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Study of Quilted Fabrics Used in Outdoor Clothing

Raziskava prešitih tkanin za vrhnja oblačila za nošenje na prostem

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Abstract

Quilted fabrics are more and more frequently used in outdoor clothing, especially jackets. They are usually composed of two or three layers connected together by sewing or thermal quilting. They are characterised by different properties, depending on the structure of the quilted fabrics. In the presented work, five variants of quilted fabrics were studied in terms of of their comfort-related properties, such as thermal resistance, thermal conductivity, thermal absorptivity, water-vapour resistance and air permeability. On the basis of the results, it was possible to assess the quilted fabrics from the point of view of their usability for outdoor clothing.
Keywords: quilted fabric, thermal insulation, thermal conductivity, thermal absorptivity, water-vapour resistance

Povzetek

Prešite tekstilije se čedalje pogosteje uporabljajo za vrhnja oblačila, še zlasti za suknjiče in jopice. Po navadi so izdelane iz dveh ali treh slojev, medsebojno povezanih s šivanjem ali toplotnim spajanjem. Njihove lastnosti so odvisne od strukture prešitih tekstilij. V tej raziskavi je bilo primerjanih pet kombinacij prešitih tekstilij z vidika udobnosti: toplotni upor, toplotna prevodnost, absorpcija toplote, odpornost proti prehajanju vodne pare in zračna prepustnost. Na podlagi rezultatov meritev je bila podana ocena uporabnosti prešitih tekstilij za vrhnja oblačila na prostem.
Ključne besede: prešite tekstilije, toplotna izolacija, toplotna prevodnost, absorpcija toplote, odpornost proti prehajanju vodne pare

1 Introduction

Clothing is defined as a textile product that covers the human body. A clothing product is made of patterns obtained on the basis of the dimensional characteristics of the human body. A clothing product is a collection of many materials, mainly textiles, selected in such a way to achieve identified utility functions. The construction and form of clothing depend mainly on the structure and shape of the human body, the functions that a product should perform, the conditions in which clothing will be used, in particular climatic conditions, customs, fashion trends, etc.

Clothing products are classified according to different criteria, such as the intended target group, manufacturing process, material and specific purpose. Clothing can be classified as single-layer or multilayer products, depending on the degree of complexity. In multilayer clothing products, there are typically three layers that perform different roles:

– outer shell,
– middle layer,
– lining.

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In winter clothing, a very important role is played by the middle layer, the basic function of which is to protect the human body against the cold. Different kinds of textile materials are used as the middle thermal insulating layer of multilayer clothing, such as traditional wadding, non-woven fabrics or polar flees. There are also innovative, highly advanced thermal insulating materials, such as Thermore® non-woven fabrics or membrane systems that ensure excellent thermal insulation connected with physiological comfort.

Thermore® offers several lines of products used as a thermal insulator in outerwear. Thermal-insulation non-woven materials are available in different thicknesses, defined as High Loft (HL), Compact (C) and Supercompact (SC). Thermore® only offers over 20 weight and thickness options in its traditional line.

Gore-Tex products represent the most popular membrane system used in outerwear. They usually consist of three or four layers: outer shell, semi-permeable membrane, thermal-insulation material and lining.

In recent years, quilted fabrics are commonly used as the middle thermal-insulation layer of outdoor clothing. Quilted fabrics are also used alone in the manufacture of outdoor clothing, particularly jackets (Figure 1).

Figure 1: Woman's jacket made of quilted material

Quilting is the process of sewing two or more layers of fabrics together to make a thicker padded material, usually to create a quilt or quilted garment. As a rule, typical quilting uses two or three layers. The thermal insulating material is sewn together with a surface material in two-layer quilting (Figure 2).

Figure 2: Example of two-layer quilted fabric made by sewing

PES fleece is usually placed between two woven fabrics (the outer fabric and lining) in three-layer quilted thermal-insulation material.

The quilting process can be performed through sewing (Figure 2) or ultrasonic quilting (Figure 3).

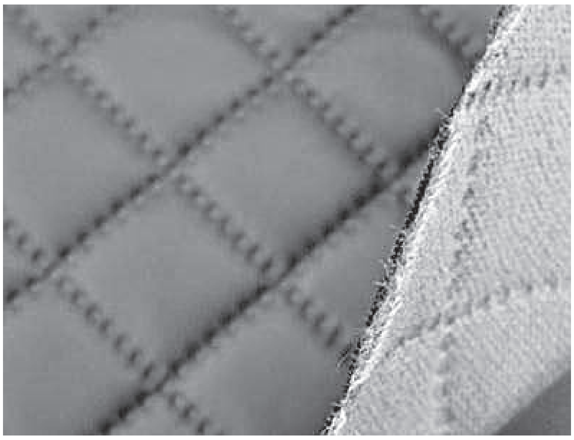

Figure 3: Example of two-layer quilted fabric made through ultrasonic quilting

The quilted fabrics can be finished in different ways, for example: PU or PVC coating, waterproof, breathable, reflective, etc. The properties of quilted fabrics, particularly their thermal insulation, have a significant impact on the ability of clothing to provide protection against the cold in an outdoor microclimate.

Quilted fabrics are a multilayer set of materials. According to studies, the properties of multilayer textile materials, particularly their thermal insulation properties, are influenced heavily by the properties of the specific fabrics used to create layers [1−3]. Studies have confirmed that the thermal resistance of multilayer textile materials is close to the sum of the thermal resistance of individual layers [2, 3]. Das et al. created a theoretical model for predicting the thermal resistance of multilayer textile packages [2]. Generally, the thermal resistance of multilayer textile packages is expected to be higher than the sum of the thermal resistance of the parallel fabrics that create such a package. This is due to air gaps between layers. Studies have shown, however, that this is not true in the case of textile materials [3]. It was determined that the flexibility and structure of textile materials, particularly their texture and the different directions of fibres in the specific materials used to create layers, result in the occurrence of two factors:

- an increased number of contact points, and
- the filling of the pores in one layer by the elements of the adjacent layer.

As a consequence, multilayer assemblies have a tighter structure than assemblies made of solid, rigid materials, with the lower amount of air between layers resulting in lower thermal resistance [4].

In the case of thermal conductivity, studies have confirmed that the equivalent thermal conductivity of a two-layer textile assembly is approximately equal to the weighted mean of the thermal conductivity of specific components with weights reflecting the thickness of layers.

In the case of assemblies composed of more than two layers, the equivalent thermal conductivity differs significantly from the weighted mean of the thermal conductivity of components [3].

The above-mentioned studies were performed for sets of materials lying parallel to one another but not joined together. In the case of quilted fabrics, we can expect the quilting process to affect the comfort-related properties of the materials used.

1.1 Aim of work

The aim of our work was to study the quilted textiles used in outdoor clothing. Different types of two- and three-layer quilted fabrics were measured in terms of their basic physical parameters and the properties that affect the thermo-physiological comfort of clothing made of such fabrics. The goal of the study was to demonstrate the difference between various quilted fabrics of seemingly similar quality. The measurement results obtained facilitated the assessment of studied quilted fabrics from the point of view of their usability for outdoor clothing.

2 Materials and methods

In the scope of our presented work, different types of quilted fabrics were measured in terms of their comfort-related properties. They were:

- three variants of two-layer quilted fabrics,
- one variant of three-layer PES quilted fabric, and
- one variant of three-layer PES/CV quilted fabric.

The set of studied quilted fabrics is presented in Table 1.

All variants of two-layer quilted fabrics were composed of PES fleece as a thermal insulation layer. In the Q1 quilted fabric, a woven fabric made of viscose fibres was used as an outer layer. In the Q2 and Q3 quilted fabrics, PES woven fabric was used as the surface layer. In the case of Q2 quilted fabric, the outer woven fabric was given a waterproof finishing. The three-layer Q4 quilted fabric (Figure 4) was composed of a middle layer made of PES fleece, and surface and bottom layers made of PES woven

Table 1: Set of studied quilted fabrics

Symbol	No. of layers	Content	Mass per square meter [gm^{-2}]	Thickness [mm]
Q1	2	PES/CV	217.2	3.22
Q2	2	PES (waterproof finishing)	129.8	2.42
Q3	2	PES	120.5	2.00
Q4	3	PES	172.5	1.56
Q5	3	PES/CV	191.4	1.30

fabrics. The three-layer Q5 quilted fabric (Figure 5) was created from PES fleece, a surface layer of CV woven fabric and a bottom layer of PES net.

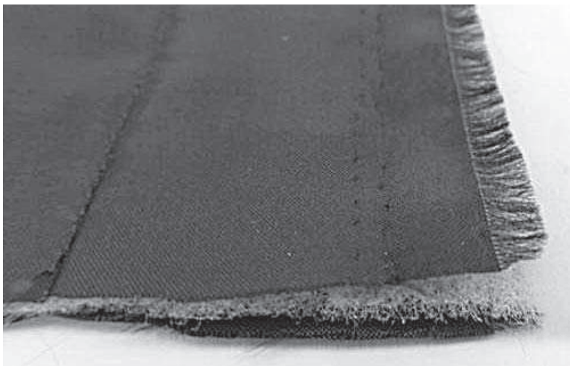

Figure 4: Three-layer Q4 PES quilted fabric

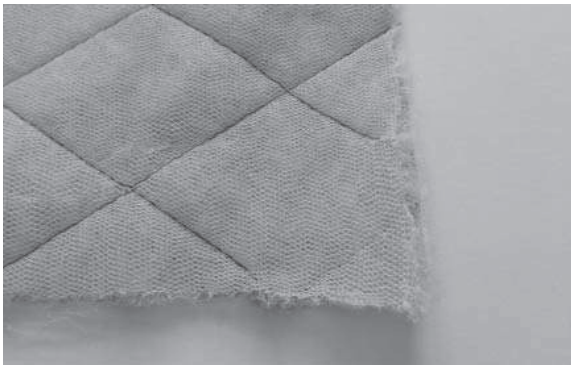

Figure 5: Three-layer Q5 PES/CV quilted fabric

All of the above-mentioned quilted textile materials were measured in terms of their properties that affect thermo-physiological comfort. The measurement of thermal insulation properties was performed using the Alambeta device. The Alambeta device is a computer-controlled instrument used to measure the basic static and dynamic thermal characteristics of textiles [1, 3–5]. It measures seven fabric properties: thermal conductivity, diffusivity, absorptivity, resistance, maximum heat flow density, a ratio of maximum and stationary heat flow density, and material thickness. The measurement of thermal insulation properties using the Alambeta device is standardised in the internal standard of the Textile Faculty of the Technical University of Liberec (Internal Standard No. 23-204-02/01 "Measurement of the thermal properties by ALAMBETA device") [5]. Measurements were performed for the right and left side of quilted fabrics. Generally, it is important to measure the fabrics in a configuration that is appropriate to the conditions in which they will be used. This means that the layer closest to the human body should adhere to the upper plate, whose temperature corresponds to the temperature of the human skin. However, quilted fabrics, particularly three-layered fabrics, are sometimes used in reversible clothing. In other cases, two-layer quilted fabrics are used in clothing in such a way that the outer woven fabric creates the lining of a jacket. In such situations, an additional fabric is used as the outer shell of the jacket. Taking this into account, measurements using the Alambeta device were taken for both sides of the studied materials.

Figure 6 presents the placement of the studied quilted fabrics during measurement with the Alambeta device.

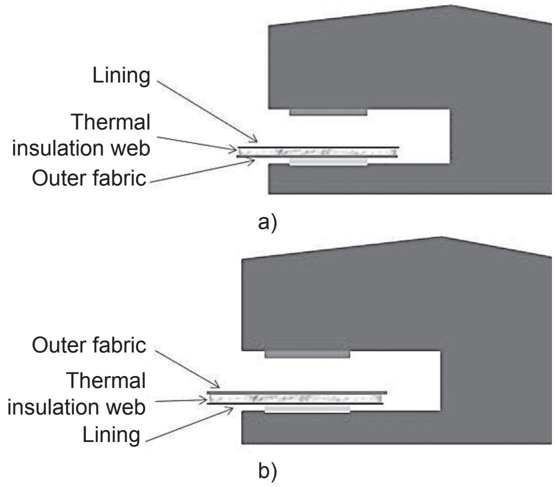

Figure 6: Placement of quilted fabric: a) in the first step of measurement using the Alambeta device, b) in the second step of measurement using the Alambeta device

Water-vapour resistance was determined using the sweating guarded hot-plate test method according to the relevant ISO standard [6]. The instrument, referred to as a "skin model", measures thermal resistance (R_{ct}) and water-vapour resistance (R_{et}). It consists of a heated metallic plate surrounded on most of its surface by a thermal insulation layer adhered to a metallic heated ring maintained at the same temperature by means of a temperature control system [6]. When assessing water-vapour resistance (R_{et}), both the measuring plate and air temperature are maintained at 35 °C (to achieve isothermal conditions), while the porous layer is continuously filled with water. Heating power, without a specimen, is then measured and saved. In the second step, the

specimen is inserted between the measuring plate and the wind channel, and the steady-state and heating power are recorded again. All power values are then used for the calculation of water-vapour resistance values according to the relevant standard [7].
Air permeability was measured according to the Polish Standard [8]. Air permeability determines the resistance of fabrics (woven, knitted and non-woven) to the passage of air [9]. The air permeability of clothing directly affects the exchange of gas between a human and their surroundings and, thus the physiological comfort of the clothing user. For this reason, air permeability is considered one of the crucial comfort–related properties of clothing.

3 Results

The results from the Alambeta device are presented in Tables 2 and 3. Table 2 presents results from the measurement of materials that were placed in such a way that the thermal-insulation non-woven fabrics adhered to the hot plate. The results obtained show that the studied quilted fabrics differ from each other in terms of their comfort-related properties. Only the thermal conductivity of the studied quilted fabrics is at the same level. This was due to the fact that all studied materials were made of the same kind of fibres, i.e. PES fibres. PES fibres were in the woven fabrics and in the fleece between the fabrics. The only exception was the Q5 material, which contained CV woven fabric as a shell.
The thermal resistance of the studied quilted fabrics ranged from 0.026 to 0.120 $m^2K\ W^{-1}$. The highest thermal resistance was recorded for the Q1 quilted material, while the lowest was recorded for the Q4 material. The thermal resistance of the studied quilted fabrics was highly dependent on their thickness (Figure 7).

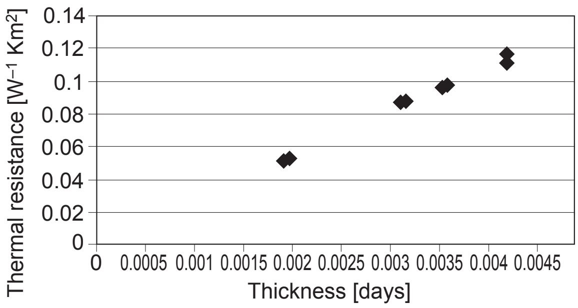

Figure 7: Thermal resistance vs thickness

Table 2: Results from the Alambeta device – thermal-insulation non-woven fabrics adhered to the hot plate of the device

Sample	Thermal conductivity [$Wm^{-1}K^{-1}$]	Thermal diffusivity x 10^{-7}[m^2s^{-1}]	Thermal absorptivity [$Wm^{-2}s^{1/2}K^{-1}$]	Thermal resistance [m^2KW^{-1}]
Q1	0.03605	5.25	49.8	0.116
Q2	0.03659	7.05	43.6	0.098
Q3	0.03569	6.10	46.2	0.087
Q4	0.03707	2.55	73.5	0.051
Q5	0.03675	3.84	59.7	0.053

Table 3: Results from the Alambeta device – outer PES woven fabric adhered to the hot plate of the device

Sample	Thermal conductivity [$Wm^{-1}K^{-1}$]	Thermal diffusivity x 10^{-7} [m^2s^{-1}]	Thermal absorptivity [$Wm^{-2}\ s^{1/2}\ K^{-1}$]	Thermal resistance [m^2KW^{-1}]
Q1	0.03757	2.59	73.9	0.112
Q2	0.03713	3.26	65.1	0.096
Q3	0.03550	3.99	56.3	0.088
Q4	0.03709	2.37	76.2	0.052
Q5	0.03720	1.88	85.9	0.052

By measuring the quilted fabrics in the opposite position (i.e. with the outer fabric adhered to the hot plate, as seen in Table 3), different values were obtained for some thermal insulation parameters. A comparison of the results is presented in Figures 8 to 11.

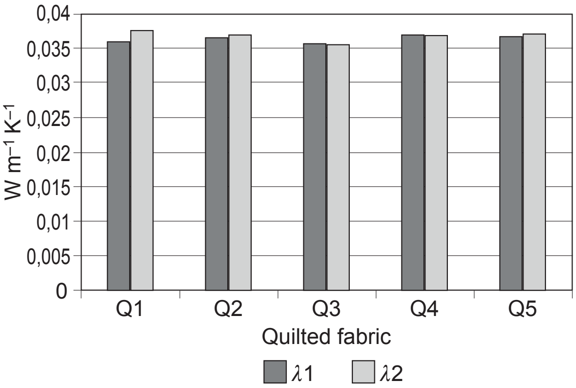

Figure 8: Thermal conductivity of studied quilted fabrics: λ_1 – placement of specimen with the thermal-insulation layer upward; λ_2 – placement of specimen with the outer fabric upward

In the figures, the results obtained by placing the materials with the thermal-insulation layer upward are marked with 1, while the results obtained by the opposite placement are marked with 2.

In terms of thermal conductivity, the results obtained by measuring the materials from both sides are very similar. There are minor differences that could be explained by the precision of measurement or the unevenness of sample structure. Particularly in the case of thermal-insulation non-woven materials, their thickness and the packing density of fibres are characterised by some irregularity.

A similar situation was seen in terms of thermal resistance (Figure 9).

Significant differences were seen in terms of the values of thermal absorptivity (Figure 10). Thermal absorptivity characterises textile materials from the point of view of their warm/cool feeling in first contact with human skin [4, 5]. A lower value of thermal absorptivity means a warmer feeling while touching. In the case of the studied materials, higher values of thermal absorptivity were recorded when the outer woven fabric adhered to the hot plate of the Alambeta device. The Q4 quilted material is the exception here. This was due to the fact that the Q4 material had the same PES woven fabric on both sides of the thermal-insulation fleece. For this reason, the placement of the Q4 quilted material did not affect the results from the Alambeta device. For other studied materials, a much warmer touch was ensured by the non-woven layer, which is traditionally considered the inner layer of quilted clothing. This should be taken into account when designing clothing made of quilted materials.

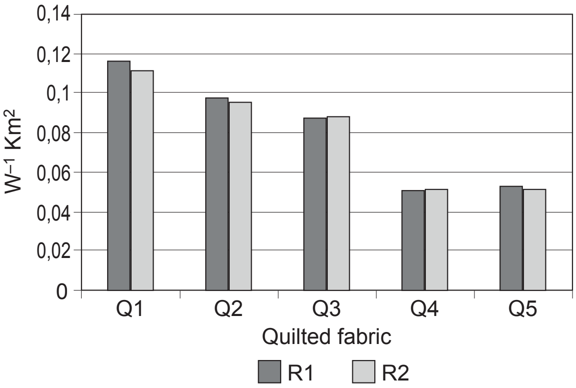

Figure 9: Thermal resistance of studied quilted fabrics: R_1 – placement of specimen with the thermal-insulation layer upward; R_2 – placement of specimen with the outer fabric upward

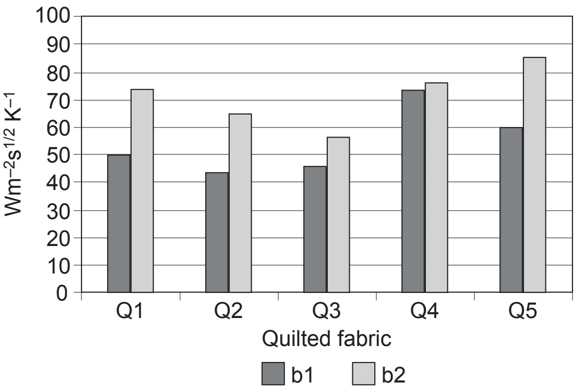

Figure 10: Thermal absorptivity of studied quilted fabrics: b_1 – placement of specimen with the thermal-insulation layer upward; b_2 – placement of specimen with the outer fabric upward

Significant differences were also recorded in terms of thermal diffusivity. The values measured when the outer PES woven fabrics adhered to hot plate are much lower than for the opposite placement of the studied samples. As with thermal absorptivity, similar thermal diffusivity values were recorded on both sides of the Q4 material (Figure 11).

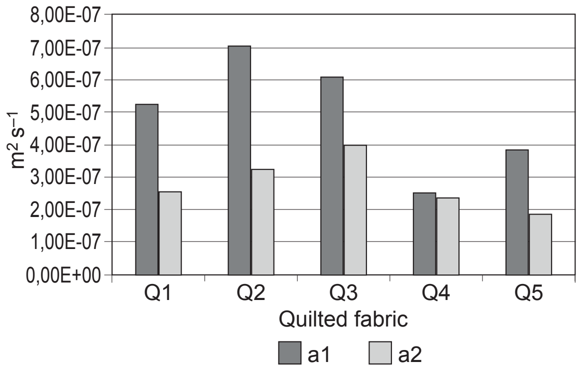

Figure 11: Thermal diffusivity of studied quilted fabrics: a_1 – placement of specimen with the thermal-insulation layer upward; a_2 – placement of specimen with the outer fabric upward

Table 4 presents the results of water-vapour resistance and air permeability.

A significant differentiation was also observed in terms of water–vapour resistance and air permeability. The highest water-vapour resistance was recorded for the Q2 quilted material, while the lowest value as recorded for the Q5 material. The highest air permeability was identified for the Q3 quilted fabric, while the lowest value was recorded for the Q2 material. The highest water-vapour resistance and the lowest air permeability of the Q2 quilted fabric was the result of the waterproof finishing of the surface woven fabric.

In terms of the functionality of the quilted fabrics, the most important role is played by their thermal resistance. It determines the protection of the clothing user against the cold. Figure 7 shows that the thickness of the quilted fabrics affects their thermal resistance. However, the quilting process also has some affect. Figure 12 presents a thermogram of a vest made of the Q2 quilted fabric. It is evident that the temperature of the vest surface is higher in the places where the vest was sewn than the temperature between seems. This means that the thermal insulation of the quilted fabric is lower where it was sewn than in areas between sewing. This confirms the effect of sewing on the thermal insulation of the quilted materials.

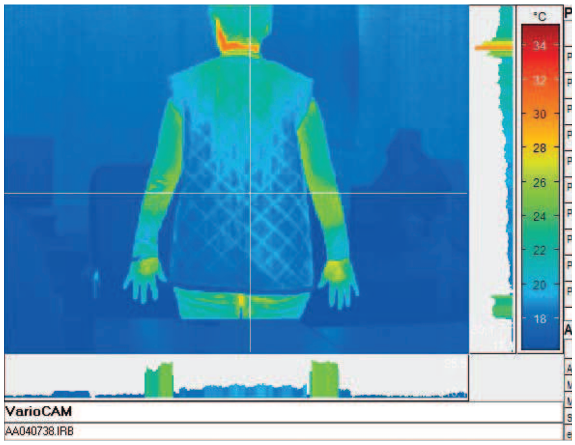

Figure 12: Thermogram of a vest made of Q2 quilted fabric

In order to use the studied quilted fabrics in outdoor clothing, we must analyse the results and choose the appropriate material, depending on the type of clothing product and its functionality.

4 Conclusion

Quilted fabrics are used in different kinds of outdoor clothing, particularly jackets. They may differ from each other in terms of their:

- structure (two- or three-layer),
- fibre composition (mostly PES, CV, CO),
- finishing (coating, reflective, waterproof, etc.),
- stitch pattern (diamond, double diamond, square, stripes, ornament stitch, etc.), and
- properties (thickness, mass per square meter, thermal insulation, air permeability and water-vapour resistance).

Table 4: Water-vapour resistance and air permeability of studied quilted fabrics

Sample	Water-vapour resistance [m^2PaW^{-1}]	Air permeability [mms^{-1}]
Q1	11.94	282.9
Q2	12.69	84.4
Q3	8.93	390.2
Q4	9.05	231.6
Q5	6.36	227.1

The presented study shows that the comfort-related properties of the quilted fabrics differ. There are also differences between the values of thermal absorptivity and thermal diffusivity measured on both sides of the quilted materials. The comfort-related properties of the quilted textiles depend of their structure, the number and fibre composition of layers, and thickness. The thermal resistance of materials made from the same kind of fibres is strongly linked to material thickness.

The type of stitch and the density thereof also affect the thermal resistance of quilted materials. Generally, stitching causes a decrease in the thermal insulation of quilted material comprising a set of parallel fabrics. However, this problem requires further study. The waterproof finishing applied to the outer fabric affects the water-vapour resistance and air permeability of quilted material.

In order to use the quilted fabrics in clothing, we must take into account the conditions in which clothing will be used and the user's expectations regarding the protective and comfort functions of clothing. Thermal resistance should be the most important factor for winter clothing. A higher thermal resistance ensures better protection against the cold. On the other hand, water-vapour resistance should be as low as possible to ensure the absorption of sweat away from the skin.

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