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Research on Optimising the Insulation of Footwear Materials Using Statistical Methods

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Abstract

In this paper, the results of research on the thermal insulation properties of textile and leather materials are presented. These materials were used in order to develop innovative footwear upper combinations with higher hygienic properties. Outer leather materials (L1, L2) and textile (T1, T2, T3, T4) were joined around the edges by stitching with leather lining materials (LG1a, LG1b, LG1c) and textiles. Moreover, the textile linings were divided into the following groups: spacer fabrics (TG2a, TG2b, TG2c), flat textiles (TG3a, TG3b, TG3c) and flat textiles based on bamboo fibres (TG4a, TG4b, TG4c, TG4d). In the next step of these investigations, the materials were joined in a two – layered composition, where for the outer layer was upper material, and for the inner – lining material. For these compositions, the thermal insulation properties were measured with the use of an Alambeta device. The following material characteristics were determined: thermal conductivity, resistance and absorptivity, which were the most important parameters from a hygienic point of view. The classification mentioned above was important from the manufacturer's point of view because it gave a set of information about optimal upper material configurations. With respect to the results obtained, the best packages from the thermal insulation point of view were as follows: L2 – TG4b, L1 – TG4b, T1 – LG1a, T2 – TG4a, T3 – TG4a and T4 – LG1a.

Key words: *thermal insulation, footwear, thermal resistance, thermal absorptivity.*

Introduction

Thermoregulation processes between the footwear interior and the environment are some of the most important elements which determine the comfort sensation of users [1]. This aspect plays a crucial role in cases of long – term exposure to external factors like temperature and the humidity of the environment. Optimal upper material packages give a possibility to provide healthy microclimate conditions, which determine foot comfort during exertion.

The thermal insulation property of upper packages is one of the most important factors which determine the temperature and humidity conditions inside a shoe volume [2, 3]. At the same time, the thermal conductivity of materials (both lining and upper) should not be a blocker for physiological functions of the foot, as indicated by the proper functioning of heat and sweat exchange between the foot surface and footwear materials and between the foot materials and the external environment. In the opposite case, when the thermal resistance is too high, the temperature and humidity in the nearest foot neighbourhood increase rapidly, and a discomfort effect arises [4]. In the literature sources, it is assumed that the optimal conditions for the human foot are created when the foot skin temperature is approximately equal to about 33 °C, whereas the humidity should be as low as possible, or at least not exceed about 65% [5]. In fact, when physical effort is intensive, inappropriately chosen footwear materials can cause a rise in humidity to the level of 85%, which defines the total discomfort zone [6-13].

The importance of material characteristics for the improving of microclimate conditions has been described by many authors. Currently, one of the most effective ways of heat buffering is the incorporation of phase change materials (PCM) into linings and upper materials [14, 15]. The materials, which contain PCMs, are able to react immediately to changes in temperature and humidity inside the shoe interior [16]. In paper [17] the authors showed that innovative textile composite liners based on special mix ratios of fibres can improve the comfort sensation for all rubber protective footwear. An other effective way to increase footwear insulation is to add socks [18]. However, stuffing socks into a shoe volume can give problems with blood circulation, and the effect can be not satisfactory for users, especially in tight footwear [19].

In the following paper, the authors focused on the classification of upper and lining footwear materials according to the thermal insulation properties of their compositions. Based on primary parameters such as thermal conductivity, thermal resistance and thermal absorptivity, the authors made material packages (leather – textile and textile – textile) which were able to improve the hygienic functions of uppers.

Materials and method

Materials

In order to determine the transient and steady state thermo – physical properties of upper packages, the materials from ***Tables 1-3*** were used.

Lining and upper materials were selected from a wide spectrum of footwear materials. The criterion of this selection was based on the hygienic characteristics of these materials, i.e. water vapour permeability and water vapour absorption. For the lining layers which lie in the nearest skin neighbourhood, the used materials were characterised by small values of water vapour absorption and high values of water vapour permeability. On the other hand, the further layer had better absorption and good permeability. This way of connection is fundamental for a correct mechanism of water vapour discharge from a shoe interior in an outward direction. The material characteristics, like mass per square meter and thickness, placed in the tables are very important from a thermal conductivity point of view because both mass and thickness have an impact on the porosity property (P), according to ***Equation (1)***:

Table 1. Upper material characteristics.

Sample name	Material description	Mass per square meter, g/m^2	Thickness, mm
T1	three-layered material, 100% cotton	645.8	2.5
T2	three-layered material cotton bound together with the use of polyurethane foam (2 mm)	550.2	3.5
T3	three-layered material cotton bound together with the use of polyurethane foam (5 mm), with a 100% polyamide + polyurethane coating	639.9	6.1
T4	cotton fabric	230.0	0.8
L1	suede leather	1678.1	1.5
L2	box calfskin	801.9	2.6

Table 2. Lining material characteristics.

Sample name	Material description	Mass per square meter, g/m^2	Thickness, mm
TG2a	knitted fabric: 56% polyester, 46% – modified polyamide + polyurethane foam	275.0	3.5
TG2b	knitted fabric: open weave 3D, 100% polyamide	342.1	3.3
TG2c	knitted fabric: 3D, 100% polyamide	354.8	3.1
TG3a	knitted fabric: 100% polyamide	162.2	0.6
TG3b	knitted fabric: 100% polyamide	110.3	0.8
TG3c	knitted fabric: 80% polyester, 20% modified polyamide	212.8	0.9
TG4a	woven fabric: 100% bamboo fibres	170.0	1.3
TG4b	frotte woven fabric: 100% bamboo fibres	500.0	0.5
TG4c	jacquard woven: 95% bamboo fibres, 5% polyester	300.0	0.5
TG4d	knitted fabric: 97% bamboo fibres, 3% elastane	320.0	1.0

Table 3. Basic properties of leather lining materials.

Sample name	Material description	Mass per square meter, g/m^2	Thickness, mm
LG1a	cowhide lining leather	103.4	1.6
LG1b	pig lining grain leather	413.1	0.7
LG1c	pig lining leather split	363.5	0.8

$$P = 1 - \frac{\frac{MPSM\left[\frac{g}{m^2}\right]}{h[m]}}{\rho\left[\frac{g}{m^3}\right]}, [\%] \qquad (1)$$

where, *MPSM* is the mass per square meter of the fabric, the thickness, and is the density of the fibre [20]. After the basic transformation of ***Equation (1)***, it can be obtained that the porosity of fabric is proportional to factor (*hρ – MPSM*). On the other hand, for leathers it was shown in [21] that the thermal resistance is a third – degree polynomial function of apparent specific weight. The packages created on the basis of analysis done for single materials were compared with one another with the use of an ANOVA test within comparative groups I-IV.

Research methodology

In order to determine the transient and steady state thermo physical properties of the upper and lining footwear materials, an Alambeta device (Sensora, Czech Republic) was used. Samples of 20 cm × 20 cm size were placed between the two plates. The bottom plate was heated to 32 °C, and the lower plate was of room temperature. The total amount of heat conducted away from the material surface per unit of time was measured. The plates adhere to the sample measured at a constant pressure of 200 Pa ± 20 Pa. The measurement stand was placed in normal climate conditions [22]. As a result of this measurement, the thermal ability of the material was ascertained by the following measurements: thermal resistance (*R*), conductivity (*λ*) and absorptivity (*b*).

The thermal insulation of footwear is measured by the rate of heat flow through the homogeneous material. The basic law which describes this process is Fourier's law of heat conduction, which can be expressed as follows:

$$Q = -A \cdot \lambda \frac{\partial t}{\partial n}, \left[\frac{W}{m^2}\right] \qquad (2)$$

where:

Q – local heat flux density, Wm^{-2};

A – surface area of conduction, m^2,

t – temperature at observed point of material, °K;

n – linear dimension in a direction perpendicular to the surface, mm;

λ – thermal conductivity coefficient, Wm^{-1}K^{-1}.

The thermal conductivity of ***Equation (3)*** describes the amount of heat which passes through surface *A* along with a temperature decrease of $\Delta t = 1\ K$ per thickness unit *h*.

$$\lambda = \frac{Q}{A\tau\frac{\Delta t}{h}}, \left[\frac{W}{mK}\right] \qquad (3)$$

The next parameter examined was the thermal resistance (*R*), which describes the ratio between the sample thickness (*h*) and thermal conductivity (*λ*) according to the following ***Equation (4)***:

$$R = \frac{h}{\lambda}, \left[\frac{m^2K}{W}\right] \qquad (4)$$

The static characteristics of heat flux through the materials are not enough to fully comprehension this phenomenon. In this case a significant role is played by dynamic characteristics: thermal absorptivity and thermal diffusivity. In this paper the authors focused on the thermal absorptivity values because they are immediately connected with comfort sensation, especially for higher external moisture conditions [23, 24]. This physical property describes the "warm – cool feeling", and was introduced by Hes [25]. Fabrics which are characterised by lower values of thermal absorptivity give a warmer feeling, while for higher values, the sensation is reversed. Thermal absorptivity (b) can be expressed by ***Equation (5)***:

$$b = \sqrt{\lambda \cdot \rho \cdot c}, \left[\frac{W\sqrt{s}}{m^2K}\right], \qquad (5)$$

where:

λ – thermal conductivity, Wm^{-1}K^{-1},

ρ – density of fabric, gcm^{-3},

c – specific heat of fabric, Jkg^{-1}K^{-1}.

Values of these parameters are a good projection of hygienic properties of the package materials according to the forecasting of thermal comfort conditions.

Results and discussion

The experimental results which were obtained for the single footwear materials gave a possibility to describe thermal insulation properties for footwear packages.

Test results for individual materials

The following studies were conducted for four groups of linings:

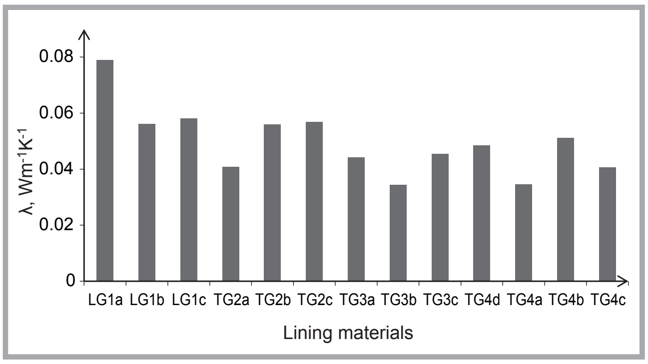

Figure 1. *Thermal conductivity of lining materials.*

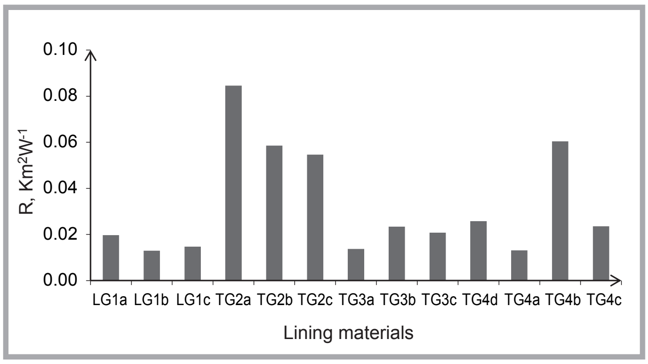

Figure 2. *Thermal resistance values for lining materials.*

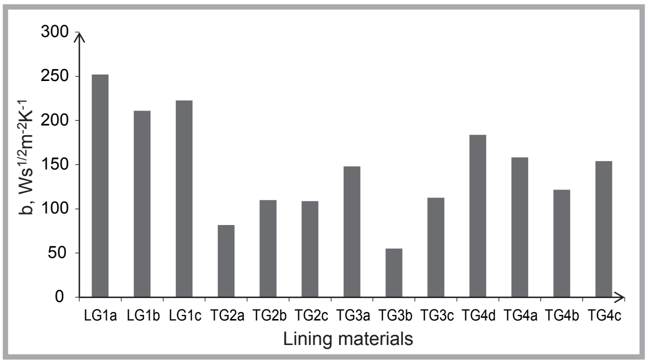

Figure 3. *Thermal absorptivity values for lining materials.*

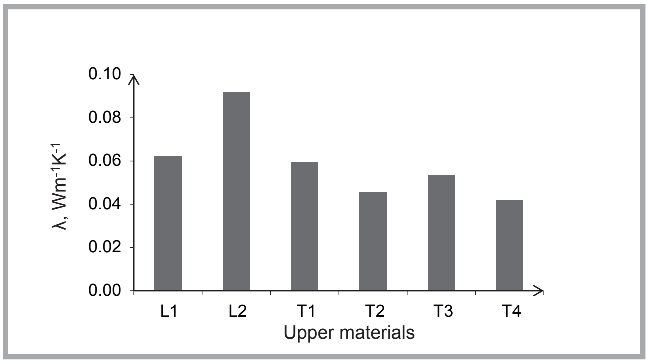

Figure 4. *Thermal conductivity of upper materials.*

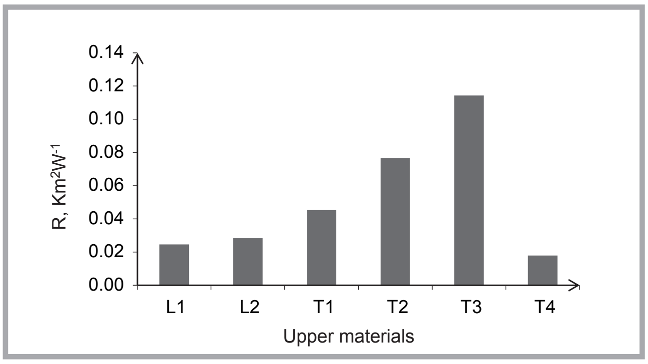

Figure 5. *Thermal resistance of upper materials.*

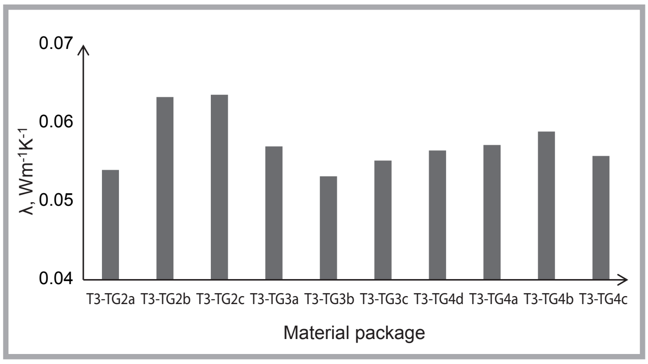

Figure 6. *Thermal conductivity of upper packages with textile lining mixed with T3 as the outer layer.*

- group I: leather (LG1a, LG1b, LG1c),
- group II: 3D knitted fabrics (TG2a, TG2b, TG2c),
- group III: textile fabrics (TG3a, TG3b, TG3c).
- group IV: textile fabrics with natural bamboo fibres (TG4a, TG4b, TG4c, TG4d).

Experimentally obtained values show that maximum thermal conductivity was reached for leather LG1a – 0.079 $Wm^{-1}K^{-1}$ (***Figure 1***).

On the other hand, the minimal value was obtained for textile fabric TG3b (0.0343 $Wm^{-1}K^{-1}$). In addition, the diversity of thermal conductivity results was stabilised at the level: 20% in group I, 17% in groups II and IV and 15% in group III.

In the case of the thermal resistance parameter (***Figure 2***), the maximum value was reached for TG2a – knitted fabric of 56% polyester and 46% polyamide and polyurethane foam – as a combining medium. Just like in the previous case, high values of thermal resistance were observed for 3D knitted fabrics TG2b (0.0585 m^2KW^{-1}) and TG2c (0.0546 m^2KW^{-1}). The coefficient of variation of the results in this group developed as follows: 22% in group I, 25% in group II, 26% in group III and 67% in group IV.

According to the dynamic indicator, the thermal absorptivity (***Figure 3***) followed from the lowest value – 55.03 $Ws^{1/2}m^{-2}K^{-1}$, reached by TG3b, to the highest – 252 $Ws^{1/2}m^{-2}K^{-1}$, reached by leather LG1a. The highest coefficient of variation – equal to 45% – was reached for materials of group III.

In the case of upper materials (***Figure 4***), leather L1 was characterised by high values of thermal conductivity – at the level of (0.0919 $Wm^{-1}K^{-1}$). At the other end was woven cotton T4 (0.0417 $Wm^{-1}K^{-1}$). In the relation of material thickness to thermal conductivity, the best insulator was three – layered textile uppers with the addition of polyurethane foam. The best

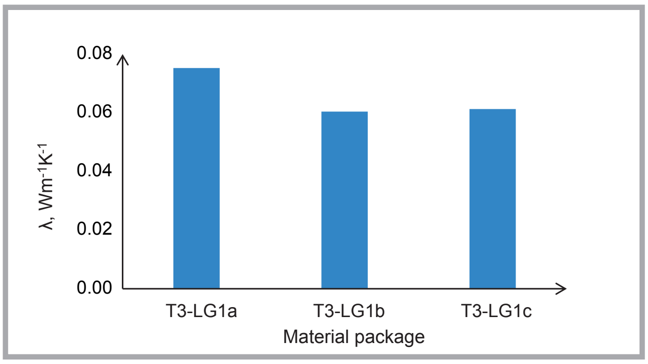

Figure 7. *Thermal conductivity of upper packages with leather lining mixed with T3 as the outer layer.*

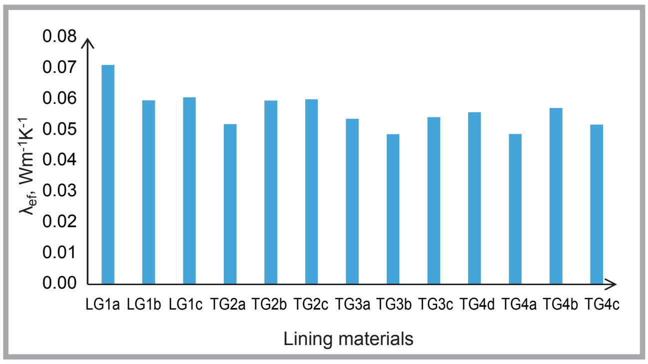

Figure 8. *Effective thermal conductivity for lining materials connected with upper L2.*

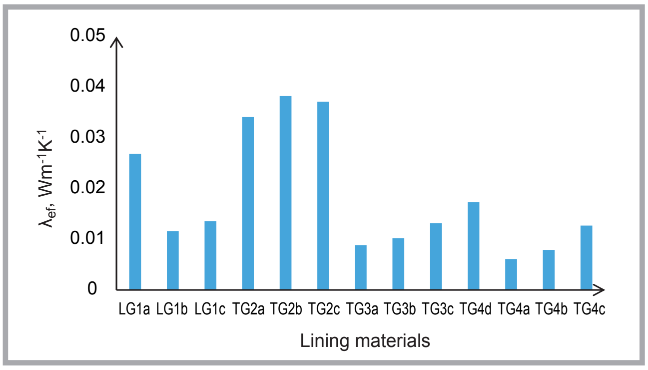

Figure 9. *Effective thermal conductivity for lining materials connected with upper T3.*

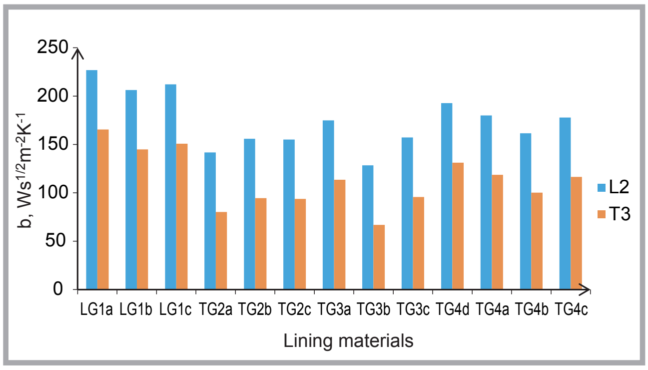

Figure 10. *Thermal absorptivity values for material packages (inner layer connected with outer T3 and L3).*

of them was T3, whose thermal resistance was equal to 0.1143 m^{2}KW^{-1}). In contrast (***Figure 5***), the lowest insulators were leather materials L2 (0.0246 m^{2}KW^{-1}) and L1 (0.0283 m^{2}KW^{-1}) and cotton material T4 (0.0179 m^{2}KW^{-1}).

According to changing external environmental conditions, which is important from the user's point of view, for upper materials the thermal absorptivity was also calculated, found to be between 307 Ws$^{1/2}$m^{-2}K^{-1} for L1 and 78 Ws$^{1/2}$m^{-2}K^{-1} for T3.

System testing results

In order to demonstrate the experimental results for the systems, the best insulator package was chosen, which was the material package created with the use of T3 as the outer layer. It was noticed that the thermal conductivity of packages with textile linings lay between 0.0532 Wm^{-1}K^{-1} for knitted polyamide fabric TG3b and 0.0636 Wm^{-1}K^{-1} for the combination with spacer polyamide knitted fabric TG2c (***Figure 6***). For leather linings, the results obtained lay between 0.0604 Wm^{-1}K^{-1} for LG1b and 0.0753 Wm^{-1}K^{-1} for LG1a (***Figure 7***).

When the sample thickness is compared to thermal conductivity, values of thermal resistance are obtained. In this case, the maximum value of thermal resistance (0.174 Km^{2}W^{-1}) was reached for TG2a, while the weakest package was TG4d (0.050 Km^{2}W^{-1}). Values obtained for leather linings lay at a similar level, from 0.101 Km^{2}W^{-1} for LG1a to 0.111 Km^{2}W^{-1} for LG1c. In respect of the thermal absorptivity property, the best packages indicated by low values of thermal absorptivity were the combinations of T3 and TG2a (82 Ws$^{1/2}$m^{-2}K^{-1}) and TG2b (86 Ws$^{1/2}$m^{-2}K^{-1}) and TG3b (88 Ws$^{1/2}$m^{-2}K^{-1}). Thus, in order to create optimal packages, it would be advisable to take ones where the thermal resistance is the highest and the thermal absorptivity – the smallest. Such conditions were fulfilled by the following packages: T3 – TG2a, T3 – TG2b and T3 – TG3b.

Optimisation issue of upper material packages

The creation of optimal thermal insulation of upper packages is possible by choosing appropriate materials as the layers of the packages formed. Using fluffy and porous materials with a loose structure is one of the ways which cause an increase in material volume and, as a consequence, an improvement in thermal insulation. On the basis of experimental results, two – layered packages were made. For these packages, the effective thermal conductivity can be expressed as follows [22]:

$$\lambda_{ef} = \lambda_w \cdot \frac{h_w}{h_w + h_z} + \lambda_z \cdot \frac{h_w}{h_w + h_z}, \qquad (6)$$

where:

λ_{ef} – effective thermal conductivity for two – layered package, Wm^{-1}K^{-1};
λ_w – thermal conductivity of inner layer, Wm^{-1}K^{-1};
λ_z – thermal conductivity of outer layer, Wm^{-1}K^{-1};
h_w – thickness of inner layer, mm;
h_z – thickness of outer layer, mm.

The highest values of thermal conductivity were reached for those packages whose outer layer was leather material L2 (***Figure 8***). Effective thermal conductivity evolved between 0.0712 Wm^{-1}K^{-1} in the composition with LG1a and 0.0487 Wm^{-1}K^{-1} in that with material TG3b. At the same time, the thermal resistance for the effective thermal conductivity calculated is proportional to the sum of thicknesses, ranging from 0.0231 m^{2}KW^{-1} for packages L2–LG1a and 0.0209 m^{2}KW^{-1} for package L2 – TG3b. The weakest packages obtained were with T3 (***Figure 9***). Thermal conductivity remained between 0.006 Wm^{-1}K^{-1} for package T3 – TG4a and 0.038 Wm^{-1}K^{-1} for package T3 – TG2b. Corresponding values of thermal resistance reached the values of 0.0009 m^{2}KW^{-1} and 0.0041 m^{2}KW^{-1}, respectively.

The highest diversity of effective thermal conductivity values was observed between the following packages: L2 – TG4b versus T3 – TG4b (0.0493 Wm^{-1}K^{-1}) and L2 – LG1b versus T3 – LG1b (0.0481 Wm^{-1}K^{-1}).

Corresponding values of thermal resistance were put into ***Table 4***.

Considering the data included in ***Table 4***, it can be pointed out that the best thermal insulation properties were reached by combining outer layer T3 with the following inner materials: TG2b (0.038 m^{2}KW^{-1}), TG2c (0.037 m^{2}KW^{-1}), TG2a (0.034 m^{2}KW^{-1}) and LG1a (0.027 m^{2}KW^{-1}). In the case of outer layer L2, the best thermal conductivity properties were can be seen in compositions with TG4b (0.057 m^{2}KW^{-1}), LG1b (0.060 m^{2}KW^{-1}) and LG1c (0.061 m^{2}KW^{-1}).

As regards the absorptivity property, which can be approximated as an algebraic sum for separate materials, higher values were observed for inner materials connected with an L2 outer layer (***Figure 10***). Due to the fact, that the thermal absorptivity property is one of the most important factor for creating better moisture management properties [26, 27], recommendations must be given for those materials or packages which have a lower absorptivity coefficient.

In order to identify the factors which determinate the thermal properties of material packages, ANOVA analysis was done within groups I-IV at a confidence level of 95%. The influence of the lining and upper layers on the cumulative values of thermal parameters was examined. In ***Table 5***, critical sets and values of the test statistics are highlighted.

The values of test statistics T lie within the critical sets, determined by a Tukey test, which was applied after the ANOVA procedure. In ***Table 6***, Tukey HSD p-values are listed.

The values listed in ***Table 6*** shows that the quality of upper materials in combination with lining materials can be a source of diversity of effective thermal conductivity. This is a consequence of differences between materials due to the thickness or porosity structure connected with the air entrapping capacity of the fabric structure [28].

Table 4. *Thermal resistance for effective thermal conductivity calculated.*

Lining materials	Thermal resistance (R_{T3}) for effective thermal conductivity (λ_{ef}) with the use of T3 as the upper layer, m^{2}WK^{-1}	Thermal resistance (R_{S1}) for effective thermal conductivity (λ_{ef}) with the use of L2 as the upper layer, m^{2}WK^{-1}	Percentage relations (R_{S1}/R_{T3}), %
LG1a	0.027	0.071	265
LG1b	0.012	0.060	514
LG1c	0.014	0.061	448
TG2a	0.034	0.052	152
TG2b	0.038	0.060	156
TG2c	0.037	0.060	162
TG3a	0.009	0.054	608
TG3b	0.010	0.049	477
TG3c	0.013	0.054	413
TG4d	0.017	0.056	323
TG4a	0.006	0.049	802
TG4b	0.008	0.057	725
TG4c	0.013	0.052	408

Table 5. *Critical sets and values of test statistics as a source of differentiation within the upper group.*

Group of materials	Critical set	Values of test statistics	p-value
I	[3.106; +∞)	9.013	<0.05
II	[3.106; +∞)	30.191	<0.05
III	[3.106; +∞)	75.386	<0.05
IV	[2.773; +∞)	24.216	<0.05

Table 6. *Set of materials which give statistically significant differences in groups I-IV.*

Group of materials	Pair compared	Tukey HSD p-value	Group of materials	Pair Compared	Tukey HSD p-value
GROUP I	L2 – T2	0.015	GROUP II	L2 – T3	0.001
	L2 – T3	0.004		L2 – T4	0.002
	L1 – T2	0.039		L1 – T3	0.004
	T2 – T3	0.009		L1 – T4	0.001
	T2 – T4	0.026		T1 – T2	0.006
	T3 – T4	0.006		T1 – T3	0.001
GROUP III	L2 – T1	0.001		T1 – T4	0.026
	L2 – T2	0.001		T2 – T4	0.001
	L2 – T3	0.001		T3 – T4	0.001
	L2 – T4	0.042	GROUP IV	L2 – T1	0.001
	L1 – T1	0.001		L2 – T2	0.001
	L1 – T2	0.001		L2 – T3	0.001
	L1 – T3	0.007		L1 – T1	0.001
	T1 – T3	0.001		L1 – T2	0.001
	T1 – T4	0.001		T1 – T4	0.029
	T2 – T4	0.001		T2 – T4	0.001
	T3 – T4	0.001		T3 – T4	0.001

Discussion

The analysis carried out in this paper showed that the possibility of creating optimal footwear packages with respect to thermal comfort properties exists for the inner and outer layers. Many aspects of layer configurations of materials are well known from garment applications. For example, in paper [29] the authors showed, that multi – layered textile – polymer composite systems with appropriate properties for each layer can provide higher comfort properties for sport's clothing. In paper [30] the authors investigated the relationships between the thermal insulation properties of single materials and multilayer textile compositions based on those materials. It was shown that on the basis of the thermal insulation properties of single textile materials, it is possible to predict the insulation properties for the thermal resistance and equivalent thermal conductivity of two – layered packages. The case of two – layered footwear material packages was analysed in papers [31] and [32], where the authors designed and analysed material packages considering physico- mechanical properties, but without the thermal insulation aspect. In paper [18] the authors described an effective way to increase insulation with new layers in the form of socks. It was shown that footwear insulation depends linearly on the number of layers. This effect is bigger in footwear with lower insulation. On the other hand, in patent [33] a new composite footwear upper was proposed, comprising a first layer of cloth material, a second layer of thermoplastic foam, and third layer of cloth material. But this formula was dedicated more for footwear used in extremely cold conditions. Similarly, in paper [14] the authors showed that doping commonly used footwear materials with microcapsules of phase change materials or carbon nanofibres can improve thermal comfort with regard to thermal energy storage during heating and cooling processes.

The problems of optimising material packages for footwear applications are very important from the user's point of view. A multitude of variables – from material characteristics to biological diversity – determine the unpredictability of some phenomena. Many authors have focused their attention on clothing, nevertheless, the nature of heat and humidity exchange processes between the skin and the external environment is different for three – dimensional subjects, as in the case of footwear.

Summary

Examination of the thermal insulation properties of single materials is a one of the most important steps to create material packages for footwear with improved hygienic properties. The optimization of footwear upper packages is the second step because it gives a possibility of eliminating weaker materials and creating compositions which can give better properties than those typically used. By using the ANOVA criterion, it was possible to find the significant differences between chosen combinations. When the differences are not significant, it is possible to replace some materials by another without losing hygienic properties. In cases where the differences are significant, the optimal material package is characterised by better properties and replacement is not recommended. This is important from the footwear manufacturer's point of view because the use of popular and cheap materials in special configurations can give an improvement in hygienic properties. The use of woven fabrics with natural bamboo fibres can improve hygienic properties with respect to water vapour management, but in order to change the thermal properties, these materials should rather have a spacer formula with a higher mass per square metre and thickness.

The different material sets proposed in this paper give a possibility to optimise the thermal insulation properties of upper packages depending on the user's expectations and environmental conditions. From each of the groups examined, the best and weakest packages were singled out, respectively as follows: L2 – TG4b, L1 – TG4b, T1 – LG1a, T2 – TG4a, T3 – TG4a and T4 – LG1a as the best insulators, and L2 – TG2a, L1 – TG2a, T1 – TG4a, T2 – TG4a, T3 – TG4a and T4 – TG2a as the least recommended packages.

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The Laboratory works and specialises in three fundamental fields:

- **R&D activities:**
  - research works on new technology and techniques, particularly environmental protection;
  - evaluation and improvement of technology used in domestic mills;
  - development of new research and analytical methods;
- **research services** (measurements and analytical tests) in the field of environmental protection, especially monitoring the emission of pollutants;
- **seminar and training activity** concerning methods of instrumental analysis, especially the analysis of water and wastewater, chemicals used in paper production, and environmental protection in the paper-making industry.

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Investigations in the field of environmental protection technology:

- Research and development of waste water treatment technology, the treatment technology and abatement of gaseous emissions, and the utilisation and reuse of solid waste,
- Monitoring the technological progress of environmentally friendly technology in paper-making and the best available techniques (BAT),
- Working out and adapting analytical methods for testing the content of pollutants and trace concentrations of toxic compounds in waste water, gaseous emissions, solid waste and products of the paper-making industry,
- Monitoring ecological legislation at a domestic and world level, particularly in the European Union.

A list of the analyses most frequently carried out:

- Global water & waste water pollution factors: COD, BOD, TOC, suspended solid (TSS), tot-N, tot-P
- Halogenoorganic compounds (AOX, TOX, TX, EOX, POX)
- Organic sulphur compounds (AOS, TS)
- Resin and chlororesin acids
- Saturated and unsaturated fatty acids
- Phenol and phenolic compounds (guaiacols, catechols, vanillin, veratrols)
- Tetrachlorophenol, Pentachlorophenol (PCP)
- Hexachlorocyclohexane (lindane)
- Aromatic and polyaromatic hydrocarbons
- Benzene, Hexachlorobenzene
- Phthalates
- Carbohydrates
- Glycols
- Polychloro-Biphenyls (PCB)
- Glyoxal
- Tin organic compounds

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