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Comfort – Related Properties of Clothing Packages with Adhesive Inserts

Abstract
The task of clothing, in addition to protecting the body against atmospheric factors, is to ensure appropriate physiological comfort for the user. Therefore it is necessary to select appropriate fabrics to create clothes that are characterised by proper comfort – related properties. Physiological comfort is affected by such biophysical properties of clothing as water vapour permeability, hygroscopicity, and thermal resistance. At present in the design of clothing, particular emphasis is placed on providing a drain of moisture from the skin layer under the clothing and on thermal comfort. This raises the question: what is the influence of an adhesive insert on the biophysical properties of clothing packages, which is the aim of the paper. Research on water vapour and heat transport was carried out in static conditions using a standardised method for a 'skin model' that simulates the processes of emitting heat and moisture which appear on human skin. An artificial skin model was used to measure the thermal resistance and water vapour resistance in equilibrium conditions.

Key words: *knot, knotted yarn, line flax spun yarn, tensile test.*

Introduction

The human is body-isothermal, hence it must maintain a constant body temperature. It means that a balance between the production and dissipation of heat should be kept. An important role in this process is played by clothing.

The main purpose of clothing is to provide the human being with physiological comfort, taking into account the climatic conditions, level of activity and individual (personal) characteristics of the human being. The human being should be ensured a feeling of comfort, which can be defined as a state of satisfaction, indicating a balance between the physiological, psychological and physical comfort components and the person, his clothes and the environment.

Research on the comfort – related properties of clothing was started a long time ago (monographs of Barton and Edholma (1957) [1], Kolesnikov (1971) [2]). Also research on the biophysical properties of clothing was carried out by Macheels and Umbach at the Hohenstain Institute [3] and continued by Umbach [4]. Although research on comfort – related properties has been undertaken by many researchers [8, 10, 16 - 18], the problem is still open. In Poland, research in the field of clothing microclimate was conducted by Bartkowiak [5], Więźlak and Zieliński [6], Frydrych [11, 12], Matusiak [13, 14] and Bendkowska [15].

The human body is a complicated thermodynamic construction. The heat balance of the human body can be distinguished from one side by the energy produced by the oxidation of food and heat from conduction, convection and radiation. On the other hand, the heat is dissipated away as a result of respiration and evaporation of water through the skin.

$$M \pm R \pm C \pm E = Q \quad (1)$$

where:
- M - thermal production of the human body as a result of metabolic processes and work,
- R - amount of thermal energy released or brought to by the human body to the surroundings by radiation,
- C - amount of thermal energy released or brought to by the human body to the environment by conduction and lifting,
- E - amount of thermal energy discharged to the environment through the body evaporation of secreted sweat,
- Q - excess or deficit of thermal energy in the body, which with balanced thermal balance Q has a zero value; if the value Q is greater or less than zero the body is heated or cooled.

The unit of the above quantities is Watt.

The difference in heat balance should be adjusted at short intervals by the action of the thermoregulatory system. A body temperature above 42 °C and below 30 °C is dangerous for human life. The removal of excess heat from the body meets the sweating mechanism. Sweating occurs when a quantity of heat produced exceeds that of heat driven off by conduction or radiation [9].

In this publication the element of novelty is to gain knowledge of the impact of clothing packages consisting of adhesive inserts and basic fabric on the physiological comfort of a human being in the clothing. This problem has not been reported yet. The scientific thesis we would like to prove is that the adhesive inserts will cause an increase in thermal insulation and much worsening of clothing breathability.

Experiment

The assessment of the comfort – related properties of the clothing material should begin with laboratory research carried out in normal climate conditions (20 ± 1 °C, 60 ± 5% RH) according to PN – EN ISO 139:2005 standard [7]. After tests are conducted on the clothing packages and analysis of results, the best material for a particular clothing application can be selected.

Clothing packages (a basic fabric + adhesive insert) were prepared by using a continuous fusing machine at the Department of Clothing Technology and Textronics of Lodz University of Technology. Measurements of parameters affecting the physiological comfort of clothing made thereof were conducted on a 'skin model' at the Textile Research Institute.

Material

The object of the research were clothing packages with adhesive inserts, which are often applied in suit or costume production [9]. An adhesive insert is defined as a textile material (most often nonwoven) which has an adhesive layer and is combined with the basic material.

*Table 1. Characteristics of the adhesive inserts; *cellulose fibres.*

Symbol of adhesive inserts	Composition	Mass per square meter, g/m^2	Number of adhesive points, cm^{-2}
A	73% PES, 27% BAMBOO*	60	72
B	73% PES, 27% SOYA	60	72
C	100% PES	58	72
D	100% PES	63	52

Table 2. Basic physical parameters describing the clothing packages.

Basic fabric	Number of weft and warp threads of basic fabric, dm^{-1}	Weave of basic fabric	Symbols of packages	Thickness, mm	Mass per square meter, g/m^2
Flax	Weft 210, Warp 190	Plain weave	Flax	0.39	163
			Flax + A	0.54	225
			Flax + B	0.55	227
			Flax + C	0.54	226
			Flax + D	0.62	229
Wool	Weft 320, Warp 300	Plain weave	Wool	0.29	159
			Wool + A	0.47	218
			Wool + B	0.44	218
			Wool + C	0.46	222
			Wool + D	0.52	221

For research purposes, four types of adhesive inserts were selected (A, B, C, D) differing in composition, mass per square meter and the number of adhesive points per cm^2. A description of the adhesive inserts is shown in ***Table 1***.

The selection of adhesive inserts should be such that they can properly coexist with the basic fabric. It is essential to choose the right fabric in terms of acceptable parameters of the thermal treatment in the technological process: temperature, time and pressure, which the clothing packages underwent. In a described experiment the thermal process parameters were the following: temperature 127 - 132 °C, time of gluing 15 - 18 s, pressure 0.2 - 0.4 MPa.

The basic fabrics chosen for the experiment were made of raw materials of natural origin: plant - flax and animal - wool. To make a comparative analysis, they had the same weave and similar mass per square meter (***Table 2***).

The basic fabrics applied in the experiment have different properties. Flax fabrics are characterised by low thermal insulation, and therefore flax clothing causes a cool feeling during its usage, due to which they are mainly used for summer clothing. Additionally flax fabrics are characterised by high hygroscopicity, and therefore they quickly absorb water and get dry.

Woollen fabrics can be derived from, for example, the coat of sheep, camels, goats or rabbits. The characteristic feature of wool fibres is their crimp, contributing to their excellent thermal insulation, due to which wool fibres are mainly applied in winter clothing. Woollen clothing not only protects the human body from losing heat but also provides physiological comfort because wool is characterised by high sorption of water in both liquid and gas forms.

Methodology

Measurement of clothing packages on the 'skin model'

In order to determine and compare the values of water vapour and thermal resistance, measurements were carried out on clothing packages on the 'skin model' at the Textile Research Institute in Lodz. The device simulates the processes of emitting thermal energy and moisture which appear on the human skin [7].

To determine the thermal resistance, the sample is placed on an electrically heated porous plate (measuring head) and the flow of air of specified parameters flows parallel to its top surface. After reaching the equilibrium state the heat quantity transmitted through the sample is measured. The thermal resistance is determined by the formula:

$$R_{ct} = \frac{(T_m - T_a) \times A}{H - \Delta H_c} - R_{ct0} \qquad (2)$$

where:
- R_{ct} – the thermal resistance in m^{2}K/W,
- T_m – the temperature of the plate in °C,
- T_a – the air temperature in the measuring chamber in °C,
- H – heating power supplied to the plate in W,
- ΔH_c – heating power correction for the measurement of thermal resistance R_{ct} in W,
- R_{ct0} – the constant of the device for measuring thermal resistance R_{ct} in m^{2}K/W,

In order to determine the water vapour resistance the sample is placed on the porous plate (measuring head) covered by a special membrane that transmits water vapour, but is impervious to water. Water is supplied to the porous plate (measuring head), but only water vapour is in contact with the sample. After reaching a fixed level of heat transfer the amount of heat penetrating the sample is measured in the humid state. The water vapour resistance is determined by the formula:

$$R_{et} = \frac{(\rho_m - \rho_a)}{H - \Delta H_e} - R_{et0} \qquad (3)$$

where:
- R_{et} – the water vapour resistance in m^{2}Pa/W,
- ρ_m – partial pressure of saturated water vapour at the surface of the measuring plate at temperature T_m in Pa,
- ρ_a – partial pressure of water vapour in the air contained in the measuring chamber at the temperature T_a in Pa,
- A – measuring plate surface in m^2,
- ΔH_e – heating power correction for the measurement of water vapour resistance R_{et} in W,
- R_{et0} – constant of the device for measuring the water vapour resistance R_{et} in m^{2}Pa/W.

Three repetitions for each measurement (fabrics and fabric packages) were made and statistical calculations performed. In ***Table 3*** the classification of fabric quality based on the water vapour resistance measurement is given [19].

Figure 1 shows the arrangement of clothing packages during measurement on the skin model.

Results

Thermal insulation

The thermal resistance is a parameter influencing the thermal insulation of clothing. To a great extent it depends on the clothing thickness. Bigger insulation is possible thanks to using thermal layers, which are often made from properly selected nonwovens. The thickness of the clothing package has the biggest influence on the values of its thermal resistance. Depending on the use of clothing, the thickness of material has to be properly selected.

In ***Figure 2***, it can be seen that the values of thermal resistance increase after the adhesive process for flax packages, which is a result of change in the package thickness. The largest value of thermal resistance is shown by the package with adhesive insert D. A significant influence on the value of thermal resistance of the clothing package is represented by its thickness, composition and mass per square meter. The use of insert D causes the highest increase in thermal insulation, hence the packages with adhesive insert D give better clothing comfort in cold days.

The analysis of thermal resistance results for the packages of wool fabric has confirmed the highest influence of adhesive insert D (***Figure 3***). As was mentioned before, adhesive insert D has the highest value of thickness. After selecting an adhesive insert for the basic fabric, we can theoretically model the biophysical properties of clothing packages. As is clear from literature [8], the smaller the value of thermal resistance, the easier heat is dissipated; therefore the thermal insulation of the clothing is lower. The concept of the thermal insulation of clothing is understood due to the feature of textiles expressing the ability to reduce heat

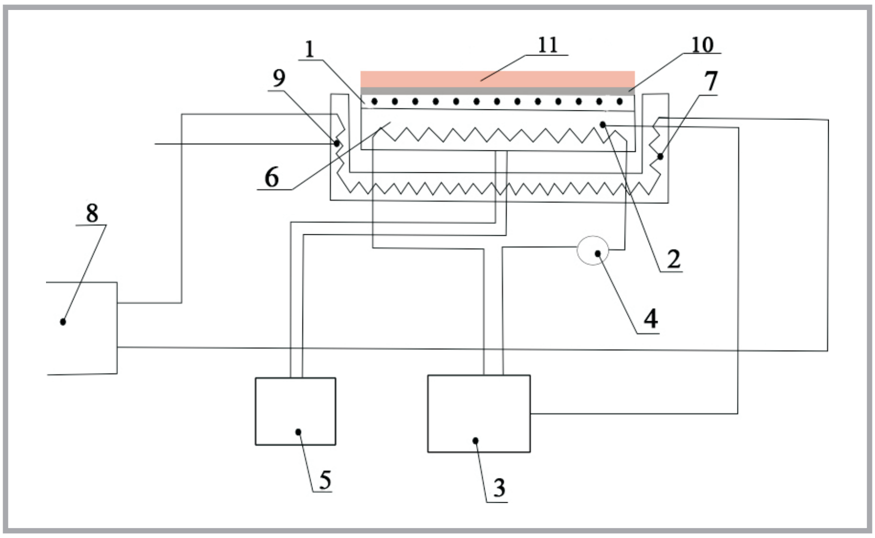

Figure 1. *Arrangement of clothing packages on the skin model; 1 - metal plate, 2 - temperature sensor, 3 - temperature controller plate, 4 - heating power, 5 - water-dispensing device, 6 - heating element, 7 - thermal insulator, 8 - temperature controller insulator, 9 - temperature sensor insulator, 10 - adhesive insert, 11 - basic fabric.*

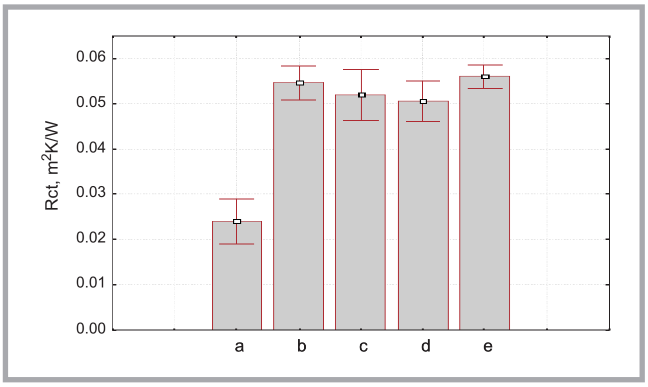

Figure 2. *Values of mean thermal resistance with standard deviations for: a) Flax, b) Flax + A, c) Flax + B, d) Flax + C, e) Flax + D.*

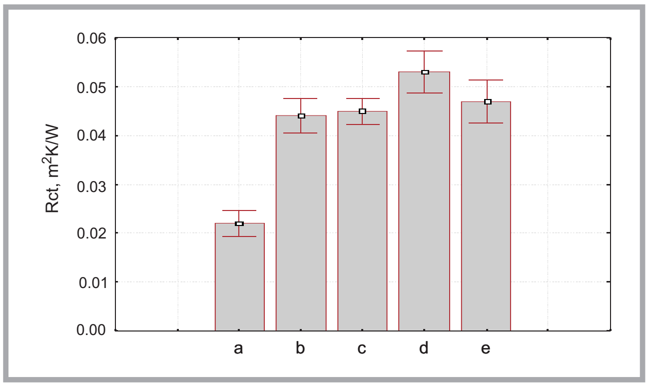

Figure 3. *Values of mean thermal resistance with standard deviations for: a) Wool, b) Wool + A, c) Wool + B, d) Wool + C, e) Wool + D.*

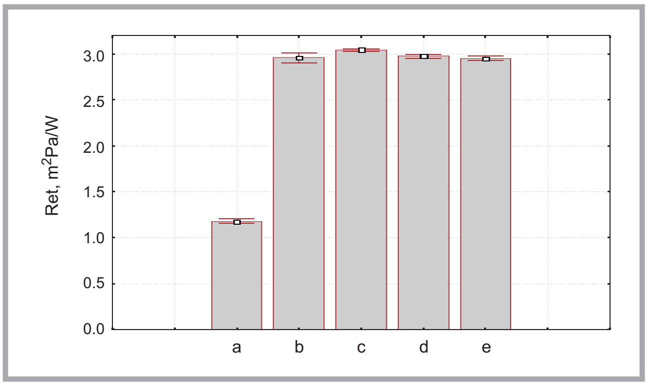

Figure 4. *Values of mean water vapour resistance with standard deviations for: a) Flax, b) Flax + A, c) Flax + B, d) Flax + C, e) Flax + D.*

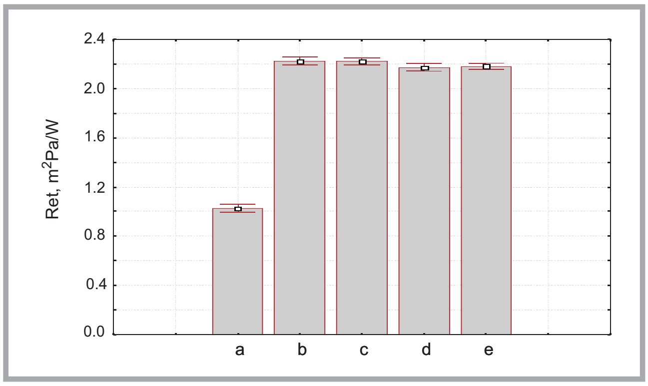

Figure 5. *Values of mean water vapour resistance with standard deviations for: a) Wool, b) Wool + A, c) Wool + B, d) Wool + C, e) Wool + D.*

Table 3. *Classification of clothing materials depending on the value of water vapour resistance.*

Water vapour resistance	Class of protection		
	1	2	3
m^2Pa/W	R_{et} above 40	20< R_{et} ≤ 40	R_{et} ≤ 20

dissipation through the body to the surrounding medium by conduction, convection and radiation [10].

Water vapour resistance

The graph in ***Figure 4*** shows values of water vapour resistance for the packages and flax fabric examined. The analysis showed that the value of water vapour resistance of the clothing packages is almost three times bigger than that of the basic fabric, which is the result of change in the thickness and the tight structure of the adhesive insert. The bigger the thickness of the package, the more the water vapour resistance increases. The volume of water vapour resistance influences the comfort of clothing made of these packages. In any case, the values of water vapour resistance are at such a level that they can be classified as very good materials (***Table 3***). The low water vapour resistance enables sweat evaporation, thus helping to maintain the thermal comfort of clothing. Hence it can be said that clothes of class 3 material are very good in terms of water vapour resistance and provide the highest level of comfort.

Analysing the graphs in ***Figure 5***, we can see an identical relationship to that of flax clothing packages, i.e., the water vapour resistance of the clothing package is more than twice higher than that of woollen fabric itself. The adhesive inserts applied contributed to increasing the values of water vapour resistance, which is consistent with literature [8], because the value of water vapour resistance depends on the thickness of clothing packages. Therefore it can be concluded that for each of the basic fabrics after the adhesive process, the water vapour resistance increased, but in the case of woollen packages the increase is a little less than that of flax packages, which results from the differences in thickness of woollen fabrics and their packages.

In the graphs in ***Figures 4*** and ***5***, it can be seen that flax fabric has a slightly larger value of water vapour resistance than wool fabric, which is a result of the influence of the bigger thickness of flax fabric than that of wool fabric (***Table 2***).

Conclusions

The results of research on the biophysical properties of clothing packages containing adhesive inserts were analysed. The research confirmed the effect of increasing the thermal insulation of clothing packages, which is a positive feature, especially regarding winter clothing. The resistance of water vapour of such packages also increases, but although the increase seems to be relatively high, the clothing packages examined remained in the same group in the material classification according to water vapour resistance (***Table 3***). The basic fabrics were made of natural fibres, thus they were characterised by very good hygienic properties. The research will be continued, where for the basic fabric composition synthetic fibres will be chosen.

Clothing packages should provide the human being with appropriate physiological comfort, which depends on the human's physical activity as well as the internal and external weather conditions. It should also be noted that by appropriate selection of both the basic fabric and adhesive insert in the process of design, the comfort-related properties of clothing packages can be modelled and, consequently, their use in clothing predicted.

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