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COMFORT-RELATED PROPERIES OF COTTON SEERSUCKER FABRICS

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Abstract:

This work concerns the comfort-related properties of seersucker woven fabrics made of cotton. Seersucker woven fabrics are characterized by alternating puckered and flat strips in the warp direction. Some researchers consider that due to this structure seersucker fabrics are characterized by very good comfort-related properties. In this work seersucker fabrics with differing repeats of the seersucker effect and different weft yarns were investigated in intense heat and high moisture transfer. Results showed that the structural factors significantly influence the comfort-related properties of the investigated cotton fabrics.

Keywords:

Seersucker, fabrics, comfort, measurement

1. Introduction

Cotton and other natural fibers, especially of plant origin, have been used in clothing for centuries. It is due to the fact that natural fibers are characterized by very good intrinsic hygienic properties. Cotton hygroscopicity causes cotton fibers to offer physiological comfort, due to cotton's ability to absorb sweat. Seersucker woven fabrics are also considered by researchers to be fabrics ensuring physiological comfort [1, 2]. The seersucker woven fabrics belong to the group of fabrics with relief [3]. They are characterized by alternating puckered and flat strips in the warp direction (Fig. 1). There are different ways to obtain such a puckered effect on the surface of woven fabrics: weaving, finishing, and thermal (finishing and weaving) methods [4 - 6]. In the weaving method the seersucker woven fabrics are manufactured from two warp sets on a loom with two loom beams [2]. One beam carries warp yarns for the flat strips and the other carries warp yarns for the puckered strips. The seersucker effect is created due to the different tension of the sets of warp yarns. According to Shaker et al. [7] the seersucker effect creates air spaces between the body and the fabric. Thus, the seersucker woven fabric provides cooling of the wearer's body in hot conditions because the puckered area of the fabric keeps the fabric away from the skin. It facilitates the circulation of air and water vapor (Fig. 1).

Investigations carried out up until now [8] confirmed that seersucker woven fabrics are characterized by high thermal resistance, much higher than the thermal resistance of typical two-dimensional woven fabrics of basic or derivative weaves. Further studies [9] showed that the thermal absorptivity of the seersucker woven fabrics in a wet state is very low in comparison to the thermal absorptivity of typical 2D fabrics in the wet state. According to Hes [10, 11], this means that examined seersucker fabrics are able to ensure physiological comfort.

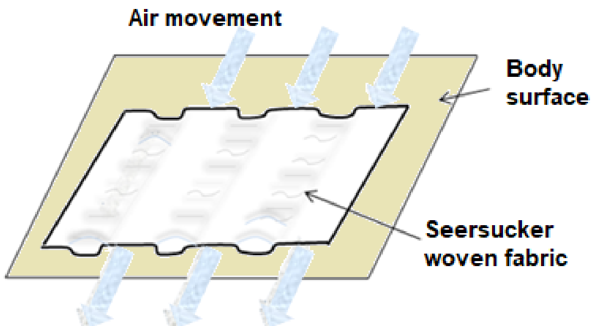

Figure 1. Schematic air movement between the seersucker woven fabric and human skin

It should be mentioned here that seersucker woven fabrics are easy to use because they do not need to be ironed. Together with its hygienic and comfort properties, clothing made of seersucker woven fabrics yields excellent utility and comfort.

The aim of this work was to assess the comfort-related properties of seersucker woven fabrics made of cotton, and to analyze the influence of the structure of seersucker fabrics on their comfort-related properties. In the analysis two structural factors were discussed: repeat of the seersucker effect and linear density of the weft yarn.

2. Materials and methods

In total, 9 variants of seersucker woven fabric of different structure were the objects of investigation. The fabrics were manufactured on the basis of the same warp sets, made of 20 tex x 2 cotton yarn. Three of these variants of seersucker woven fabrics have been investigated here:

- variant MM1 – width of puckered and flat strips appropriately: 4 mm and 8 mm,
- variant MM2 – width of puckered and flat strips appropriately: 8 mm and 17 mm,
- variant MM3 – width of puckered and flat strips appropriately: 10 mm and 37 mm.

Three kinds of cotton yarns used as weft have been studied: 20 tex x 2, 25 tex x 2, 30 tex x 2. The fabrics were finished using a tensionless method. The finishing process included washing, rinsing, and drying.

The basic structural parameters of the investigated fabrics are presented in Table 1.

The fabric variants differ in the range of the repeat of the puckered strips and type of weft yarn. Measurements of the comfort-related properties have been performed by using the Alambeta, Permetest, and MMT (Moisture Management Tester) devices.

The Alambeta by Sensora (Czech Republic) is a computer-controlled instrument for measuring the basic static and dynamic thermal characteristics of textiles [12 – 15]. This method belongs to the so-called plate methods. The acting principle of the Alambeta relies on the convection of heat emitted by the hot upper plate in one direction through the measured sample to the cold bottom plate. By means of the Alambeta the following properties are measured: thermal resistance, thermal conductivity, thermal diffusivity, and thermal absorptivity. The instrument directly measures the stationary heat flow density (by measuring the electric power at the known area of the plates), the temperature difference between the upper and bottom fabric surface, and the thickness of fabric. The device calculates the real thermal resistance for all fabric configurations. Thermal absorptivity and the thermal diffusivity are calculated on the basis of the properties measured using algorithms appropriate for homogeneous materials [16].

The Permetest by Sensora (Czech Republic) is an instrument for the nondestructive determination of water-vapor resistance, thermal resistance, and relative water-vapor permeability of flat materials: fabrics, nonwovens, foils, and paper sheets [17, 18]. It is considered to be a portable “skin model.” It acts according to the procedure described in ISO 11092 [19]. In the case of measurement by means of the Permetest the puckered surface of the seersucker fabrics can disturb the air flow.

The measurement of the parameters characterizing the liquid moisture transport was performed using the Moisture Management Tester M 290 by SDL Atlas, according to the device manual based on the AATCC Method 195-2011. The Moisture Management Tester (MMT) is an instrument designed to measure the dynamic liquid transport properties of textiles in three aspects [20 – 22]:

- absorption rate: moisture absorbing time for inner and outer surfaces of the fabric,
- one-way transport capability: one-way transfer of liquid moisture from the inner surface to outer surface of fabric,

Table 1. The basic parameters of the investigated seersucker woven fabrics

	Unit	Value								
Repeat variant	-	**MM 1**			**MM 2**			**MM 3**		
Weft yarn	-	20 tex x 2	25 tex x 2	30 tex x 2	20 tex x 2	25 tex x 2	30 tex x 2	20 tex x 2	25 tex x 2	30 tex x 2
Symbol	-	MM 1/1	MM 1/2	MM 1/3	MM 2/1	MM 2/2	MM 2/3	MM 3/1	MM 3/2	MM 3/3
Warp density	cm^{-1}	13.8	13.5	13.8	13.7	13.8	13.4	12.8	13.0	13.1
Weft density	cm^{-1}	12.0	11.6	10.8	11.8	11.0	10.6	11.7	11.2	10.5
Mass per square meter	$g\ m^{-2}$	221.9	253.0	262.6	217.0	236.8	254.6	205.4	227.1	243.5
Take up – warp I	%	16.2	6.4	10.1	5.8	7.9	8.6	6.3	8.3	12.1
Take up – warp II	%	53.8	62.4	60.4	41.6	52.2	44.8	44.0	48.0	45.4
Take up - weft	%	14.7	15.8	13.5	14.8	14.0	13.0	15.3	15.2	17.9

- spreading/drying rate: speed of liquid moisture spreading on the inner and outer surfaces of fabric.

The device is controlled by PC and the MMT290 software. Measurement is performed for samples cut into 80 mm x 80 mm squares. For each fabric 5 repetitions of measurement are performed. During the test a predefined amount of test solution (synthetic sweat) is introduced onto the upper side (skin side) of the fabric, and then the test solution is transferred onto the material in three directions [20]:

- spreading outward on the upper surface of the fabric,

- transferring through the fabric from the upper surface to the bottom surface,

- spreading outward on the bottom surface of the fabric.

Obtained results have been analyzed using the statistical tools available in the TIBC® STATISTICA™ version 13.3 software. In order to confirm the statistical significance of the relationships between the structural and comfort-related properties of fabrics the two-way analysis of variance (ANOVA) was applied to analyze the measurement data. In general, the purpose of ANOVA is to that examine the influence of two different categorical independent variables on one continuous dependent variable. The two-way ANOVA aims to assess the main effect of each independent variable and also the interaction between them. In the statistical analysis the variant of seersucker effect (repeat of the puckered strips) and linear density of the weft yarn were applied as main factors – independent variable. The comfort-related parameters were taken as dependent variables.

3. Results and discussion

The results of measurement by means of the Alambeta are presented in Figures 2, 3, and 5.

Fig. 2 presents thermal conductivity of the investigated fabrics. The highest thermal conductivity is observed for the fabrics representing the MM3 variant of the repeat of the seersucker effect. It is also clearly seen that the linear density of weft yarn also influences the thermal conductivity of the fabrics. The higher linear density of the weft yarn, the higher the thermal conductivity. It is easy to explain because the heat conduction takes place mostly in the fibrous material. Thicker weft yarn means larger amount of fibrous material in the fabric.

Table 2 presents results from the ANOVA for thermal conductivity. In applied software the interpretation of the results is the following:

- when $p \leq 0.05$ – there is statistically significant difference between within-group and between-groups variability,

- when $p > 0.05$ – the difference between within-group and between-groups variability is statistically insignificant.

In the table below, the effects which are statistically significant at the level of significance $p = 0.05$ are emphasized in bold italics. The meaning of symbols used in tables with the ANOVA results is the following:

SS – sum of squares,

df – degree of freedom,

MS – mean square,

F – variable of F - distribution,

p – statistical significance.

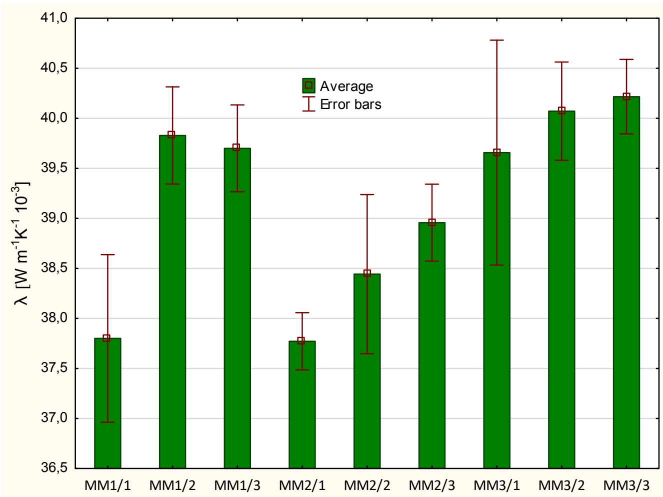

Figure 2. Thermal conductivity of the seersucker woven fabrics according to the Alambeta

Table 2. The results of ANOVA for the thermal conductivity of the investigated seersucker woven fabrics

	SS	df	MS	F	p
Constant term	***94516.51***	***1***	***94516.51***	***186204.0***	***0.000000***
Repeat of the seersucker effect	***19.49***	***2***	***9.75***	***19.2***	***0.000001***
Linear density of the weft yarn	***14.49***	***2***	***7.24***	***14.3***	***0.000011***
Repeat of the seersucker effect/Linear density of the weft yarn	***9.09***	***4***	***2.27***	***4.5***	***0.003431***
Error	26.90	53	0.51	-	-

Statistical analysis confirmed that the repeat of seersucker effect and linear density of weft yarn have statistically significant influence on the thermal conductivity of the seersucker woven fabrics being investigated. There is also statistically significant interaction between both main factors.

The next figure (Fig. 3) presents the thermal resistance of the fabrics. In this case the relationships between the structure of the fabrics and their thermal resistance are not obvious. A very clear tendency is observed for the fabrics representing the MM3 variant of the repeat of seersucker effect. Thicker weft yarn results in higher thermal resistance. In the case of the fabric variants MM1 and MM2 it is difficult to find any tendency. In the case of the fabrics representing the MM1 variant of the seersucker effect the thermal resistance is at similar level for fabrics of different weft yarns. In the group of fabrics with the MM2 repeat of the seersucker effect the highest thermal resistance was stated for the fabric with middle thickness of weft yarn – 25 tex x 2.

It is difficult to explain it. Fig. 4 presents the scheme of measurement of the seersucker fabrics by means of the Alambeta. While measuring the sample is placed between two plates: warm and cold. In the case of the seersucker woven fabrics there are the air gaps between the fabric surface and both plates. Air trapped in the gaps is a good thermal insulator. Due to this fact the volume of the air gaps, and the amount of air they hold, influences the results from the Alambeta. The volume of the air gaps depends on the width of the flat strips but also on the intensity of the seersucker effect.

All mentioned factors and interactions between them mean that the influence of the structure of the seersucker woven fabrics on their thermal-insulation properties is a complex phenomenon and needs further investigations.

Statistical analysis (Table 3) confirmed that influence of the repeat of seersucker effect and linear density of the weft yarn on the thermal resistance of fabrics is statistically significant at the significance level 0.05.

Fig. 5 presents the thermal absorptivity of the seersucker woven fabrics. Thermal absorptivity is a surface property of fabrics – an objective measure of warm-cool feeling of fabrics during the first contact of the fabric with a human skin. The higher the level of thermal absorptivity, the cooler is the feeling [10].

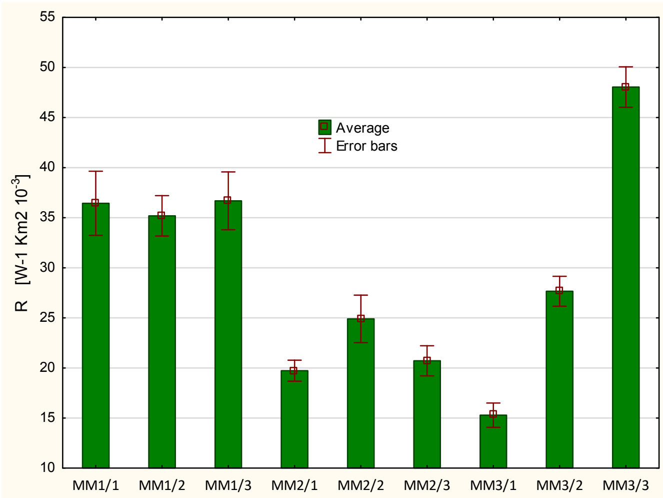

Figure 3. Thermal resistance of the seersucker woven fabrics according to the Alambeta

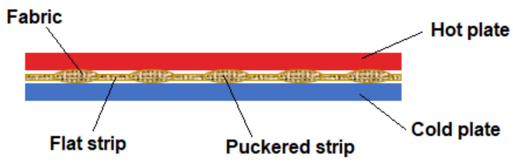

Figure 4. The scheme of placement of the seersucker fabric while measuring with the Alambeta

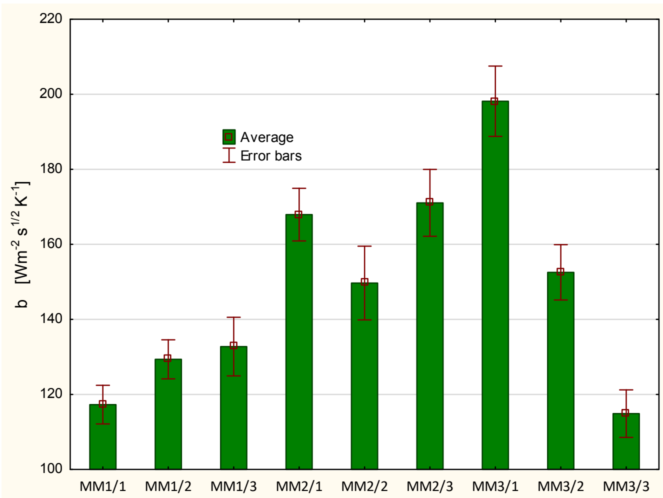

Figure 5. Thermal absorptivity of the seersucker woven fabrics according to the Alambeta

Table 3. The results of ANOVA for the thermal resistance of the investigated seersucker woven fabrics

	SS	df	MS	F	p
Constant term	***53484.80***	***1***	***53484.80***	***10642.43***	***0.00***
Repeat of the seersucker effect	***2180.31***	***2***	***1090.16***	***216.92***	***0.00***
Linear density of the weft yarn	***1311.76***	***2***	***655.88***	***130.51***	***0.00***
Repeat of the seersucker effect/Linear density of the weft yarn	***2442.30***	***4***	***610.57***	***121.49***	***0.00***
Error	266.36	53	5.03	-	-

Observed tendencies are different for fabrics with different repeats of the seersucker effect. For the fabrics with the MM1 repeat of the seersucker effect, the value of thermal absorptivity increases with an increase of the linear density of weft yarn. For the fabrics with the MM3 repeat of the seersucker effect, the tendency is opposite – thermal absorptivity decreases with an increase of the weft yarn thickness. And finally, for the group of fabrics with the MM2 repeat of the seersucker effect, the lowest value of thermal absorptivity was stated for the fabric with the weft yarn of intermediate thickness – 25 tex x 2. Stated relationships are statistically significant. Also the interaction between the main factors was assessed as statistically significant at the significance level 0.05 (table 4).

The results from the Permetest are presented in Figs. 6, 8, and 9. Fig. 6 shows the thermal resistance of the seersucker woven fabrics.

Thermal resistance of the investigated seersucker woven fabrics according to the Permetest is different than the thermal resistance measured using the Alambeta. It is obvious because the procedure of measurement using the Permetest is also different than in the Alambeta. The Permetest is the one-plate device. The sample is placed on the hot plate (Fig. 7). In the testing channel an air movement takes place at velocity 0.3 m/s. It causes the forced heat convection. Such convection does not occur in the Alambeta. Due to this fact the values of thermal resistance according to the Alambeta and Permetest cannot be the same. Additionally, the puckered surface of the puckered strips in the seersucker woven fabrics disturbs the air flow. Hes [14] called this effect the “boundary effect.” It significantly influences the results from the Permetest. From the point of view of the low air disturbance in the measuring channel, the direction of sample placement plays an important role. The puckered strips can be parallel or perpendicular to the direction of air movement. It influences the measurement results.

Comparison of the thermal resistance measured for samples placed in different directions was performed for grey seersucker woven fabrics. Generally, thermal resistance of the grey seersucker woven fabrics is significantly higher that the thermal resistance of the finished fabrics. The results confirmed the influence of the direction of sample placement on the results. Thermal resistance stated for samples placed in such a way than the puckered strips were perpendicular to the air movement was higher than for samples with the puckered strips parallel to the air movement (fig. 8). Disturbance of the air movement by the puckered surface of samples causes a

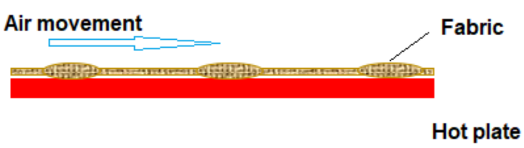

Figure 7. The scheme of placement of the seersucker fabric while measuring with the Permetest

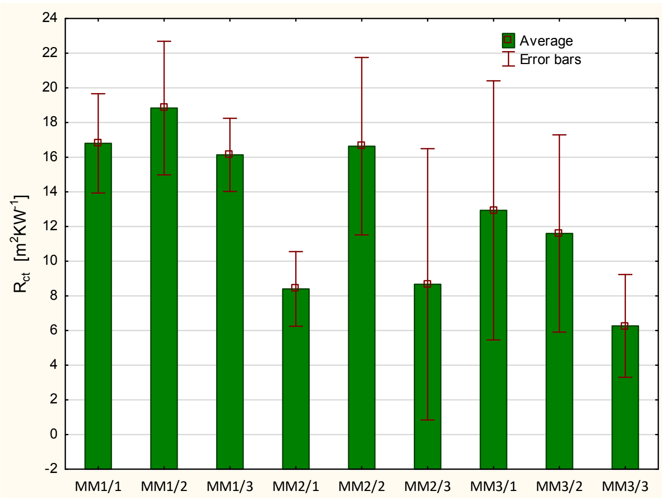

Figure 6. Thermal resistance of the seersucker woven fabrics according to the Permetest

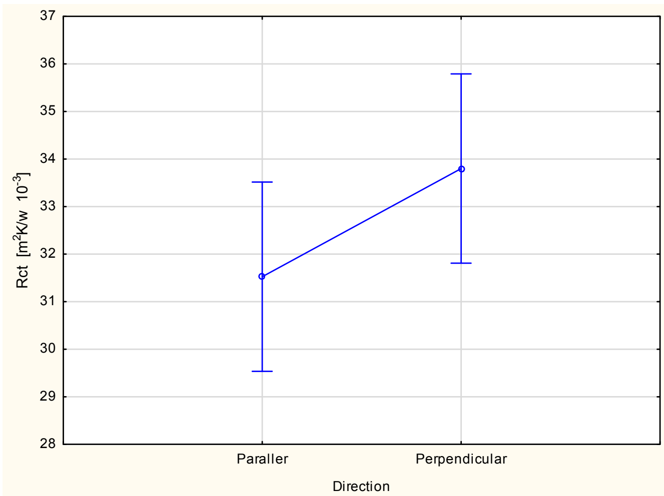

Figure 8. Influence of the direction of puckered strip in relation to direction of air movement in the Permetest measuring channel on the thermal resistance of the seersucker woven fabrics

Table 4. The results of ANOVA for the thermal absorptivity of the investigated seersucker woven fabrics

	SS	df	MS	F	p
Constant term	***1358230***	***1***	***1358230***	***20218.70***	***0.000000***
Repeat of the seersucker effect	***15425***	***2***	***7712***	***114.81***	***0.000000***
Linear density of the weft yarn	***5381***	***2***	***2691***	***40.05***	***0.000000***
Repeat of the seersucker effect/Linear density of the weft yarn	***20569***	***4***	***5142***	***76.55***	***0.000000***
Error	3560	53	67	-	-

Table 5. The results of ANOVA for the thermal resistance (Rct) of the investigated seersucker woven fabrics

	SS	df	MS	F	p
Constant term	***4505.979***	***1***	***4505.979***	***1155.379***	***0.000000***
Repeat of the seersucker effect	***258.139***	***2***	***129.069***	***33.095***	***0.000001***
Linear density of the weft yarn	***128.581***	***2***	***64.290***	***16.485***	***0.000085***
Repeat of the seersucker effect/Linear density of the weft yarn	***89.281***	***4***	***22.320***	***5.723***	***0.003746***
Error	70.200	18	3.900	-	-

large dispersion of measurement results from the Permetest. It was reflected by the error values.

Table 5 presents the ANOVA results for the thermal resistance of the seersucker woven fabrics according to the Permetest. Statistical analysis confirmed that the influence of the main factors on the thermal resistance and the interaction between the main factors are statistically significant.

Water-vapor resistance and relative water-vapor permeability of the seersucker woven fabrics also depend on the main structural factors: repeat of the seersucker effect and linear density of weft yarn (Figs. 9, 10). Statistical analysis confirmed that the relationships are significant at the significance level 0.05. In spite of differences between particular fabric variants, we can state according to the value of the relative water-vapor permeability that the fabrics ensure good physiological comfort. In all cases the relative water-vapor permeability is higher than 50 %.

In the case of the water-vapor resistance and relative water vapor permeability the influence on them of the repeat of seersucker effect a is statistically significant at the significance level 0.05, while influence of the linear density of weft yarn was assessed as insignificant (Tables 6 and 7).

Interaction between the main factors is also statistically significant.

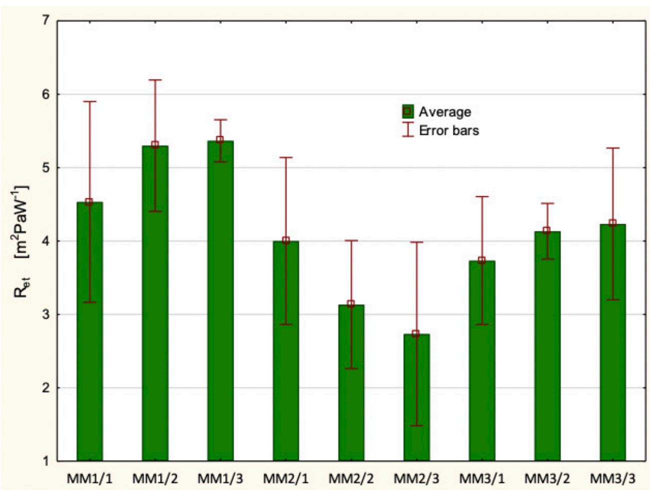

Figure 9. Water-vapor resistance of the seersucker woven fabrics according to the Permetest

An assessment of the liquid moisture transport is the last part of the presented investigations. First, it should be mentioned that gray seersucker woven fabrics do not transfer the liquid moisture. The synthetic sweat remains on the inner surface of measured sample (fig. 11).

In the case of the finished fabrics, their ability to absorb and transfer the liquid moisture strongly depend on the seersucker effect. It was also stated that the transport of liquid moisture depends on the place in which the test fluid is dispensed (fig.

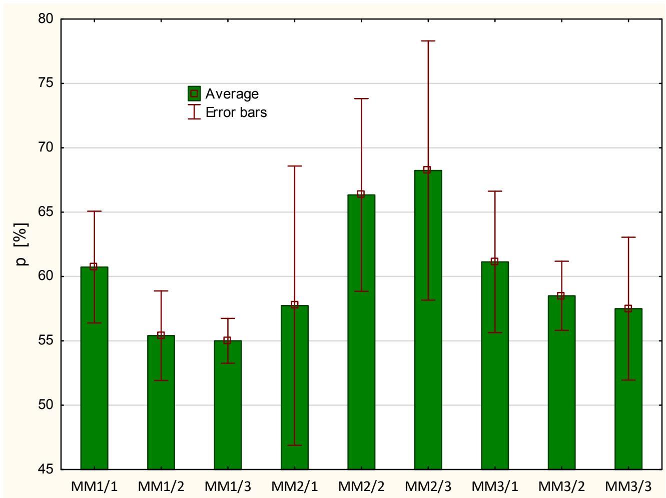

Figure 10. Relative water-vapor permeability of the seersucker woven fabrics according to the Permetest

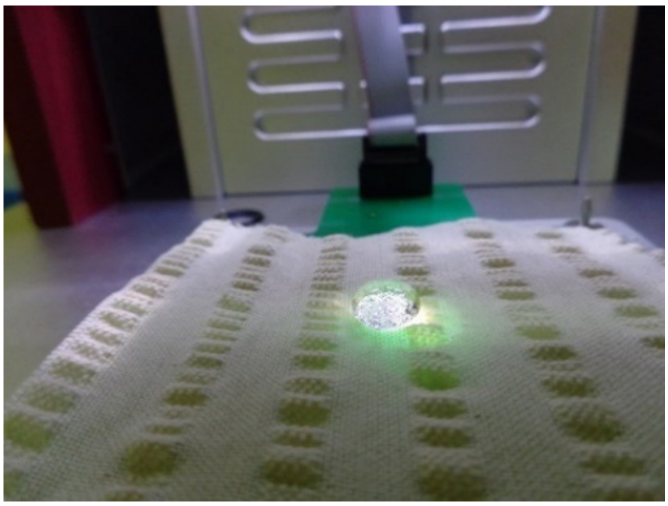

Figure 11. The drop of the synthetic sweat remaining after measurement of the grey seersucker fabric by means of the MMT device

Table 6. The results of ANOVA for the water-vapor resistance (Ret) of the seersucker woven fabrics

	SS	df	MS	F	p
Constant term	***460.4537***	***1***	***460.4537***	***3062.131***	***0.000000***
Repeat of the seersucker effect	***14.3474***	***2***	***7.1737***	***47.707***	***0.000000***
Linear density of the weft yarn	0.0496	2	0.0248	0.165	0.849141
Repeat of the seersucker effect/Linear density of the weft yarn	***4.1726***	***4***	***1.0431***	***6.937***	***0.001459***
Error	2.7067	18	0.1504		

Table 7. The results of ANOVA for the relative water-vapor permeability p of the seersucker woven fabrics

	SS	df	MS	F	p
Constant term	***97404.11***	***1***	***97404.11***	***14331.94***	***0.000000***
Repeat of the seersucker effect	***238.02***	***2***	***119.01***	***17.51***	***0.000060***
Linear density of the weft yarn	0.65	2	0.32	0.05	0.953762
Repeat of the seersucker effect/Linear density of the weft yarn	***269.79***	***4***	***67.45***	***9.92***	***0.000201***
Error	122.33	18	6.80		

12). On the flat area the liquid moisture is spread much better than on the puckered area. However, when the clothing made of the seersucker woven fabric is worn, the puckered surface adheres to the human skin and is in first contact with the liquid sweat. Due to this fact, this paper presents the results for samples in which the puckered strip is placed in the central point: that is, where the testing solution is deposited. The measurement was also performed for samples with the flat strip at the central point. However, taking into account the conditions of use, the results for samples with the flat strip in the central point of the sample have no significant practical importance.

The MMT provides 10 different parameters characterizing the transport of liquid moisture through the fabrics. The most important are R and OMMC. The R is an accumulative one-way transport index. It characterizes the liquid transport from the inner to the outer side of the fabric. A fabric with good accumulative one-way transport from the inner fabric side to the outer side (high value of the parameter) offers good sweat management to the wearer. It is due to the fact that with a high accumulative one-way transport index the fabric keeps the skin of the wearer dry: it transports the perspiration towards the outer side of the fabric, which is away from the skin. Positive and high values of the R parameter show that liquid sweat can be transferred from the skin to the outer surface easily and quickly. Unfortunately, for all measured fabric variants the values of the R parameter are negative (Fig. 13).

The OMMC (Overall Moisture Management Capacity) is in the range from 0 to 1. In some cases a large deviation of the OMMC value for particular variants have been observed. Such deviation is caused by the specific structure of the seersucker woven fabrics. Especially, individual results for samples representing the MM 2/2 and MM 3/1 variants differ significantly

Figure 12. Spreading the liquid moisture on the flat and puckered surface of the seersucker fabric

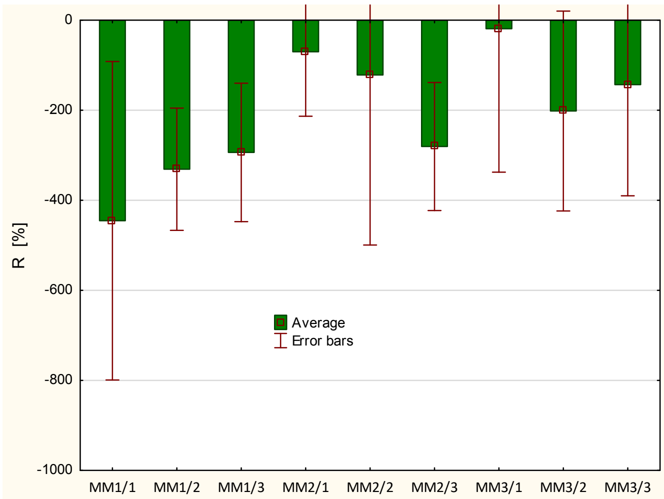

Figure 13. Accumulative one-way transport index R of the seersucker woven fabrics

from other results for these variants. It can be caused by the fact that the drops of the testing solution fell on the place where there is free space between the threads of both sets: warp and weft. In this place the testing solution will easily pass from the inner to the outer surface of measured sample. In another case the drop fell on the puckered part of the sample. In this place the liquid is spread on the surface. It does not pass (or passes very slowly) from the inner to the outer surface. Due to this fact, calculated values of the error bars show the negative minimum values. But such values are impossible because, as was mentioned above, the minimum value of the OMMC parameter is 0. Taking this into account in Figs. 14 and 15, the error bars are not presented.

The manual of the MMT [20] suggests a classification for moisture management capability according to the OMMC value as follows:

0 a 0.2 – very poor,

0.2 a 0.4 – poor,

0.4 a 0.6 – good,

0.6 a 0.8 – very good,

0.8 a 1.0 – excellent.

This study shows that repeat of the seersucker effect influences the values of parameters characterizing the moisture transport in the fabrics. Statistical analysis by means of the two-factor ANOVA confirmed that the stated influence is statistically significant at the significance level 0.05 (table 8 and 9). The linear density of the weft yarn influences only the OMMC parameter significantly.

It should be mentioned here that the results measured for samples in which the flat area was the point of introducing the synthetic sweat are significantly better. What's more, the

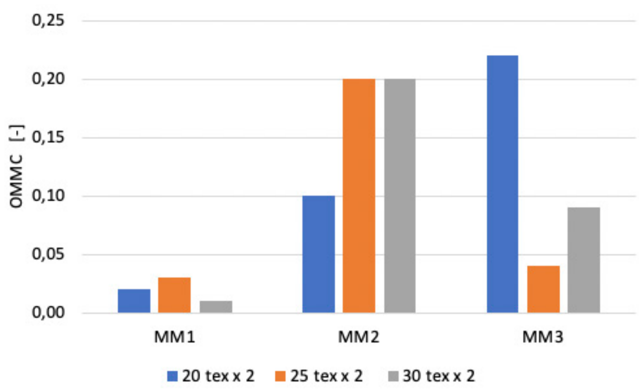

Figure 14. Overall moisture management capacity OMMC of the seersucker woven fabrics

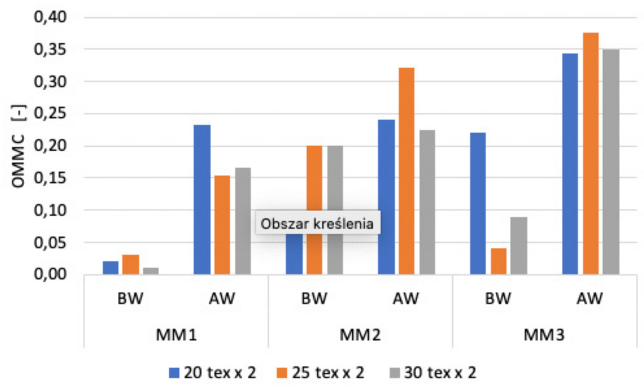

Figure 15. The overall moisture management capacity of the seersucker woven fabrics before (BW) and after washing (AW)

Table 8. The results of ANOVA for the one-way transport index R of the seersucker woven fabrics

	SS	df	MS	F	p
Constant term	38645	1	38645	0.40528	0.526170
Repeat of the seersucker effect	***2169605***	***2***	***1084803***	***11.37657***	***0.000044***
Linear density of the weft yarn	353132	2	176566	1.85168	0.163556
Repeat of the seersucker effect/Linear density of the weft yarn	***1032046***	***4***	***258011***	***2.70582***	***0.035935***
Error	7723686	81	95354		

Table 9. The results of ANOVA for the overall moisture management capacity OMMC of the seersucker woven fabrics

	SS	df	MS	F	p
Constant term	***4.087812***	***1***	***4.087812***	***89.04249***	***0.000000***
Repeat of the seersucker effect	***0.905814***	***2***	***0.452907***	***9.86541***	***0.000146***
Linear density of the weft yarn	***0.331431***	***2***	***0.165716***	***3.60969***	***0.031499***
Repeat of the seersucker effect/Linear density of the weft yarn	0.449564	4	0.112391	2.44815	0.052775
Error	3.718593	81	0.045909		

measurement of washed fabric samples provided much better results from the point of view of ability of the seersucker woven fabrics to transport the liquid moisture (Fig. 15).

4. Conclusions

Performed investigations confirmed that the structural parameters: repeat of the seersucker effect and linear density of weft yarn influence the comfort-related properties of seersucker woven fabrics. However, sometimes is difficult to define clear tendencies for the structural parameters and properties characterizing the seersucker woven fabrics in relation to thermo-physiological comfort. Investigations showed also that an assessment of seersucker woven fabrics is a complex problem. The cutting of the laboratory sample and the direction of placement of the sample in the testing device can influence the results.

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