Gabriela Kosiuk, Małgorzata Matusiak*

Lodz University of Technology, Faculty of Material Technologies and Textile Design, Institute of Architecture of Textiles,
Lodz, Poland,
* e-mail: malgorzata.matusiak@p.lodz.pl

Effect of Quilting on Selected Thermo-Insulation Properties of Textile Multilayer Packages

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Abstract
The quilting process involves stitching two or more layers of fabrics to produce a thicker material, typically to make heat-insulating products. In addition to stitching, ultrasonic quilting is increasingly used. Quilted multi-layered textile materials are widely used in outerwear, especially in autumn and winter conditions. The aim of the work was to analyse the impact of the quilting process on the thermal insulation properties of multilayer textile packages. Three-layer packages were quilted using different quilting parameters. Then, the thermal protection properties of the packages were tested before and after subsequent quilting steps. Alambeta and Permetest instruments were used to test the thermal insulation properties of the packages. Based on the research performed and statistical analysis of the results obtained, it was found that quilting has a significant impact on the properties affecting the heat protection of multi-layer textile packages. Thermal conductivity, thermal resistance and thermal absorptivity depend on the number of quilting seams, stitch type and thread thickness used for quilting. Generally, quilting causes a decrease in the thermal resistance of multi-layer packages of textile materials.

Key words: *multilayer materials, quilting, thermal resistance, thermal absorptivity.*

Introduction

In outerwear, regardless of the type, the user should not be adversely affected by negative side effects. In order to avoid them, clothing must have properties that influence its heat resistance and the user's good thermal comfort. According to Hes, such properties are as follows [1]:
- thermal insulation,
- water-vapour permeability,
- air permeability.

The value of particular parameters for an appropriate feeling of thermal comfort depends mostly on the kind of clothing and climatic conditions in which the clothing will be used. Thermal insulation expresses the amount of heat that flows per unit of time through a unit of the material surface, with the same temperature difference on both sides of the clothing [2]. When the clothing has adequate thermal insulation, it protects the human body from excessive and unwanted loss of heat to the environment. The measure of the thermal insulation of materials is thermal resistance [3].

Water-vapour permeability plays a very important role in shaping the ability of clothing to provide thermo-physiological comfort. It is the ability to absorb sweat through a clothing product. Water-vapour permeability occurs as a result of the diffusion of water-vapour through the pores contained in the material structure – between threads and between fibres. Water-vapour permeability determines thermal comfort due to sweat released by the body from the skin surface during the physical activity of a person. Materials characterised by low water-vapour permeability retain water-vapour in their own interior, possibly stopping the transport of moisture, which causes condensation on the inner surface of the material. This may cause the user of the clothing to feel discomfort [3, 4].

Air permeability, is a property of a textile product that influences the shaping of climate parameters under clothing during its use. Air permeability affects the utility value of clothing products in a direct and indirect way. A direct impact takes place as a result of the circulation of gases between the human body and the environment. A indirect impact on the functional values of textile products derives from the interdependence between air permeability and thermal insulation. Air permeability influences the thermal protection properties of the clothing product, especially in the case of clothing that does not adhere closely to the surface being protected [5-7].

Quilted materials are commonly used as the middle thermal insulation layer of outerwear, for instance in winter jackets. The quilting process involves stitching two or more layers of fabrics to make a thicker material, usually to create quilted bedclothes or quilted clothing. As a rule, a typical quilting uses two or three layers

Figure 1. *Thread quilting [http://matex-tkaniny.pl/pl/produkty/tkanina-pikowana].*

Figure 2. *Ultrasound quilting [http://tkaninypikowane.pl/pikowanie_tkanin.html].*

of textile materials. The thermal insulation material is sewn together with surface material in double-layer quilting [8]. In three-layer quilting thermo-insulation nonwoven is placed between two woven materials: an outer shell and lining.

Quilting with threads is a traditional method that involves sewing a fabric or fabrics to thermal insulation material. Depending on the material thickness selected, the thread and needle are adjusted to it and the size. ***Figure 1*** shows an example of thread quilting.

Ultrasonic quilting is an innovative method of fabric quilting which takes place without the use of thread and needles [8]. The ultrasonic quilting process consists in heating the material using ultrasonic waves and pressing through direct pressure. This method allows to create regular patterns on the material and to warm the fabric with a nonwoven. In the quilting process an additional nonwoven fabric is permanently bonded with the outer material, woven or knitted. This method also allows to emboss various patterns and shapes onto materials. As a result, clothing and accessories made of quilts are distinguished by original designs, which affect their aesthetic values [8-10]. A very important advantage of this method is the lack of holes, which in quilting threads are created by needles. Thanks to this, ultrasonic quilted material does not leak water, which makes it ideally suited as an “outdoor” fabric, i.e. used in an open space. ***Figure 2*** shows an example of ultrasonic quilting.

Ensuring the thermal stability of the human body is one of the most important functions of clothing. The heat-insulating properties play a key role in the maintenance of heat by the human body, especially in winter conditions; in the worst of such the human body must first and foremost stay dry. To achieve this, the clothing should keep moisture away from the skin, and at the same time keep air close to the body dry and warm. It is also necessary to protect the body from rain and snow. To ensure all these functions at the same time, clothing for outdoor use, especially in winter conditions, is usually designed as a multi-layer structure [11]. The thermal insulation properties of multilayer textile packages depend on the type, number and order of layers as well as on the properties of the materials that make up the individual layers [3, 11, 12].

In multi-layer clothing, each layer is created by a single textile material with properties adequate to its function. Numerous studies have shown that the thermal resistance of a package of materials is close to the sum of that of individual materials, increased by a so-called contact resistance [3, 11, 12]. However, in the case of textile products, it was found that that there is often no surface contact resistance. In addition, it was found that the equivalent thermal conductivity of two-layer textile material is similar to the weighted average of the thermal conductivity of the individual materials making up the package, with the weights corresponding to the thickness of the individual materials [3, 11].

In the case of such parameters as thermal absorptivity and thermal diffusivity, no definite relationships between the values of these parameters for the material package and those of individual materials

Figure 3. *Set of quilted materials.*

Table 1. *Basic properties of fabrics applied in the quilted packages.*

Parameter	Unit	Value		
		Top layer	Middle layer	Lining
Weave	–	plain	–	Plain
Mass per square metre	gm^{-2}	187.2	45.0	107.3
Warp density	dm^{-1}	560	–	210
Weft density	dm^{-1}	310	–	170
Thickness	mm	0.26	4.28	0.46

Figure 4. Prepared multilayer package quilted using a lockstitch and 80 tkt thread after the third step of sewing.

Figure 5. Prepared multilayer package quilted using a zig-zak stitch and 80 tkt thread after the sixth step of quilting.

Table 2. Results from the Alambeta for multilayer textile packages quilted with a lockstitch using tkt 120 thread.

	R, $W^{-1}Km^2$ 10^{-3}		λ, W m^{-1} $K^{-1}10^{-3}$		b, $Wm^{-2}s^{1/2}K^{-1}$	
	ā	SD	ā	SD	ā	SD
L0	99.7	13.4	46.5	1.3	87.2	3.4
L1	102.7	10.2	43.8	0.6	58.9	4.6
L2	97.0	5.3	45.9	2.2	84.6	4.6
L3	97.5	7.3	45.1	1.4	78.5	3.4
L4	92.2	8.9	47.1	0.1	95.5	6.1
L5	90.1	8.1	46.4	0.9	96.2	5.1
L6	88.8	4.6	45.8	0.9	89.7	5.2

Table 3. Results from the Alambeta for multilayer textile packages quilted with a lockstitch using tkt 80 thread.

	R, $W^{-1}Km^2$ 10^{-3}		λ, W m^{-1} $K^{-1}10^{-3}$		b, $Wm^{-2}s^{1/2}K^{-1}$	
	ā	SD	ā	SD	ā	SD
L0	103.5	3.7	47.4	2.4	83.6	2.2
L1	107.0	7.0	44.8	0.3	61.6	5.5
L2	96.1	5.7	47.7	1.6	89.2	0.4
L3	100.5	5.7	44.5	0.3	78.4	7.0
L4	95.1	2.0	45.5	2.4	88.3	4.3
L5	91.1	2.3	45.4	1.6	95.3	4.8
L6	88.13	5.5	46.0	1.0	97.9	9.0

Table 4. Results from the Alambeta for multilayer textile packages quilted with a zig-zak stitch using tkt 120 thread.

	R, $W^{-1}Km^2$ 10^{-3}		λ, W m^{-1} $K^{-1}10^{-3}$		b, $Wm^{-2}s^{1/2}K^{-1}$	
	ā	SD	ā	SD	ā	SD
L0	102.0	5.1	48.0	2.6	85.2	1.1
L1	101.9	5.3	44.4	1.8	70.9	2.4
L2	101.3	5.1	43.8	1.8	87.6	1.5
L3	69.7	2.0	42.4	1.8	77.2	5.8
L4	93.1	6.2	44.5	1.3	95.6	2.6
L5	84.7	3.6	45.4	1.1	91.7	4.7
L6	86.3	2.5	45.1	4.3	89.3	3.0

Table 5. Results from the Alambeta for multilayer textile packages quilted with a zig-zak stitch using tkt 80 thread.

	R, $W^{-1}Km^2$ 10^{-3}		λ, W m^{-1} $K^{-1}10^{-3}$		b, $Wm^{-2}s^{1/2}K^{-1}$	
	ā	SD	ā	SD	ā	SD
L0	117.0	4.6	48.8	0.8	81.4	2.8
L1	109.7	0.6	47.4	2.5	76.2	3.2
L2	106.3	3.2	48.0	1.4	78.5	5.0
L3	105.0	1.0	44.5	1.0	79.6	3.0
L4	95.2	2.4	47.1	0.6	89.5	1.0
L5	94.2	0.7	45.3	0.9	92.4	3.2
L6	90.8	0.8	45.7	0.5	92.1	5.8

forming the layers have been found till now.

When the multilayer textile package is quilted, the parameters of quilting also play a very important role in shaping the comfort-related properties thereof, which should be taken into consideration while designing quilted materials and clothing. Numerous scientific works have been performed on the topic of multilayer textile materials, their design and performance [11-18]. However, the aspect of quilting has not been investigated till now.

The aim of the work presented was to analyse the impact of the quilting process on the thermal insulation properties of multi-layer textile packages. The analysis made it possible to observe how the quilting process contributes to shaping the heat-protective properties of multi-layer packages of textile materials.

Experimental

First, quilted three-layer packages were prepared. The top layer was a typical woven fabric for quilted jackets; the middle layer was a warming insert – polyester nonwoven, while the third layer was polyester lining woven fabric. The basic properties of materials applied in the quilted packages are presented in ***Table 1***.

The samples of fabrics had a shape of a square of 17 cm sides. The order of layers is presented in ***Figure 3***. The quilting process was conducted on two kinds of sewing machines: lock stitch and zig-zag, with the use of two kinds of sewing threads of different thickness: tkt 80 and tkt 120. Tkt (ticket number) expresses the thickness of the sewing thread. A higher ticket number means thinner thread.

The quilting process was performed in subsequent steps. The plan of the experiment is presented in ***Figure 4***.

The pictures above (***Figures 4*** and ***5***) present examples of multilayer packages after quilting.

Measurement of thermal insulation properties of the packages was made using Alambeta and Permetest test devices, both manufactured by Sensora (Czech Republic). The Alambeta is a double plate device for measurement of the thermal insulation properties of textile materials: thermal conductivity, absorp-

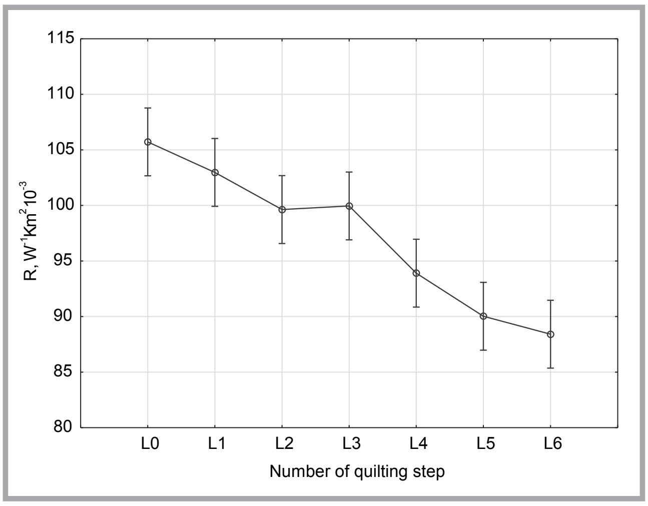

Figure 6. *Thermal resistance vs. number of sewings.*

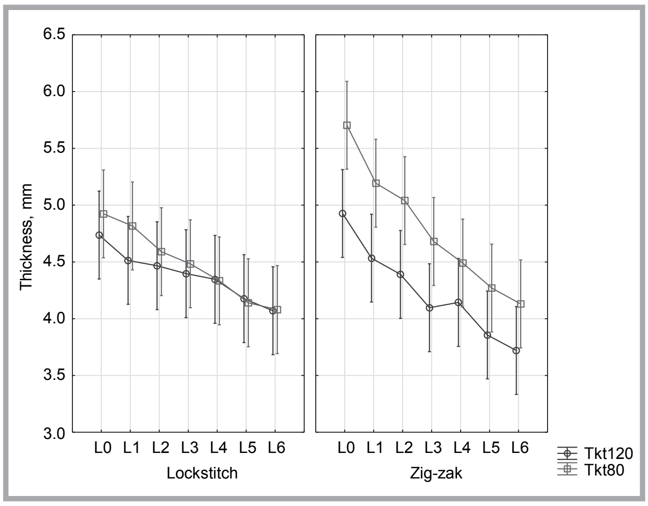

Figure 7. *Changes in package thickness due to the quilting.*

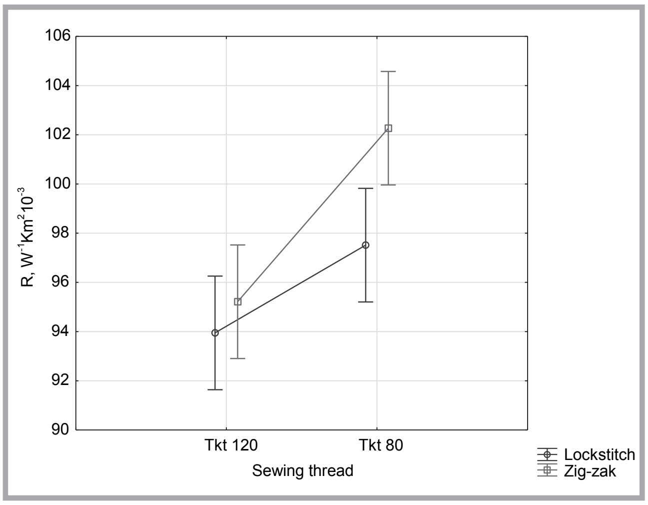

Figure 8. *Thermal resistance as a function of the kind of stitch and thread number.*

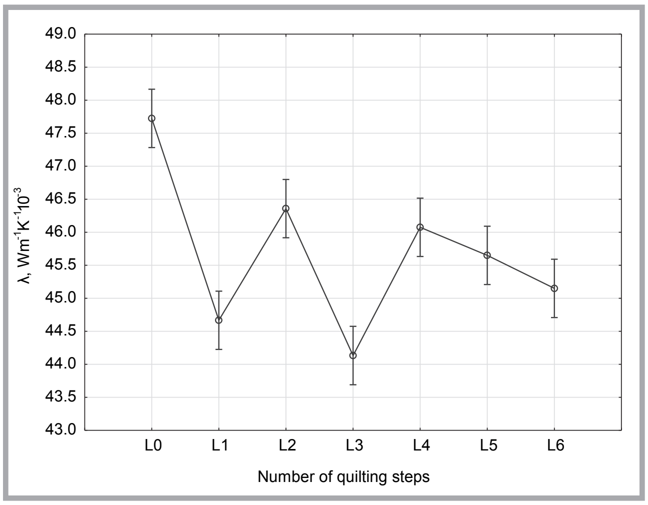

Figure 9. *Changes in thermal conductivity of the multilayer textile packages due to quilting.*

tivity, diffusivity, resistance, the ratio of maximal and stationary heat flow density, peak heat flow density and fabric thickness [1-3, 13, 15-17]. The Permetest is a portable "skin model". It measures thermal resistance, water-vapour resistance and relative water-vapour permeability. In the work presented measurement by means of the Permetest was made in the range of the water-vapour resistance and relative water-vapour permeability [3].

Measurements by means of the Alambeta were made before quilting and after subsequent steps of quilting. In the case of the Permetest, the measurement was performed before quilting and after the last step of quilting. Measurements were carried out in standard climatic conditions. For each package 3 repetitions were performed, and next the mean value from the results of 3 repetitions was calculated as a final result.

In order to analyse the influence of quilting and its parameters on the thermal insulation of the multilayer quilted packages, statistical analysis by means of ANOVA was carried out. The number of quilting steps, the kind of stitch, and the number of sewing thread were taken as the independent variables.

Results and discussion

The results of measurement by means of the Alambeta are presented in ***Tables 2-5***, in which the following symbols are applied: *L0 – L6* – steps of quilting (sewing), *R* – thermal resistance, *λ* – thermal conductivity, *b* – thermal absorptivity, ā – arithmetic mean, *SD* – standard deviation. *L0* refers to the packages without quilting.

Thermal resistance is one of the most important properties of materials and clothing for outdoor usage. It determines the ability of clothing to protect the human body against cold. Results obtained show that the quilting process causes a decrease in the thermal resistance of the multilayer quilted textile packages (***Figure 6***).

It is due to the fact that successive steps of sewing cause a decrease in the package thickness. The changes in package thickness are different for packages quilted with a lockstitch and zig-zak stitch. Moreover, the thickness of threads also influences changes in thickness of the quilted multilayer textile packages (***Figure 7***).

It was also noted that the thermal resistance of the quilted multilayer packages is higher when quilting is performed using a zig-zak stitch rather than a lockstitch. The thread number also influences the

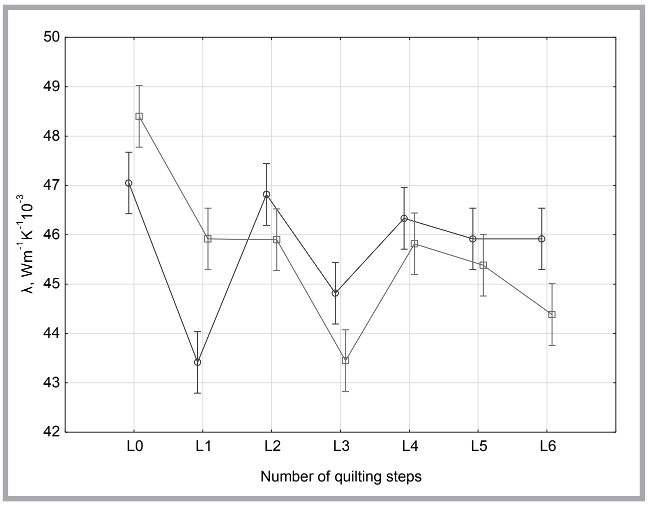

Figure 10. Changes in effective thermal conductivity of the multilayer textile packages as a function of the sewing step and kind of stitch.

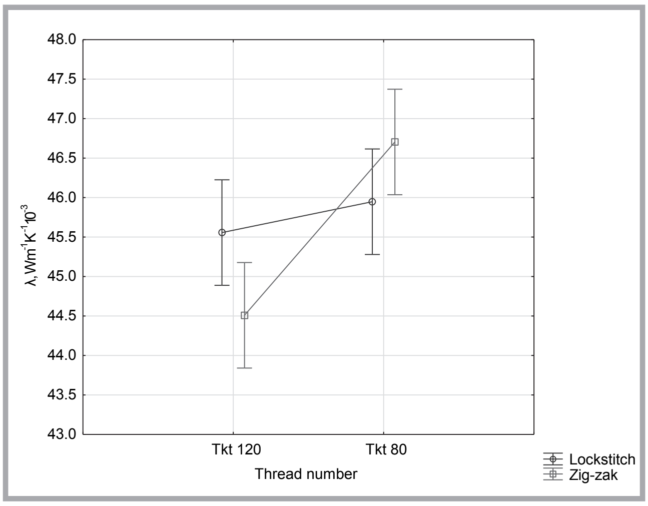

***Figure 11**. Changes in the effective thermal conductivity of the multilayer textile packages as a function of the thread number and kind of stitch.*

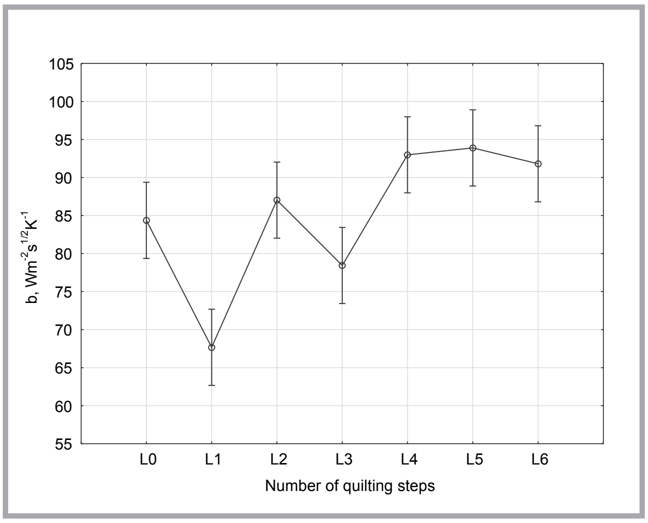

***Figure 12.** Changes in thermal absorptivity of the multilayer textile packages due to the quilting.*

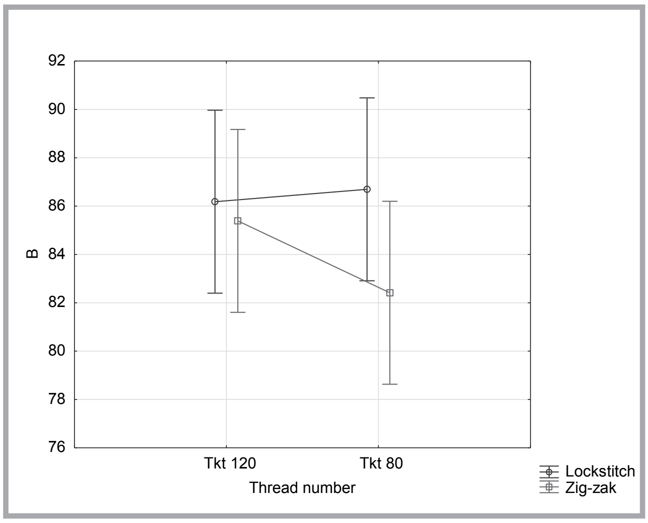

***Figure 13.** Thermal absorptivity as a function of the kind of stitch and thread number.*

thermal resistance of quilted materials (***Figure 8***). Statistical analysis confirmed that the influence of the number of quilting steps, stitch kind and thread number on the thermal resistance of quilted textile materials is statistically significant at the probability level $p = 0.05$.

Thermal conductivity decreased after 6 steps of quilting. However, at the beginning of the experiment, after successive steps of sewing, the thermal conductivity oscillated: after the first and third sewings, a decrease in thermal conductivity was observed (***Figure 9***).

Changes in the effective thermal conductivity are presented in ***Figures 10*** and ***11***. Generally, thermal conductivity is a feature of the material. In the work presented it depends of the fibres used in the fabrics investigated. Thus it does not rely on the fabric thickness. However, in the case of the multilayer textile packages, these are not homogenous materials. Due to this fact we analysed the so-called effective or equivalent thermal conductivity, which is usually determined for heterogenous materials [20]. The results obtained showed that the effective thermal conductivity of the quilted packages is modified by the kind of stitch (***Figure 10***). Similar to the thermal resistance, the ANOVA results confirmed that the influence of the number of quilting steps, stitch kind and thread number on the value of effective thermal conductivity is statistically significant at the probability level $p = 0.05$. There is also a statistically significant interaction between the kind of stitch and thread number applied in quilting (***Figure 11***).

Thermal absorptivity characterises fabrics in the aspect of the warm/cool feeling in the first contact of human skin with the material. Higher thermal absorptivity means a cooler feeling while contact with it [3, 19]. The quilting process influences the values of thermal absorptivity (***Figure 12***).

Similar to the thermal conductivity, at the beginning of the experiment, the oscillation of thermal absorptivity can be observed. Finally, after the last step of quilting, the value of thermal absorptivity is higher than that of thermal absorptivity before the quilting process. Both the thread number and kind of stitch influence the value of thermal absorptivity. The influence of the thread number on thermal absorptivity is modified by the kind of stitch applied in quilting (***Fig-***

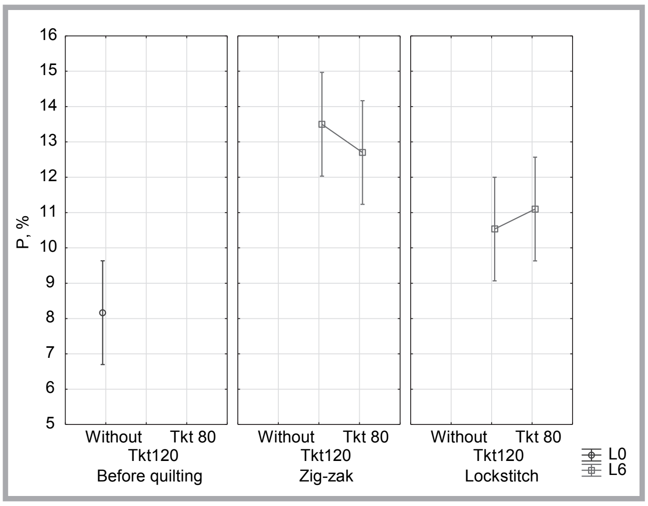

Figure 14. Relative water-vapour permeability of textile packages before and after quilting.

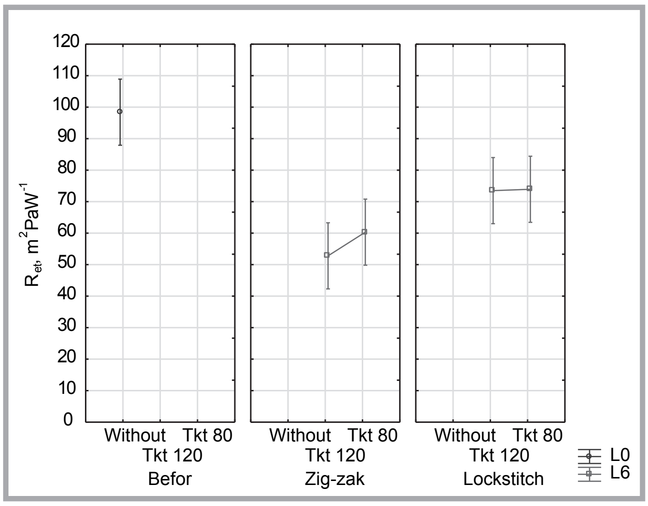

Figure 15. Water-vapour resistance of textile packages before and after quilting.

ure 13). Statistical analysis confirmed that the interaction between the thread number and kind of stitch is statistically significant at the probability level p = 0.05.

Table 6 presents the results from the Permetest. The following abbreviations were applied: *L0 – L6* – steps of quilting (sewing), *P* – relative water vapour permeability, R_{et} – resistance to water vapour, ā – arithmetic mean, *SD* – standard deviation.

The measurements performed showed that the quilting process influences the relative water-vapour permeability of the quilted textile packages. In the same way it affects the ability of quilted textile packages to ensure physiological comfort.

The dependence of the relative water-vapour permeability on the thread thickness and kind of stitch is presented in ***Figure 14***. The graph shows that the quilting process improved the water-vapour permeability of the quilted textile packages significantly. It can also be seen that the zig-zak stitch provides better (higher) relative water-vapour permeability, which for the packages tested is between 12 and 14%. This is not too high taking into account that the value of relative water-vapour permeability can be in the range from 0 to 100 %.

The next graph (***Figure 15***) shows the water-vapour resistance of the quilted textile packages in dependence on all independent factors: thread thickness, kind of stitch and number of seams. It is clearly visible that all independent factors analysed affect the water-vapour resistance of multilayer quilted packages. Of all variants of the quilted packages, the lowest value of water-vapour resistance was noted for the zig-zag stitching package using tkt 120 thread.

Table 6. *Results from the permetest.*

	P, %		R_{et}, m^2 Pa W^{-1}	
	ā	SD	ā	SD
Lockstitch, thread tkt 120				
L0	8.2	0.4	98.4	6.5
L6	10.5	1.5	73.5	13.9
Lockstitch, thread tkt 80				
L0	8.2	0.4	98.4	6.5
L6	11.1	0.6	73.9	4.3
Zig-zak stitch, thread tkt 120				
L0	8.2	0.4	98.4	6.5
L6	13.5	1.9	52.8	8.8
Zig-zak stitch, thread tkt 80				
L0	8.2	0.4	98.4	6.5
L6	12.7	0.2	60.3	1.1

Summing up

The aim of this work was to analyse the impact of the quilting process on the thermal insulation properties of multilayer textile packages. The analysis made it possible to notice how the quilting process contributes to the thermo-physiological comfort of usage of multi-layer clothing.

The investigation focuses on the quilting process and properties of quilted multilayer packages. Alambeta and Permetest instruments were used to test the thermal insulation properties of the packages, determining the parameters characterising the ability of the quilted materials to provide thermo-physiological comfort.

The research and results obtained allowed to formulate the following conclusions:

- The quilting process and its most important parameters, i.e. the number of seams, the type of machine stitch, and the thickness of the thread, affect the thermal insulation properties of multi-layer textile packages.
- The quilting process causes a decrease in thermal resistance of multilayer materials. Quilting with thicker thread (tkt 80) provides higher thermal resistance than that with thinner (tkt 120) thread. When using a zig-zag stitch, thermal resistance is higher than when using the lockstitch.
- After analysing the results of the thermal resistance measurement, it was found that from the point of view of the heat insulation of the packets,

the best effect was obtained by using a zig-zag stitch and the tkt 80 thread.

- In terms of the effective thermal conductivity of the packages, the analysis showed that the number of stitches and thread thickness have a statistically significant influence on shaping this parameter. The thermal conductivity of the quilted packages is higher with the use of thread with a trade number tkt 80 than with with tkt 120 thread.
- The use of a thinner thread, tkt 120, provided a higher value of thermal absorptivity than with the use of a thicker thread – tkt 80. When quilting with a lockstitch, the value of thermal absorptivity is higher with the use of thread with a trade number tkt 80 than when using tkt 120 thread.
- The influence of the kind of stitch on the thermal absorptivity value of quilted packages is modified by the thread thickness.
- All factors of the quilting process analysed influence the water-vapour resistance and relative water-vapour permeability of the multilayer quilted packages.
- Packages sewn with a zig-zag stitch have higher relative water-vapour permeability than that sewn with a lockstitch. The zig-zak stitch provides better relative water-vapour permeability, which is between 12 and 14%.

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