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Proposal of Objective Assesment of the Phenomenon of Light Passage through Blackout Fabrics

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Abstract

The paper presents some possibilities of measuring light passed through textile products applicable as sunshade window curtains. The existing measurement methods were analysed and a new method for measuring the barrier properties and transparency of flat textile products was proposed based on linear measurement. The idea of measurement was established for the purpose of identifying the optical properties of blackout fabrics applied as internal screens for public interiors. Preliminary research has shown that blackout fabrics obtained by weaving technology – so called weaving blackout (not a coated blackout) have a varied structure. In this case, the characteristics of this structure determine the level of barrier properties. The mechanism of light passing through such structures is special and requires specific measurement conditions. The paper presents an original research methodology dedicated especially for blackout fabrics. The new methodology and indicators for assessing the barrier effect in the VIS radiation band can be adopted by industry.

Key words: *shading fabrics, blackouts, light barrier properties, visible radiation (VIS), curtains, public buildings.*

Introduction

Shading fabrics, called blackout fabrics, are present on the textile market as coated or multilayer fabrics. The woven blackout fabrics (only produced withs the weaving technique, with no support of finishing treatment) widely applied in public buildings gain barrier properties against visible light from their special structure. They are fabrics of complex structure made with technology of a superimposed thread arrangement or multilayered fabric technology. A barrier structure appears when adequate parameters and properties of the thread material are combined with a suit of weaves at certain conditions of the weaving process. Polyester textured yarns – multifilament polyester silk – are the most common, and the use of one thread order (warp or weft) coloured black enhances the darkening effect. Blackout fabrics are constructed mainly on the basis of satin weave, the weaving process of which yields sufficiently high density and filling of the fabric with threads. All of these conditions support producing a compact structure, impermeable to light.

Blackout fabrics are commonly expected to darken a room completely. The exact and only classification of blackout fabrics is given in the EN 14501:2005 standard [1]. According to the standard, there are two kinds of darkening fabric: blackout and dimout. The criterion of division proposed is the level of light intensity for which these products constitute a barrier. Consequently blackout fabrics are those capable of stopping light of 100000 lux intensity, while dimout fabrics stop light of 1000 lux. *Figure 1* presents the classification of darkening fabrics and products (darkening systems) by opacity, included in the PN-EN 14501:2005 standard [1].

The methodologies used to assess the barrier effect of textiles should refer to the above classification in their procedures. The lighting conditions of the samples and parameters of the light sources of instruments and research work stands should be precisely defined and accordance with the PN-EN 14501:2005 standard [1].

In Poland and worldwide alike, the point measurement (spectrophotometric) of light transmission coefficient – transmittance T [%] is commonly used to evaluate the optical properties of textiles. The process of identifying the optical properties of darkening fabrics is based on the PB/17:2007 [2, 3] test procedure, developed by the Textile Research Institute in Łódź on the basis of the PN-EN ISO 13758-1 standard [4]. The standard above appears in the technical specifications of darkening fabrics, which operate on the Polish fabric market for buildings. It is based on the spectrophotometric method for measuring the amount of light passing through a textile product. The test result is the arithmetic mean of the measurement results of light that is passed through a sample at a given point determined by the size of the spectral slot of the spectrophotometer.

A fabric structure is often compared to architecture, since it is never a simple, monostructural form, especially in the case of darkening fabrics, whose structure is a compilex of weaves of several intermingled layers. Due to the different configurations of threads in the complex structure of such fabrics, there are mutual displacements of threads between the layers, and the threads are crossed (especially at the layers' junctions). Local disturbances of barrier properties appear as a consequence of that phenomenon, which is manifested by the clearances in the fabric structure. For this reason, it is reasonable to assume that the point measurement methods applied may be suitable for coated blackout fabrics with a homogeneous structure. On the other hand, for woven blackout products it is necessary to develop a method sensitive to the local disturbances described above. This work aims at defining the optimum conditions for measuring the barrier properties of blackout fabric produced only with weaving technology, without any aid of finishing processes (coating).

The study was divided into three parts because of the measurement conditions used: point, linear and areal. Research started with the use of the available PB/17:2007 research methodology, in ac-

cordance with the PN-EN ISO 13758-1 Standard, which is an example of point-based measurement methodology. Afterwards the measurement of optical barrier properties of a defined fabric surface was performed with the use of digital image analysis as a proposal of areal measurement. Conclusions from the preliminary works allowed the Authors to develop their own measuring device as well as an original research method based on linear measurement of light passing through a fabric.

The test stand presented for assessing the level of barrier properties of a darkening fabric was constructed for further use by authorised laboratories or manufacturers and users of blackout fabrics.

Experimental

Materials

Inspiration for the study came from observations of the structures of blackout fabrics available on the fabric market for buildings. Blackout fabrics of documented barrier efficiency were selected for the study. Those products have been found to vary considerably in their construction. The organoleptic assessment indicates that they may exhibit a varied level of barrier properties. However, all fabrics feature very good masking properties, according to the available methodology for evaluation of barrier properties. The problems of point-based measurements in assessing the optical properties of blackout fabrics were examined in an earlier paper entitled 'Subjective Interpretation and Objective Evaluation of Blackout Fabric's Barrier Properties" [5].

Below, **Figure 2** shows examples of blackout fabrics with defined, highly satisfactory barrier properties (fabrics 1, 2 and 3). The main criterion for the selection of fabrics to study was the most differentiated structure. In the preliminary organoleptic evaluation, the samples feature different barrier properties. **Figure 2** shows a view of the blackout fabrics used for further investigation.

Comparing the structures above, it should be noted that there are visible differences between them in their structure [6]. Fabric 1 is one-color, has a smooth, uniform structure, and is difficult to recognise in the initial assessment. Fabric 2 has a distinct weaving structure that is easily recognizable due to the use of ornamen-

tal yarns with increased linear density. Fabric 3 features a smooth surface, with a visible drawing of the fabric structure, and contrasting adornment print.

Detailed analysis of the fabrics allows to recognise the manufacturing tech-

nology [7, 8]. Fabric 1 is an example of a mono-structural, monochromatic fabric, made according to the technology of layered warp threads, with a 1/4 satin weave. Multi-structural Fabric 2 is made with the technology of double fabrics, based on satin weave 1/5, using a deco-

Table 6 — Opacity of fabrics — Classification

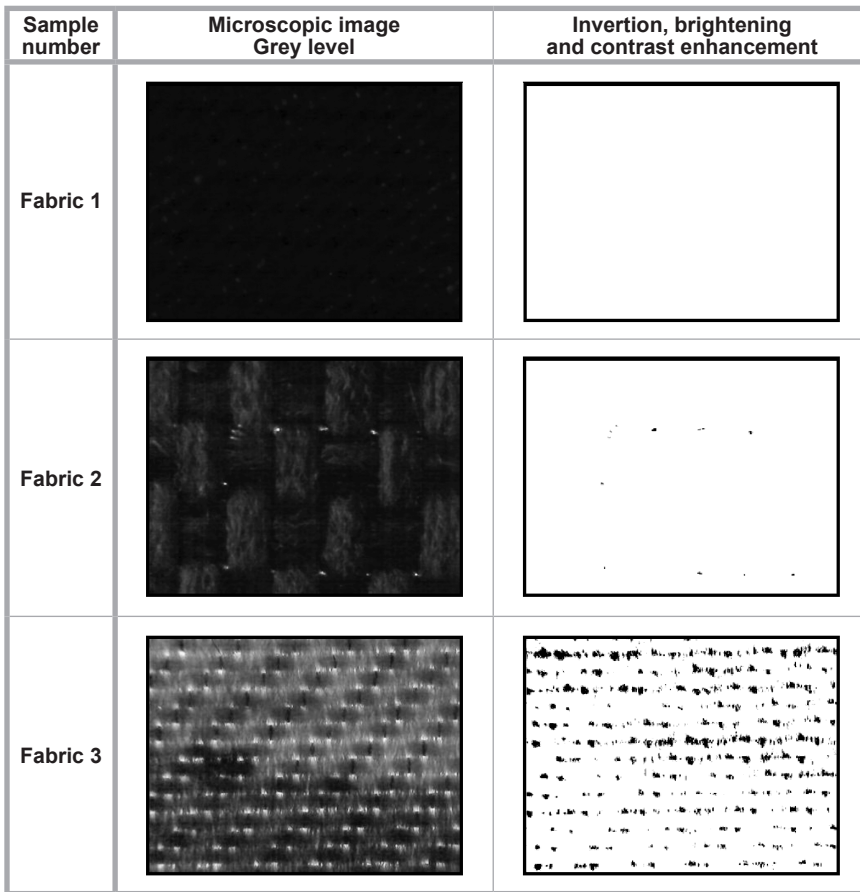| Opacity control of fabric	Classification of fabric
No light perceived when tested under 1 000 Lux	Dim out
No light perceived when tested under 100 000 Lux	Black out

Table 7 — Opacity control of products — Classification

Product performance	Product classification	Class
No light perceived when tested under more than 10 Lux	Dim out	1
No light perceived when tested under more than 1 000 Lux		2
No light perceived when tested under more than 75 000 Lux	Black out	3

Figure 1. Classification of darkening fabrics and products. Part of the PN-EN 14501:2005 standard [1].

| Fabric 1 | Fabric 2 | Fabric 3 |

Figure 2. View of blackout fabrics selected for analysis.
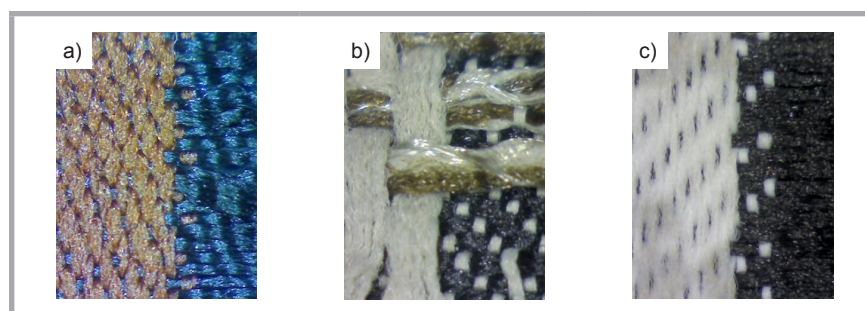
Figure 3. View of the structures of blackout fabrics, magnification 50x: a) structure of fabric 1, b) structure of fabric 2, c) structure of fabric 3.

Sample number	Microscopic image Grey level	Invertion, brightening and contrast enhancement
Fabric 1		
Fabric 2		
Fabric 3		

Figure 4. View of clearances in the structures of blackout fabrics.

rative yarn. Fabric 3 is mono-structural, printed, and made with the technology of fabrics with layered warp threads, and with a 1/6 weave. In fabrics 1-3, multi-filament polyester silk was used as the material. Parameters of the yarns are included in *Table 1*.

Basic technological parameters of blackout fabrics 1-3 are presented in *Table 1*.

Analysis of the technological parameters confirms that fabrics 1-3 differ significantly in terms of the areal density, thickness and thread density.

In the further part of the study, micro-observations and comparisons of fabric structures were made on the basis of their digital image. The images were recorded using a Delta Optical Smart optical

microscope (Poland) under 50x magnification. The light source was an LED panel with a power of 1260 lm (18 W) and a 220x220 mm luminous area of 68 000 lux intensity. The image acquired was digitally processed using the widely-available ImageJ digital image analysis software. The ImageJ program is a tool for analysing and processing digital images, most commonly used in medical image analysis.

Figure 4 presents the structures of fabrics recorded by optical microscope and their digital conversions. The following settings were applied: 8bit, invertion, brightening and contrast enhancement, which allowed to extract the clearances out of the images. The clearances should be considered as structure faults that testify to the reduced level of barrier fabric properties.

Analysis of the fabrics' structures validates the subjective preliminary assessment. The fabrics feature a varied morphological structure, and hence different levels of their barrier properties could be expected. The images shown in *Figure 4* confirm this phenomenon.

Methodology and results
Current state
Spectrophotometric measurements of the optical properties of textiles are made using a double-beam spectrophotometer equipped with an integrating sphere. According to the PN-EN ISO 13758-1 Standard [4], for each sample, the radiation transmission is calculated as the arithmetic mean for a specified range of wavelength λ. In the case of ultraviolet and visible light, we exploit the following formulas:

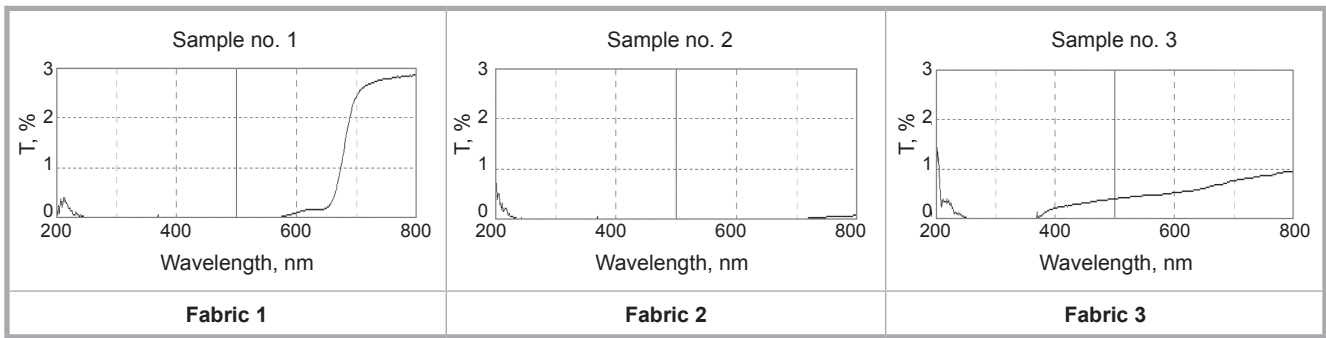$$UVA = \frac{1}{m} \sum_{\lambda=315}^{400} T_i(\lambda) \qquad (1)$$

and

$$UVB = \frac{1}{k} \sum_{\lambda=290}^{315} T_i(\lambda) \qquad (2),$$

and

$$VIS = \frac{1}{n} \sum_{\lambda=400}^{700} T_i(\lambda) \qquad (3)$$

where: T_i – radiation spectral transmittance in the sample and at wavelength λ, nm; m, k, n – numbers of measurements taken at a constant bandwidth for the radiation range examined.

In the first part of the experimental work, the screening level of fabrics 1, 2 & 3 was checked with the point-method assessment of barrier properties. Research procedure PR/17/2007 [2] of the Textile Research Institute in Lodz, Poland was used, developed on the basis of the PN-EN ISO 13758-1 standard, which addresses tests of light transmittance within the visible range of 400-700 nm.

The research was carried out with a dual-beam spectrophotometer UV-VIS, Jasco V-550, (Japan) equipped with an integrating sphere. Samples of the flat textile product after acclimatisation were placed in the transmission socket of the integra-

Table 1. Structural parameters of blackout fabrics [5].

Number of sample	Cover Factor, % (4174:1994)	Areal density, g/m²	Thickness, mm	Weft yarns		Warp yarns	
				Linear density, dtex	Density, treads/dm	Linear density, dtex	Density, threads/dm
1	100	248	0,61	167/36	350	84/36	1000
2	99,93	315	1,60	334/78; 220/48	160; 320	334/72; 84/36	100; 800
3	91,56	206	0,50	167/36	280	84/36	1000

Figure 5. *Analysis of the barrier properties based on the measurement of test material transmittance, according to the PN-EN ISO 13758-1 standard [5].*

tion sphere (without stress, adhering to the surface of the opening). Transmission measurements were performed every 5 nm using a spectral gap 4 nm wide. The final result is the arithmetic mean of all calculated mean light transmittances in the range of 400-700 nm according to ***Equation (3)***. Results of analysis of the test material's barrier action are shown in ***Figure 5***.

Based on the results of the analysis, it is justified to conclude that the methodology qualifies test fabrics applied to products with very good barrier properties. The transmission level of light radiation that passes through the sample does not exceed 1%. Fabric 1 in the final visible range at wavelengths of about 680-700 nm shows an increase in transmittance to the level of 2-2.5%. The result can be explained by the radiation absorption resulting from the chemical structure of the yarn's dye in fabric 1. However, the level of transmittance observed indicates very good protective properties, as confirmed by the PN-EN ISO 13758-2 standard [9].

It should be also noted that due to the heterogeneity of the test material, which are textiles, more specifically flat textile products, measurement should be made at 4 measurement spots at least [10]. If the material is multi-coloured or of varied structure, then at least 2 samples of each colour or structure should be taken. [2]. In view of the recommendations above, it can be concluded that a lack of measurement objectivity has already been observed. Moreover the result of the test is the arithmetic mean of transmittance of radiation passing through a sample at a given point determined by the size of the spectral gap of the spectrophotometer. This narrows the measurement to a point, thus with 4 repetitions information about the fab-

ric structure equals 0 (the probability of detecting the clearance is equal to 0). The annotation above can be interpreted as follows: conditions of point-based measurement combined with the characteristics of the test material may affect the result of measurement. Therefore the method assumes the uniformity of the fabric structure by considering it as a homogeneous filter. The more this method cannot be applied to the evaluation of blackout fabrics is when complex architecture of a product requires the use of a method very sensitive to discontinuities (microclearances).

Another approach to determining the level of barrier properties is presented by sources that link optical barrier properties with a product fill coefficient, for example the AS 4174:1994 Standard [11]. John Javorniczky [12] refers the AS 4174:1994 Standard in his works. The Standard specifies the requirements for protective fabrics, including ways of determining the fill factor, as well as measuring the transmission of UV and solar radiation. According to this standard, the cover factor primarily serves to classify blackout fabrics into 3 groups in terms of efficiency (***Figure 6***).

Bilimis [13] describes a method of measuring passing light using a UV-Vis Cary 1/3E spectrophotometer in relation to the coverage ratio. The cover factor is determined with ***Equation (4)***:

$$CF = 100 - \%Tave \qquad (4)$$

where: %Tave is the mean transmittance of 10 measurements at a given wavelength λ.

The cover factor (CF) is one of basic parameters of a fabric structure, which determines its final destination. Many special features of products such as air permeability, thermo-physical clothing comfort, UV barrier and chemical barrier properties are closely related to this parameter. CF is defined as the ratio of the surface covered with threads to the total area of the product [14].

It is logical to say that a product with a high CF satisfies the requirements of a barrier condition for visible light. For blackout fabrics, the scattering range of this factor should be specified.

The surface measurement of blackout fabrics was based on the works of Tapias et al. [14], who presented the possibility of objective measurement of the fill factor using digital image analysis. Post-processing of a microscopic image of a fabric brought the possibility of presenting the CF as the ratio of the gray pixel number to the total pixel number, while white pixels represented the clearances ("holes"). First the image of the fabric structure was trimmed to eliminate incomplete views of the yarns. Then several procedures of thresholding the gray

SYSTEM OF CLASSIFYING THE BLACKOUT EFFICIENCY	
UVE, %	CATEGORY OF PROTECTION
80.0-90.9	EFFECTIVE
91.0-94.9	VERY EFFECTIVE
95.0 +	MOST EFFECTIVE

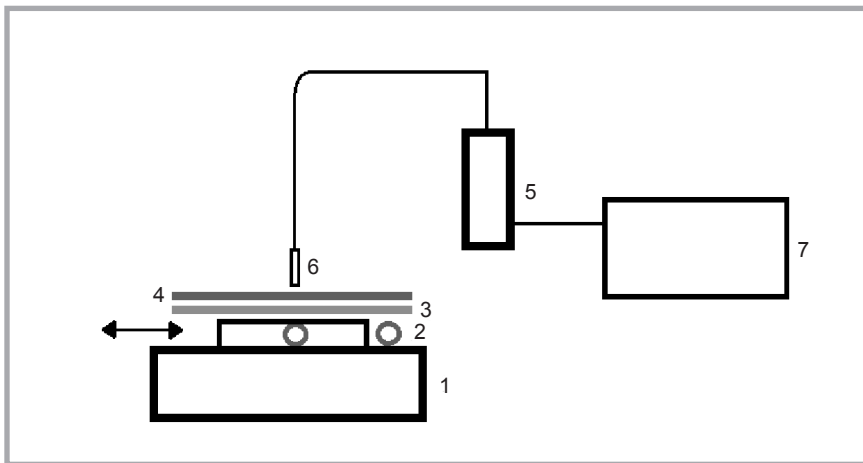**Figure 6.** *Human shade protection fabrics, performance requirements from AS 4174:1994 [10, 11].*

Figure 7. Schematic view of research station for testing blackout properties.

shades were applied, i.e. the reduction of the greyscale to a binary image. It is worth noting that digital image analysis yielded results comparable to subjective judgment.

Based on the work on the surface evaluation of woven structures cited above, a similar approach was proposed for blackout fabrics. Images resulting from the post-processing of microscopic photographs are shown in *Table 2*. Fabric samples were recorded with a resolution of 640x480 pixels and with the 8-bit greyscale.

The use of digital image analysis to evaluate the structure and parameters of textiles is known from the literature [15-18]. Image software has been proposed as a tool for computer image analysis [19]. Image processing is based on simple functions. The following operations were used: converting to greyscale, the brightness and contrast improving and thresholding procedures. The preliminary activities allowed to identify the image areas that exhibit structural irregularities. Those tests serve to recognise objects that differ from the fabric background, ie. the clearances. Greyscale is a range of values from 0 to 255. In this case, an optimum brightness range of 0 to 127 was selected, which facilitated detailed detection of the clearances.

The pores in the fabric structure were determined with the greyscale, where 0 was black and 255 was white. A value of 127 meant the highest gray level acceptable as a clearance. Images were analysed only in the channel of colours described. Pixels with values higher than the threshold value were considered white. Moreover the scaling of the image's brightness applied makes it easier to distinguish the clearances (ie. areas not covered by threads) from a shine or light transmission by the yarns.

The next stage was measurement and morphological analysis of the images made. The following features were selected for extraction: number of pixels, total area occupied by clearances, average pore size and percentage of area they occupy. Results of the analysis are presented in *Table 2*.

Based on the analysis it can be stated that a considerable variation in values was observed, which confirmed a subjective evaluation of the fabrics. Fabric 1 exhibits no clearances, being a 100% barrier for visible light. The structure is uniform and has no local anomalies.

According to the subjective evaluation, fabric 2 features a tight structure with sequences of clearances occurring regularly. The repetitive sequence of single

clearances is particularly unfavourable, because it is noticeable to the human eye. The quantitative analysis shows that there is a small amount of clearances in the structure, as they only occupy 0.07% of the area examined.

Fabric 3 proved a far looser structure, and it is therefore justified to state that it had clearances in each structural module. A significant share of the clearances in the fabric structure were visible to the naked eye. The above-described digital image analysis of the sample area supports this assessment. The numerical data presented in *Table 2* prove that the structure of fabric 3 has a big number of clearances of relatively large size, occupying almost 8.5% of the sample's total area. It can be concluded that digital image analysis can be used to evaluate the barrier properties of textiles provided the limit values of the most important parameters are defined, such as the pixel count, average pixel size, % of area.

Developing new research methodology
The next part of the study was focused on the development of original research methodology for evaluating the barrier properties of blackout fabrics.

The goal of the new blackout fabric testing methodology was to effectively detect local structural disturbances (such as those observed in sample 2), that is, to develop a suitably sensitive test procedure applicable for assessing the structure of blackout fabrics.

A research station was constructed for the new methodology. The measuring system consisted of a sliding table with a determined step of 0.01mm (1) equipped with micrometric screws (2) and a light source (3) resting on the table, with a sample of fabric (4). The main measurement instrument was an HR 2000+ Spectrometer from Ocean Optics (5), equipped with a light probe (6), the end of which was fixed to the arm of the stand above the sample of fabric (4). The spectrometer was connected to a computer (7) with a USB interface. The view of the station is presented in the *Figure 7*.

Preparation of the work stand for the tests consisted of operations that determined the reproducibility of the results. Fabric samples were fixed in frames that ensured accurate adherence to the light source resting on the sliding table

Table 2. Summary of computer image analysis of fabrics examined.

Sample	Count, pixels	Total area, pixels	Average size, pixels	% of area
1	0	0.000	NaN	0.000
2	13	221	17	0.072
3	760	25918	34.103	8.437
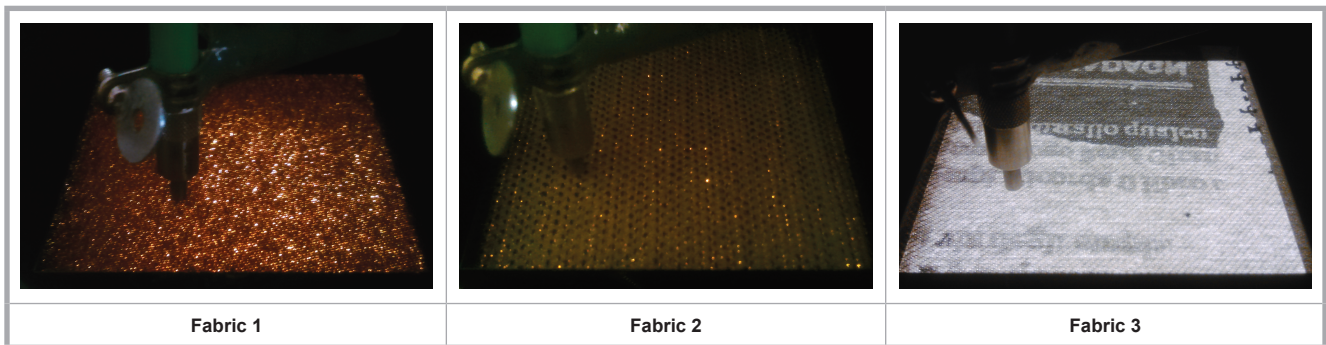
Figure 8. View of the structures of the blackout fabrics tested under measurement conditions

of the instrument. In addition, the system of fixing the samples in the frames caused them slight tension, thus forcing conditions such as the actual vertical suspension. Then the spectrometer's optical fibre tip was attached to the instrument's arm, stabilising it in the arm holder, along an axis perpendicular to the test surface. The tip was set at 1mm above the sample. The spectrometer was controlled by the Spectra Suite program [20].

Fabric structure views recorded during the photometric tests are shown in *Figure 8*.

Views of the structures under light passing-through reveal differences in the intensity and nature of light passage through the fabrics. This can be a homogeneous "glow" of the entire structure (fabric 3) with passing light of lower intensity (dampened by the fabric). A heterogeneous glow of the structure in the scope of dampened intensity was recorded, as well as increased intensity originating from the clearances. Then changes in light intensity are observed across the entire surface (fabric 1). The case described proves the correctness of the structural design, but also a lack of adequate structure density. Other fabric structures produce more negative feelings. They have visible clearances of much higher intensity compared to the rest of the structure. Fabric 2 has clusters of single clearances, covering the entire surface of the sample. Such repeated single clearances, due to the layout and higher intensity level, contrast with the rest of the structure, which allows to recognise them easily. It should be noted that both phenomena are unfavorable. However, the worst are those related to the maximum intensity coming from the clearances. The occurrence of clearances – the spots deprived of yarns – is unacceptable in the structure of blackout fabrics.

Prior to the analysis, the spectrometer was calibrated using a dataset provided by the manufacturer – Ocean Optics. Then the instrument was reset with the use of the "Dark Current" option. The device's converter gives a certain level of intensity before registering a signal. It is the so-called fixed signal component, characteristic for the individual device. The launch of the research consisted in compensation of the initial signal by recording data measured with the optical fibre fully darkened, along with reference conditions of the light source (*Figure 9*).

Each measurement required setting the integration time, which is equivalent to the exposure time in a camera, and the longer it takes, the longer the photons are read by the detector. Thus the integration time affects the accuracy of measurement. The more darkening the fabric has, the longer the integration time should be, and hence the result of the measurement will be in the so-called useful measuring range. According to the Spectra Suite manual, for a representative result, the integration time should be adjusted so the maximum value from the measurement is approximately ¾ of the total measurement scale. When examining the

blackout fabrics, it is suggested to tend towards the result concentration as close as possible to the saturation point within the measurement scale. This will yield the lowest noise to signal ratio.

The results were recorded as numerical data both in tables and graphical presentations of intensity I, jw as a function of the wavelength λ, nm. The maximum value of the peak corresponding to the maximum intensity from a clearance was read, and then a continuous record of characteristics of the fabric structures in the form of animation was made. A 15 mm long structure was analysed, which allowed to the research to cover several weave reports. Within the material recorded, a cyclicality of radiation intensity changes was observed typical for each fabric structure, depending on the size of the weave report.

For presentation purposes, the continuous recording was simplified, i.e. the frames that follow each other at the same time intervals were selected from the animation, which enabled to analyse 30 frames from the animation. Graphs of signal intensity "I" for individual wavelengths λ are the result of photometric analysis of blackout structures results of the analysis

Figure 9. *Spectral characteristics of the light source at an integration time of 4000 ms.*
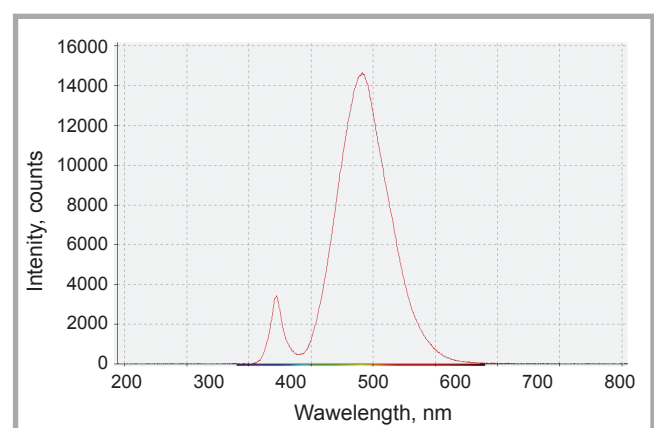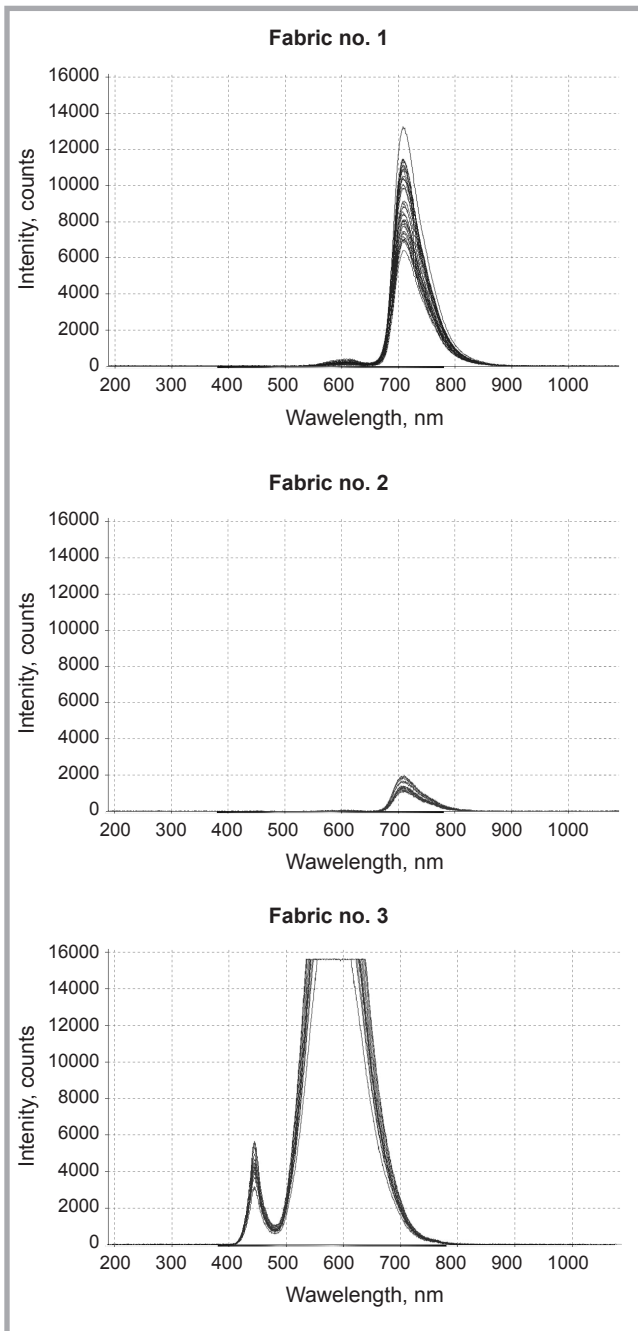
Figure 10. *Comparison of fabric structures by linear method, using fixed integration time Ti = 500 ms.*
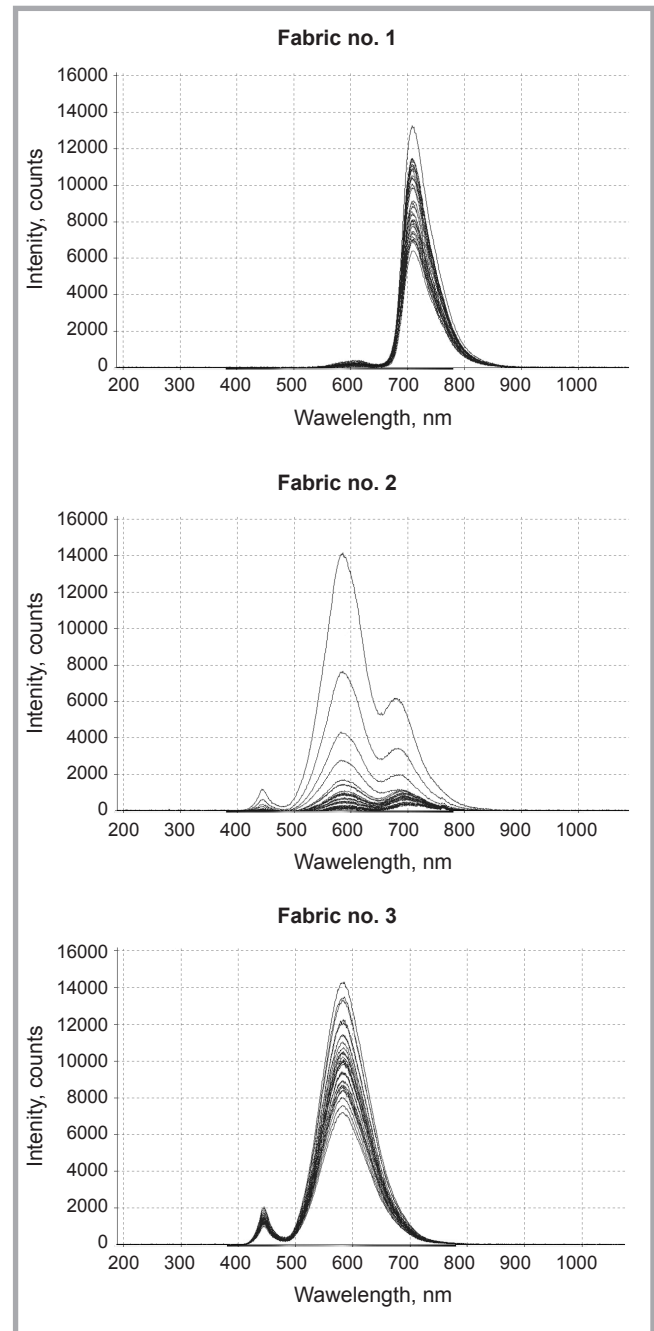
Figure 11. *Analysis of radiation intensity I [i] as a function of wavelength λ. Integration times: 3 ms; 4 ms; 0.3 ms respectively.*

in the form of aggregated graphs derived from the animation of the structure run are presented in *Figures 10* and *11*. A full comparison of fabrics during the analysis of structures for the same integration times shows clearly their wide range of quality. *Figure 10* presents a record of characteristics of the fabrics examined, at a constant integration time of 500 ms. For quantitative purposes, however, it was necessary to adjust the integration time for each sample. Differences in the intensity of the radiation were so great that they prevented analysis of the samples with the same setting of the integra-

tion time. The maximum value of the intensity from the structure of fabric 1 was recorded at an integration time of 3 seconds, of fabric no. 2 – 4 seconds, and of fabric 3 – 0.3 second. *Figure 11* presents a record of characteristics of the fabrics tested at the time of integration individually selected for each sample.

Observation of a larger range of measurements derived from animation enables a more complete assessment of fabric structures. It is worth noting that both maximum and minimum values can be observed. The maximum values provide

information on the clearances, while the minima show the overall quality of the blackout structure apart from clearances ie. the background.

A comparison of the maximum intensity values within the clearances will be possible after determining the factor correcting the application of variable integration times 'a', expressed by the rate of the fabric integration time examined (Ti_{tk}) to the integration time of the light source ($Ti_{św}$), compared to the value of reference intensity of the light source. It is defined with *Equation (5)*.

$$a = (Ti_{tk}/ Ti_{św}) V_{św} \qquad (5)$$

In addition, due to the nonlinearity of the light source spectrum, an assumption was made that the intensity values for the entire spectrum tested should be summed up, since no single value is representative. Otherwise readings of maxima should have been made at the same frequency as the maximum in the light source was recorded at; however, this was impossible due to the effect of the fabric colours on the spectral characteristics.

The permeability P, % for one wavelength (6), or for a frequency range (7), is determined by the following formulas:

$$P = \frac{V_{tk}}{\left(\frac{T_{itk}}{T_{iśw}}\right) \cdot V_{św}} \cdot 100 \qquad (6)$$

$$P = \frac{\sum\limits_{380}^{780} V_{tk}}{\left(\frac{T_{itk}}{T_{iśw}}\right) \cdot \sum\limits_{380}^{780} V_{św}} \cdot 100 \qquad (7)$$

Thus the fabric's darkening capability Z_{tk} (compared to the value of reference intensity of the light source, while preserving the time scale of integration for all measurements) is:

$$Z_{tk} = 100 - [P] \qquad (8),$$

where:
Z_{tk} – darkening capability expressed in percentage
P – permeability of the fabric structure

A summary of the analysis of the barrier phenomena assessment in blackout fabrics carried out with the linear method is presented in **Table 3**.

Quantitative analysis revealed differences between darkening capabilities of the fabrics tested classified as blackout ones. According to the data given in **Table 3**, fabric 3 exhibits weaker darkening properties. Compared to fabric 2, an over 13 fold (13.47) decrease in structural barrier properties is observed, as apparent from the ratio of $P_{tk3} : P_{tk2}$. Fabric 3 is considered a structure permeable to light throughout all of its area.

Differences in fabric structures, and thus in the darkening properties, were very evident at the preliminary stage of the study, during observations of structures under measurement conditions. (**Figure 8**). The analysis performed, presented in **Table 3**, confirms the hypothesis of different levels of barrier properties in the fabrics tested.

Table 3. Summary of the analysis of photometric assessment of the fabric structures

	Light source	Fabric no. 1	Fabric no. 2	Fabric no. 3
Integration time Ti, ms	4	3000	4000	300
Intensity value from the measurement I_0, jw	14781	13182.67	14129.33	14171.33
$\sum I_0$, jw	3477257	1834687	3787377	3375041
Correction factor „a"	–	750x14781	1000x14781	75x14781
P, %	–	0.12	0.095	1.28
Z_{tk},%	–	99.88	99.905	98.72

The intensity of the clearance „I_0" within the study was measured in relative units (jw). The intensity of the light source recorded in the initial measurement made at the beginning of photometric tests was taken as a reference. Knowing the intensity of the light source, we can quantify the intensity values from the clearances and, at the same time, find the intensity threshold allowable for the blackout fabrics. With the methodology presented, the indices of barrier properties can be precisely determined on the basis of the darkening capability Z_{tk} calculated.

■ Summary and conclusions

As a part of the work, the possibility of applying the current methods of measuring the barrier properties of flat textile products was checked in relation to blackout fabrics. Two research procedures were analysed: the first based on point measurement and conducted according to PR/17/2007 [2], the other – area-based, conducted according to the procedure of digital image analysis.

The available research method based on point measurement proved to be ineffective. The lack of appropriate sensitivity of the method to local structural dislocations disqualifies it for application in the assessment of blackout fabrics. Spot-based methods for measuring the levels of barrier properties of fabrics were not found to be objective regardless of the methodology applied, and therefore cannot be used to assess the opacity of the fabrics.

Afterwards the results of evaluation of the phenomenon of shielding against visible light by blackout fabric were presented with the use of digital image analysis. The method was demonstrated to be objective. Identifying the presence of clearances as well as their effect on light barrier properties in blackout structures requires, however, an improvement in providing reproducible recording conditions.

In the subsequent part of the work, an original method of linear tracking of the structure of blackout fabrics was presented. A measurement work stand was built for detecting structure defects. Interpretation of graphical results is reduced to the analysis of "min" and "max" levels, where "min" determines the permeability of the fabric structure in the background, while the "max" value determines the permeability within the clearance. In addition, the difference between "min" and "max" describes the homogeneity of the structure. A full, graphical image of the quality of the blackout fabric structure was obtained. Quantitative analysis of the structure justifies the conclusion that blackout fabrics are those whose darkening capability $Z_{t\backslash k}$ is above 99%. Moreover analyses of the "min" and "max" levels, as well as the "max-min" difference, become the complement. On the basis of the study carried out, a conclusion can be made that the "ideal" characteristics of the blackout structure should be patterned based on the characteristics of fabric 2 (**Figure 10**). The reference point is the result of intensity measurements at the level max = 2000 jw, and max-min within the range 0-1000 jw. (provided the reference conditions presented in this paper are retained). Linear interference tracking was proven to provide a very detailed and objective assessment of the barrier effect of blackout fabrics.

Both the test stand and methodology of evaluating the darkening capabilities of blackout fabrics developed have been adapted for further implementation in industrial applications.

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References

1. PN-EN 14501:2005. Blinds and shutters. Thermal and visual comfort. Performance characteristics and classification.
2. Procedura badawcza PR/17/2007. Płaskie wyroby włókiennicze. Badanie

Transmisji światła w zakresie od 400 nm do 700nm wg PN-EN ISO 13758-1:2007

3. Hemka L. Opracowanie metodyki badań oraz kryteriów oceny właściwości barierowych dla UV materiałów wyposażenia wnętrz i do budownictwa. Prace Instytutu Elektrotechniki, vol. 245, 2010, p. 301-317.

4. EN ISO 13758-1:2001 – Textiles. Solar UV protective properties, Part 1

5. Szkudlarek J, Snycerski M. Subjective Interpretation and Objective Evaluation of Blackout Fabric's Barrier Properties. *Fibres and Textiles in Eastern Europe* 2016; 24, 5(119): 44-49.

6. Szosland J. *Struktury tkaninowe*, Handbook, 2007, ISBN 83-86492-42-2

7. Nycz E, Owczarz R, Średnicka L. *Budowa tkanin*, Handbook, 1990, ISBN 83-02-03229-8, WSIP

8. Zajkiewicz H. *Budowa tkanin*, Handbook, 1975, WSiP

9. PN-EN ISO 13758-2 – Textiles. Solar UV protective properties – Part 2: Classification and making of apparel.

10. Lewartowska J, Sójka-Ledakowicz J, Gajdzicki B, Kudzin M, Prosiak P. Spektrofotometryczna ocena współczynnika UPF dzianin bawełnianych zgodna z normami europejskimi. In: N-T POOMT, Promieniowanie Optyczne – Oddziaływanie, Metrologia, Technologie, Lądek Zdrój, 2005, p.93-100.

11. AS 4174:1994 – Synthetic shadecloth. Requirements for shade cloth ISBN 0 7262 8774

12. Javorniczky J. Review of the Synthetic Shadecloth Standard AS 4174:1994, 3rd International Conference on UV & Skin Cancer Prevention, Melbourne Australia 7-11 December 2015, access: http://uvandskincancer2015.org/cms/wp-content/uploads/2016/02/Javorniczky_ John_ Review-of-the-synthetic-shadecloth.pdf

13. Zafira Bilimis, Measuring the cover and shade protection factors of synthetic shadecloth, www.agilent.com/,Marc, 2011, Publication Number SI-A-1149, access: https://www.agilent.com/cs/library/applications/uv68.pdf

14. Tapias M, Ralló M, Soteras J E, Algaba Joaquín I M, Ascensión Riva Juan. Objective measure of woven fabric's cover factor by image processing Objetive Measure of Woven Fabrics Cover Factor by Image Processing. *Textile Research Journal* 01/2010; 80(1). DOI: 10.1177/0040517509104471.

15. Jie Zhang, Binjie Xin, Xiangji Wu. A Review of Fabric Identification Based on Image Analysis Technology. *Textiles and Light Industrial Science and Technology* 2013; 2, 3.

16. Drobina R, Machnio M S. Application of the Image Analysis Technique for Textile Identification. *Autex Research Journal* 2006; 6, 1. ISSN 1470-9589

17. Perzyna M. Evaluating the geometry of the structural elements in knitted fabrics in a computer image analysis system. Przegląd Włókienniczy 2000, 5: 24-26, ISSN:17318645.

18. Ruru Pan and all. Applying Image Analysis for Automatic Density Measurement of High-tightness Woven Fabrics. *Fibres and Textiles in Eastern Europe* 2015; 24, 2(110): 66-72.

19. Image J, available: http://rsb.info.nih.gov/ij/download.html

20. Materiały informacyjne firmy Ocean Optics http://oceanoptics.com/wp-content/uploads/SpectraSuite.pdf