wearing, Summer sport Instep part – good moisture transport, good air permeability
B3	98% polyester 2% Lycra	Welt: turned welt, Leg, foot: plain jersey with inlaid rubber thread (2:1), single jersey jacquard, Heel, toe: plating fabric	Casual activity, combined structure for good close-fitting (tight)
Classic series			
C1	65% cotton 30% PP – Siltex 5% Lycra	Welt: turned welt, Leg: plain jersey with inlaid rubber thread (3:1), Heel, toe: plating fabric	Antibacterial effect (Siltex), Instep part – fixing strip
C2	68% cotton 30% polyester 2% Lycra	Welt: turned welt Leg, heel, toe: plating fabric	Healing and soothing effects - extract from the Aloe Vera
C3	67% cotton 31% polyamide 2% Lycra	Welt: turned welt, Leg: plain jersey with inlaid rubber thread (3:1) Foot, bottom part – plush fabric Heel, toe: plating fabric	Instep part – fixing strip, Bottom part - loop fabric for shock, absorption during walking
Functional series			
F1	50% CoolMax 30% cotton 10% PP – Siltex 7% polyamide 3% Lycra	Welt: turned welt with inlaid rubber thread, Leg: plain jersey Foot: plain jersey with inlaid rubber thread (3:1), Heel, toe: plating fabric	For outdoor sports, Wicking sweat away from the skin, Suppression of unpleasant odors
F2	75% Merino wool 20% PP – Siltex 5% Lycra	Welt: turned welt, Leg: plain jersey Foot: float fabric, single jersey jacquard Heel, toe: plating fabric	Pro outdoor and indoor sports, Instep part - special structure for ventilation, Antibacterial effect (Siltex), No unpleasant odors,
F3	45% Outlast 25% PP, 20% wool, 5% Lycra	Welt: turned welt Leg, foot, heel, toe: plush fabric	Winter mountain hiking, padded No bruising zones, anatomically shaped for L/R, excellent thermoregulation

3. Methods

The experiment was divided to two steps. In the first step the subjective physiological feelings of probands during wearing of socks were recorded. In second step the objective parameters of moisture management and thermal insulation properties of socks were tested. In the end the results from both part of experiment were compared.

The performance of socks was investigated by two ways: subjective evaluation and objective measurements. Before being tested, the socks had been conditioned for 24 hours. The testing and measurement were carried out in an air-conditioned room under constant relative humidity of 55 % and the temperature of 21°C.

3.1. Subjective evaluation of physiological comfort.

Subjective physiological feelings were tested by a group of 7 probands within their 30 minutes physical activity on stationary bike. A special questionnaire to collect information from probands was created. This questionnaire included physiological feelings of proband before physical activity, during (after 15 minutes from start of activity), immediately after and 15 minutes after physical activity. Proband were inquired about feelings of cold / heat, moist, fitting of socks, irritation of socks, overall comfort of socks. Questions had a closed character in the form of opposing terms (bipolar adjectives), divided into five-point scale (1 was the best and 5 the worst value). After physical activity the socks were weighted and compare with weigh before test in order to investigate the sweat over weight.

3.2. Objective evaluation of liquid moisture transport by Moisture management tester.

Objective evaluation of liquid moisture transport was tested by standardized measurement with laboratory equipment Moisture management tester (MMT). MMT was developed to quantify dynamic liquid transport properties of knitted and woven fabrics through three dimensions: absorption rate – time for absorption of moisture on fabric's face and back surfaces, one-way transportation capability – one-way transfer from the fabric's back surface to its face surface, spreading/drying rate – the speed at which liquid moisture spreads across the fabric's back and face surfaces [9].

3.3. Objective measurement of heat transport.

Thermal conductivity analyser (TCi) was used for objective measurement of heat transport. TCi employs the Modified Transient Plane Source (MTPS) technique in characterizing the thermal conductivity and effusivity of materials. The socks were tested in both dry and wet condition. The quantity of synthetic sweat was based on the data from subjective evaluation.

4. Result and discussion

4.1. Subjective evaluation of physiological comfort

Data from all probands for all socks were averaged and processed into graphs.

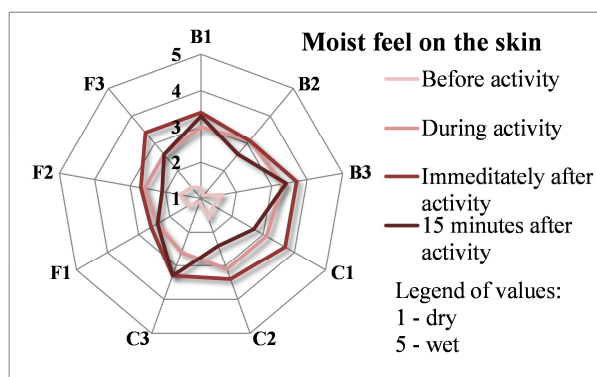


Figure 1. Graph based on the average of seven tested probands for moist feeling on the skin.

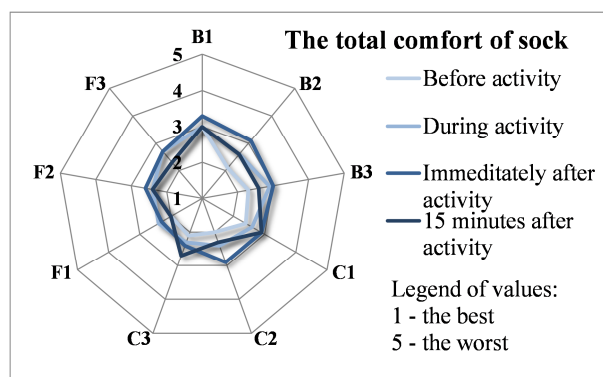











Figure 2. Graph based on the average of seven tested probands for total comfort feeling.

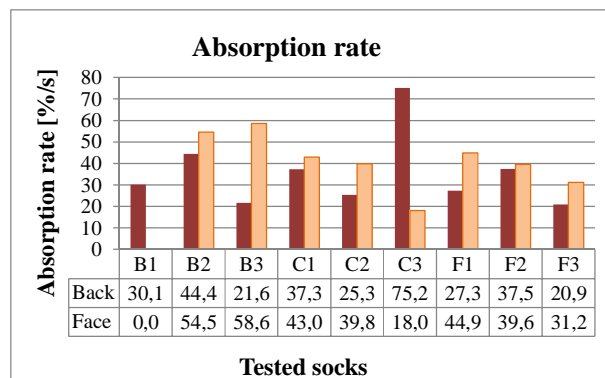
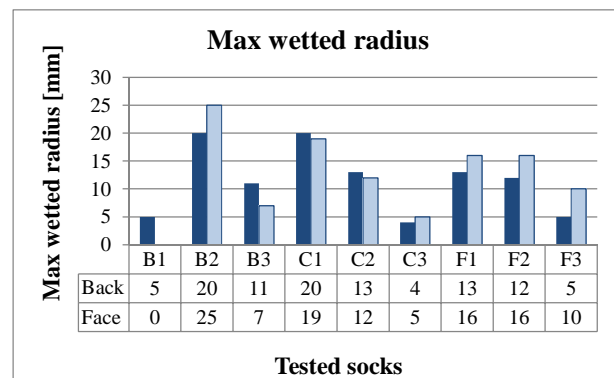
Table 2. Location of places with the biggest wet. Visual evaluation. Weight over of sweat.

Sock	Wet places map	Over sweat [g]	Sock	Wet places map	Over sweat [g]	Sock	Wet places map	Over sweat [g]
B1		1,236	C1		0,406	F1		0,604
B2		0,393	C2		0,661	F2		0,747
B3		0,776	C3		0,616	F3		3,108

Overall, these results indicate that the socks B1 (100% cotton) are evaluated as the worst from all tested socks. Questionnaires reported very bad fitting (shape adaption), very bad ability of drying out during and after sport activity. Socks F1 (Coolmax / cotton / polypropylene) were evaluated as the best. Questionnaires felt minimal amount of moisture, their feet were heated within sport activity and after activity provided optimal state of comfort.

4.2. Objective evaluation of liquid moisture transport by Moisture management tester

Comparison of two important parameters between all tested socks is presented in Figure 3, Figure 4. Average values of moisture transport investigated by MMT are shown in Figure 5.

**Figure 3.** The graphs of absorption rate of tested socks investigated by MMT.**Figure 4.** The graphs of maximal wetted radius investigated by MMT.

Lower values of absorption rate in face side indicated small or none transport of moisture between sides (surfaces) of sock (moisture content in back side was significantly higher than in face side).

The graph of maximal wetted radius shows that the 100% cotton sock B1 has the smallest wetted surface. This parameter is indicator of bad draying out ability. Speed of drying out is inversely depended on a wetted radius size. On the contrary the sample of 100% polypropylene sock had the large wetted surface.

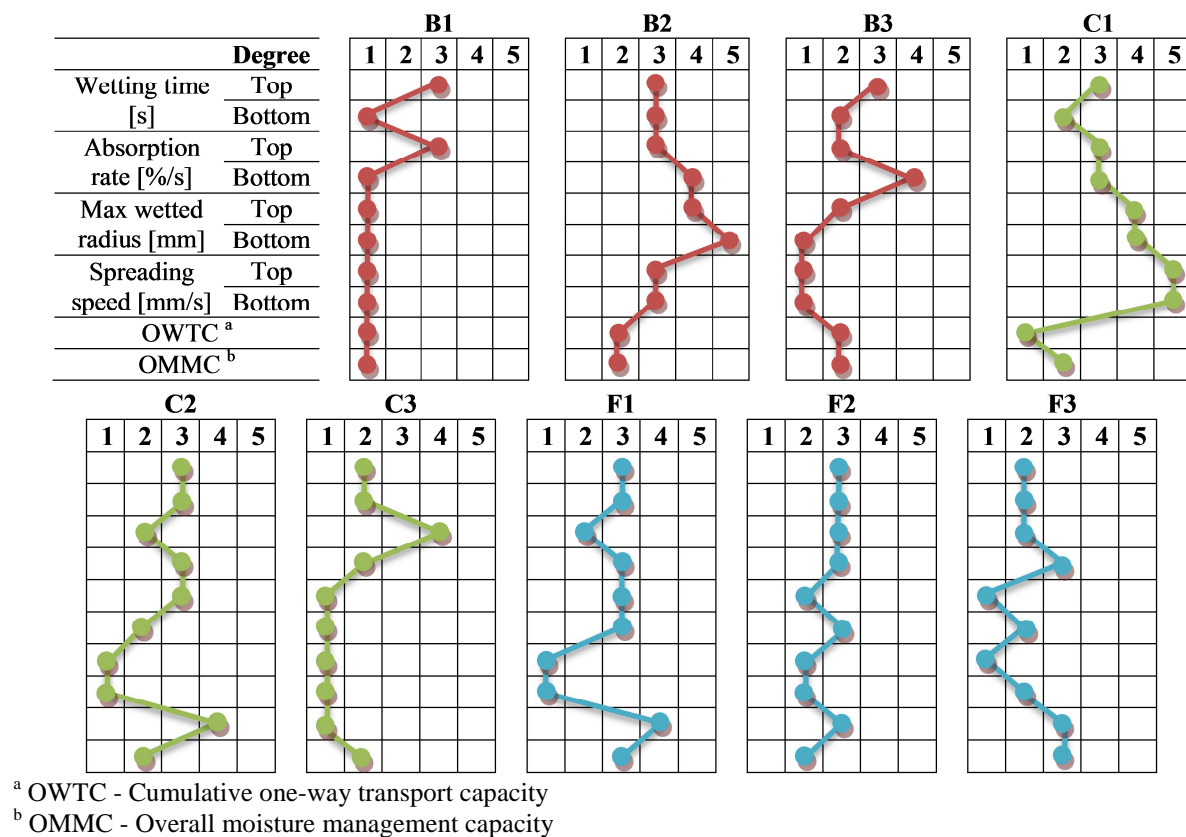


Figure 5. The graphs of liquid moisture transport parameters investigated by MMT.

Overall, the results from MMT do not confirmed the fact that the socks from “Functional Series” achieve the best transport of liquid moisture how the manufacturers declare. The results show slow or middle the wetting time for all samples of socks, absorption rate is very small in keys of sock B1 (100% cotton) and spreading speed is the worst. This sock has the smallest max wetted radius too; it means that this sock has very bad drying ability. OWTC parameters shows negative values for socks B1, C1, C3 which demonstrate that water content of fabric’s face surface is lower than its back one. This indicates that the liquid introduced onto the back surface transfers to the face surface not so fast.

4.3. Objective evaluation of heat transport

The results obtained from objective measurement of heat transport are summarised in Figure 6 and Figure 7. The presented values are average from measurement of four different places on the sock.

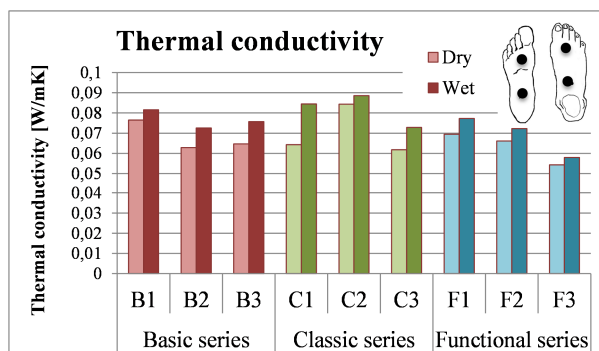


Figure 6. The graph of thermal conductivity for dry and wet socks.

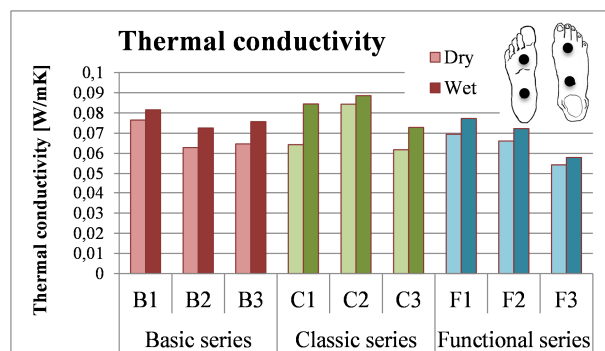


Figure 7. The graph of thermal effusivity for dry and wet socks.

The graphs show that knitted structure affects significantly both thermal effusivity and thermal conductivity. When sock becomes wet thermal effusivity and thermal conductivity increases and sock seems to be “colder”. Wearer can feel discomfort in this case. Polypropylene or wool/polypropylene blend (sock B2, F2) shows good ability of thermal and moisture transport from point of view of fiber content. Further, especially the plain jersey with bottom loom or plating supports moisture and heat transport in this sock in term of knitted structure.

5. Conclusion

The results both subjective and objective evaluation have shown that the pattern of sock, porosity, and further fiber content and surface finishes have the greatest influence on transport of liquid moisture transport. It is ideal that the sock is quick-absorbing and quick-drying. Only one type from all tested socks reached this key idea parameter – namely B2 (100% polypropylene). These socks are knitted from several patterns (mainly plain jersey and plain jersey with bottom loom and insert thread). It is essential that the socks transport the sweat outside to the surrounding environment during physical activity. Subjective evaluation of probands confirms the results of MMT that socks B2 have good drying ability.

From the results it is evident that the socks from 100% natural fibers e.g. cotton has good absorption properties, however the results of subjective evaluation probands mentioned that they felt discomfort after 30 minute of sport activity due to slow moisture transport. Knit fabrics produced from natural fibre reach equilibrium more slowly than knit fabrics composed of synthetic fibres.

Thermal properties measurements confirm other studies in terms of increasing thermal conductivity and effusivity by increasing the volume of water (sweat) held by a socks. Polypropylene or wool/polypropylene blend in combination with plain jersey (with bottom loom) structure or plating indicate very good ability of thermal and moisture transport in order to ensure physiological comfort of wearer.

Further research should be undertaken to investigate the influence of maintenance on physiological comfort of socks. It would be interesting to determine the 100% cotton sock behaviour after several cycles of maintenance.

6. References

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