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Water Vapour Resistance of Knitted Fabrics under Different Environmental Conditions

Abstract
The comfort of textile materials has been the focus of many investigations since the concern for personal well-being and improving the quality of life started to become an important issue. The aim of this paper is to simulate water vapour transfer through knitted fabrics under different environmental conditions. In this investigation knitted fabrics using 100% cotton, 50/50% cotton/modal, 100% viscose and 100% Tencel® yarns of 20 tex were used. The measurement of water vapour resistance was carried out on a sweating guarded hotplate in standard conditions (as stated in ISO 11092) and in simulated environmental conditions of three European cities from different geographical zones. The results indicate the influence of environmental conditions (temperature and relative humidity) on the transfer of water vapour that occurs due to the above-mentioned conditions and the influence of the raw material on the rate of water vapour transfer under each pair of environmental conditions defined.

Key words: *thermophysiological comfort, water vapour resistance, environmental condition, knitted fabric, yarn.*

Introduction

The comfort of textile materials has been the focus of many investigations since the concern for personal well-being and improving the quality of life started to become more significant. The comfort of textile materials is mostly related to the transfer of heat and water vapour through textile structures and investigations are basically related to the mechanisms of transfer during normal wear or in transient conditions. During normal wear, the flux of heat and moisture vapour has to maintain the thermoregulation of the human body and to establish a feeling of thermal comfort. In other words, the clothing has the role of a thermoregulatory system. In transient wear conditions, where sweating is caused by different levels of activity or different climatic conditions, the sweat must be rapidly managed by the clothing. In such conditions, the ability of clothing ensembles to transport water vapour is an important determinant of physiological comfort. If it is not possible to avoid sweat accumulation in the clothing, the sweat should be removed from the skin surface to the surface of the underwear/next-to-skin wear, or to fabric layers further out in the clothing ensemble. After the body has stopped sweating, the textile fabric should release the vapour held to the atmosphere in order to reduce the humidity on the surface of the skin. The textile fabrics that block the passage of water vapour allow the condensation of water vapour and formation of liquid moisture, which directly causes the sensation of discomfort.

The knitted fabrics used for the production of underwear or any kind of next-to skin wear are in contact with human skin, and therefore it is especially important for them to achieve a good comfort sensation. Owning to their looped structure, knitted fabrics have good stretchability, which is an important element in the achievement of optimal sensorial comfort. At a given activity level and defined environmental conditions, the ranges in which the knitted ensemble will be defined as comfortable depends on the rate at which the fabric allows water vapour to pass through it.

A considerable amount of work has been done on water vapour mechanisms and heat transfer trough different textile structures [1 - 3]. Regarding the setting of conditions, most authors defined the controlled conditions as the following: an air temperature of 20 °C,and a relative humidity of 65% for the investigation of heat resistance, or 35 °C and 40% during the investigation of water vapour resistance. Investigations have also been carried out to compare conditions defined in different standards [4], like ISO [5] and ASTM [6]. Some of the authors conducted investigations under specific climate conditions, such as in extreme cold or in a hot and humid environment [7 - 11]. In order to provide an objective criterion for thermal comfort that includes combinations of different factors influencing comfort, laboratory experiments with human participants were carried on. During the experiments, the Predicted Mean Vote (PMV) was determined, as an index that expresses the quality of a thermal environment as a mean value of the votes of a large group of persons that give their rates according to the seven-point thermal sensation scale (+3 hot, +2 warm, +1 slightly warm, 0 neutral, -1 slightly cool, -2 cool, -3 cold) [12 - 15]. A psychrometric chart for the typical summer assembly of 0.5 clo determined using the PMV model is shown in ***Figure 1***. The limitations of the model are the fact that it is applicable to indoor environments only, and for limited situations where metabolic rates are between 1.0 - 1.3 met and the air speed is less than 0.20 m/s [16].

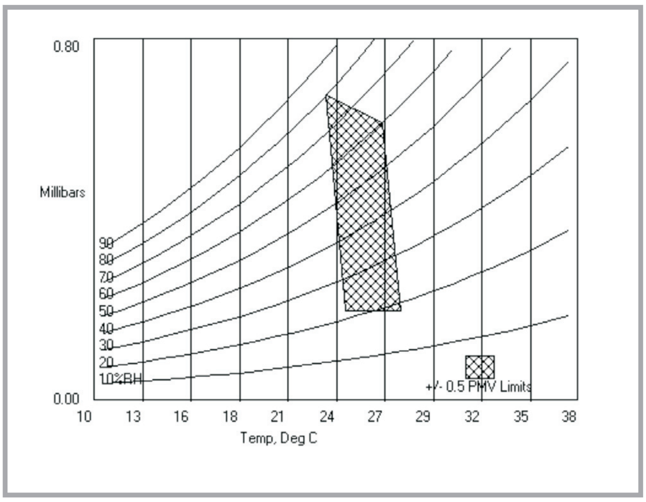

Figure 1. *Limits of thermal comfort.*

The aim of this paper is to simulate water vapour transfer through knitted fabrics under different environmental conditions. For the investigation four fabrics were knitted from cotton, cotton/modal, viscose and Tencel® yarn of 20 tex. The fabrics were designed to have the same knit construction and similar constructional parameters but to differ only in the raw material. By selecting fabrics with no more than one difference, the group of test materials should allow to examine the effect of the raw material on water vapour resistance. The range of knitted fabrics produced was intended to be used for the construction of next-to-skin wear (either lightwear or underwear). Such assemblies are mostly worn in hot environments i.e., during the summer period. The results indicate the influence of environmental conditions (temperature and relative humidity) on the transfer of water vapour that occurs due to the above-mentioned conditions. They were also used to investigate the influence of the raw material on the rate of water vapour transfer under each pair of environmental conditions defined.

Materials and methods

The single cotton, cotton/modal, viscose and Tencel® yarns were used to knit single jersey knitted fabrics on a circular knitting machine of count E28. In the process of knitting, the input tension was set at 3-4 cN. The knitted fabric designation is shown in ***Table 1***.

For all the knitted fabrics, the following parameters were measured: horizontal density, vertical density, loop length, loop module, density coefficient, area density, tightness factor and fabric weight.

The measurement of water vapour resistance was firstly carried out on the sweating guarded hotplate (SGHP), according to the ISO standard [5]. The Standard defines the setting up of the following conditions: an air temperature of 35 °C and a relative humidity of 40%. The hotplate is covered with a semi-porous cellophane sheet during the measurement, and water is supplied to the surface of a porous metal plate by a dosing device, as in ***Figure 2***. The water vapour resistance measured on the SGHP was determined according to the following equation:

$$R_{et} = (p_s - p_a)/(H/T) - R_{et0}, \text{ in m}^2 \text{ Pa W}^{-1} \quad (1),$$

where:
- R_{et} - evaporative resistance of sample only,
- p_s - saturation vapour pressure at hotplate surface,
- p_a - ambient partial vapour pressure,
- H - heating power supplied to the measuring unit,
- A - area of measuring unit,
- R_{et0} - bare plate evaporation resistance.

The thermal resistance (R_{ct}) was measured in order to calculate the water-vapour permeability index (i_{mt}). Calculations of the water-vapour permeability (W_d) and water-vapour permeability index (i_{mt}) were carried out according to the following equations:

$$W_d = 1/(R_{et} \cdot \Phi \cdot T_m), \text{ in g m}^{-2} \text{ h}^{-1} \text{ Pa}^{-1} \quad (2)$$

$$i_{mt} = S \cdot R_{ct}/R_{et} \quad (3),$$

where:
ΦT_m - latent heat of vaporisation of water at temperature T_m of the measuring unit,

Table 1. *Knitted fabric designation.*

Fabric designation	Fabric description
C	100% cotton
CM	50/50% cotton/modal
V	100% viscose
T	100% Tencel®

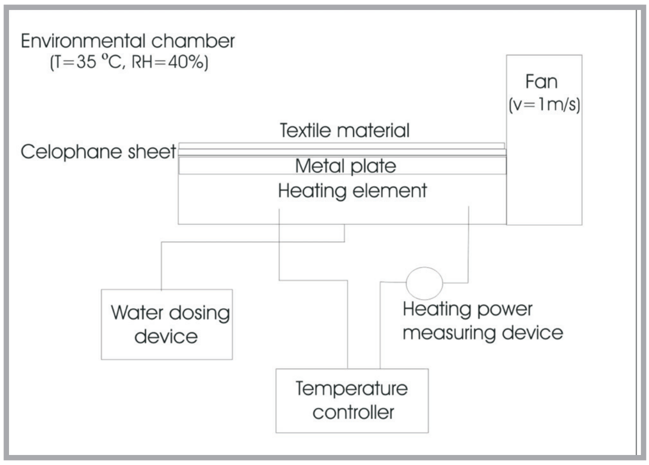

Figure 2. *Scheme of sweating guarded hotplate.*

Table 2. *Average values of temperature and humidity* [12].

	Athens	Zagreb	Helsinki
Mean temperature, ºC	**27**	**20**	**16**
Max temperature, ºC	36	33	28
Min temperature, ºC	17	8	4
Average humidity, %	**43**	**58**	**65**
Max humidity, %	83	94	99
Min humidity, %	13	23	26

Table 3. *Knitted fabric parameters.*

Fabric parameter	C	CM	V	T
Horizontal density, cm^{-1}	12.8	13.0	13.0	13.1
Vertical density, cm^{-1}	18.0	19.5	20.1	20.1
Wale spacing, mm	0.78	0.77	0.77	0.76
Course spacing, mm	0.56	0.52	0.50	0.50
Loop length, mm	2.9	2.7	2.7	2.6
Density coefficient	0.71	0.67	0.65	0.65
Area density, cm^{-2}	230.4	253.5	261.3	263.3
Tightness factor, $tex^{1/2}$ cm^{-1}	1.54	1.66	1.66	1.72
Fabric weigth, g m^{-2}	145	126	125	120

Table 4. *Water vapour permeability and permeability index.*

Fabric designation	C	CM	V	T
Water vapour permeability, g m^{-2} h^{-1} Pa^{-1}	0.37	0.37	0.39	0.40
Water vapour permeability index	0.34	0.34	0.33	0.34

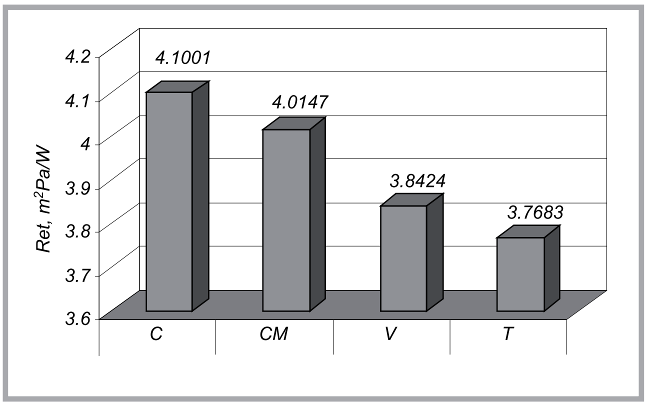

Figure 3. Water vapour resistance measured according to ISO 11092.

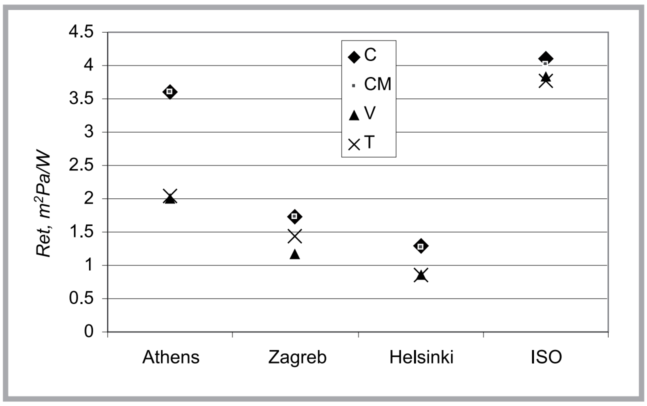

Figure 4. Water vapour resistance measured under different environmental conditions

S the ratio of R_{et} and *Rct* for air, a constant equal to 60 Pa/K

In the next step of the investigation, the range of knitted fabrics produced were subjected to various environmental conditions during measurements on the SGHP. In order to simulate real-life environmental conditions, information regarding the conditions of three European cities from different geographical zones was obtained. The following cities (from the south, centre and north of Europe) were chosen: Athens, Zagreb and Helsinki. Athens enjoys a typical Mediterranean climate, whose weather is characterised by mild winters and hot dry summers. Throughout the year, temperatures average 32 ºC in summer and 12 ºC in winter. Zagreb's climate is continental, with four separate seasons. Summers are hot and dry, while winters are cold. The average temperature in winter is 1 °C and in summer 20 °C. Helsinki has a humid continental climate, meaning that the average temperature of the coldest month is no more than -3 °C. Summers are usually pleasantly warm: daily maximum temperatures during the summer-months are usually around 18 - 26 °C, while temperatures above 30 °C are very uncommon.

The environmental conditions of the cities were obtained from history reports [17] and average values for August 2007 were calculated. The details including the mean, maximal and minimal average temperature, as well as the mean, maximal and minimal average humidity are given in ***Table 2***.

Results

Results of the measurement of the knitted fabric parameters are shown in ***Table 3***.

Results of the water vapour resistance measured at standard conditions are given in ***Figure 3***, while results of the water vapour permeability and permeability index are shown in ***Table 4***.

Results of the water vapour resistance measured in different environmental conditions, as defined in the previous chapter, are shown in ***Figure 4***.

Conclusions

The purpose of the experiments was to clarify and investigate the transfer of water vapour in different conditions through knitted fabrics produced from different raw material (cotton, cotton/modal, viscose and Tencel®).

The following conclusions can be drawn according to the results obtained:

1. The water vapour transfer through textile structures is basically governed by the vapour pressure difference. Therefore, the water vapour resistances of the knitted fabrics investigated under different conditions differ due to the vapour pressure difference between the plate (skin) and ambient air. The pressure difference is bigger in climate conditions with a lower temperature and higher humidity (16 °C and 65% RH). In such conditions, textile fabrics allow the passage of a higher amount of water vapour.

2. The fabrics investigated are basically used for the production of light wear, which is mostly worn during the summer period throughout Europe regardless of geographic latitude. If the conditions in the cities chosen are compared to the psychrometric chart for assemblies of 0.5 clo, it can be concluded that the assemblies are optimal for conditions in Athens. On the other hand, wearing a 0.5 clo assembly in Helsinki could result in a feeling of discomfort.

3. The fabrics were designed to have the same knit construction and similar constructional parameters but to differ in raw material. Therefore, the group of test materials should allow to examine the effect of the raw material on water vapour resistance. When comparing the cotton and cotton/modal fabrics, it can be observed that there is not much difference between their water vapour resistances. The same could be concluded when comparing the fabrics from viscose and Tencel®. There is an obvious difference between the resistances of the two groups, where cotton and cotton/modal fabrics provide bigger resistance to water vapour transfer.

4. The findings imply that viscose and Tencel® assemblies pose a minor barrier to water vapour transfer. Therefore, they would result in a drier feeling than in the case of cotton or cotton/modal assembly. By contrast, a cotton and cotton/modal assembly might be perceived as wetter. Considering the climatic conditions, viscose and Tencel® assemblies should be prefered in hot climates, such as Athens, where the body sweats intensively.

References

1. *Tugrul Ogulata R.: The Effect of Thermal Insulation of Clothing on Human Thermal Comfort, Fibres & Textiles in Eastern Europe Vol. 61, No. 2, 2007, pp. 67-72.*
2. *Petrulyte S., Baltakyte R.: Investigation into Wetting Phenomenon of Terry Fa-*

brics, Fibres & Textiles in Eastern Europe, Vol. 69, No. 2, 2008, pp. 62-66.
3. Varga K., Schädel U., Nilsson H., Persson O., Schuster K. Ch.: Measuring the Heat of Wetting of Textile Fibres by Reaction Calorimetry, Fibres & Textiles in Eastern Europe, Vol. 15, No. 5-6, 2007, pp. 64-65.
4. McCullough E., Huang J. & Kim, C.S., An Explanation and Comparison of Sweating Hot Plate Standards, Journal of ASTM International, 1, 7, 2004.
5. ISO 11092:1993 Textiles - Physiological effects - Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test).
6. ASTM F 1868-XX, Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate.
7. Meinander H., Anttonen H., Bartels V., Holmer I., Reinertsen R.E., Soltynski,K., Varieras S.: Manikin measurements versus wear trial of cold protective clothing (Subzero project), European Journal of Applied Physiology, 92, 2004., pp. 619-621.
8. Osczevski R. J.: Water vapour transfer through a hydrophilic film at Subzero temperatures, Textile Research Journal Vol. 66, No. 1, 1996., pp. 24-29.
9. Salopek I., Skenderi Z.: Thermophysiological comfort of knitted fabrics in moderate and hot environment, Proceedings of 3rd International Ergonomics Conference, Ergonomics 2007 June 13rd-16th, 2007, Stubičke Toplice, Croatia, pp. 287-293.
10. Yang K., Jiao M. L., Chen Y.-S., Li J., Zhang W.-Y.: Analysis and Prediction of Dynamic Heat-Moisture Comfort Property of Fabric, Fibres & Textiles in Eastern Europe Vol. 68, No. 3, 2008.
11. Konarska M., Sołtyński K., Sudoł-Szopińska I., Chojnacka A.: Comparative evaluation of clothing thermal insulation measured on a thermal manikin and on volunteers, Fibres & Textiles in Eastern Europe Vol. 61, No. 2, 2007, 73-79
12. Bjarne W. O., Brager G. S.: A better way to predict comfort, ASHRAE Journal, 2004., pp. 20-26.
13. ASHRAE Standard 55-66 (American Society of Heating, Refrigerating and Air-Conditioning) Engineers: Thermal Comfort conditions, New York, 1996.
14. ISO 7730:1994 Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.
15. Fanger P. O.: Thermal comfort – Analysis and applications in environmental engineering McGraw-Hill Book Company, USA, 1972.
16. Schiller Brager G., de Dear R. A.: Standard for Natural Ventilation, ASHRAE Journal, October 2000.
17. http://www.wunderground.com; accessed October 22, 2007.

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