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# Experimental Identification of Light Barrier Properties of Decorative Jacquard Knitted Fabrics

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**Abstract**
*A new and original research method was developed and a measuring stand designed for identification of light barrier properties of textiles. The parameters of decorative knitted fabrics measured are the following: transmission and reflection of light, surface cover factor in correlation with the structure of the pattern, and the type of stitch as well as the kind and properties of yarns. The computer stand constructed for measuring light barrier properties of textiles is already the subject of a patent application. Using this measuring stand the authors measured and analysed light barrier properties for thirty variants of decorative jacquard knitted fabrics varying in the pattern and type of threads.*

**Key words:** *decorative jacquard knits, curtain, light barrier properties, light intensity, light transmission, light reflection, surface cover factor.*

## Introduction

The structures of knitted jacquard curtains placed in windows are a barrier against sunlight. An important issue of assessing the barrier properties of decorative textiles is determining the attenuation degree and reflection of solar radiation. Jacquard warp knitted fabrics are characterised by having a considerable amount of pattern reports. Available measuring devices defining optical values (transmission and reflection of light), such as spectrophotometers or devices using the Ulbricht sphere, have a relatively small measuring area (about 4 $cm^2$) [1 - 4]. For the structure of decorative fabric, the area is too small to determine the optical parameters of the pattern report [5 - 7].

In order to determine the level of light barrier properties of jacquard knitted structures, a research method was developed and a measuring stand designed for identification of optical properties of textiles.

## Assumptions of instrumental method for measuring light barrier properties

The method developed for experimental evaluation of the optical properties of decorative jacquard fabrics leads to the determination of the optical properties of knitted structures, simultaneously determining the surface porosity of the product's structure (***Figure 1***). This method consists of two steps: measurement – determination of optical properties of textiles, recording an image of the product tested on the experimental stand, and analysis - evaluation of the relationship between the properties of knitted fabrics tested in an environment of specialised software.

As a result of measurements we obtain values of transmission, reflection of light and a recording of an image of the prod-

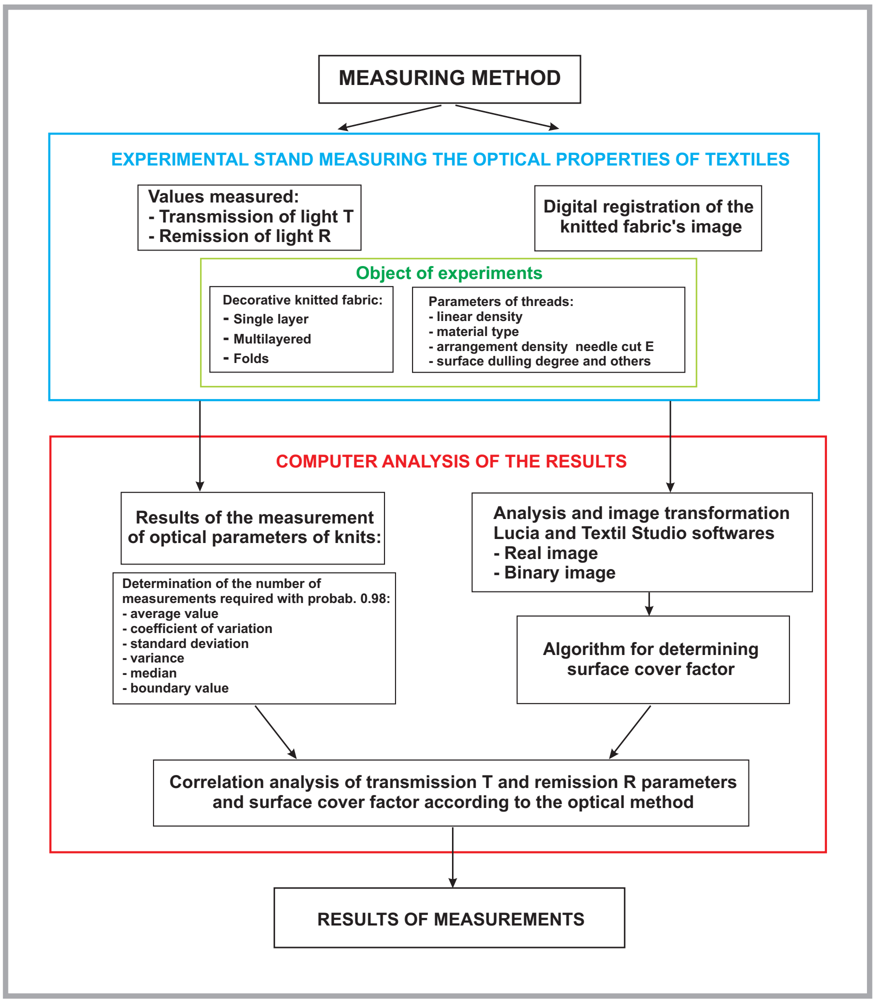


***Figure 1.*** *Methodology of determining optical and structural parameters of decorative jacquard knitted fabrics.*



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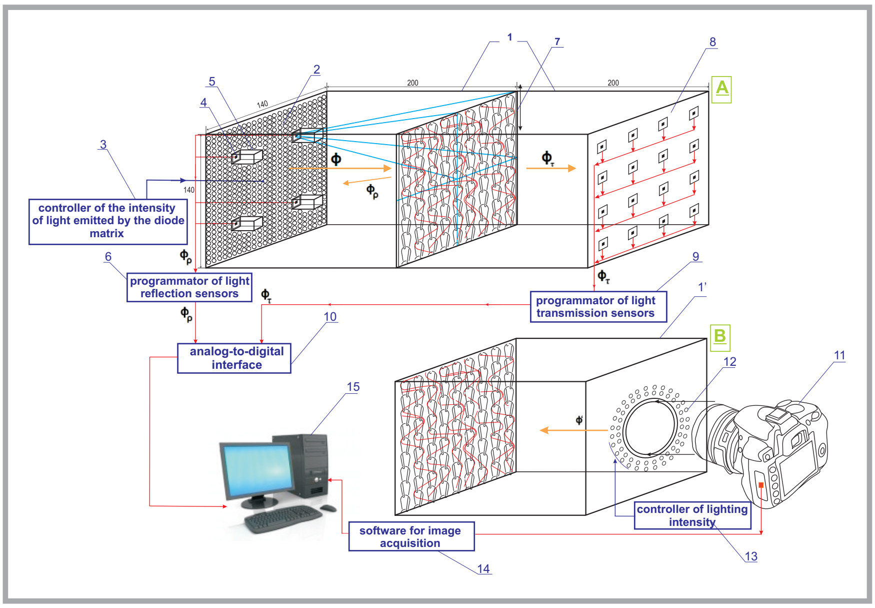


***Figure 2.*** *Scheme of experimental stand measuring light barrier properties of decorative jacquuard knitted fabrics; 1 - measuring tunnel, 2 – light source in the form of a diode matrix, 3 – controller of the intensity of light emitted by the diode matrix, 4 – one out of four sensors measuring light reflected from the knitted fabric, 5 – tunnel around the reflected light sensor, 6 – programmator of light reflection sensors, 7 – frame with a sample of decorative knitted fabric, 8 – set of sensors registering the intensity of light, 9 – programmator of light transmission sensors, 10 – analog-to-digital interface, 1' – tunnel (interchangeable) registering an image of the knitted fabric sample, 11 – camera, 12 – diode illuminating knitted fabric, 13 – controller of lighting intensity, 14 – software for image acquisition, 15 – computer; A – stage of measuring optical properties of decorative knitted fabrics - transmission and reflection of light; B – stage of registering an image of the knitted fabric tested.* φ *– stream of incident light,* $\varphi_\rho$ *– stream of light reflected from the surface of knitted fabric,* $\varphi_\tau$ *– stream of light transmitted through the knitted fabric,* φ' *– stream of light illuminating the surface of the knitted fabric while being photographing.*

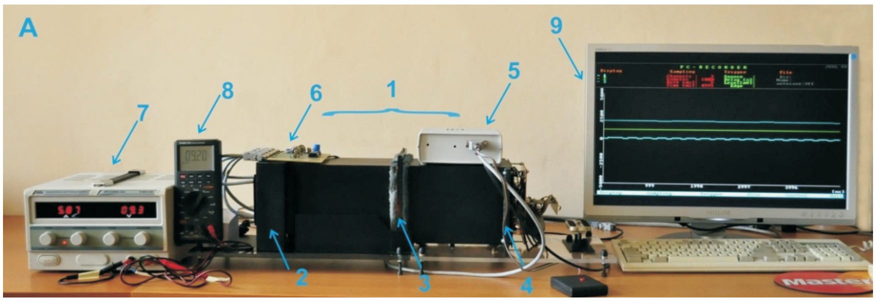


***Figure 3.*** *Experimental stand measuring light barrier properties of textiles, 1 – measuring tunnel, 2 – diode matrix, 3 – measuring frame, 4 – sensors of light transmission, 5 – programmator of transmission sensors, 6 – programmator of light reflection sensors, 7 – controller of light source intensity, 8 – meter determining the value current supply intensity of the matrix, 9 – results seen on a computer screen.*

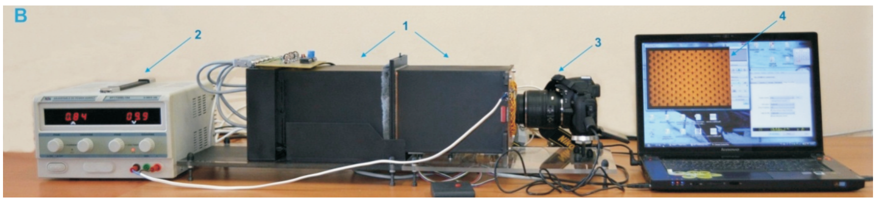


***Figure 4.*** *Measuring stand at the moment of photographing the material tested, 1 – measuring tunnel, 2 – power supply of light, 3 – digital camera, 4 – computer with software for image acquisition.*

uct investigated. The object of the study are decorative knitted fabrics of different configurations: a single arrangement, multi-layer and in the form of folds. Threads varied in terms of linear density, type of material, the density of arrangement, the character of the structure and degree of fogging of the surface. Moreover other textiles including woven and nonwoven fabrics were able to be tested.

After obtaining values of the parameters measured and recording the images, an analysis of results is conducted determining the statistical parameters.

An image of the knitted fabric tested is transformed into a binary image and analysed by analytical software - LUCIA and Textile Studio. On the basis of the algorithm developed [8] the value of the surface filling factor $z_p$ of the knitted fabric is determined.

The values measured and determined (T, R and $z_p$) are subjected to an analysis of correlation, on this basis of which the influence of many structural factors is determined, i.e. the yarn type of the pattern, stitch type of the background, the value of porosity and the percentage value of components of the knitted fabric for the light barrier properties of the textiles tested.

## Project of the measuring stand

The idea of the measuring stand used to identify the light barrier properties of textiles is related to the observation of decorative products in the living area [9, 10]. It is assumed that a decorative product, such as curtains or drapes, is fixed 20 cm from the window surface, while the observer visually assessing the intensity of light passing is located 20 cm from the surface of the textile curtain. It is also assumed that the parameters of the light source and possible regulation of the intensity of the radiation emitted are related to the conditions of daylight. The measuring stand has four basic elements of its structure: a light source, a holder for a knitted sample and sensors determining the intensity of the reflected and transmitted light and a digital recording of the fabric's image. According to the specific methodology of measurements, the measuring stand (***Figure 2***) has two modules of structure - module A and module B. The principle module of structure is variant A, determining optical parameters of the products. Module B is used to collect images of the knitted fabric structure tested.

## Configuration of the measuring stand

The stand measuring the light barrier properties of textiles is constructed in the

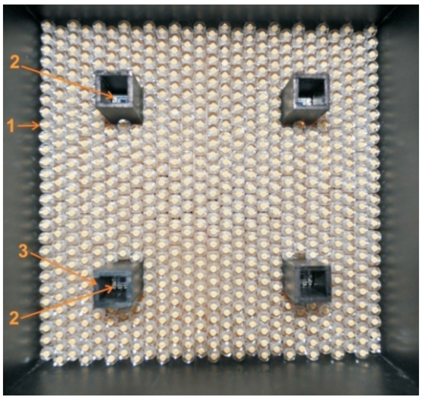

*Figure 5. Diode matrix (light source) and four sensors of light reflection covered with tunnels.*

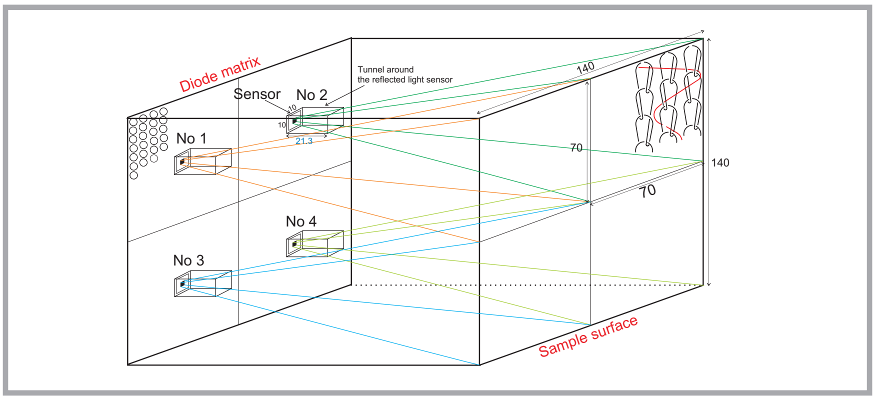


***Figure 6.** Arrangement of sensors measuring light reflection in the aspect of receiving a light signal.*

form of a tunnel (1), which has a light source on one side (2). The plane has the form of a light diode matrix, whose intensity is regulated by a controller (3). In the surface of the light matrix there are four sensors (4) measuring light reflected from the surface of the material tested. These sensors are covered from the light matrix with screening tunnels (5). The measuring activity of the sensors of light reflection is controlled by a programmator (6). In the middle part of the tunnel (1) a measuring frame is located (7) for fixing the sample - knitted fabric, woven fabric or yarn. The area of the knitted fabric measured is 196 $cm^2$ (14 × 14 cm). The back part of the tunnel is a set of sixteen sensors (8) receiving the light going through the sample's surface. The programmer controls the order of reception of signals from these sensors (9). The signals from the sensors of reflection and transmission of light are transferred through an analogue – digital converter (10) to the computer (15).

In order to determine the parameters of the structure of the knitted fabric an exchangeable part of the tunnel (1 ') is used, to which a digital camera (11) is mounted. Inside the tunnel, there are two circles of 56 diodes (12) illuminating the material tested, the intensity of which is regulated by the controller (13). The recording of the sample's image is obtained with the use of a computer program (14). Photographs of the research stands are presented in ***Figures 3 and 4***. The computer stand measuring the light barrier properties of textiles is subject to a patent application P-400770 [11].

## Significant elements of the measuring stand arrangement

The front wall of the tunnel is the light source, a light plane in the form of a matrix, consisting of 689 diodes (***Figure 5***). The design of the matrix provides a uniform illumination of the whole surface of the material tested.

A novelty in the concept of the diode matrix structure is linking the function of the light emitter with a simultaneous readout of reflection values of the light reflected from the surface of the structure tested. For this purpose, the sensors of reflected light are arranged on the surface of a light source. They are covered with screening tunnels in order to ensure the elimination of light emitted from the matrix. The location of the sensor (placed in the center of one quarter of the matrix surface) and the length of the tunnel surrounding it are designed in a way that the light-sensitive part of the sensor, a square with an area of 2.29 × 2.29 mm, receives the light reflected from only one fourth of the fabric (***Figure 6***). Comparing the values of signals from the four sensors, we obtain information about the distribution of light reflected from the structure of the jacquard knitted fabric.

An important step in the designing of the measuring stand was the selection of the light source element, such as diodes of the LED type. Characteristics of the spectral distribution of diodes is very similar to that of daylight. The graph (***Figure 7***) summarises the spectral characteristics of LED diodes the spectral characteristics of daylight as a function of the wavelength.

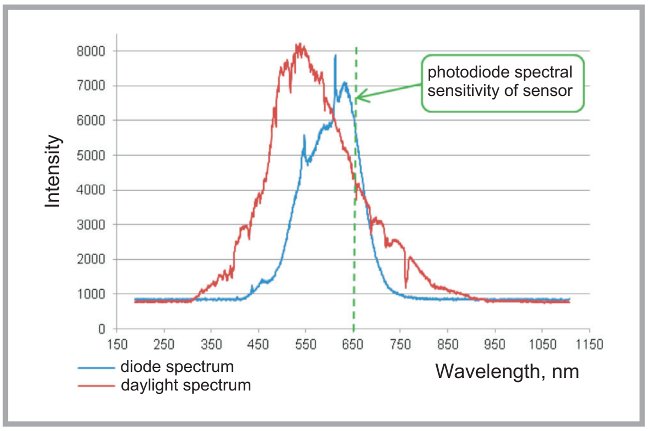


***Figure 7.** Spectral distribution of the diode and daylight with the optical sensitivity of a sensor.*

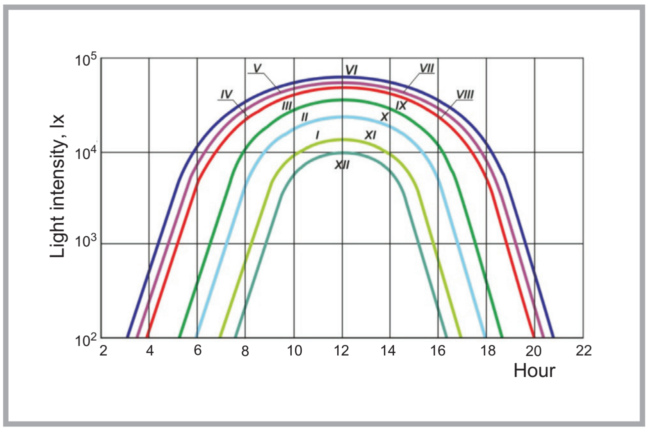


***Figure 8.** Changes in intensity of light depending on the time of day (Roman numerals stand for months)[12].*

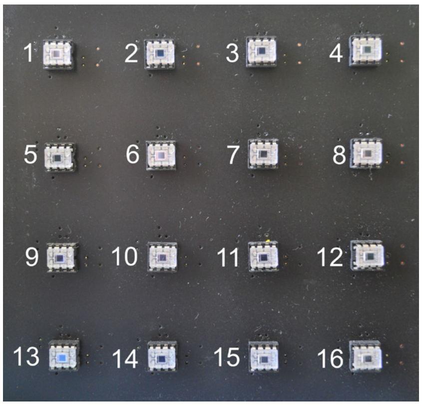


***Figure 9.** Sensors of light transmission and their numeration.*

Additionally the graph presents the spectral sensitivity of the photodiode of the sensor measuring the transmission and reflection of light. The best sensitivity is obtained for the photodiode of the sensor operating in the range of the light spectrum equal to 650 nm, which is very close to the maximum of the spectrum of light emitted by the diode. Both characteristics of the light source and spectral sensitivity of photodiode sensors are properly selected, thus ensuring the proper quality of measurements of the light barrier properties of textiles.

The light source designed has the ability to regulate the intensity of the light emitted. The conditions of light intensity in the measuring tunnel can be related to that occurring in any month of the year and any time of the day. To illustrate and determine the distribution of the intensity of light obtained for particular times of the day and months of the year, the authors used a diagram presenting the dependencies of light intensity on the time of exposure to light for the central European geographical location (***Figure 8***). The greatest intensity of light occurs in the afternoon hours and during the summer months. The changes in the light spectrum over the hour of the day were not taken into consideration while designing the graphs.

The second key element of the structure of the measuring stand is the set of sensors measuring the intensity of light passing through the fabric structure (***Figure 9***), which is placed on the back wall of the tunnel and is composed of sixteen sensors generating voltage as a function of light intensity. Individual signals from the sensors and the total average value define the transmission of light passing through the structure of decorative knitted fabric.

In order to read the values of the intensity of light passing, the scaling of sensors was performed, whose results can be seen on the calibration graph (***Figure 10***). It presents a linear dependence between the values of signals received by the sensors (in mV) and the light intensity expressed in lux. The levels of light intensity inside the measuring tunnel were characterised at different distances from the surface of the diode matrix. Variable values of light emission intensity are generated by the current values of the light source.

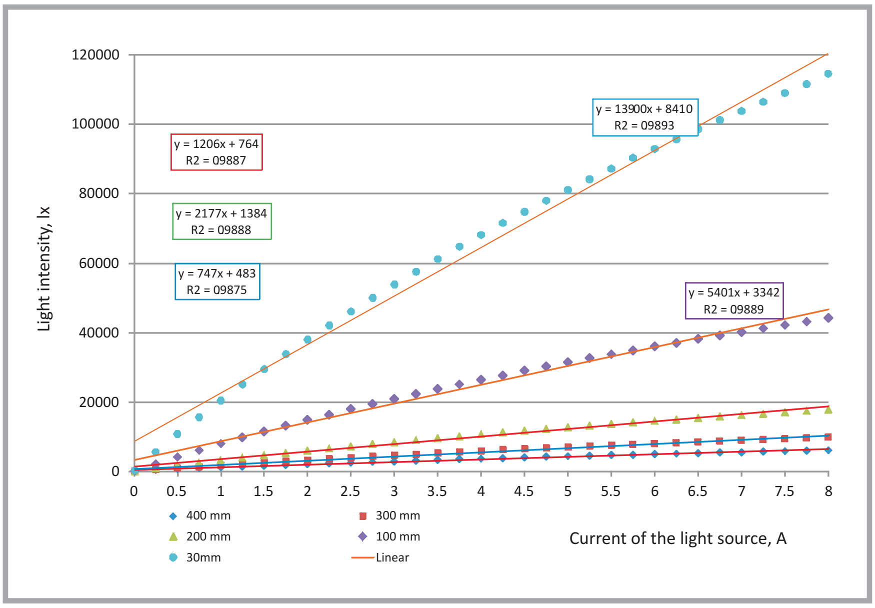


***Figure 10.** Calibration graph – dependence of emitted light intensity on that of the current supplying the light source, determined at various distances from the matrix surface: 30, 100, 200, 300 and 400 mm.*

Regardless of the distance from the surface of the matrix, the intensity of light emitted is proportional to the intensity of current supplying the matrix. For a standard design of the instrument, i.e. for which the distance from the back wall of the tunnel with the sensors of light transmission is 400 mm, we obtain a suitable calibration curve situated the lowest on the graph. With the use of calibration curve function y = 747x + 483 the values of the intensity of the supplying current, expressed in the unit of intensity of light radiation, are converted. The graph of scaling also refers to the sensors of light reflection due to the identical design and technical parameters.

The design of the device ensures constant intensity of the light source (fluctuations of light emitted occur at a level of only 0.1%), a linear dependency between the values of the voltage sensors as a function of the intensity of light emitted, the light tightness of the measuring tunnel, as well as the repeatability and lack of systematic errors caused by the elements used along with power supplies and controllers.

The measuring stand designed and constructed in the form of a measuring tunnel can be used in various types of studies of optical properties of textile structures. The use of a typical light source that emits UV radiation in the tunnel system as well as the use of one of the typical probes measuring the value of light in the entire UV range or in one of the bands of UVA, UVB or UVC makes it possible to determine the light barrier properties of textiles against UV radiation.

## Analysis of optical properties of decorative knitted fabrics

The measurement of optical properties of the barrier structures was conducted by obtaining signals from two sets of sensors. The graph of the data analysed by the computer system presents collective results of parameters of the light measured. Measurements of the barrier properties of decorative structures were carried out for 23 patterns of jacquard warp knitted fabrics made by the 3-needle technique of knitting on a type 4F-NE warp knitting machine by Karl Mayer of RJSC, with the needling number of E14. These structures vary in the design and size of the pattern report. Knitted fabrics investigated are made of a structure

**Table 1.** *Results of optical parameters of decorative jacquard knitted fabrics; the squared papers of pattern reports for the particular pattern numbers are presented in* ***Figure 11***.

| No pattern | Surface cover factor, $z_p$, % | Light reflection R, lx for: | | | | Light transmission T, lx for: | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 - intensity emitted. 13007 lx („VI" 6 h) | 2- intensity emitted 46236 lx („VI" 8 h) | 3 - intensity emitted. 61363 lx („VI" 10 h) | 4 - intensity emitted. 66232 lx („VI" 12 h) | 1 - intensity emitted. 13007 lx („VI" 6 h) | 2- intensity emitted. 46236 lx („VI" 8 h) | 3 - intensity emitted. 61363 lx („VI" 10 h) | 4 - intensity emitted. 66232 lx („VI" 12 h) |
| 156B | 32.2 | 197 | 739 | 940 | 1032 | 475 | 1680 | 2234 | 2376 |
| 16 | 41.47 | 249 | 918 | 1210 | 1302 | 406 | 1462 | 1936 | 2092 |
| 154 | 47.47 | 281 | 1014 | 1340 | 1440 | 373 | 1342 | 1775 | 1912 |
| 137 | 49.74 | 298 | 1082 | 1421 | 1527 | 346 | 1251 | 1651 | 1786 |
| 103 | 59.39 | 352 | 1267 | 1662 | 1781 | 287 | 1047 | 1388 | 1499 |
| 129 | 63.19 | 352 | 1266 | 1663 | 1782 | 273 | 1003 | 1325 | 1437 |
| 143A | 64.78 | 387 | 1389 | 1817 | 1949 | 247 | 913 | 1214 | 1311 |
| 160 | 65.58 | 393 | 252 | 1838 | 1975 | 1402 | 923 | 1222 | 1316 |
| 135 | 76.58 | 467 | 183 | 2150 | 2297 | 1645 | 682 | 912 | 978 |

of basic stitches and design stitch. The background stitch of the knitted fabric is a chain and weft thread stitch of laps 1 $t_u$ made of yarn of 76 dtex, the stitch of the design weft threads is made of textured yarn KDK of 334 dtex linear density . In total, 30 variants of decorative knitted fabric samples were used in this research.

Measurements of optical values of light transmission T and reflection of light R were conducted for four different levels of the intensity of light emitted by the matrix. All the levels correspond to the intensity of light for the month of June at selected times of the day, taking into account the attenuation of light by the window pane of 20%. The first level refers to the intensity of light occurring at 6 am (intensity equal to 13007 lx), the second level corresponds to the intensity of light at 8 am (intensity equal to 46236 lx), the third level  to the intensity at 10 am (intensity equal to 61363 lx), and the fourth level  to the intensity of light at 12 am (intensity equal to 66232 lx). For each variant of the knitted fabric the values of the surface cover factor $z_p$ were determined using the optoelectronic method.

The selected variants of knitted fabric with  designs of a squared paper pattern determined and the parameters of the light barrier are presented in ***Table 1***. Pictures of stitches for selected reports of patterns in the actual course of yarn are shown in ***Figure 11***.

Results for the whole set of materials tested are presented in ***Figure 12***.

The results of measurement show the correlation between the structural parameter of decorative knitted fabric and its optical properties. With an increase in the surface cover factor of the knitted fabric, the light transmitted is attenuated and the value of light reflected from the surface of the knitted fabric increases. Equations of the empirical model of dependencies between the intensity of the reflected and transmitted light as a function of the relative cover factor present a linear relationship with the value of the coefficient of correlation $R^2$ close to unity. For certain lighting conditions and the relative cover factor the absolute values of the increase

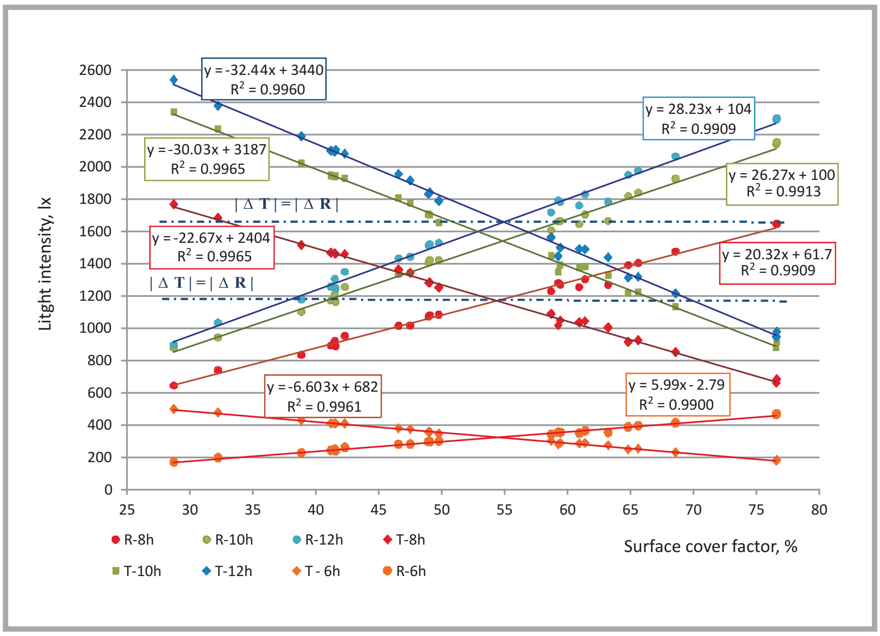


**Figure 12.** *Dependencies of reflected and transmitted light intensity on the surface cover factor of the knitted fabric.*

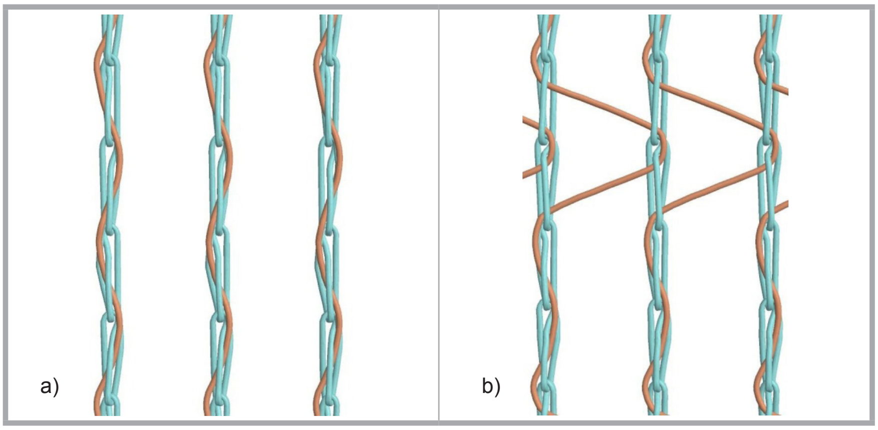


**Figure 13.** *Stitches of background  decorative knitted fabric. a) variant A ($z_{p.A}$ = 24%) and b) variant B ($z_{p.B}$ = 35%).*

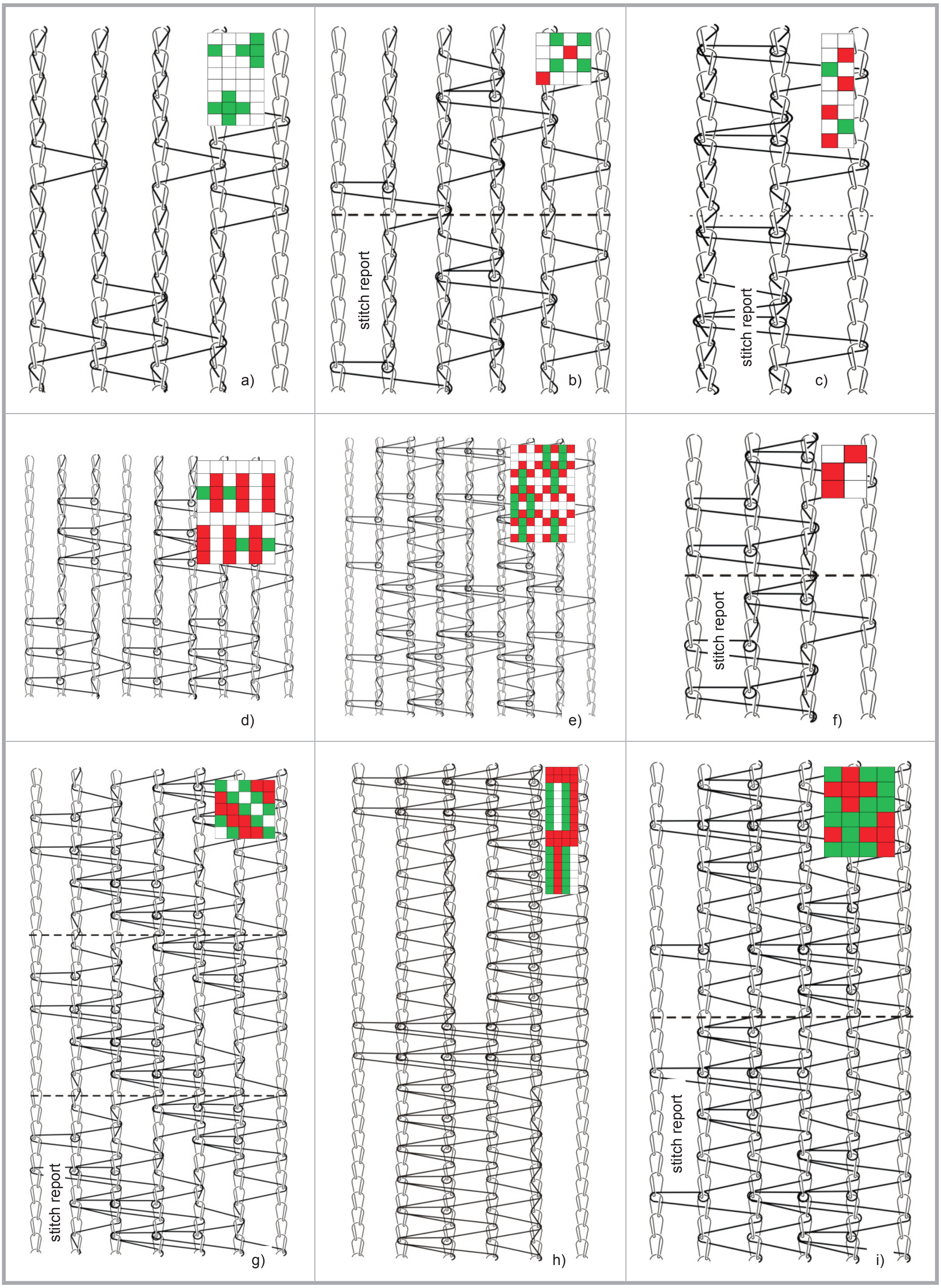


***Figure 11.*** *Real arrangement of threads in stitch reports of knitted fabrics marked by 'pattern number' according to Karl Mayer co.; a) pattern 156B, b) pattern 16, c) pattern 154, d) pattern 137, e) pattern 103, f) pattern 129, g) pattern 143A, h) pattern 160, i) pattern 135; in the right upper corner of each stitch picture, the square paper of the pattern report is shown.*

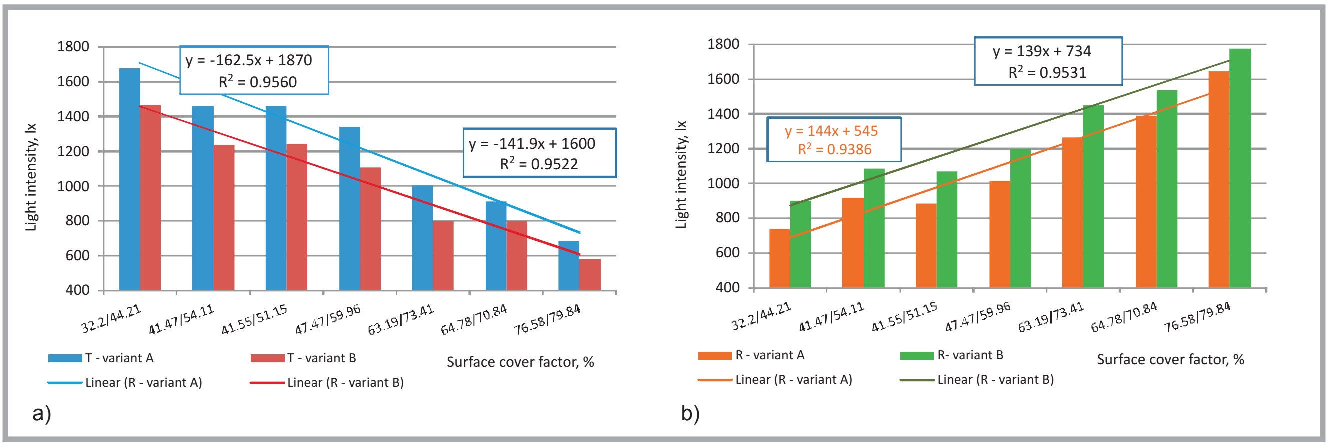


***Figure 14.*** *Graphs of transmission and reflection of light for knitted fabrics of various structure of background stitch.*

in the transmission of light are equal to the values of an increase in the reflection of light $|\Delta T| = |\Delta R|$.

The type of background stitch used is important for the formation of barrier properties of decorative knitted fabrics. ***Figure 13*** presents the actual arrangements of the variants of background stitches, where variant A is a stitch of chain and weft thread of 1 $t_u$ lap, and variant B - is a stitch of chain and weft thread of 2 $t_u$ laps in every second course.

The graphs in ***Figure 14*** show the results of measurements of transmission and reflection of light for seven different knitted fabrics varying in the pattern for two types of stitch of basic background. The surface cover with the threads of "basic" background knitted fabric was determined. The way the course of the background thread in the structure of the pattern of the decorative knitted fabric affects the value of transmitted and reflected light. The increased value of the surface cover factor of the background for variant B increases the value of reflected light in the range from 7 to 22%, which also reduces light transmission.

## Conclusions

1. A new and original instrumental method for measuring and analysing light barrier properties of textiles including knitted fabrics, woven fabrics and groups of parallel threads was elaborated.
2. The measuring st2and designed and constructed can be used to measure the transmission and reflection of light as well as to record digital images of knitted fabric. The significant advantages of the measuring stand constructed are that it is suitable for samples of knitted fabrics of a significant size, has a light matrix imitating the actual conditions of daylight, is equipped with modern photodiodes in sets measuring with high accuracy and repeatability the parameters of light and that it generates minimal systematic errors of measurements considering the construction of electronic elements, electrical power suppliers, digital regulators and computer interfaces.
3. The results of measurements of the barrier properties of decorative knitted structures presented show significant correlations between the values of light transmission and reflection determined and the surface porosity parameter of decorative knitted fabric. The dependence of the intensity of reflected and transmitted light on the relative cover factor is determined by linear functions, while an absolute increase in transmission and reflection for a specific structure of knitted fabric stitch and light conditions are equal, $|\Delta T| = |\Delta R|$.
4. There is a relation between the intensity of light reflected and transmitted, and the type of background stitch of decorative knitted fabric.


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