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COMPLEX CHARACTERIZATION OF COTTON FABRIC THERMO PHYSIOLOGICAL COMFORT

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ABSTRACT

The main aim of this paper is evaluation of physiological Index of Comfort IC as a complex combination of individual fabrics properties connected with physiological comfort. The influence of the cotton fabrics structure on the selected parameters characterizing the physiological comfort of fabrics is investigated as well. The structural parameters of woven fabrics are collected into total volume porosity. Measurements of the thermal insulation parameters are performed by the sweating guarded hotplate test. Assessment of the air permeability is performed according to the procedure described in standard. The correlations between total volume porosity and above mentioned properties influencing the physiological comfort are investigated.

INTRODUCTION

Nowadays people are more and more interested in clothing assuring the physiological comfort. Physiological comfort is strongly connected with the thermal comfort, which is defined as a state of satisfaction with the thermal conditions of environment. Thermal comfort can be defined as “that condition of mind which expresses satisfaction with the thermal environment” [1]. The reference to “mind” indicates that it is essentially a subjective term however there has been extensive research in this area and a number of indices exist, which can be used to assess environments for thermal comfort [2]. Fanger [3] suggested three conditions for comfort. These are: heat balance of body as well as the proper mean skin temperature and sweat rate within limits required for comfort. The influence of the clothing on the heat and moisture exchange between the human being and surroundings is very complicated. It depends on many factors connected with environment, i.e. air temperature, air movement and humidity. No less important role is played by the raw material as well as the micro- and macrostructure of clothing [4].There is a lot of fabrics’ properties which influence the physiological comfort. Thermal insulation properties, air permeability and water-vapour resistivity are considered as the most important parameters.

The aim of the presented work is to describe the procedure for evaluation physiological Index of Comfort IC as a complex combination of individual fabrics properties connected with physiological comfort. This procedure is connected with so called utility value concept [8]. The influence of the cotton fabrics structure on the parameters characterizing the physiological comfort of fabrics is investigated as well.

NOMENCLATURE

RT	[$m^2 K W^{-1}$]	thermal resistivity
TC	[$Wm^{-1}K^{-1}$]	thermal conductivity
RE	[$Pa\ m^2W^{-1}$]	vapour transport resistivity
AP	[l/m^2s]	air permeability
AM	[$g\ m^{-2}$]	areal mass
IC	[-]	Physiological Index of Comfort
u	[-]	partial comfort function
PO	[-]	volume porosity
Ty	[tex]	yarn fineness
TH	[mm]	fabric thickness

Special characters

ρ_f	[kgm^{-3}]	fibre density

Subscripts

j	index of characteristic R
i	index of variant V

INDEX OF COMFORT

Thermal comfort is generally connected with sensations of hot, cold dry cold or dampness in clothes and is usually associated with environmental factors, such as moisture transport, thermal conductivity and air permeability. Problem is how to create complex criterion as proper combination of these or other measurable characteristics.

One of the first attempts was introduction of special units ***clo*** or ***tog*** dealing with thermal comfort characterised by thermal resistivity RT [m^2 K W^{-1}] or value of thermal conductivity TC [$Wm^{-1}K^{-1}$]

$$RT = \frac{TH}{TC} \quad (1)$$

where TH is fabric thickness. Prediction of the thermal conductivity of fibrous structures is therefore important for the purposes designing of new fabrics and prediction of their ability to provide thermal comfort.

There exists a variety of models for prediction of thermal conductivity of multiphase materials which can be used for prediction of textile fabrics thermal conductivity. Militky [13] used the plain weave cell model for computation of volume porosity and then various two phase models for prediction of cotton type fabrics thermal conductivity. The best according to the experimental data was simple linear mixture model corresponding to the parallel arrangements of phases.

The ***clo*** and ***tog*** *are* measure of thermal resistivity and includes the insulation provided by any layer of trapped air between skin and clothing and insulation of clothing itself. One ***tog*** is equal to 0.1 m^2 K W^{-1} and ***clo*** is equal to 1.55****tog***. One ***clo*** corresponds to intrinsic insulation of business suit worn by sedentary resting male in a normally ventilated room at 21^{o}C and 50 % RH and air ventilation of 0.1 m/s. In these conditions are man feelings as quite comfortable. For winter clothes is suitable ***clo*** around 0.8 and for summer conditions is ***clo*** around 0.5 (generally, lower RT leads to state to be more cool).

The important parameter connected with thermo physiological comfort is so called vapour transport resistivity RE [Pa m^2W^{-1}]. It was evaluated that water vapour resistivity < 13 m^2Pa/W corresponds to good comfort [10]. The wear comfort vote for normal wear situation WC_T (the best is WC_T = 6) is defined as: WC_T = 57.6*RE [11]. The so called moisture permeability index IM combines both vapour and thermal resistivity: IM=66.6*RT/RE. These and other indices are oversimplified, contain dimensional constants and are not reflecting the transform of measurements to the psycho physical scale.

The proposed physiological Index of Comfort IC is complex criterion closely related to the well known problem of complex evaluation of variants [9]. For complex evaluation of variants, the **X** matrix of the (n x m) is available containing for individual V_1,.....V_n variants - here fabrics (**X** matrix rows) the values of selected R_1,.......R_m characteristics - here comfort characteristics (**X** matrix columns). The x_{ij} element of the matrix thus expresses the value of the j - th characteristic of R_j for the i - th variant of V_i. The aim is to sort individual variants in the order of their importance. In economics several different methods are used in this field and most of them are based on preferential relations [9]. A special technique is the so called "useful effect method" or "base variant method". Base variant practically represents an ideal state where individual characteristics get optimum values. By means of o_j (j = 1,...m) values for individual characteristics of a base variant, dimensionless standard quantities u_{ij} are calculated. If the increase of the R_j characteristic is accompanied by the increase of comfort, the standard quantities are calculated according to the relation

$$u_{ij} = \min(\frac{x_{ij}}{o_j}, 1) \quad (2)$$

In opposite case, the dividend and the divisor are interchanged. The complex criterion of usefulness U(R) = U(u) is then aggregating function i.e. suitable weighted average. Modification of this approach for expressing of textiles quality is shown in the work of Militký [8]. Generally a question may arise whether a suitable aggregating function really exists [9].

The procedure for evaluation physiological Index of Comfort IC starts with specification of K properties R_1 ,...,R_K characterizing comfort (e.g. thermal resistivity, water vapour resistivity, areal weight). Based on the direct or indirect measurements it is possible to obtain some comfort characteristics x_1 ,...,x_K (mean value, variance, quantiles etc.). These characteristics represent comfort properties. Functional transformation of these characteristics (based often on the psycho physical laws) lead to partial comfort functions

$$u_i = f(x_i, L, H) \quad (3)$$

where L is value of characteristic for just non acceptable value (smallest u_i usually = 0) and H is value of characteristic for just fully acceptable product (u_i equal to highest value = 1). Physiological Index of Comfort IC is weighted average of u_i with weights b_i

$$IC = ave(u_i, b_i) \quad (4)$$

Weight b_i corresponds to the importance of given comfort property. The weighted geometric mean used as average has following advantages:

- For zero value of u_i is also IC = 0. This means that non acceptable comfort property cannot be replaced by combinations of other comfort properties.

- Geometric mean is for not constant u_i always lower that arithmetic mean. This reflects evaluation based on the concept that the values of comfort properties close to unsatisfactory fabric are more important for expressing the IC than those close to optimum fabric.

For the case oft thermo physical comfort are selected properties and weights extracted from properties characterizing utility value of clothing collected in [12] see Table 1).

Table 1: Selected comfort properties for summer dress having direct contact with body

Property	a	b	c	d	y_a	y_d	b_i
Air permeability AP	100	400	600	1000	0.01	0.6	0.304
Areal mass AM	40	80	120	170	0.4	0.08	0.377
1/RT	12	18	20	24	0.08	0.80	0.319

The partial comfort functions $u(x_i)$ are in fact psycho physical variable expressing the sensation (V) of comfort connected with stimulus (S) i.e. measured characteristic of comfort properties.

Schematic representation of transformation of measurements to partial comfort functions is shown in the Figure 1.

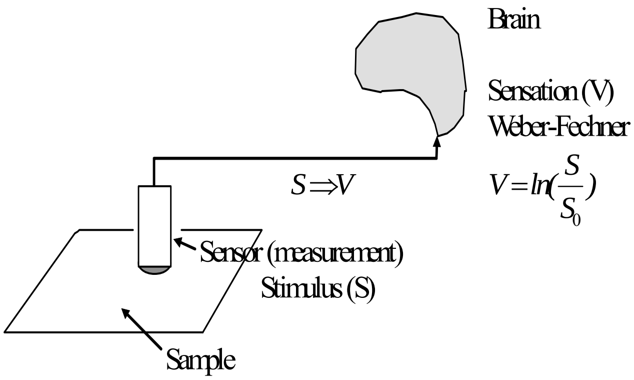


Figure 1: Transformation to the psychophysical scale, S_0 is threshold value (sensitivity limit)

The nonlinear transformation to partial comfort functions for cardinal utility values is given in the work [8]. For practical expression of IC it is sufficient to replace standardization and nonlinear transformation to the partial comfort functions by the piecewise linear transformation.

For one side bounded properties the partial comfort function is monotone increasing or decreasing function of quality characteristic x The piecewise linear transformation of partial comfort function is here composed from three pieces (two are constant and the linearly increasing or decreasing dependence is placed between them).

For two side bounded comfort properties is partial comfort function monotone decreasing on both sides from optimal (constant) region and the piecewise linear transformation has form shown in the Figure 2.

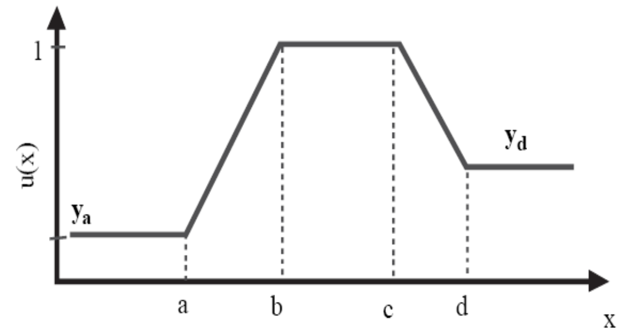


Figure 2: Transformation into to partial comfort functions

The parameters a, b, c, d,. y_a and y_d for the case of summer dress having direct contact with body are given in the Table 1.

Physiological Index of Comfort IC is then weighted geometrical average simply calculated from the relation

$$IC = \exp\left(\sum_{j=1}^{K} b_j * \ln(u_j)\right) \quad (5)$$

When forming the aggregating function IC from experimentally determined values of individual comfort properties, the statistical character of the x_j quantities can be considered and the corresponding variance D(IC) can be determined as well [8].

PROGRAM PIC

Program PIC written in MATLAB is based on the above-proposed procedure. The Bootstrap type technique described in [10] has been applied for computation of the statistical characteristics of Physiological Index of Comfort IC. This technique is based on the assumption that for each property Rj characterizing comfort the mean value $\overline{x}_j$ and variance s_j^2 are determined by standard treatment of the measured data. The procedure of the statistical characteristics of Physiological Index of Comfort IC estimation is divided to the following parts:

I. Generation of $x(k)_j$ (j=1,.....m) values having normal distribution with mean values $\overline{x}_j$ and variances s_j^2

II. Calculation of the Physiological Index of Comfort IC(k) using the relation (5).

III. The steps I and II are repeated for k=1,.....n (usually n=600 is chosen).

IV. Construction of a histogram from the values IC(k) (k=1,.....n) and computation of the estimators of mean value E(IC), variance D(IC), skewness and kurtosis.

EXPERIMENTAL PART

The 14 different kinds of the cotton fabrics for the summer clothing were investigated. There were the plain woven fabrics made on the basis of the same warp: cotton combed yarn of the linear density 15 tex. All fabrics were produced at the same nominal warp sett - 270/dm and at the same nominal weft sett - 145/dm. Differentiation of the fabric structure was achieved by the application of the different weft yarns fineness Ty = 20 tex, 25 tex, 30 tex, 40 tex, 50 tex and 60 tex. Moreover, for fabric production the carded and combed cotton yarns were used as a weft. All fabrics were finished by the same classic - starch finishing. As characteristics of fabric structural parameters connected with transport comfort properties the total volume porosity PO was computed. This porosity is defined by relation

$$PO = \frac{volume\ of\ air\ spaces}{total\ fabric\ volume} = 1 - \frac{AM}{TH * \rho_f} \qquad (6)$$

where AM is areal mass, TH is fabric thickness and ρ_f is cotton fibre density (1560 kgm^{-3}).

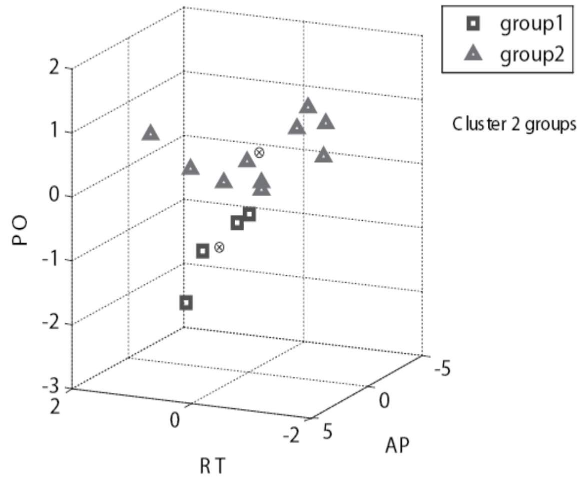
The thermal resistivity of fabrics was measured by means of the sweating guarded hotplate test according to Polish Standard PE-EN 31092.As a measure of air permeability the volume of the air transferred from the fabric area unit in the time unit at the constant pressure difference was assessed. Measurement was done according to Polish Standard PN-EN ISO 9237:1998.

The results of measurement and PO are given in the Table 2. Relative errors of RT and AP measurement were under 10 %.

Table 2: Basic parameters and thermal properties of the woven fabrics

No	**Fabric thickness TH** [mm]	**Areal mass** [gm^{-2}]	**Thermal resistivity RT** [m^2KW^{-1}]	**Air permeability AP** [$dm^3m^{-2}s^{-1}$]
1.	0.319	76.4	0.180	958.9
2.	0.295	68.9	0.180	1213.6
3.	0.314	77.6	0.175	1081.3
4.	0.301	68.3	0.180	1323.7
5.	0.421	132.3	0.185	376.5
6.	0.360	99.2	0.185	733.4
7.	0.359	100.3	0.187	709.7
8.	0.391	113.3	0.185	828.1
9.	0.335	86.8	0.178	1075.8
10.	0.333	84.4	0.175	958.9
11.	0.339	89.1	0.174	1009.0
12.	0.334	85.9	0.168	1091.1
13.	0.329	85.8	0.169	1088.3
14.	0.354	87.4	0.173	1047.9

The set of prepared fabrics was analyzed by multivariate statistical methods for evaluation of potential sources of heterogeneity (clusters and outliers). The variables form table 2 were used for investigation. The cluster analysis and profiles plot were selected. Detailed description of these techniques is given in the book [6]. Results are presented in the Figures 3 and 4.



a.

Figure 3: Check of prepared fabrics: -. Cluster analysis

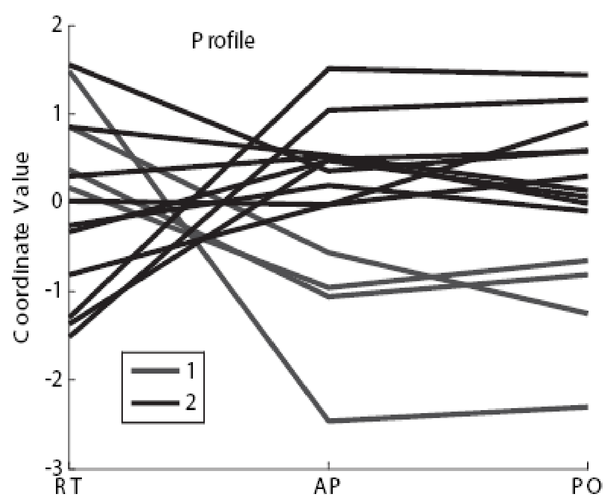


Figure 4: Check of prepared fabrics: -. Profiles plot

It is visible that the fabrics are separated into two categories mainly due to air permeability and close connected volume porosity. Both these differences are connected with variation of weft yarn fineness.

RESULTS AND DISCUSSION

The correlation map for RT, AP and PO is given on the figure 6. The paired correlation coefficients are given in the individual cells. The strong correlation between AP and PO is visible from the scatter graphs on the figure 5 as well. Detailed description of these techniques is given in the book [6].The correlation between RT and PO is not so strong but still significant. This result is in accordance with air permeability analysis published in [7].

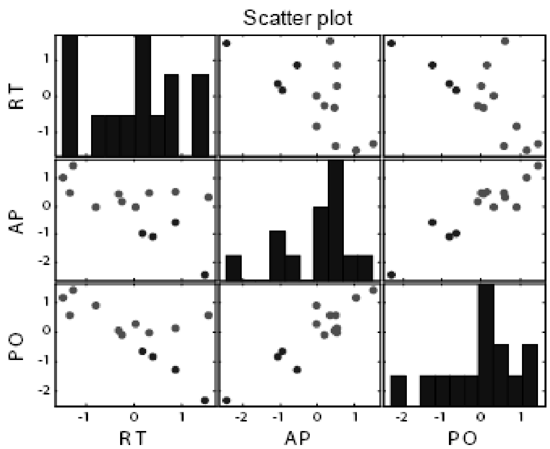


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Figure 5: Scatter plots for thermal resistivity RT air permeability AP and volume porosity PO.

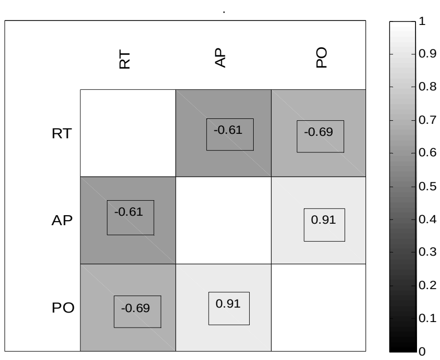

Figure 6: Correlation map for thermal resistivity RT air permeability AP and volume porosity PO

The results of linear regression of thermal resistivity RT on the volume porosity PO is given on the figure 7 results of regression for air permeability AP on the volume porosity PO is given on the Figure 8.

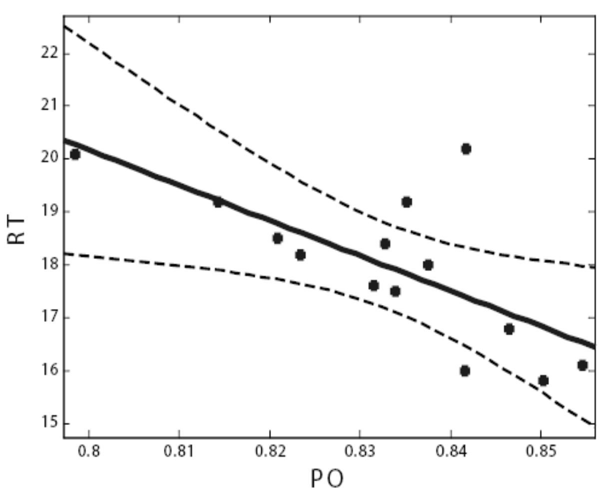

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Figure 7: Dependence of thermal resistivity RT on volume porosity PO:

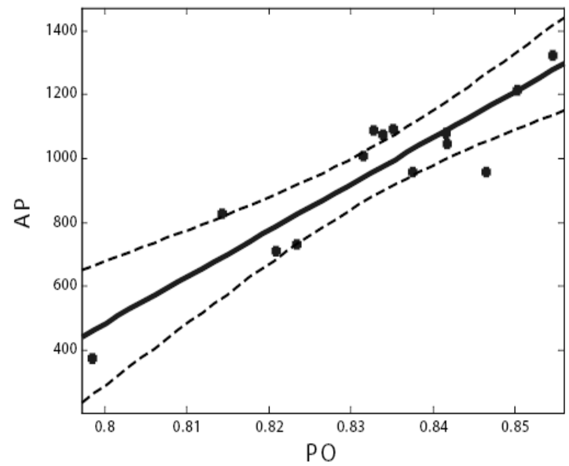

Figure 8: Dependence of air permeability AP on volume porosity PO

The physiological Index of Comfort IC was computed from eqn. (5) with parameters given in the Table 1. The results are shown in the Figure 9 as dependence of IC on the volume porosity PO.

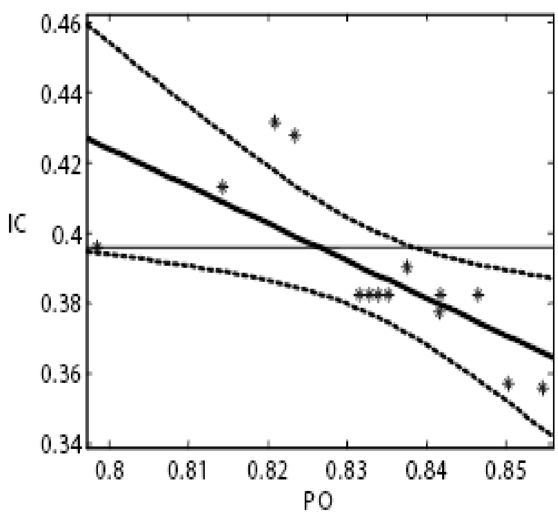

Figure 9: Dependence of physiological Index of Comfort IC on volume porosity PO

It is visible that the differences between individual fabrics physiological Index of Comfort are not very high due to selection of individual limits given in the Table 1. These constants are based on the inspection of fabrics having wide variation of construction, composition and therefore comfort properties.

The selected fabrics are from this point of view very similar. On the other hand it is clear that there exists correlation between porosity and IC. For summer clothing is expected that higher porosity leads to the higher thermo physiological comfort.

b.

CONCLUSION

On the basis of the carried out investigations the strong correlation relationships were find out between the total volume porosity of cotton woven fabrics and their properties influencing the physiological comfort. There is possible to shape the thermo - physiological features of fabrics according to user's needs by the appropriate designing of fabrics structure.

The proposed parameter: fabrics physiological Index of Comfort allows an assessment of the total physiological comfort of cotton fabrics on the basis of their particular comfort properties. It is possible to use IC for the case of more comfort related properties or properties connected with another types of comfort (sensorial, psychological etc.)

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