INNOVATIVE 3D COTTON TEXTILES ENSURING THERMO-PHYSIOLOGICAL COMFORT

Małgorzata Matusiak
Lodz University of Technology,
Faculty of Material Technologies and Textile Design,
Institute of Architecture of Textile,
Lodz, POLAND
malgorzata.matusiak@p.lodz.pl

Abstract

Paper presents innovative textile materials made of cotton and its blends with advanced chemical fibres. The seersucker woven fabrics were developed in order to obtain the materials ensuring thermo-physiological comfort. In developed fabrics cotton fibres were applied together with advanced man-made fibres such us: moisture management fibres and silver containing filaments.
Investigations confirmed that the fabrics are characterized by excellent comfort-related properties. Additionally the fabrics exhibit the surface properties making possible to apply the newly elaborated fabrics in functional clothing products, for instance in therapeutic or antiaging clothing.

Key words: cotton, woven fabrics, man-made fibres, physiological comfort

Introduction

Assurance of the thermal stability of the human being is one of the most important functions of clothing. Clothing creates a barrier between the skin surface and surroundings. The barrier influences not only the heat exchange by the convection and radiation but also by the evaporation of an excreted sweat. The influence of clothing on the heat exchange between the human being and surroundings is very complicated. It depends on many factors. The micro- and macrostructure of clothing and thermal-insulation properties of particular materials creating clothing layers are considered as one of the most important factors from the point of view of thermo-physiological comfort.
Thermal or thermo-physiological comfort can be defined as "that condition of mind which expresses satisfaction with the thermal environment" [1]. The reference to "mind" indicates that it is essentially a subjective term. However, extensive research has been performed in this area and a number of indices exist, which can be used to assess environments for thermal comfort [2]. Fanger suggested three conditions for thermo-physiological comfort. These are: heat balance of body as well as the proper mean skin temperature and sweat rate within limits required for comfort [3]. Thermal comfort is generally connected with sensations of hot, cold, dry or dampness in clothes and is usually associated with the environmental factors, such as: temperature, humidity and wind velocity as well as specific features of human body and parameters of clothing set (fig. 1).

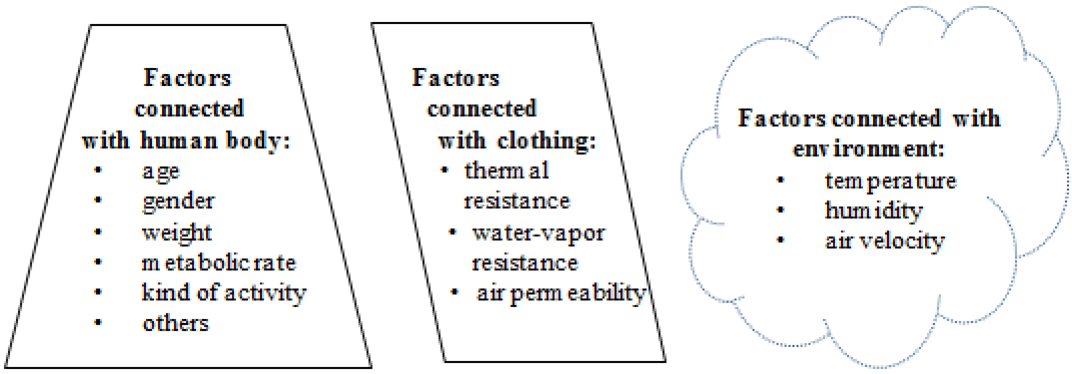


Fig. 1. Main factors influencing a thermo-physiological comfort

Different textile materials and their sets are applied in thermal-insulation clothing. Traditionally, the fabrics ensuring the thermal insulation are made of wool fibres. It is due to the features of wool fibres as natural insulators. Wool insulates against heat and cold. It is comfortable in both hot and cold weather because it absorbs moisture vapour. The crimp of the wool fibres and their resilience make them stand apart from each other creating air gaps between the fibres. Unventilated air trapped in the air gaps is an excellent thermal insulator [4]. The thermal insulation of fabrics and clothing can be improved by appropriate structure of fibres and fabrics, for instance an application of innovative thermal insulation fibres, such as hollow fibres made of synthetic polymers. The air inside the hollow fibres increases the thermal resistance of fibres and fabrics made of them.

In the area of thermal insulation improvement there are some developments concerning cotton yarns. The *Spinair* and *Lunafa* yarns by Kurabo can be mentioned here as the examples of thermal insulating yarns [5, 6]. The *Spinair* is so called “hollow cotton yarn” whereas the *Lunafa* is cotton and wool layered yarn.

Thermal insulation of textile materials can be improved by increasing their thickness. The higher is the thickness the better is thermal insulation. However, the increment of the thermal insulation with the increase of thickness runs in an asymptotic way. Moreover, increasing the thickness of fabrics and clothing causes the limitation of freedom of movement. Due to this fact it is justified to look for ways of improving clothing thermal insulation other than by enhancement of fabric thickness. For instance, it can be done by creation of fabrics of a 3D (*three-dimensional*) structure of high porosity. The air trapped in pores inside the 3D textile materials is a very good thermal insulator. The knitted or woven spacer fabrics are the examples of textile materials of high thermal insulation. There are also other types of the 3D woven fabrics. Into this group some kinds of two-layer woven fabrics with smooth surface and the 3D woven fabrics with the textured surface created by different elements such as: plisse or pleated fabrics, terry fabrics, velvet fabrics, seersucker fabrics can be included.

The seersucker fabrics create a unique 3D woven structure. Such 3D structure is usually received on loom by an application of two warps of different tension [7, 8]. A typical seersucker structure is characterized by an occurring the puckered strips in warp direction. The word “seersucker” came into English from Persian, and originates from the words: "Sheer" and "Shakar". They meaning is: "milk and sugar", probably from the similarity of smooth and rough stripes along the fabric to the smooth texture of milk and the lumpy texture of sugar [9].

To make the seersucker woven fabric, two loom beams are needed: one beam carries warp yarns for the flat (basic) strips; the other carries warp yarns for the puckered strips. During weaving, adjustments are made to make the puckered stripe warp yarns feed forward faster than the flat stripe warp yarns. This results in different tension of warp yarns and following it a localized buckling of the fabric in the areas of the fast-feeding yarns [7]. This makes the pucker in the wrinkled strips in warp direction. The seersucker fabrics have good comfort properties due to the puckered structure. The puckered effect generates air spaces between body and the fabric (fig. 2). It ensures a cooling the user's body in hot conditions, because the puckered area of the seersucker fabric holds the fabric away from the skin [10].

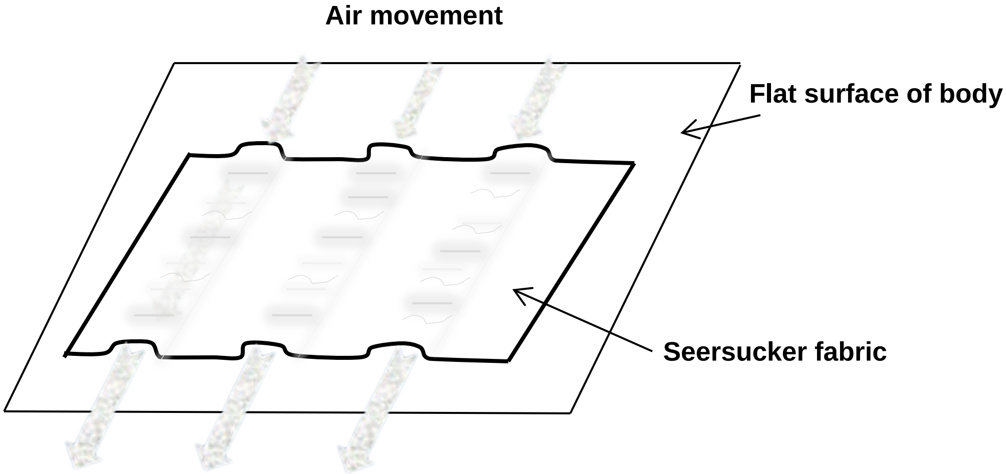


Fig. 2. The scheme of air movement between the seersucker fabric and flat surface of human skin

Experimental

In the presented work the seersucker woven fabrics were developed. Three variants of the seersucker woven fabrics were the objects of the investigations. They were:

- typical cotton seersucker woven fabric – sample S 1,
- the seersucker woven fabric with seersucker effect in both directions: warp and weft – sample S 2 and S 3.

All fabrics were manufactured on the basis of the same warps made of 20 x 2 tex cotton yarn. The typical seersucker structure of the Sample S 1 was achieved by an appropriate combination of warp yarns: basic and puckering of different tension while weaving. The same yarn 20 x 2 tex CO was also applied in weft (fig. 3).

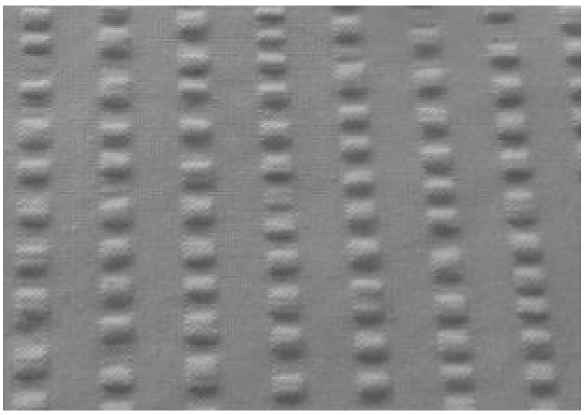


Fig. 3. The seersucker fabric S 1

In order to obtain the seersucker effect in weft direction the elastomeric yarn 37 tex PU 57/PES 33 was applied in turns with non-elastic weft yarns (fig. 4).

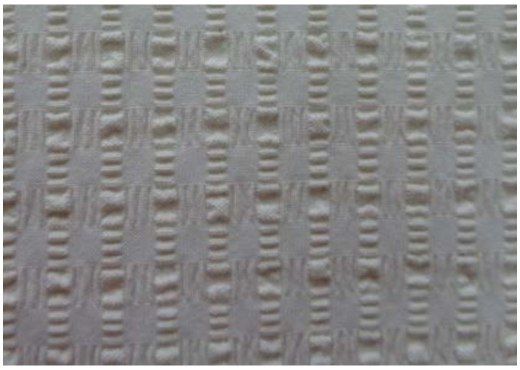
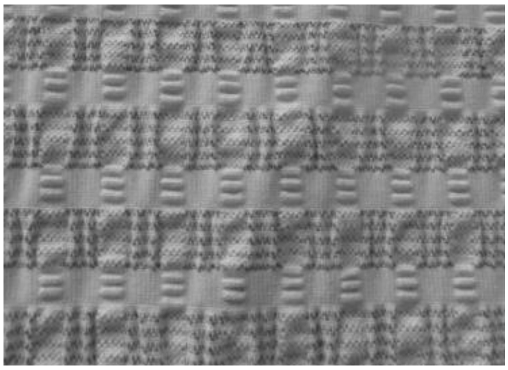
a)  *b)* 

Fig. 4. The seersucker fabrics with seersucker effect in both directions: a) the sample S 2, b) the sample S 3

In the fabric S 2 the following weft yarns were applied:
- 20 x 2 tex cotton,
- 12 x 2 tex drirelease® See Cell Active.

Whereas, in the fabric S 3 the following not-elastic weft yarns were introduced:
- 20 x 2 tex cotton,
- 235 dtex/34x2 Shieldex®.

Dri*release*® is a blend of specific hydrophobic synthetic fibres with hydrophilic fibres of optimized share of components. In the applied yarn the profiled PES fibres were blended with the SeeCell active fibres with antimicrobial and skin care features. The specific combination of hydrophobic and hydrophilic fibres allows pulling moisture away from the skin and fast drying.

Shieldex is a silver plated polyamide yarn of anti-static and anti-bacterial properties. Both weft yarns were applied in order to improve the functionality of the designed cotton seersucker fabrics, especially to provide the thermo-physiological comfort and antibacterial properties.

The measurements of fabrics were done in the range of their comfort-related properties. The Alambeta device was applied in measurement of such thermal insulation properties of the seersucker fabrics as:
- thermal conductivity,
- thermal resistance,
- thermal absorptivity.

Measurement by means of the Alambeta was performed in dry and wet state of fabrics. The measurement in wet state allows assessing the fabrics from the point of view of their ability to ensure the physiological comfort. The material is assessed according to the value of the thermal absorptivity in wet state. The lower value of the thermal absorptivity means better ability of fabric to ensure the physiological comfort. According to Hes [11] the value of the thermal absorptivity higher than 350 - 400 $Wm^{-2} s^{1/2} K^{-1}$ causes unpleasant feeling of clothing user and the discomfort in contact with wet material.

The results for the seersucker woven fabrics were compared with the results for typical (flat) cotton woven fabrics. Two variants of cotton fabrics were taken for comparisons: in plain (sample P) and twill 3/1 (sample T) weave.

The seersucker woven fabrics were also measured in the range of their friction properties. The measurement was done due to idea that the fabrics can be applied in anticellulite and antiaging clothing. The designed seersucker fabrics are characterized by rough surface of textured micro-topography with small convex and concave places evenly distributed on the fabric surface. With contact with the human skin they can provide the micro-massaging effect. The seersucker fabrics samples S 2 and S 3 were also measured in the range of their antibacterial properties. The measurement was performed according to standard AATCC Test Method 100 – 1998.
Figure 5 presents the thermal conductivity of the investigated fabrics. It can be seen that in dry state the thermal conductivity of the designed seersucker fabrics is at the same level than the thermal conductivity of typical flat fabrics taken for comparison. Wetting the fabrics caused significant increase of the thermal conductivity.

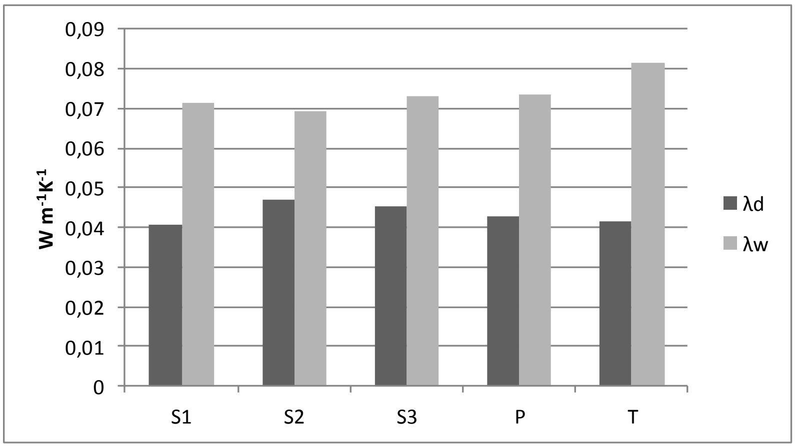


Fig. 5. Thermal conductivity of the investigated fabrics in dry and wet state: λd – in dry state, λw – in wet state

From the point of view of the human body protection against cold the thermal resistance is the most important property of the fabrics and clothing. It determines the ability of fabrics and clothing to provide the thermal insulation. In dry state the thermal resistance of the seersucker woven fabrics is more than twice higher than the thermal resistance of typical flat woven fabrics (fig. 6). It results from the differences in fabric thickness (fig. 7). Wetting the fabrics caused significant reduction of the thermal insulation of fabrics. It is due to presence of water in the fabrics' structure. The changes of the thermal resistance due to the wetting are more significant for the seersucker fabrics than for flat fabrics. (fig. 6). Wetting the fabrics caused also the changes in the fabric thickness. It is due to the swelling the fabrics under the influence of water.

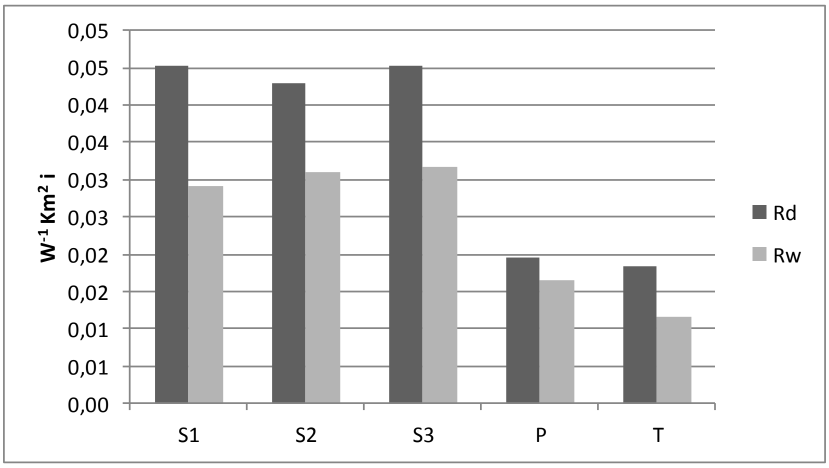


Fig. 6. Thermal resistance of the investigated fabrics in dry and wet state: Rd – in dry state, Rw – in wet state

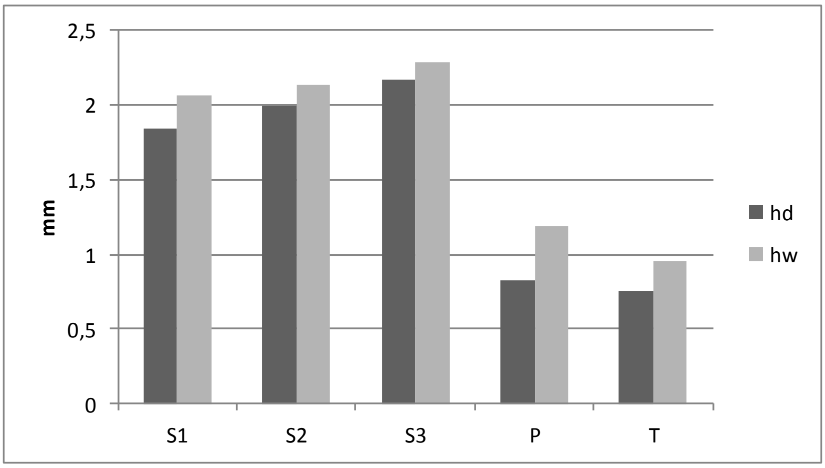


Fig. 7. Thickness of the investigated fabrics in dry and wet state: hd – in dry state, hw – in wet state

Thermal absorptivity of fabrics is presented in the figure 8. Thermal absorptivity is a surface property, which allows assessment of the fabric's character in the aspect of its "cool - warm'' feeling. Fabrics with a low value of thermal absorptivity give a "warm" feeling, whereas fabric with a high value of the thermal absorptivity – "cool" feeling. Hes [11] suggested a measurement of the thermal absorptivity of fabrics in the wet state as a measure of ability of fabrics to ensure the physiological comfort due to the moisture management ability. In the case of wet fabrics the value of thermal absorptivity below the 350 – 400 $Wm^{-2}\ s^{1/2}\ K^{-1}$ means a good ability of fabrics to ensure a physiological comfort. In the case of the investigated seersucker fabrics they thermal absorptivity in dry state is much lower than thermal absorptivity of the flat woven fabrics. It means that the seersucker fabrics provide a warmer feeling than the typical flat woven fabrics taken for comparison. In wet state each measured fabric is characterized by the thermal absorptivity lower than 350 $Wm^{-2}\ s^{1/2}\ K^{-1}$. It means that all fabrics are good from the point of view of the physiological comfort. However, the seersucker woven fabrics are characterized by significantly lower thermal absorptivity than the woven fabrics of plain and twill weave. It means that the seersucker fabrics are better from the point of view of the moisture management than the flat woven fabrics.

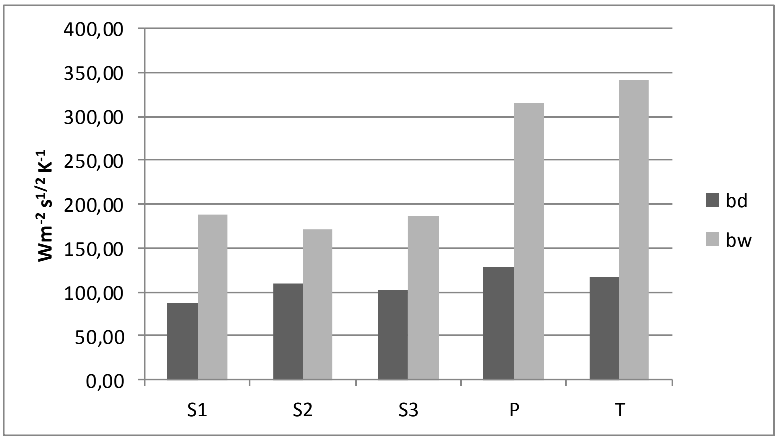


Fig. 8. Thermal absorptivity of the investigated fabrics in dry and wet state: bd – in dry state, bw – in wet state

Air permeability is also important comfort-related property of fabrics. It determines the resistance of fabrics to the passage of air [12]. Air permeability of clothing directly influences a gas exchange between a human being and surroundings and in the same way the physiological comfort of clothing user [13, 14]. It is strongly connected with the carbon dioxide release by human body, necessity of sweat carrying from the human skin and body ventilation. In the indirect way the air permeability of fabrics influences their thermal insulation, because the air movement through the textile material causes the forced convection of heat.

Air permeability of the investigated seersucker fabrics is in the range from 117 till 177 mms^{-1}. It is higher than the air permeability of the plain woven fabric taken for comparison but lower than air permeability of the twill fabric (fig. 9). It is difficult to compare the fabrics in the aspect of their air permeability because they are characterized by quite different structure. It is commonly known and confirmed by the investigations that the structure of fabrics, their weave as well as their porosity determined by the density of warp and weft yarns and yarn thickness influence the air permeability.

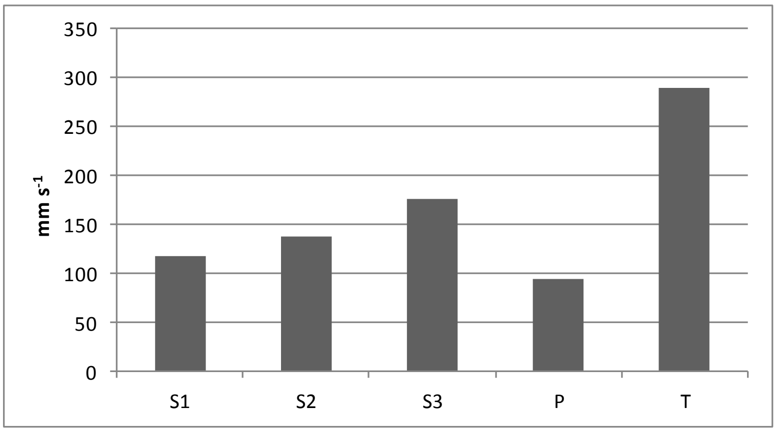


Fig. 9. Air permeability of the investigated fabrics

The seersucker woven fabrics are characterized by similar values of friction coefficients (fig. 10). In all cases the values of friction coefficients in weft direction are higher than in warp direction. It is advantageous relation taking into account the direction of fabric cutting while making clothing patterns as well as conditions of clothing usage.

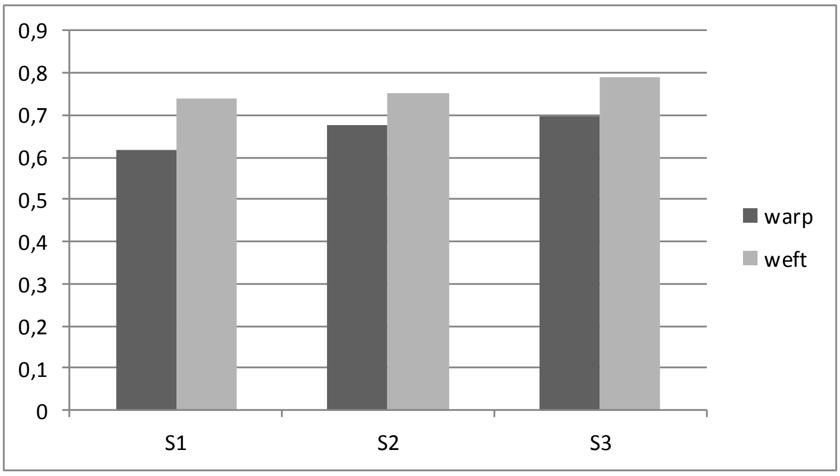


Fig. 10. Friction coefficients of the investigated seersucker woven fabrics

Unfortunately, the antibacterial tests did not confirm the antibacterial properties of the designed seersucker fabrics. Probably, the share of antibacterial yarns (drirelease® and Shieldex®) in the samples S 2 an S 3 was too low.

Summing up

Performed investigations showed that the seersucker woven fabrics have good thermo-physiological properties. They are characterized by much higher thermal resistance than the typical flat woven fabrics of the basic weaves. Measurement of the thermal absorptivity in the wet state confirmed that the seersucker fabrics have good quality from the point of view of the moisture management. The air permeability of the seersucker fabrics is enough to ensure the proper human body ventilation. Rough surface of the seersucker fabrics makes them possible to provide the micro-massaging effect.
In order to ensure the antibacterial properties it is necessary to increase significantly the share of antibacterial components in fabrics.

Acknowledgment
This work is financed by National Science Centre, Poland in the frame of the project titled „Geometrical mechanical and biomechanical parameterization of the three-dimensional woven structures", project No. 2016/23/B/ST8/02041.

References

1. ASHRAE Standard 55-66: Thermal Comfort Conditions, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York (1966).
2. Parsons, K.C.: Ergonomics Assessment of Environments in Buildings, Proceedings of the CIBS Technical Conference (1985).
3. Fanger, P.O.: Thermal Comfort, Danish Technical Press, Copenhagen, (1970).
4. Matusiak M.: Thermal Insulation of Woven Fabric for Clothing. Monograph, Works of Textile Research Institute, Special Edition, Lodz (2011), ISBN 978-83-911544-7-2.
5. Andrysiak J., Sikorski K., Wilk E., Matusiak M., Investigation of an Innovative "Cotton Hollow" Yarn, Fibres & Textiles in Eastern Europe (2014); 22, 5(107), pp. 33-37.
6. http://www.kurabo.co.jp/division/yarn/english/lunafa/index.html

7. Gandhi K., Woven Textiles Principles, Technologies and Applications", 1st ed., Woodhead Publishing, New Delhi, (2012), pp. 142 – 158,
8. Matusiak M., Fracczak L., Investigation of Waviness of 3D Woven Fabrics, chapter in: Innovations in Clothing Design, Materials, Technology and Measurement Methods, edited by Frydrych I., Bartkowiak G., Pawlowa M., Lodz University of Technology 2015, pp. 166 – 182
9. The American Heritage Dictionary of the English Language: Fifth Edition. 2015, available from: < https://ahdictionary.com > 02.03.2016
10. Matusiak M., Fracczak L., Comfort-related properties of seersucker fabrics in dry and wet state, International Journal of Clothing Science and Technology, (2017) Vol. 29 Issue: 3, pp. 366 - 379, https://doi.org/10.1108/IJCST-09-2016-0106
11. Bajzik V., Hes L., Dolezal I., Changes in thermal comfort properties of sportswear and underwear due to their wetting, Indian Journal of Fibre & Textile Research, (2016) Vol 41, June, pp. 161-166
12. Xiao X., Xuesen Zeng X., Bandara P., Long A., Experimental Study of Dynamic Air Permeability for Woven Fabrics, Textile Research Journal (2012), 82(9), pp. 920 – 930.
13. Matusiak M., Thermal Comfort Index as a Method of Assessing the Thermal Comfort of Textile Materials, Fibres and Textiles in Eastern Europe, (2010), Vol. 79, Issue 2, pp. 45 – 50.
14. Hes L., De Araujo M., Djulay V., Effect of Mutual Bonding of Textile Layers on Thermal Insulation and Thermal Contact Properties of Fabric Assemblies, Textile Research Journal (1993), 63: pp. 749 – 76.