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Influence of textile properties on thermal comfort

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Abstract. This study reports on the impact of textile properties on thermal comfort. The fabric weight, thickness, porosity, moisture regain, air permeability and density have been considered and correlated to the thermal and water vapour resistance, permeability index, thermal conductivity and effusivity, and moisture management capacity. Results suggest that moisture transfer is affected by thickness, density and moisture regain whereas thermal transfer by air permeability and density.

1. INTRODUCTION

The understanding of heat and moisture transfers through clothing is a major concern for engineering and scientific researchers, designers, developers, and manufacturers. A lot of scientific papers deal with this topic. The garment is defined as a barrier for heat and vapor transport between the skin and the environment. It is composed of fibers materials, air enclosed between skin and garment, and still air bounded to the outer surface of it [1].

Considering sedentary activities, transport of water into fabric is governed by different mechanisms, i.e.: evaporation, sorption, desorption, diffusion, condensation [2-4]. For the transport of heat transfer through textile it can be considered others phenomenon such conduction, convection and radiation [2, 5].

Heat and moisture transfers influence the comfort of the wearer. The comfort can be defined as a pleasant state of physiological, psychological, and physical harmony between a human and its environment. It depends of the activity of the wearer, the type of clothing, the climatic environment (humidity, temperature, and wind velocity) and the sensibility of each subject.

Beside, different clothing properties affect also the thermal comfort like the design of fabric with its structure, fibers composition, porosity, i.e. The goal of this study is to analyze the influence of these factors on comfort.

2. METHODS AND MATERIALS

Fabrics tested are underwear composed of fibers sensible of moisture. The table 1 gives information about these samples. Fabric weight was calculated according to ISO 12127 and fabric thickness with ISO 5084 at a pressure of 0.1 kPa. Air permeability is determined with FX3300 Textest device

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according to ISO 9237 and it corresponds to an air flow passing perpendicularly through the fabric under a pressure of 196 Pa. Hot Disk device let us measuring thermal conductivity and diffusivity of fabrics according to ISO 22007-2. Thermal resistance (R_{ct}) and water-vapour resistance (R_{et}) are measured thanks to a sweating guarded hot plate under conditions indicated in ISO 11092.

The determination of Overall Moisture Management Capacity (OMMC) of fabrics is evaluated by a Moisture Management Tester (MMT) from Atlas.

Table 1. Description of test sample.

Sample code	Fabric design	Fabric weight (g/m²)	Thickness (mm)	Density (g/cm³)	Relative porosity (%)	Moisture regain	Rct (m².K/W)	Thermal conductivity λ (W/m.K)	Thermal effusivity (mm²/s)	Air permeability (l/m²/s)	Ret (m².Pa/W)	Imt	OMMC
A	1×1 interlock	215.2 ± 2.4	1.31 ± 0.03	1.335	87.7 ± 2.9	1.75	0.0315	0,086 ± 0.002	0.348 ± 0.008	1740 ± 14	4.47	0.42	0.204 ± 0,019
B	1x1 interlock	155.8 ± 4.5	1.22 ± 0.08	1.2045	89.4 ± 8.5	5.18	0,039	0,083 ± 0.001	0.357 ± 0.050	2100 ± 29	3.87	0.60	0.325 ± 0,017
C	1x1 interlock	156.6 ± 2.3	1.096 ± 0.06	1.2386	88.5 ± 6.1	3.36	0,035	0,085 ± 0.004	0.344 ± 0.044	2107 ± 45	3.85	0.55	0.386 ± 0,020
D	1x1 interlock	177.0 ± 3.4	1.026 ± 0.05	1.5	88.5 ± 6.0	8.5	0,023	0,139 ± 0.005	0.410 ± 0.029	1477 ± 28	2.83	0.49	0.633 ± 0,027

3. RESULTS AND DISCUSSION

Pearson's equation let us to determine the contribution of textile properties on the heat and moisture transfer through materials (table 2).

Table 2. Pearson's coefficient of textile properties.

Textile properties	R_{ct}	Thermal conductivity	Thermal effusivity	R_{et}	I_{mt}	OMMC
Fabric weight	-0.401	0.054	-0.020	0.404	**-0.929**	-0.375
Thickness	0.520	-0.711	-0.660	**0.900**	-0.236	**-0.935**
Porosity	0.449	-0.041	0.128	-0.350	**0.944**	0.260
Moisture regain	-0.564	0.855	**0.922**	**-0.963**	0.251	**0.921**
Air permeability	**0.950**	-0.845	-0.794	0.513	0.709	-0.528
Density	**-0.990**	**0.924**	0.859	-0.654	-0.618	0.680

3.1 Influence of fabric design

Thermal resistance is representative of heat insulation and it is calculated with the equation (1) from Skin Model measurement.

$$R_{ct} = \frac{(T_m - T_a);A}{H - \Delta H_c} - R_{ct0} \qquad (1)$$

With, R_{ct} the thermal resistance (m².K/W), T_m the temperature of the measuring unit (K), T_a the air temperature in the test enclosure (K), A the area of the measuring unit (m^2), H the heating power supplied to the measuring unit (W), while ΔH_c is the correction term for heating power (W), and R_{ct0} (m^2.K/W) is the apparatus constant determined as the « bare plate » value (m².Pa/W).

Also, the water vapour resistance is calculated according to ISO 11092 by the equation (2).

$$R_{et} = \frac{(P_m - P_a);A}{H - \Delta H_e} - R_{et0} \qquad (2)$$

With, R_{et} the water vapour resistance (m².Pa/W), P_m the water vapour partial pressure (Pa) at the surface of the measuring unit at temperature T_m, P_a the saturation water vapour pressure (Pa) of the air in the test enclosure at temperature T_a, A the area of the measuring unit (m^2), H the heating power supplied to the measuring unit (W), while ΔH_e is the correction term for heating power (W), and R_{et0} (m^2.Pa/W) is the apparatus constant determined as the « bare plate » value (m².Pa/W).

According to table 2, thermal resistance is affected by air permeability and density of fabrics. The density of fibers increases whereas the thermal resistance decreases and it is the opposite tendency between thermal resistance and air permeability. Thermal conductivity which is strongly related to thermal resistance is dependent of the clothing structure and more specifically of fiber density. Besides, water vapour is linked with the thickness and the moisture regain of materials.

Water vapour permeability index (I_{mt}) gives information about the breathability of fabrics; this parameter is calculated from thermal and water vapor resistance by equation (3). It varied between 0 (impermeable fabric) and 1 (permeable fabric).

$$I_{mt} = 60\times\frac{R_{ct}}{R_{et}} \qquad (3)$$

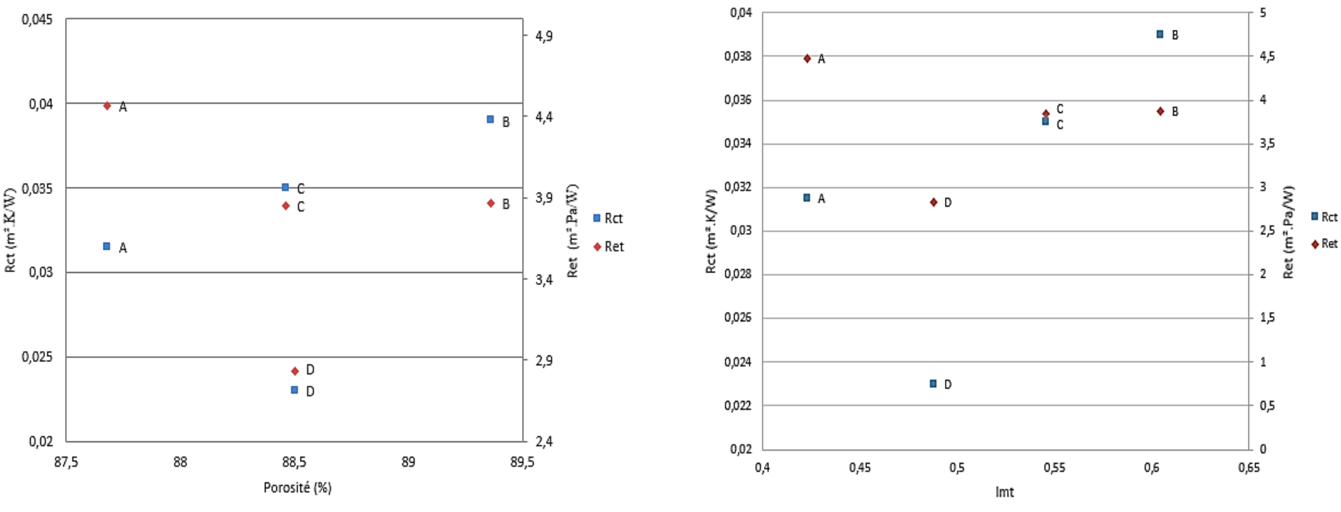
With, I_{mt} the water vapour permeability index (dimensionless), R_{ct} the thermal resistance (m².K/W), R_{et} the water vapour resistance (m².Pa/W).

I_{mt} is influenced by fabric structure like fabric weight and porosity defined in equation (4).

$$P = (1-\frac{m}{\rho\times e}) \qquad (4)$$

With P the relative porosity (%), m the fabric weight (g/m²), ρ the fiber density (g/m³), and e the fabric thickness (m).

Dependency of thermal and water vapour resistance to porosity and I_{mt} is evaluated by the Figure 1. A fabric provides an optimal comfort when $I_{mt} \approx 0.3$ [6]. For fabrics studied, any sample shows this value. Indeed, the sample A has the slowest value of I_{mt} equal to 0.42 (Figure 1.b).



(a) (b)

Figure 1. (a) R_{ct} and R_{et} vs. porosity, (b) R_{ct} and R_{et} vs. I_{mt}.

Sample B has the highest value of R_{ct} and porosity (Figure 1.a), and the sample A, the highest value of R_{et} with the lowest porosity. On the contrary, the fabric D shows lowest values of R_{et} and R_{ct} for middle porosity. In the Figure 1.b, R_{ct} increases with the rise of I_{mt} and the R_{et} decreases for low value of I_{mt}.

3.2 Thermophysiological properties

Thermal effusivity, correlated to thermal conductivity by equation (5), is also named the first thermal contact feeling. The main factor explaining variations of thermal effusivity is the moisture regain according to table 2. The warmer feeling is obtained with a low value of thermal effusivity, and the coolest feeling with high moisture regain [7].

$$b=\sqrt{\lambda.\rho.C_p} \qquad (5)$$

With, b the thermal effusivity (mm²/s), ρ the density (g/cm³), C_p the specific heat capacity (J/kg/K), and λ the thermal conductivity (W/m.K).

In general (Figure 2), fabrics presented low moisture regain and low thermal effusivity, provide a warmer feeling like sample A and C. In contrary, the fabric D has the highest moisture regain and thermal effusivity, so it gives a cooler feeling. With weak porosity, thermal diffusivity decreases, and with high porosity, its evolution is inverted.

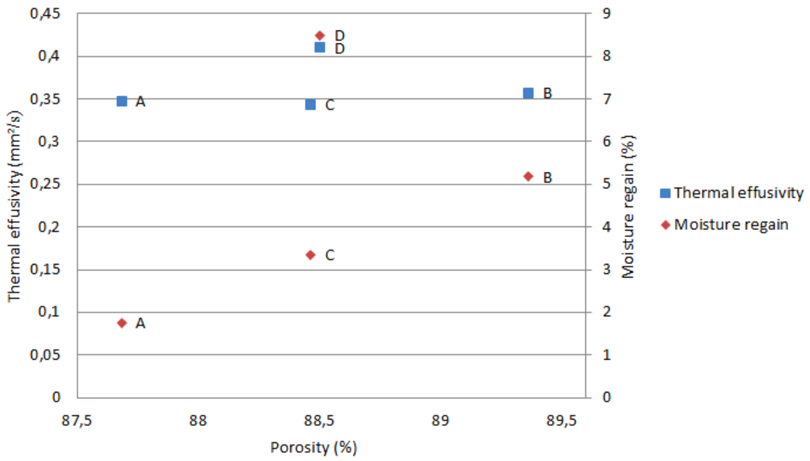


Figure 2. Thermal effusivity and moisture regain vs. porosity.

3.3 Mass transfer and moisture management properties

The Overall Moisture Management Capacity (OMMC) index indicates the capacity of fabrics to manage the transport of liquid moisture. The table 3 summarizes index numbers obtained with the MMT device.

Table 3: Index numbers of fabrics moisture management properties.

Sample ode	WT_{Top} (s)	WT_{Bottom} (s)	AR_{Top} (%/s)	AR_{Bottom} (%/s)	MWR_{Top} (mm)	MWR_{Bottom} (mm)	SS_{Top} (mm/s)	SS_{Bottom} (mm/s)	R (%)	OMMC
A	3	3	4	4	3	2.5	2.5	2	1	2
B	3	3	3.5	4	4.5	4.5	2.5	3	2.5	2.5
C	4	4	4	4	5	5	4	4	2	2.5
D	3	3	3.5	3.5	2.5	2.5	2	2	5	4

Fabric D shows the highest liquid overall moisture management capacity (index of 4) and one-way transport capability (R). So, the sweat at the skin surface can be easily removed and quickly transferred to the outer surface of the fabric. Besides, the spreading rates (SS) and wetted radii index (MWR) are low, in this case, the liquid pass through the fabric without wetting it.

In contrary, the sample A has the lowest OMMC. The one-way transport capability of this fabric is the smallest; the sweat cannot carry away from the skin to the upper surface easily. Besides, the wetting time (WT) and the absorption rate (AR) are significant, so this fabric dries slowly (R low) and absorbs a high quantity of water.

The spreading rates, wetted radii, absorption rate, and wetting time of sample C are the most important. In contrary the one-way transport capability index is low. This fabric absorbs quickly the water and dries slowly.

The sample B shows an intermediate behavior compare to others fabric, its OMMC is good (index of 2.5).

According to table 2 and figure 3, the moisture regain and thickness of fabric influence this parameter. When the OMMC increases, the moisture regain follows the same tendency and the thickness decreases.

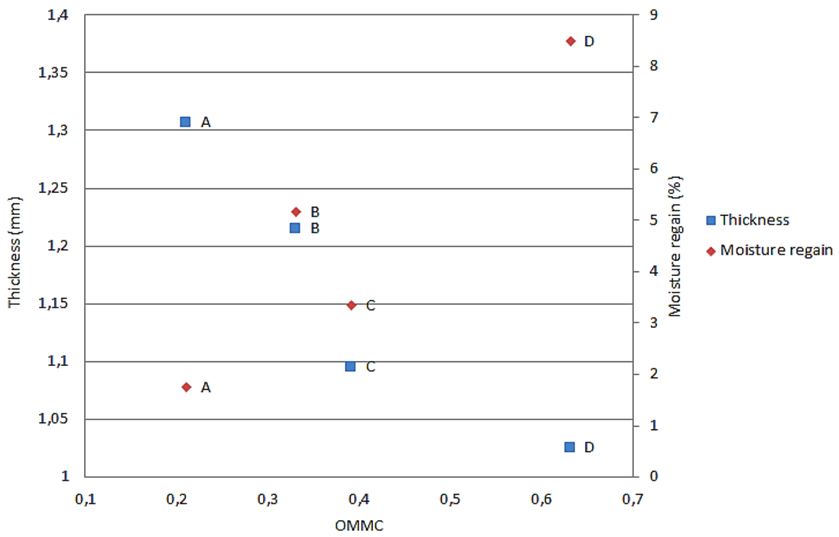


Figure 3. Thickness and moisture regain vs. OMMC.

CONCLUSION

The purpose of this study was to determine the relationship between textile properties and thermal comfort of four underwear fabrics. It was found that moisture transfer through textiles was mainly affected by thickness, density and moisture regain whereas thermal transfer by air permeability and density.

Sample D presents the highest moisture management capability with a thin material composed of hygroscopic fibers, low water vapour permeability index (I_{mt}) and a cooler feeling.

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