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Subjective Interpretation and Objective Evaluation of Blackout Fabric's Barrier Properties

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Abstract
This work presents an experimental approach and the results of preliminary measurements of the light barrier properties of shading fabrics (blackouts). Based on literature it can be stated that there is a lack of requirements for fabrics with barrier features against sunlight. Woven blackouts which obtain shading properties through their structure need the development of objective methods, measurement indicators, and assessment criteria. Research was conducted on six woven blackouts, commonly used in public buildings as curtains. According to the conventional method, the level of transmittance evaluated was confirmed. All samples feature very good protection against visual radiation (VIS). However the subjective interpretation contributed to the discovery of differences between the samples. The questions raised are as follows: What differences are acceptable? How to qualify blackout fabrics properly? To demonstrate the ineffectiveness of the standard method, computer image analysis was used.

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

Introduction

In public buildings like hotels and other MICE areas (Meetings, Incentives, Conferences and Exhibitions), all interior furnishing, especially textile items, have to meet special requirements. Two of them are obligatory for curtains - fire resistance and blackout features. Requirements for fire resistance can be easily defined using available European and local standards [1]. In contrast, there are no defined stipulations concerning barrier properties to visible light.

Exploratory research was carried out on the basis of the standards, technical specifications and literature reports. No information about the acceptable level of validity of the curtain fabric's barrier properties and their classification was found. Barrier features, mainly the barrier properties against UV radiation of textiles, are analysed by spectrophotometric methods based on PN-EN ISO 13758-1 [2]. Thus far no one cared to check whether this methodology could be applied to blackout fabrics.

It can be stated, that research on the shading systems only focused on the heating load reduction of draperies [3, 4]. Another paper was related to the performance of shadings depending on their daylight characteristics [5 - 7]. None of the literature reviewed defined the acceptable level of light barrier properties nor the methods of qualifying the blackouts. There have been cases where the investor defined a satisfactory level of barrier properties (based on feelings when the fabric was put on window glazing). The process of identifying the optical barrier features of blackouts is a significant problem for manufacturers and users. The subject of the main special requirements for curtains like shading (above fire resistance) should be defined clearly and precisely.

It is worth emphasising that the fabrics presented in the article owe their barrier properties to the special construction. Regarding the assortment of curtains, the anti-sunlight protective properties result from a proper combination of the parameters of the material, weave, and weaving process, and not from the finishing treatment. The coated blackout fabrics used in buildings as curtains have been replaced by woven blackout fabrics. The mechanism of darkening by coated fabrics is not a combination of so many parameters as for woven blackouts. Therefore deviations are expected from the standards that have been defined so far by coated blackout fabrics. The woven blackout fabrics have not yet been analysed in terms of the impact of their structure on the level of barrier properties. The structural analysis proved that such materials are ostensibly homogeneous and require individual evaluation criteria.

This study presents a method for qualifying woven blackout fabrics to be used for barriers against visible light. The aim of the work was to identify experimentally blackout fabrics proposed as curtains, their structures, basic parameters and the level of barrier properties. First of all the methodology commonly used was applied. The results allowed to conclude that the testing conditions were insufficient for blackout type fabrics with a complex structure. Consequently the image analysis technique was proposed as a widely available tool. The method was useful as an objective way of evaluating the fabric appearance and features. Many interesting studies have been conducted recently to evaluate fabric geometry. This research was based on reports about the identification of channels in woven fabrics influencing barrier features [8,9]. Wilbik-Hałgas, for example, examined the surface porosity and structural channels of knitted fabrics using computer image analysis. The effectiveness of darkening in the case of woven blackouts is associated with their geometry and structural parameters, which create a tendency to form clearances. Determining the size and amount of clearances on the fabric surface tested will be an introduction to guidelines for designing woven blackout fabrics. Based on the literature consideration of this problem, it seems that the digital image analysis technique has not been applied for estimation of the VIS-barrier properties of curtains. This work confirms that method presented can be useful and adequate for blackout fabrics.

Experimental

Materials

There are two techniques for obtaining blackout fabrics: laminating and weaving. Woven blackouts, also known as a blackout with black weft, are commonly used for curtains in the design of window spaces.

Six of the woven blackout fabrics often used as curtains in hotels were tested. Images of the samples are presented in ***Figure 1***.

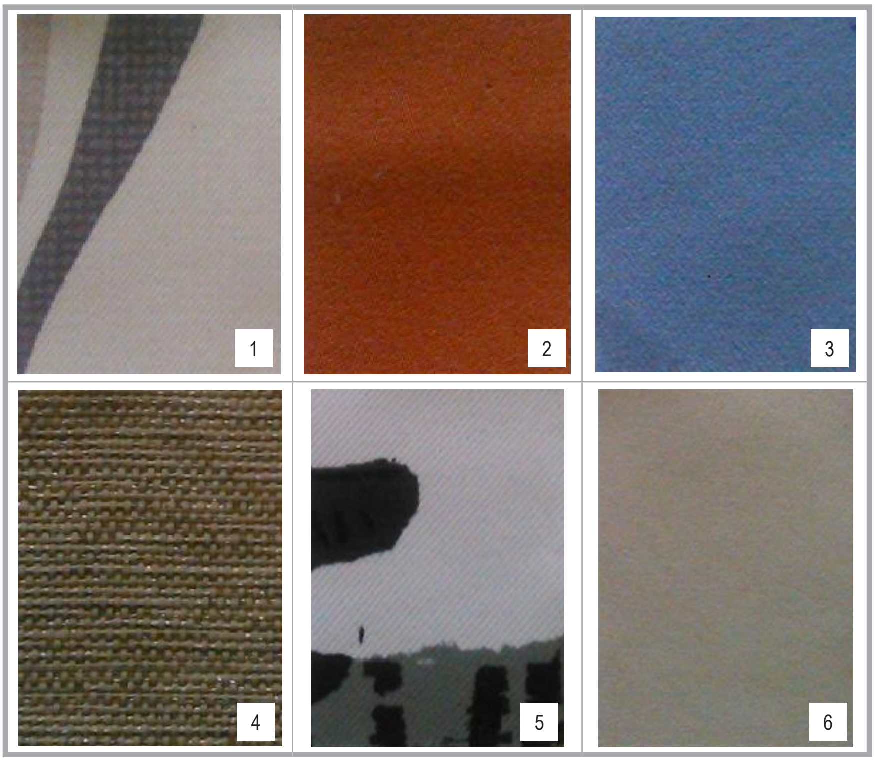


Figure 1. *Blackout fabrics presently used in public spaces.*

Fabrics of this type have a smooth, homogeneous structure without any pattern. As we can see in ***Figure 1***, the blackout effects designed are accomplished by:
- printing (fabrics 1 and 5)
- monochromatic dyeing (fabrics 2, 3, 6)
- using decorative threads (fabric 4)

Due to the fundamental feature of blackout fabrics - darkening the spaces, developing an adequate fabric structure is mandatory. Comparing the appropriate parameters of yarns, weaves and the cover factor can lead to the obtainment of optical barrier properties [10, 11].

First structural parameters of the fabrics tested were described. Some of the basic ones are shown in ***Table 1***.

Table 1. *Structural parameters of blackout fabrics*

Number of sample	Mass per square meter, g/m2	Thickness, mm	Weft yarns		Warp yarns	
			Linear density, dtex	Density, treads/dm	Linear density, dtex	Density, treads/dm
1	295	0.68	167/48	280	84/36	400
2	248	0.61	167/36	300	84/36	1000
3	285	0.75	167/36	360	84/36	1000
4	315	1.60	334/78; 220/48	160; 320	334/72; 84/36	100; 800
5	206	0.50	167/36	140	84/36	1000
6	268	0.60	167/36	320	84/36	1000

Furthermore constructional analysis of samples was conducted. It can be stated that blackout fabrics have complex structures with a build-up warp or weft yarns system (samples 1, 2, 3, 5, 6) as well as a multilayer design (sample 4). Constructions of woven blackouts are designed on the basis of sateen weaves in accordance with the criteria of structural correctness [10, 12]. Applying textured polyester threads of multifilament fibres and increased density of threads in the fabric structure intensifies the darkening effect (the parameters are presented in ***Table 1***). In addition, the mechanism of darkening is supported by the appearance of one internal arrangement of black coloured threads.

The sunlight-barrier properties of curtains arise from a proper combination of the parameters of the material, weave and weaving process. The structures of blackout fabrics presented vary from one another and they are only apparently homogeneous.

Methods

Measurements of light barrier properties with the standard method

In the next stage of the research, the level of light barrier properties of the blackout fabrics was evaluated. Tests were carried out using a 550 Jasco UV/VIS spectrophotometer equipped with an integrating sphere in accordance with the test procedure (The Lodz Textile Research Institute's own procedure no. PR/17/2007 Flat Textiles, Examination of the light transmission within the range of 400 nm to 700 nm) [13], based on PN-EN ISO 13758-1 [2]. In order to verify the level of optical barrier properties, the light transmittance was determined within the wavelength range of 400 - 700 nm. The results are presented in ***Figure 2***.

Based on the experimental results, the transmittance level evaluated was 0 - 1%. The presence of a higher peak in sample no. 2 (above 2%) should be explained by the effect of absorption within the red band - the colour of sample no. 2. That observation could be neglected because it occurred almost outside the visible area analysed. In the UPF/SPF classification system, according to AS/NZS and BS EN standards [14, 15], a level of transmission less then 2.5% (UPF in

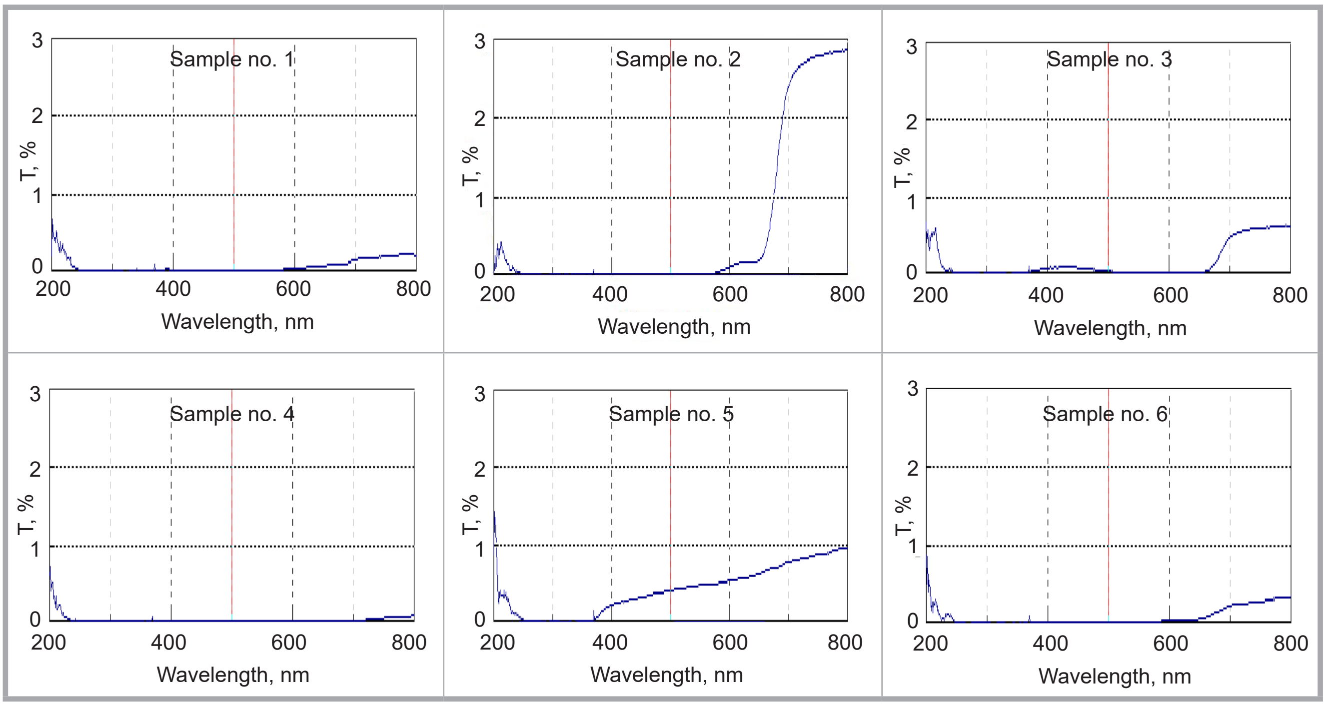


Figure 2. *Spectral transmittance T of fabrics tested at wavelength λ.*

a range 40 - 50+) is deemed an excellent protection category [16].

It can be concluded that there is very good protection against visible light (VIS) by each sample, regardless of different constructions. Differences in transmitted light could be observed with the naked eye. However, another conclusion arises that the method is ineffective, Due to the complicated structure, the blackouts require special measuring conditions which should be developed exclusively for such fabrics.

A simple test stand was constructed for analyzing the mechanism of light passage through the fabric. The samples were put on an LED light source (panel) and images were recorded by an Optical Digital Microscope at 50× magnification (Delta Optical Smart, Poland). First many kinds of light sources were tested that had to satisfy the requirements regarding surface homogeneity, stability in time and size of the lighting area. The illumination intensities were adjusted experimentally. Accordingly filters were used for intensity control. It is important to eliminate additional excitation manifested by the lighting of yarns. ***Figure 3*** presents images of the samples.

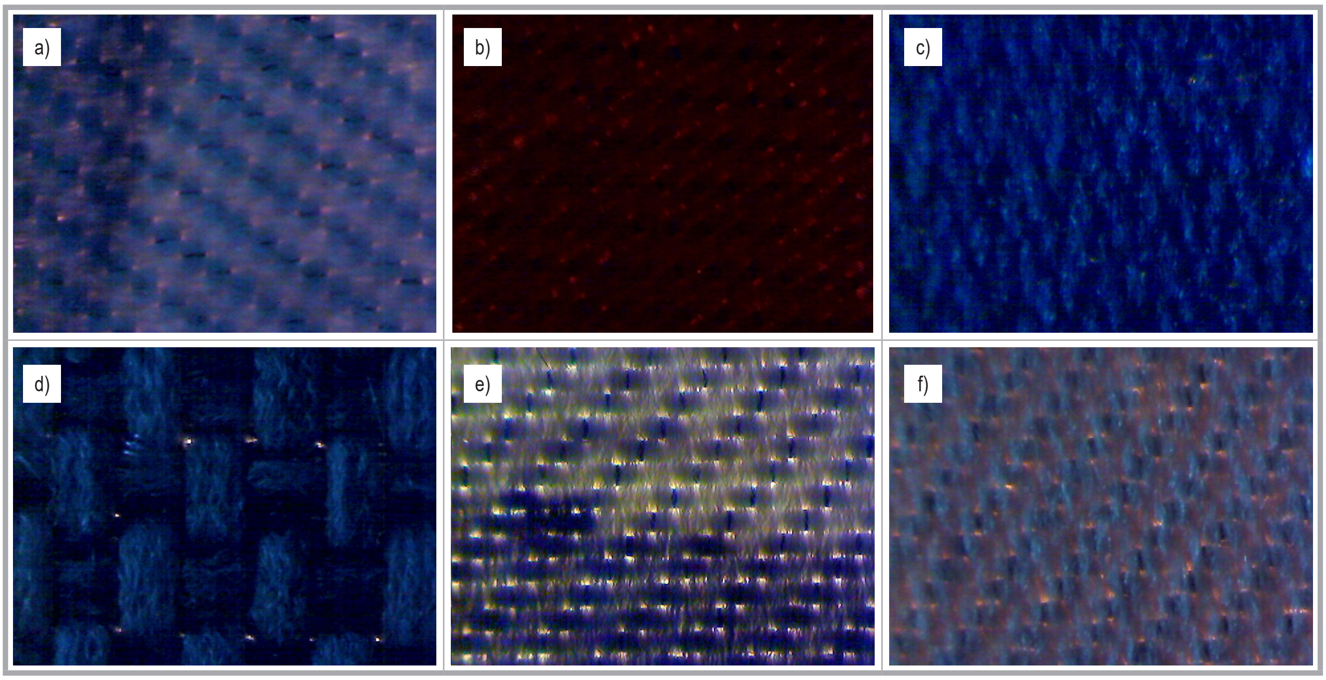


Figure 3. *Images of blackout fabrics and transmitted light. a) Sample no. 1, b) Sample no. 2, c) Sample no. 3, d) Sample no. 4, e) Sample no. 5, f) Sample no. 6.*

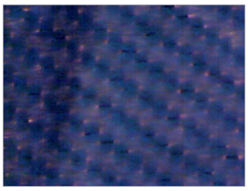
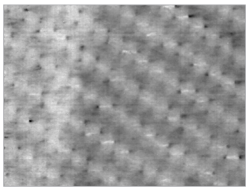
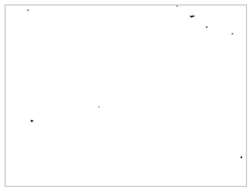
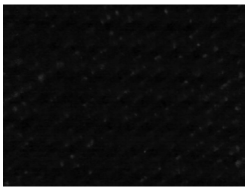
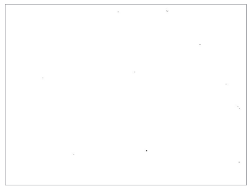
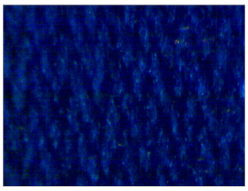
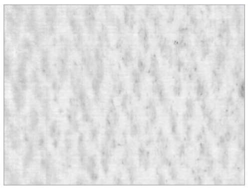
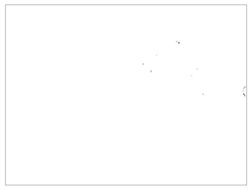
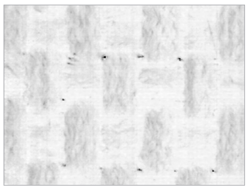
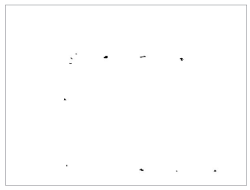
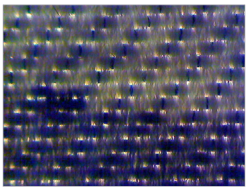
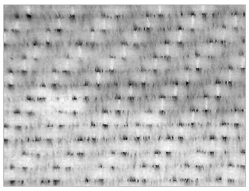
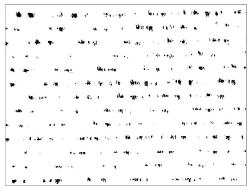
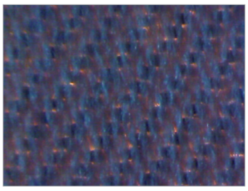
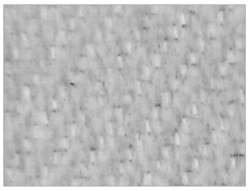
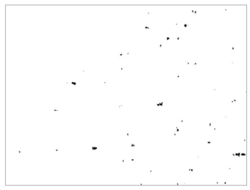
Detailed microscopic analysis of the woven structures confirmed the initial subjective evaluation of the fabrics. The light transmitted through the area observed revealed the interstices. All fabrics had dissimilar internal structures, and the analysis of yarn and weaving parameters confirmed it (***Figure 2***). Consequently their barrier properties were expected to be different, but could not be concluded based on the results of transmittance tests obtained. Such a discrepancy proved that the research method was inadequate for blackout fabrics. Searching for an appropriate objective methodology is the aim of the further part of the research.

Measurements of light barrier properties of blackouts

As stated before, the images of fabric structures allowed for observation of irregularity disclosing the inner clearances. There are applications of image analysis techniques widely known for identification of fabric structures. For the authors, studies related to the recognition of faults and the determination of their causes were of significance [17, 18]. Some researchers focused on channels or spacing between thread formation in woven fabric structures like Polipowski et al. [8]. They identified and determined the channel spacing surface in real products and proposed the use of 3D computer image analysis as opposed to 2D analysis. In recent years Ruru Pan et al. [19] used image analysis in order to identify the parameters of high-tightness woven fabrics. An important discovery was the significance of what was the way of illumination, leading to the conclusion that the structure details of samples are better examined with transmitted rather than with reflected light. The kind of light source also impacts the quality of the images. In our research a LED panel source was chosen which illuminated uniformly the whole area of the fabrics analysed. There are known studies on the influence of the structural parameters of woven fabric on barrier properties against UV [20,21]. The subjects are similar, but the researches did not use image analysis methods.

Image recording was done as the first step of computer image analysis. Afterwards research on typical digital images was conducted with ImageJ software [22]. All samples were imaged at a resolution of 640 × 480 pixels at the 8-bit gray level. Processing based on simple functions was applied [23]. The following operations were carried out: variation of the gray scale, contrast improvement and the threshold procedure [24 - 26].

Table 2. Images of samples after processing.

Number of sample	Grey scale images 640 × 480 pixels 8-bit, 300 K	Images after processing	
		Inversion and contrast enhancement	Brightening balance
1			
2			
3			
4			
5			
6			

On the grey scale the images varied from 0 to 255. The number of brightness levels (which facilitated clearance detection) was chosen in the range of 0 - 127. The pores were determined by the grey level value, where black had a grey level of 0, and white 255. The threshold level of 127 means the maximum grey level accepted as a clearance. The images were only analysed in selected colour channels. Pixels with values higher than the threshold value were projected as white. Scaling the brightness accurately allowed to distinguish between the clearances (meaning the places not covered by threads) and the effect of gloss or light conduction through the yarns. Results of the image processing are shown in ***Table 2***.

We conducted preliminary image processing with the analysis of particular object thresholds, which allowed to identify the image areas which exhibited structural irregularity. This research involved recognising objects that differ from the fabric background - namely the clearances.

The next stage was measurement and morphological analysis. The following feature extractions were selected: pixel

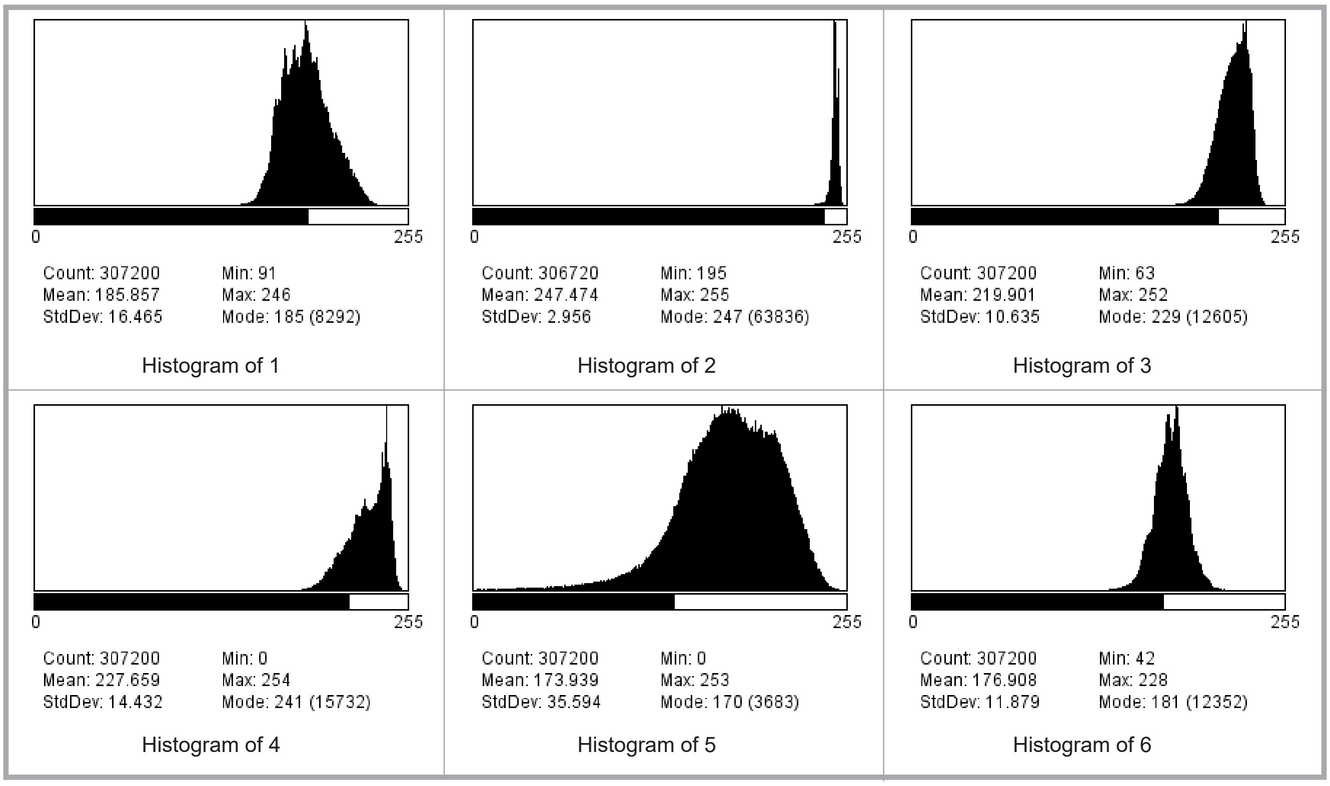


Figure 4. *Histograms of clearance distribution.*

Table 3. *Summary analysis of samples area.*

Sample	Count, pixels	Total area, pixels	Average size, pixels	% of area × 100
1	9	116	10.889	0.038
2	0	0	NaN	0.000
3	6	15	2.500	0.005
4	13	221	17.000	0.072
5	760	25918	34.103	8.437
6	65	759	11.677	0.247

count, total area, average size and percentage of area.

Results and discussion

The investigation was aimed at measuring the area of pores and to compare the samples. Therefore the number of pixels which belonged to clearance areas and the number of pixels in pores related to the total pixels are the most important indicators of blackout quality. Comparison of these parameters leads to establishing an acceptable level of their barrier properties.

Results of the analysis of the distribution, amount, and quality of clearances are presented in ***Figure 4*** and ***Table 3***.

The above histograms describe the distribution and occurrence frequency of clearances on the samples' surface. Histograms of the distribution of gray values in the active image or selection were calculated and displayed. The horizontal axis represents the possible gray values and the vertical axis shows the number of pixels found for each gray value. A characteristic distant from the value of 255 means the appearance of a clearance. The histogram of sample No. 2 should be considered as a model characteristic in relation to the blackout fabrics. The results of detailed surface analysis (quantitative interpretation) of each sample are shown in ***Table 3***.

First of all we observed that the method presented disclosed the differences between samples, which meant the method was sensitive enough. The results showed that the differences among the fabrics tested were in the range from 3 to 339 pixels in the pore area. Sample No. 5 showed the worst barrier properties. It had the biggest number of clearances, which was confirmed by the subjective assessment of its disrupted barrier properties. Samples 2 and 3 had the characteristics close to perfection, as we can see in ***Figure 4*** and ***Table 3***. Than we could conclude that the acceptable level of light transmission between the values 10 - 15 expressed in pixels should be adopted for blackouts. Blackouts should a have percentage of the pore area las for sample No. 2 evaluated in the range of about 0.001%. The acceptable size of pores should be about 1 - 2 pixels.

It was stated that the ratio of the total surface area of the pores to that accompanying the average size and amount of pores are the most important indicators for blackouts. However, attention should be paid to the distribution of clearances, because of their great importance due to visual perception. They should not stand out, as Ii is most adverse when arranged in a repetitive sequence, which is particularly discernible to the human eye, as in fabrics No. 4 and 5.

Summary and conclusions

Blackout fabrics should block the sunlight. Such a capability is necessary to satisfy the need of shading public interiors. These features are achievable by a complex construction (multilayer or built-up structures) and comparison of threads and weaving structural parameters presented in ***Table 1***. Those differences are the consequences of the irregularity and diversity of the structure, as was determined.

To evaluate the barrier properties of fabrics, a standard spectroscopy procedure based on the European Standard was applied. According to the standard method, the fabrics proved to have very good barrier properties. However, concerning transmitted light, the samples of blackouts behaved in a dissimilar manner.

Detailed microscopic analysis of blackout structures disclosed that the conventional spectrophotometric spot measurement method presents an inaccurate level of light barrier properties. The method is not sensitive enough to local interference of the fabric structure. The clearances are formed in different ways, as a cluster of several individual ones (samples 5, 6) or distributed over the whole surface (sample 4). The distribution of clearances denies the suitability of the spectrophotometric method proposed in the Standard [2].

Digital image analysis was indicated as the simplest, cheapest and most available diagnostic tool for evaluating the light barrier properties of blackout fabrics. The key advantage of this method is the analysis of a bigger surface of samples, which reveals the heterogeneity of fabrics. The results achieved with the method match the subjective assessment of a receiver. The method can be applied for preliminary classification of woven blackout fabrics. Based on the results of the research presented, we can state initially that the estimation factors of the darkening performance and further classification of blackout fabrics must rely on the testing methods specially dedicated for darkening fabrics, Such activity may be first carried out on the basis of assessment of the ratio of the average size and percentage of pore area.

The analysis above and proposals defined are an inspiration for further research in order to search for optimal solutions for darkening systems with the use of weaving technology as well as for new methodology of assessing them.

Nowadays blackouts have homogeneous structures that exhibit differences in light barrier properties. The question for the future is how to objectively obtain such properties in non homogeneous structures?

Works on the innovative design of blackout fabrics are being conducted at the Institute of Textile Architecture of Lodz University of Technology.

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