34th INTERNATIONAL COTTON CONFERENCE
21-23 March 2018, Bremen (Germany)

Comparative analysis of biophysical fabric properties in aspect of their use in the reference clothing for comfort testing

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Currently used methods of ergonomic assessment of protective clothing depend on the subjective feeling of research participants and don't take into consideration all aspects of its use. Therefore, more and more work is undertaken towards the development of new research tools for the ergonomic assessment of protective clothing. Research was carried out also at the Central Institute for Labour Protection - National Research Institute. A new methodology will take into consideration a variant of reference clothing, which is related to the results of ergonomics research of protective clothing. Preparation of the reference clothing initiated by picking the appropriate fabric is based on the results of parameters influencing the physiological and sensorial comfort. In the current part there are presented results of different fabric parameters, which are related to physiological comfort, i.e., the thermal resistance, water vapor resistance, hygroscopicity and air permeability.

The aim of this work was to study the influence of constituent fiber content and fabric structure parameters on their biophysical properties and selecting the fabric ensuring the highest level of physiological comfort.

Materials and methods

The material selection criterion was the low mass per square meter and appropriate raw materials, i.e., the contents of both the hydrophilic (cotton or viscose) and hydrophobic fiber (polyester). Both kinds of fiber can provide satisfactory biophysical and biomechanical properties.

Table. 1. Fabric characteristics

Symbol	Raw materials	Linear density [tex]		Weave	Number of threads per 1 dm [dm^{-1}]		Mass per square meter [g/m^2]	Thickness [mm]
		warp	weft		warp	weft		
A	Tencel 30% PES 70%	32.0±0.56	29.2±0.63	twill 2/1 S	389±1.30	241±0.84	196.9±1.51	0.29±0.005
B	cotton 65% PES 35%	28.3±0.72	27.4±0.77	twill 2/1 S	370±1.67	238±0.71	190.0±1.24	0.38±0.007
C	cotton 50% PES 50%	20.8±0.66	19.5±0.59	satin 4/1(2)	545±1.64	325±1.34	184.9±0.93	0.36±0.005
D	cotton 35% PES 65%	31.1±0.65	32.1±0.65	twill 2/1 S	382±1.73	244±1.48	212.7±0.56	0.37±0.000
E	cotton 35% PES 65%	29.8±0.52	30.0±0.67	twill 2/1 S	401±1.10	237±1.67	207.4±0.72	0.40±0.0005
F	cotton 85% PES 15%	19.6±0.61	18.6±0.65	reinforced twill 2/2 S	572±2.05	320±1.48	196.6±1.69	0.38±0.003
G	cotton 35% PES 65%	18.4±0.45	24.1±0.58	twill 2/1 S	521±1.41	238±1.87	176.4±0.54	0.35±0.000

The selected fabrics were tested in terms of following parameters related to physiological comfort: thermal resistance, water vapor resistance, hygroscopicity and air permeability. Research was carried out in CIOP-PIB according to the methods described in the appropriate standards (Table 2).

The measurements of thermal resistance and water vapor resistance were performed on the selected fabric samples with the use of 'skin model'; whereas the measurements of fabric air permeability were carried out on the air-permeability instrument at the pressure difference of 100 Pa between the inner and outer side of the fabric.

Table 2. Methodology of fabric measurements

Parameter	Unit	Test method
Thermal resistance	m^2·K/W	EN ISO 11092:2014
Water vapor resistance	m^2·Pa/W	EN ISO 11092:2014
Hygroscopicity	%	PN-P-04635:1980
Air permeability	mm/s	EN ISO 9237:1995

Results and discussion

Results of measurement of individual fabrics are presented graphically in the bar graphs (Figures 2 - 3).

Thermal resistance

In the case of reference clothing there will be more advantageous, if it is made of fabric with the lower thermal resistance, which is tantamount to a greater ability to heat exchange between the human body, clothing and environment.

The fabric G indicated the lowest value of thermal resistance, which is understandable, because this fabric is characterized by the lowest mass per square meter and relatively small thickness. Comparing the value of thermal resistance of fabrics with the identical raw materials (fabrics D, E and G), it is clear that this parameter increases with the increase of mass per square meter. A high content of polyester fibers in relation to the cotton fibers certainly influenced the low value of thermal resistance of fabric G. It is known from the literature that the polyester fibers indicate much lower thermal insulation than the cotton fibers.

The impact of raw materials on the value of fabric thermal resistance can be seen, especially in the case of fabrics B and E with the identical weave, but extremely different content of cotton and polyester fibers. The fabric B with the higher content of cotton fibers indicates the higher thermal resistance (Fig. 2a).

Aside from the fabric G, the fabric F is also characterized by the low value of thermal resistance, despite the high content of cotton fibers. It can result from the kind of weave, because this fabric has a reinforced twill weave, which is characterized by the smaller number of interlaces than the twill weave used in the case of other fabrics (exception - fabric C). In turn, the smaller number of interlaces in the fabric influences the higher ability to heat exchange.

Fig. 1. The reference clothing

Water vapor resistance

The low value of water vapor resistance decide about a high level of physiological comfort. Conducted research indicated that the lowest value of water vapor resistance showed the fabric G (Fig. 2b). Low value of this parameter (except the low mass per square meter and small thickness) can be influenced by the appropriate raw materials. The best effect was reached for cotton/polyester fabrics with the highest content of polyester fibers. Polyester fibers as the hydrophobic ones practically do not absorb moisture, but there are able to transmit it by the diffusion to hydrophilic fibers, so that the moisture is drained from the skin surface, giving the user the feeling of comfort.

Moreover, in Fig. 2b we can see that the water vapor resistance of viscose/polyester fabric A is significantly higher in comparison to other fabrics made on the basis of cotton and polyester fibers. The cotton/polyester fabric D with a similar content of polyester fibers as the fabric A, identical weave and similar warp and weft densities exhibits more than twice less the water vapor resistance than the viscose/polyester fabric A. Therefore, the decisive influence on the value of R_{et} has a kind of hydrophilic fibers.

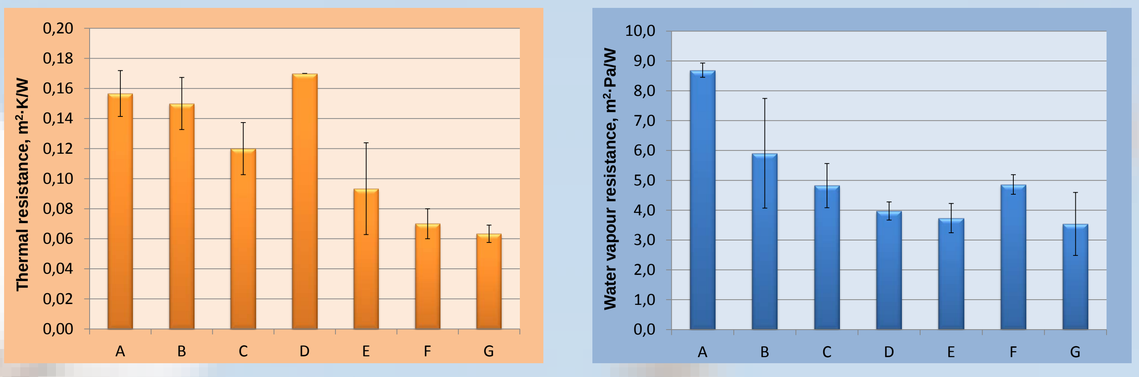

Fig. 2. Comparison of: a) thermal resistance, b) water vapor resistance of examined fabrics

The classification of clothing materials in terms of water vapor resistance was proposed by the Hohenstein Institute, a leading German research institute.

- $R_{et} \leq 5$ m^{2}Pa/W (materials with a very good water vapor resistance),
- 5 m^{2}Pa/W < $R_{et} \leq 20$ m^{2}Pa/W (materials with a good water vapor resistance),
- 20 m^{2}Pa/W < $R_{et} \leq 35$ m^{2}Pa/W (materials with an acceptable water vapor resistance),
- $R_{et} > 35$ m^{2}Pa/W (materials with an insufficient water vapor resistance).

It can be concluded that all fabrics, except the fabrics A and B, meet the requirements for materials with the very good water vapor resistance. Fabrics A and B may be put in the category of materials with the good water vapor resistance.

Hygroscopicity

Research has shown that the cotton/polyester fabric B was characterized by the highest hygroscopicity (Fig. 3a). This is mainly due to the high content of cotton fibers. The fabric F has somewhat less hygroscopicity than the fabric B despite the higher content of hydrophilic fibers able to absorb moisture. This is probably due to the significantly higher warp density in the structure of fabric F, which directly affects the decrease of fabric porosity and thereby, the limitation of the ability to absorb moisture.

High hygroscopicity is also exhibited by the polyester/viscose fabric A, mainly due to the content of viscose fibers (Tencel), which are known as highly absorbent fibers. In spite of the high hygroscopicity, this fabric exhibits the very low water vapor resistance compared with the other fabrics. In turn, the fabric G has both the high capacity to absorb moisture (the hygroscopicity less only approximately 1% of hygroscopicity of fabric B) and very low water vapor resistance, which in fact allows for evaporation of secreted sweat.

Air permeability

Research showed that the highest value of air permeability has the fabric G (Fig. 3b). High value of the air permeability of this fabric was undoubtedly due to its small thickness. In addition, this fabric has the smallest mass per square meter and it is characterized by the relatively small weft density (Table 1). Although the warp yarn relatively numerous occur in the fabric, their linear density is significantly less than the linear density of warp in other fabrics. These factors cause that in the structure of fabric G there are pores determining its high air permeability.

The air permeability of other fabrics is in the wide range of 60.1 to 158.5 mm/s. The lowest value of less than 70 mm/s was achieved for the fabrics D and E, which were characterized by the highest mass per square meter of all the tested fabrics.

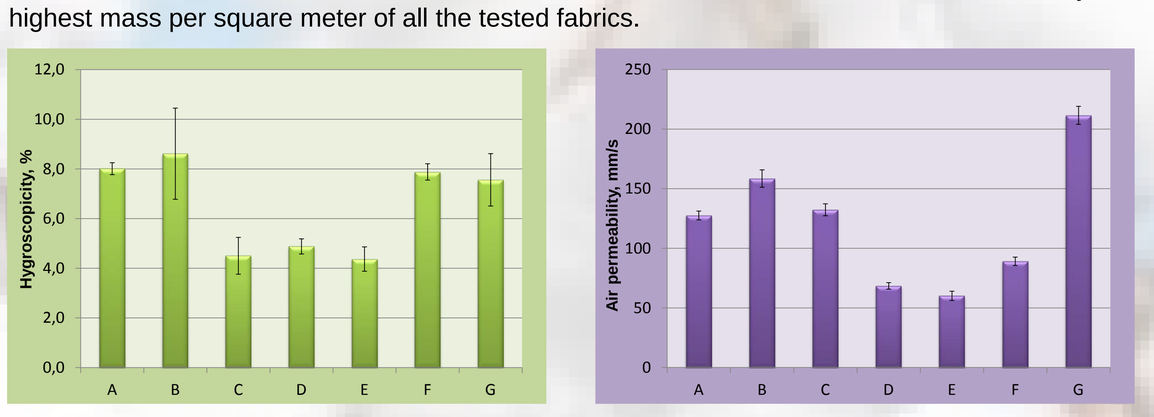

Fig. 3. Comparison of: a) hygroscopicity b) air permeability of examined fabrics

Conclusions

Performing the selection of fabric to the reference clothing there was a need to analyze the impact of various fabric parameters on the user's physiological comfort.

Research showed that the fabric G is the best in terms of the thermal resistance. This is mainly due to its low mass per square meter and relatively small thickness. The low value of thermal resistance of this fabric also results from the highest content of polyester fibers, which are known as fibers with the low thermal insulation. The fabric G is characterized also by the lowest water vapor resistance. According to the classification proposed by the Hohenstein Institute the fabric G can be classified as the fabric of very good water vapor resistance. In terms of hygroscopicity fabrics A, B and F were better than the fabric G, what may be due to the high content of Tencel fibres or cotton fibers having a big ability to absorb moisture. However, the highest air permeability at the level more than 200 mm/s is guaranteed by the fabric G. The high value of this parameter results from the high porosity of this fabric. Thus, the analysis of biophysical parameters of fabrics shows that the highest level of physiological comfort of fabric G was made by the following raw materials: 35% cotton/ 65% PES.

The poster is based on the results of Phase III of the National Programme "Safety and working conditions improvement", funded in the years 2014-2016 in the area of tasks related to services for the State by the Ministry of Family, Labour and Social Policy (The Programme coordinator: Central Institute for Labour Protection – National Research Institute).