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Analysis of Selected Physical Properties of Membrane Fabrics Influencing the Utility Comfort of Clothing

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Abstract
By carrying out measurements of the thermoinsulation properties of clothing materials, we can obtain a lot of valuable information regarding the wide characteristics of these materials. Knowing thermoinsulation property values of clothing material, we can start the proper designing of thermoinsulation clothing by selecting and combining fabrics in such a way that we obtain clothing of very good thermal properties. In this paper the results of evaluation of the thermoinsulation parameters of membrane fabrics are presented. Measurements were carried out for 12 different clothing materials with half-permeable membranes for the inner as well as for the outer side of the material. An analysis of results is given.

Key words: *membrane fabrics, thermo-insulation parameters, utility comfort, thermal resistance, thermal conductivity, thermal absorption, thermal diffusion.*

Introduction

Thermoinsulation properties have a great influence on utility comfort. The significance of thermoinsulation properties results from the fact that they aid the thermoregulation system of the human organism in such a way that they assure the user appropriate physiological comfort in different climate conditions as well as during the various physical efforts of the clothing user. Problems concerning physiological comfort have been undertaken many times and described in literature [1 - 4].

Measurements of the thermoinsulation properties of clothing rely mainly on determination of the thermal resistance, thermal conductivity, diffusion and absorption [5 - 9]. Knowledge of values for these parameters creates a basis for clothing designers because they are a part of clothing material characteristics, which allow for the conscious material designing of clothing articles able to fulfill functions determined by the clothing character on the one side: and on the other - to assure the clothing user appropriate comfort in different conditions of use. It should be emphasised that it is very difficult to carry out explicit measurements of thermal properties due to the different research conditions [10 - 13], which is the reason why literature data differ, often even for similar fabrics.

Over recent years waterproof clothing articles made of membrane fabrics have been implemented on the market. In the majority they are not air permeable but have the important vapour permeability property. In the case of clothing materials, they allow for the free transmission of water vapour molecules and, simultaneously, are a barrier for humidity and harmful external factors (physiological fluids, chemicals and so on) [10]. Semi-permeable membranes cause an increase in clothing thermo-insulation. Heat losses appear mainly when air goes through the textile material layer easily. Clothing with membranes reduces the air permeability from the outside to the inside of the clothing to a minimum, designed to maintain the body's temperature, which should be kept at an appropriate level even in strong windy environmental conditions. Nevertheless, the membranes are thin, thus they do not have good thermoinsulation properties. Therefore, in the

Table 1. *Description of clothing materials with membranes examined.*

Designation	Material	Kind of laminate	Components		
			membrane	outside fabric	inside layer
A	Sympatex	input two-layer	PBT	nonwoven PES	-
B	Sympatex	two-layer	PBT	PES	-
C	Sympatex	two-layer	PBT	PES	-
D	Sympatex	two-layer	PBT	PES	-
E	Gore-tex	input two-layer	PTFE	-	nylon knit fabrics
F	Gore-tex	two-layer	PTFE	PES	-
G	Gore-tex	two-layer	PTFE	-	nylon knit fabrics
H	Thermoactive 2L	two-layer	PU	PA	-
I	IThermoactive 2L (5000/5000)*	two-layer	PU	PA	-
J	Thermoactive 2L (10000/8000)*	two-layer	PU	PA	-
K	Thermoactive 2L Seria Guide (13000/11000)*	two-layer	PU	PA	-
L	Thermoactive 3L	three-layer	PU	PA	nylon knit fabrics

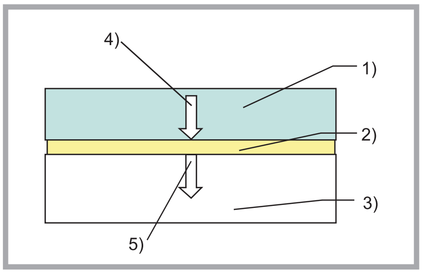

Figure 1. *Alambeta measurement principle for a non-stationary heat flow state; 1 - heated plate, 2 - sample measured, 3 - lower plate, 4 - heat flow $q_1(\tau)$, 5 - heat flow $q_2(\tau)$.*

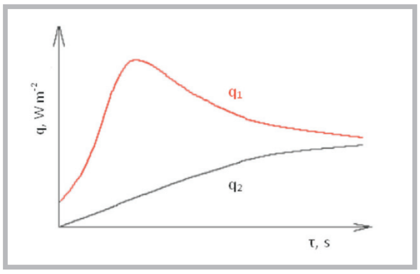

Figure 2. *Graph of the values of heat flows at a non-stationary heat flow state; q_1 - heat flow from heated plater to the sample, q_2 - heat flow from the sample to the lower plate.*

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case of low temperatures, it is necessary to apply additional insulation layers [11].

The aim of this research was the comparison of the thermal insulation of a wide range of properties of clothing materials with membranes of different raw material and structure. By comparing the results of measurements carried out under similar conditions, special attention was given to evaluating the textile parameters by changing the direction of heat flow.

Materials and methods

Materials

Characteristics of clothing materials with membranes are presented in ***Table 1***.

Methods

The measurements presented are related to selected interactive properties, i.e., thermal insulation, air and vapour permeability. For determination of thermo-insulation parameters, an Alambeta device produced by Sensora was used [14].

The principal of function of the Alambeta device consists of the mathematical evaluation of the process of heat transmission through the material tested caused by its thermal conductivity forced by the different temperatures of the bottom (lower) plate of ambient temperature and the measuring heated plate (***Figure 1***). After insertion of the sample the head moves down, and the heat ($q_1 = f(\tau)$) flows from the heated plate to the sample, accumulating in it during the non-stationery state, and from the sample to the lower plate $q_2 = f(\tau)$ (***Figure 2***). Next, both heat flows stabilise at a similar level, and the thermophysical properties and thickness of the samples measured can be evaluated.

The sample thickness is measured by an optoelectronic incremental sensor connected to a screw. The measuring head pressure is set and adjusted. The heat flow density is detected using thermocouples that measure the temperature gradient across a very thin plastic foil.

The maximum heat flow through the sample $q_{\max}$ is described by the equation:

$$q_{\max} = \frac{b \cdot dt}{\sqrt{\pi t}}, \qquad (1)$$

where:
b – thermal absorption, in $Ws^{1/2}/m^2K$,
dt – thermal difference.

The value of the coefficient of thermal conductivity λ_{mean} is calculated based on the following equation:

$$\lambda_{mean} = \frac{q(\infty)h}{(t_g - t_d) + k\,q(\infty)}; \qquad (2)$$

where:
$q(\infty)$ – stationary heat flow determined as a mean value of $q_1(\infty)$ and $q_2(\infty)$,
t_g – temperature of the measuring plate,
t_d – temperature of the lower plate,
kq – coefficient of correcting the heat drops during the measurement,
h – sample thickness.

The thermal resistance is determined from the relationship:

$$R = \frac{(t_g - t_d) + k\,q(\infty)}{q(\infty)h}; \qquad (3)$$

And can be calculated from the relation:

$$R = \frac{h}{\lambda} \qquad (4)$$

The thermal diffusion is determined by the equation:

$$a = \frac{\lambda}{\rho c} \qquad (5)$$

where:
λ – the thermal conductivity,
ρ – the fabric density,
c – the specific heat capacity.

The thermal absorption is determined by:

$$b = \sqrt{\lambda \rho c} \qquad (6)$$

The ratio of maximal and stationary heat flow is evaluated by:

$$p = \frac{q_{\max}}{q_s} \qquad (7)$$

The stationary heat flow is determined by:

$$q_s = b\,\Delta t/(\pi t)^{1/2} \qquad (8)$$

The device registered seven parameters simultaneously, which are given in following ***Table 2***.

The thermoinsulation parameters were measured by the Alambeta for two directions of heat flow. We assumed the following:

- 'outside': i.e., the laminate is placed in such a way that the outer fabric is directly below the heating head,
- 'inside': the outer fabric is on the lower plate.

Additionally, in order to determine the influence of fabric structure parameters on thermoinsulation properties, the following tests were made:

- mass per square meter – in accordance with PN-EN 12127:2000,
- air permeability – in accordance with PN-EN ISO 9237:1998,
- vapor resistance – in accordance with PN-EN 31092:1998,
- thickness – in accordance with PN-EN ISO 5084:1999.

For these tests the following equipment was used:

- FF – 12 device for measurement of air permeability made by Hungary,
- legalised balance WA 31,
- model of M257b 'artificial skin' for determination of vapour permeability, made by SDL International Great Britan.

The water vapor resistance was determined by means of the 'skin model'. The device is equipped with a 'sweating guarded hotplate', described as a 'skin model plate', which simulates the coupled emission of heat and water vapour from the skin. The sample tested is situated on the electrically heated plate; the flow of conditioned air is directed parallel to its upper surface. The water vapour resistance R_{et} was determined for the following parameters:

- temperature of both surface plates and air $T_m = T_a = 308.15$ K;
- relative humidity of air $H_a = 40\%$; air flow velocity $v_a = 1$ m/s.

The water vapor resistance R_{et} is defined by the equation:

$$R_{et} = \frac{(p_m - pT_a)\cdot A}{H - \Delta H_e} - R_{eto}, \text{ in } m^2Pa/W, \qquad (9)$$

where:
p_m = 5620 Pa is the partial pressure of saturated water vapour at a temperature of 308,15 K,
p_a = 2250 Pa is the partial pressure of water vapour at relative humidity $H_a = 40\%$,
ΔH_e denotes the constant of thermal power during tests of water vapour to permeability,
R_{eto} is the constant for the device [15].

All measurements were made in normal climatic conditions, i.e., at a temperature of 20 °C ± 1 °C and relative humidity of 65% ± 2%.

Table 3. *Results of the basic physical parameters of the fabrics tested.*

Designation as on Table 1	Thickness, mm	Mass per square meter, g/m^2	Density, kg/m^3	Water – vapour resistance, m^{2}Pa/W
A	0.37	53.11	150.80	11.70
B	0.20	126.63	506.51	1210
C	0.23	127.34	538.45	10.47
D	0.26	128.84	926.97	12.59
E	0.16	54.67	344.89	6.38
F	0.26	163.91	646.57	10.04
G	0.23	96.10	423.35	8.84
H	0.16	141.11	884.72	16.07
I	0.33	224.30	697.66	30.72
J	0.33	202.04	615.02	26.49
K	0.09	97.19	1017.70	21.22
L	0.45	225.92	508.83	16.74

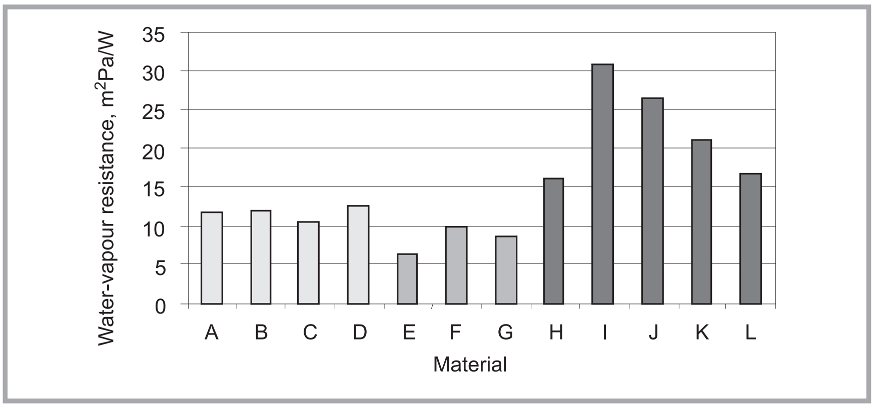

Figure 3. *Water vapour resistance of membrane clothing materials;* ▢ *- Sympatex,* ▨ *- Gore-tex,* ■ *- Thermoactive.*

Results and analysis

Basic physical parameters and water vapour resistance

Results of the fabrics tested are presented in ***Table 3***.

As can be seen, the materials selected for testing, available on the market, are characterised by a wide range of parameter values.

In order to answer the question: which laminate has better 'breathability', we had to establish which one has the lowest water vapour resistance; to do this measurements of water vapour resistance were performed. The results obtained are presented in ***Table 3*** and ***Figure 3***.

On the basis of the results presented in ***Figure 3***, it can be seen that the lowest values of water vapour resistance were found for laminates from the Gore-tex group (E ÷ G), which are at a level of 8.42 m^{2}Pa/W. Gore-tex laminates have the best properties among the laminates examined because of the fact that the lower the water vapour resistance of the laminate, the better its ability of sweat transmission from the skin of a human body.

The lowest water vapour resistance of the Gore-tex laminates was shown by laminate E, in which the PTFE membrane is laminated with fine delicate knitted nylon fabric. It should be pointed out that it is the thinnest of the Gore-tex type laminates, which confirms the proportional influence of the thickness on its water vapour resistance.

Second in terms of vapour permeability are Sympatex laminates with the PBT membrane, (A ÷ D) showing a water vapour resistance of 11.72 m^{2}Pa/W. The worst 'breathability' was shown by Thermoactive laminates (H ÷ L) for which the level of water vapour resistance is 22.25 m^{2}Pa/W.

Such a differentiation in values is caused mostly by the kind of membrane used in laminates. The membrane made of PTFE, which is a part of Gore-tex laminates, assures the best 'breathability'; whereas the polyurethane membrane used in Thermoactive laminates has the biggest vapour resistance (almost 3 times higher than the Gore-tex laminates), which can lead to discomfort during clothing utility. A good example showing the influence of the kind of membrane on water vapour resistance is a comparison of laminates D (Sympatex) and E (Gore-tex), which are of a similar thickness (laminate D – 0.14 mm, laminate E – 0.15 mm) but show different water vapour resistance values (laminate D – 12.59 m^{2}Pa/W, laminate E – 6.38 m^{2}Pa/W).

The majority of laminates show water vapor resistance values in the range $R_{et} \leq 20$ m^{2}Pa/W; only for a few laminates from the Thermoactive group are values of water vapour resistance in the range $R_{et} > 20$ m^{2}Pa/W.

Knowing the classification of thermoinsulation clothing in the aspect of this parameter, (***Table 4***) it can be stated that almost all laminates belong to class 3, thus they have "good" biophysical properties. Only the majority of Thermoactive laminates belong to the lower class – class 2, therefore they are of an "average" level in this resspect.

Thermoinsulation parameters

In ***Table 5*** the thermoinsulation parameters assessed by the Alambeta device are listed.

Since all the parameters assessed on the Alambeta are related to homogeneous materials, whereas the materials tested in our research are typically multilayered structures, in the parameters of laminates assessed by the Alambeta device should be considered only as the substitute val-

Table 2. *Parameters registered by the Alambeta device.*

Symbol	Unit	Definition
λ	$Wm^{-1}K^{-1}$	(2)
a	m^2s^{-1}	(5)
b	$Wm^{-2}s^{1/2}K^{-1}$	(6)
R	Km^2W^{-1}	(3)
h	mm	
p	-	(7)
q_s	Wm^{-2}	(8)

Table 4. *Classification of water vapour resistance according to the literature [16].*

Water vapour resistance R_{et}, m^2·Pa/W		
Class		
3	2	1
$R_{et} \leq 20$	$20 < R_{et} \leq 40$	$40 < R_{et}$

Table 5. *Set of mean values for the Alambeta parameters.*

Designation	Thermal conductivity coefficient, $Wm^{-1}K^{-1}$ × 10^{-3}		Thermal diffusion, m^2s^{-1} × 10^{-6}		Thermal absorption, $Wm^{-2}s^{1/2}K^{-1}$		Thermal resistance, Km^2W^{-1} × 10^{-3}		The ratio of maximal and stationary heat flow		The stationary heat flow, KWm^{-2}	
	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside	outside	inside
A	30.30	35.16	0.51	0.20	48.78	77.25	11.65	11.20	1.01	1.36	0.62	0.92
B	49.00	53.93	0.11	0.06	155.33	222.67	3.87	3.83	1.00	1.11	1.38	1.55
C	37.42	38.23	0.06	0.05	146.80	171.50	6.05	6.03	1.08	1.19	1.05	1.23
D	49.37	53.17	0.09	0.08	163.67	190.67	5.17	4.80	1.07	1.19	1.20	1.41
E	25.83	25.45	0.03	0.07	127.50	94.91	6.29	6.41	1.22	1.01	1.20	0.97
F	43.32	42.76	0.05	0.02	193.05	267.40	5.96	5.83	1.05	1.44	1.10	1.53
G	33.75	33.16	0.05	0.05	149.65	134.40	6.45	6.91	1.35	0.87	1.31	0.97
H	41.87	40.48	0.04	0.01	204.10	351.60	3.88	3.74	1.01	1.43	1.37	2.01
I	69.15	65.72	0.10	0.02	217.65	392.95	4.78	4.97	1.02	1.77	1.23	2.02
J	65.49	63.78	0.04	0.03	205.90	360.80	5.02	4.98	1.02	1.77	1.19	2.01
K	22.09	26.17	0.01	0.01	205.65	213.75	3.67	3.65	0.94	1.05	1.45	1.47
L	48.17	48.58	0.04	0.05	212.90	212.50	9.25	9.30	1.39	1.52	1.07	1.13

ues of these parameters. However, the measurements performed can serve to arrange the results obtained according to the decreasing or increasing values.

Using two factor variance analysis, the influence of two factors (the kind of fabric or laminate and its side) on specific thermoinsulation parameters were assessed. Also interactions between factors were analysed, which was done using the module ANOVA/MANOVA of Statistics.

The following designations of independent factors were assumed:
1 – kind of the laminate,
2 – side of the laminate (outside or inside).

The two-factor variance analysis showed that in the case of all parameters measured, both factors are significantly important.

Thermal resistance

Mean values of thermal resistance for the outside and inside side are presented in ***Figure 4***.

The analysis showed that the kind of laminate has a significant influence on the value of thermal resistance. The values of this parameter obtained are over a broad range (from 3.5 to 11.5 Km^2/W). A big differentiation in values results from the different thicknesses of laminates. Knowing the thickness of particular laminates, it can be easily noticed that the thicker the laminate (laminates L and A having the biggest thickness), the higher the value of thermal resistance, hence better protection against the cold. In order to obtain materials of good insulation properties, attention should be paid to their thickness, remembering that the clothing should not be too heavy because it would worsen utility comfort.

Differences in thermal resistance between both sides of laminated fabric are statistically insignificant, which could be foreseen taking into account that the heat transmission through the samples tested occurs only by heat conduction and not by radiation or convection. In this way it should not depend on the direction of heat flow.

Thermal conductivity coefficient

Mean values of thermal conductivity coefficient for the left and right side are presented in ***Figure 5***.

Measurement of the thermal conductivity coefficient should be considered as a confirmation of the thermal resistance. Measurements of the thermal conductivity coefficient of layered materials by the Alambeta device are the most controversial quantity measured by this device. The values of the thermal conductivity

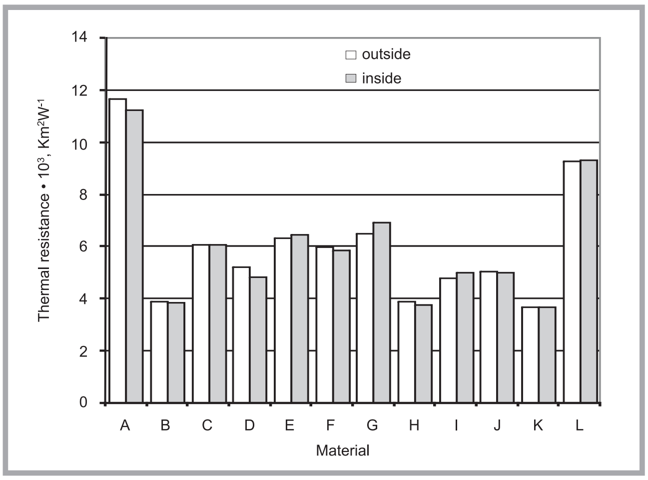

Figure. 4. *Mean values of thermal resistance for the outside and inside.*

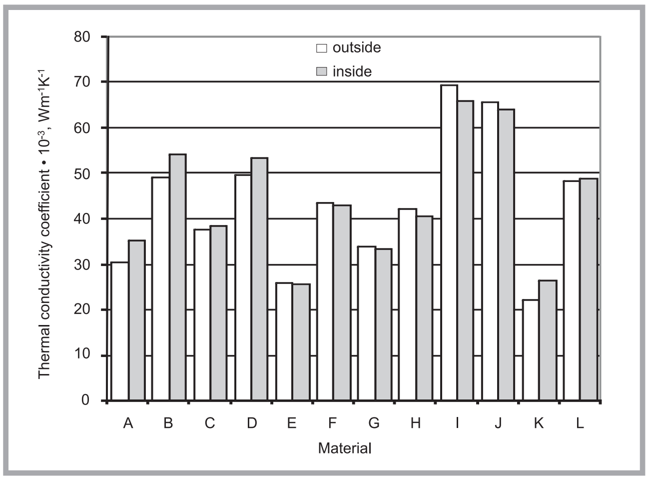

Figure. 5. *Mean values of thermal conductivity coefficient for the outside and inside*

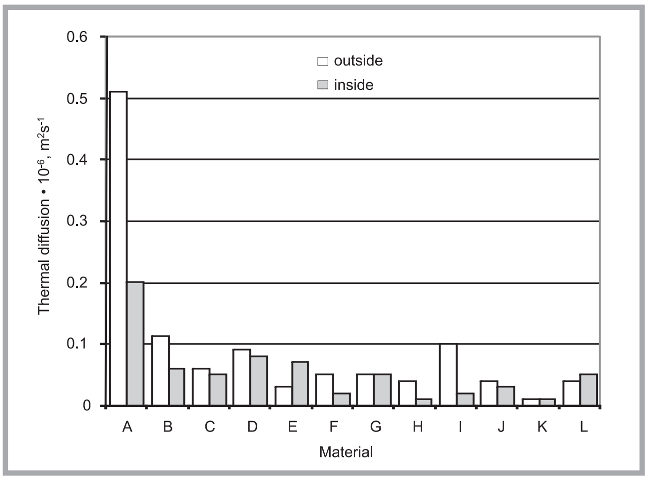

Figure 6. Mean values of thermal diffusion for the outside and inside.

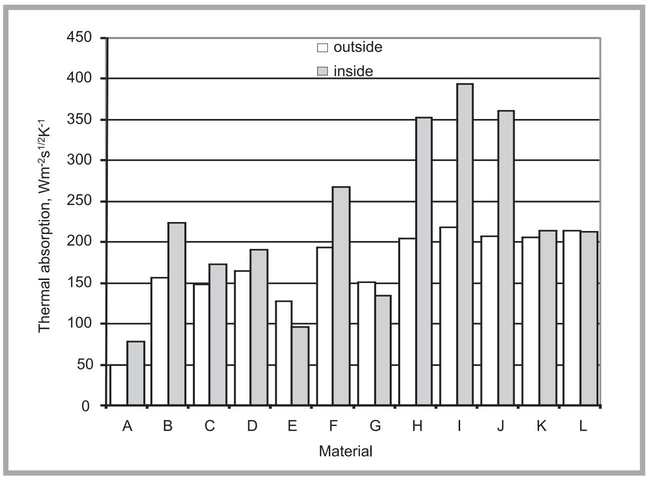

Figure 7. Mean values of thermal absorption for the outside and inside.

coefficient cannot be considered as the opposite of thermal resistance as the thermal resistance depends on the thickness of the sample, whereas thermal conductivity is a feature of the material tested. Therefore, sample K is characterised by the lowest values of these two quantities, which was most surprising. The kind of laminate has a significant influence on the values of thermal conductivity. The value of the thermal conductivity coefficient should not depend on the direction of heat flow; the differences measured can be caused by measuring errors, which can result from the inaccuracy of thickness measurement (about ± 0.01 mm in relation to the thickness range 0.09 – 0.45 mm), differences in the theoretical relations of thermal conductivity between homogenous and layered materials, and finally on the slight influence of thermal radiation.

Thermal diffusion

Mean values of thermal diffusion for the outside and inside are presented in ***Figure 6***.

It results from the analysis that the kind and side of laminate significantly influence the value of thermal diffusion, values of which are similar for the majority of laminates. The exception is laminate A, whose value is significantly higher than for the other laminates. In two layer Sympatex the PBT membrane is placed on a PES nonwoven. For this laminate and for the others, (B, E, F, H, I) the values of thermal diffusion for the outside are much higher than for the inside in comparison to the diffusion for the rest of the laminates. The different properties of this laminate result from its specific structure. Probably the structure of the nonwoven, which is used in laminate A, caused such high values of thermal diffusion for the outside.

Analysing the data characterising laminate A (***Table 3***), it can be easily noticed that this laminate has the lowest density, which causes the high values of thermal diffusion. For the majority of laminates, the thermal diffusion measured for the outside is higher than for the inside irrespective of the kind of membrane and outer fabric. These differences result mainly from the different structure of both sides.

Thermal absorption

Mean values of thermal absorption for the outside and inside are presented in ***Figure 7***.

Thermal absorption, also called the coefficient of heat adapting, is a surface property which decides on the warm or cold handle: the higher the value of this parameter, the worse (less pleasant) the handle is. On the basis of the analysis carried out, it results that the kind of laminate significantly influences thermal absorption. Different values of thermal absorption for particular laminates are a result of differences in the surface of outer fabrics and in the handle shown by these fabrics. In ***Figure 7***, it can be observed that laminates A and E have the lowest values of thermal absorption :

- laminate A - two layer laminate Sympatex with a PBT membrane placed on a thin PES nonwoven,
- laminate E – Gore-tex, a PTFE membrane is mounted on fine PA knitted fabric.

Analysing the data in ***Table 3*** and ***Figure. 5***, it can be concluded that low values of thermal absorption are caused:

- in the case of laminate A - by the low density of this material; whereas
- in the case of laminate E - by the low thermal conductivity.

The low density of laminate A results from the application of nonwoven as a membrane background. Additionally, nonwovens belong to textiles of the lowest thermal absorption and are therefore warm and pleasant to the touch.

The side of the laminate also influences the value of thermal absorption. For the majority of laminates, the values of thermal absorption measured for the outside are lower than for the inside, which is not strange because the inside of the laminate is a membrane foil; this is rather not pleasant nor warm to the touch. Laminates are used on the outer layer in clothing (for example in jackets), hence the user does not feel the cold handle of the membrane directly because it is at a distance from the human body (on another clothing layer).

Different behavior is shown in the case of fabrics E and G, for which the absorption values measured on the outside are higher. This results from the fabric structure, in which the membrane is laminated with the lining, creating the outside of the laminated fabric.

In the case of laminate L, the values of thermal absorption measured on the inside as well as on the outside are of the same level. The different behaviour of this laminate results from its specific

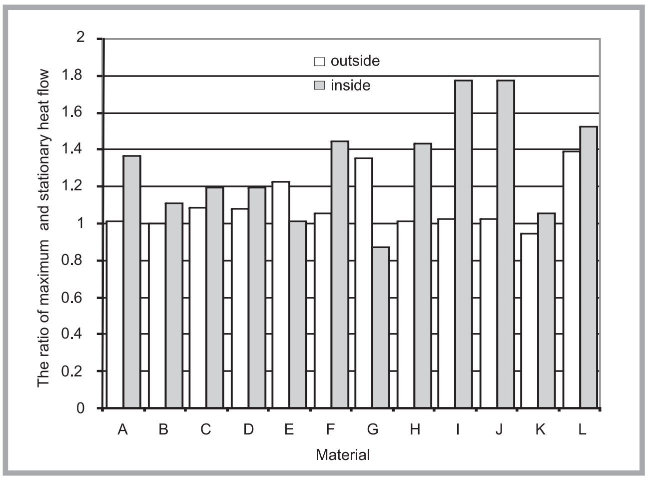

Figure. 8. Mean values of the ratio of maximum and stationary heat flow for the outside and inside.

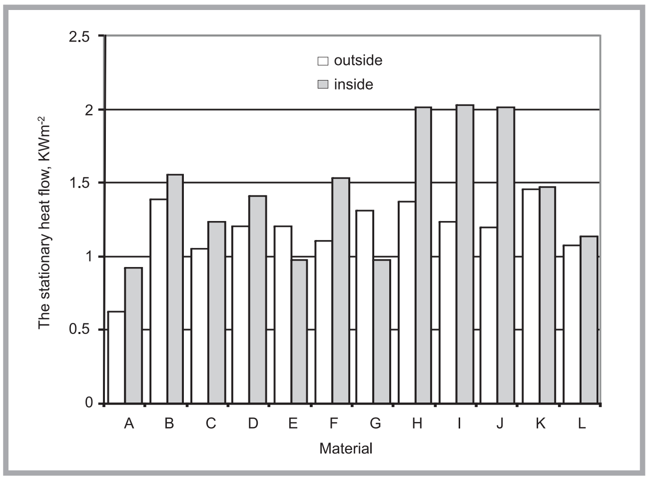

Figure 9. Mean values of the stationary heat flow for the outside and inside.

structure: it is a three – layer laminate (only one) in which the membrane is surrounded on one side by the outer fabric and on the another – by lining. It can be noticed that laminates from the Thermoactive group have higher values of thermal absorption than those like Goretex or Sympatex, hence they are warm and pleasant to the touch.

Ratio of maximum and stationary heat flow

Mean values of the ratio of maximum and stationary heat flow for the outside and inside are presented in ***Figure 8***.

At the moment of contact between a cold material and the human skin, the heat flux, i.e., q_{max} starts to go from the skin to the fabric. After a given time heat flow is established at a determined level q_s – so-called stationary heat flow. The ratio of the maximum q_{max} to stationary heat flow q_s is one of the parameters characterising clothing thermo-insulation, and, similar to thermal absorption, it is a surface property [4].

The analysis carried out showed that the value of this parameter is influenced by the kind of laminate as well as by its side. The values of the maximum and stationary heat flow ratio are lower for the outside than for the inside, which concerns the majority of laminates. The exceptions are laminates E and G. The differences can result from the different properties of both sides, where the outside is a membrane and the inside – knitted underline.

From the utility point of view, the fact that the maximum and stationary heat flow ratio measured for the inside is higher than for the outside is not advantageous; it leads to a more rapid worsening of the fabric handle (is unpleasant and cool) on the inside of the laminate than on the outside, hence directly at the human skin. In the case of laminates, it does not really negatively influence their general properties because they are placed on outer clothing, thus they are not in direct contact with the human body.

Stationary heat flow

Mean values of the stationary heat flow for the outside and inside are presented in ***Figure 9***.

The results obtained are controversial as the direction of heat flow should not influence the value of heat flow considering that heat transmission to the bottom plate takes place only through the conductivity of materials. It seems that other kinds of heat transfer play a certain role in the phenomena. The kind of laminate significantly influences the value of stationary heat flow because the values obtained for this parameter are significantly different for particular laminates. For the majority of laminates, the inside shows higher values than the outside; for laminates H, I and J the differences are extremely high (these laminates have simultaneously the highest values for this parameter out of all of the samples examined). Such a phenomenon is extremely disadvantageous because the heat is transmitted faster from the surface of human skin than in the subsequent material layer; it decreases their thermo-insulation properties.

From the point of view of thermo-insulation properties, the stationary heat flow should achieve low values because in this case the heated air layers between the human body and examined fabric transmit heat to the material more slowly, causing less heat lost.

It results from ***Figure. 9*** that the lowest values of stationary heat flow at the place of contact are shown by laminate A (Sympatex), which is caused by its low thermal absorption, because a proportional relationship exists between the absorption and heat flow density. This also explains the high values of this parameter for laminates H, I and J (being Thermoactive laminates of different breathability and waterproofness), which have high values of thermal absorption.

Discussion of results

The remarks and conclusions of this article concerning fabrics laminated with half-permeable membranes were made on the basis of an analysis of some of the most important thermoinsulation parameters. As a result of this, the following statements can be made:

- thermal resistance is directly proportional to the fabric thickness and inversely proportional to the thermal conductivity coefficient. Laminates of higher thickness are characterised by the best thermo-insulation.
- for the majority of laminates the values of thermal absorption coefficient are high because they are characterised by a smooth surface, especially on the membrane side
- values of the maximum and stationary heat flow ratios are different for some laminates depending on the way the sample is placed during measurement (side of laminate being in contact with

heating head). Generally, the values of the maximum and stationary heat flow ratios for the laminates examined showed that these laminates are characterised by bad surface properties (cold to the touch), which results mostly from the fact that their surfaces are very smooth.

The analysis of the thermal diffusion values of membrane clothing fabrics showed that in the case of laminates, there are differences between the outer and inner side of the fabric; for some laminates (A, B, E, F, H and I) the differences are very high. Generally, the values of thermal diffusion are low in the case of laminates, which confirms the small ability of these fabrics to transport heat through pores. Laminates are not permeable to air (in this case we consider vapour transport) because they have only micro-pores enabling heat diffusion.

The Alambeta device measures thermal resistance as well as sample thickness and has in its algorithm such parameters as sample area, power, and temperature difference, which can create some ambiguity during measurement of multilayered structures. This can also be the cause of big errors during the measurement of thin samples, which can cause differentiated results when the head flows from the right side or in the opposite direction.

Conclusions

- The best thermoinsulation properties are shown by laminate A from the Sympatex group. Its low thermal conductivity, as well as having the warmest handle, lowest stationary heat flow and highest thermal resistance at a thickness similar to the rest of the laminates caused that it is the best thermal insulator from the all the laminates examined.
- In additional to laminate A from the Sympatex group, Goretex laminates are characterised by good thermal properties. Goretex laminates have the lowest thermal conductivity, a low value of heat flow at the place of contact , and the highest thermal resistance. Besides, they are warm and nice to the touch.
- Besides Sympatex A laminate, the second best with respect to good thermal properties are shown by Sympatex laminates, which showed a higher thermal conductivity and lower thermal resistance than Goretex and are colder to the touch .
- The worst thermoinsulation properties are shown by laminates from the Thermoactive group, which showed the highest thermal conductivity, the lowest thermal resistance and the highest heat flow. Among them the best thermoinsulator is the three-layer laminate L, in which the membrane is hidden between the outer fabric and the lining. Such a construction caused better properties, which result mainly from its higher thickness than of the rest of the Thermoactive laminates.
- Two-layer laminates show worse thermoinsulation properties for the inside than for the outside, which is not good for the clothing user, because the left side of the laminate is closer to the user’s skin during utility. The three-layer laminate L and two-layer laminates (E and G) (the outer layer is created by a membrane) showed better thermoinsulation properties for the inside than for the outside. During clothing manufacture using two-layer laminates there is a need to use an additional layer (lining or heating layer) due to the mechanical protection of the membrane and a necessity to avoid a feeling of cold when in contact with the user’s skin.
- Gore-tex laminates showed the lowest values of water vapour permeability resistance – on average 8.42 m^2Pa/W, and simultaneously they have the best ability to remove sweat from a human being.
- Sympatex laminates show a water vapour permeability resistance of 11.72 m^2Pa/W. Thermoactive laminates are third, with at the same time the worst ‘breathability’ – 22.25 m^2Pa/W.
- Generally we can say that carrying out measurements of the thermoinsulation properties of clothing materials, we can obtain very valuable information regarding the wide characteristics of these materials. Knowledge of these characteristics allows to assess how clothing created from these materials will protect the user against negative atmospheric conditions, for example, cold, rain, or strong wind. Knowing parameter values of these clothing materials, we can start to design clothing correctly, as well as choose and combine materials in such a way to create clothing of good thermoinsulation properties.

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