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RESEARCH ON TRANSPORT OF CONCENTRATED SOLAR RADIATION FOR LIGHTING PURPOSES

BADANIA NAD TRANSPORTEM SKONCENTROWANEGO PROMIENIOWANIA SŁONECZNEGO DO CELÓW OŚWIETLENIOWYCH

A b s t r a c t

This article presents the parameters of concentrated light, transmitted by optical fiber. A parabolic mirror was used for concentrating the solar radiation. An analysis of the spectrum of light reflected from the parabolic mirror and transmitted by using of variable length of the optical fibers is presented. The article also shows the simulations of the focused solar radiation with the transmitter in the form of fiber. This allowed to show the propagation of radiation inside the fiber and the distribution of the luminous flux on the important areas of the system. On the basis of this analysis, it is proved that the solar radiation concentrating system can be successfully used for lighting purposes.

Keywords: light transmission, optical fiber, concentrated solar radiation

S t r e s z c z e n i e

W artykule zaprezentowano parametry skupionego światła przetransmitowanego za pomocą światłowodów. Koncentrację promieniowania słonecznego osiągnięto za pomocą parabolicznego lustra. Zaprezentowano analizę widma światła odbitego od koncentratora i przetransmitowanego za pomocą światłowodu o zmiennej długości. Ponadto zaprezentowano wyniki symulacji komputerowych układu transportującego skupione światło za pomocą światłowodów. Dzięki temu możliwe było przedstawienie sposobu propagacji światła wewnątrz światłowodu, a także rozkładu natężenia promieniowania na istotnych powierzchniach systemu. W rezultacie wykazano, że skoncentrowane promieniowanie słoneczne może być z powodzeniem zastosowane do celów oświetleniowych.

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Słowa kluczowe: transmisja światła, światłowody, skoncentrowane promieniowanie słoneczne

1. Introduction

Aiming to reduce the energy consumption has nowadays become one of the most important priorities of the society. Lighting is one of the sectors of technology, which is most modernised and enjoys a great interest of the users. This is due to the fact that the standard lighting modernisation does not require a lot of work and financing. However, one should remember that the light is still the most expensive form of energy. Taking into account the process of production of electricity, its transmission and conversion to radiation, for lighting sources nowadays used as standard, the approximate energy efficiency of light production is as follows: a light bulb – 1.5%, a fluorescent – 3.5%, LED – 9% [1].

The fact is that the Sun provides the Earth's surface with light for several hours a day. Usually, this natural and free light source is to some extent used through the windows and partially glazed facades. However, often during daytime we use electric light due to insufficient amount of daylight reaching the deeper areas of rooms, or also in case of rooms without windows. In such situations, it would be very advantageous to provide light by using the lighting systems with the use of daylight. Another argument for the maximum use of the sunlight for lighting purposes is the fact that the spectrum of energy-efficient electric light is completely different from the spectrum of daylight (Fig. 1). It should be mentioned

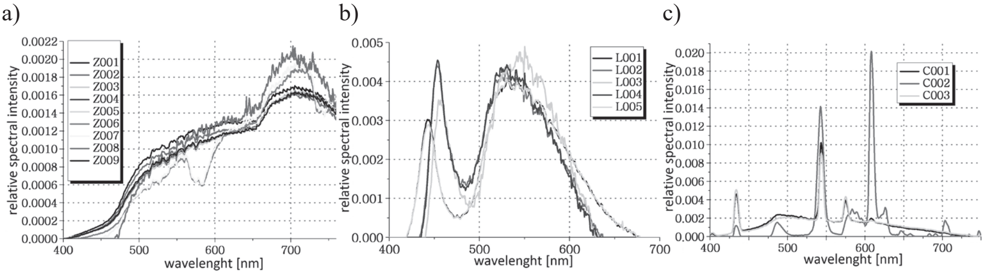

Fig. 1. Light spectrum: a) bulb, b) LED, c) fluorescent light [3]

here that it is the solar radiation that is the healthiest type of lighting for humans. The spectrum of light from the lamps is discontinuous, and white LED lamps emit too many short-waves [2]. Only the incandescent lighting emits a spectrum closest to daylight, but it is also the least efficient.

Thus, the lighting based on systems that use daylight from solar radiation is not only the healthiest, but also brings significant energy savings. There are many technological passive solutions, which are characterised by a cheap and simple construction, however, the main drawback is the inability to control their operation. This disadvantage is eliminated by active systems consisting of concentration and light transmission. Here, the difficulty is the fact that they are more expensive and have a more complex structure. Currently, in the Department of the Sustainable Development of Energy at AGH in Cracow, Poland a research connected to this topic takes place. Partial results and their analyses are presented in this article.

2. Description of the research position

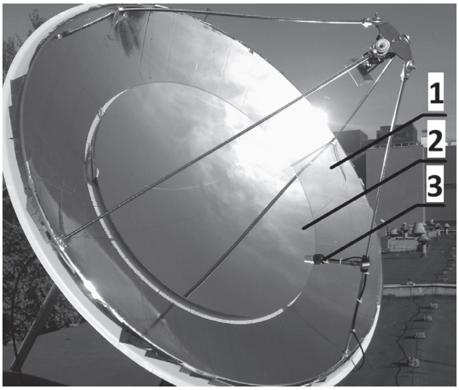

Fig. 2. One of the fibre head locations by the concentrator: 1 – reflective foil, 2 – parabolic mirror, 3 – head of the fibre optic cable

In order to transmit more light than in the standard fibre system, the solar radiation concentrator has been used. The device consists of a parabolic mirror with a diameter of 1.2 m mounted on a plate with a diameter of 1.8 m filled with reflective foil (Fig. 2). For the concentrator to work properly, it has been integrated with the system tracking the location of the Sun based on the astronomical algorithm.

For the transmission of the concentrated light the fibre optic cable was used, with a length of 10 m consisting of 25 wires (each having a diameter of 0.75 mm). Near the focus of the concentrator, the head of the fibre optic cable was placed (Fig. 2), while the second end of the fibre was placed in the darkroom. Both on the roof and in the darkroom the light intensity sensors were placed, and were integrated with the programmable measurement and control PLC system. In addition to light intensity measurement, also the radiation spectrum study was performed transmitted using one fibre optic wire with the diameter of 0.85 mm and the optic spectrometer Science–Surplus with the detector Sony ILX511 linear CCD.

3. Examination of the concentrated light transport

One of the most important features in the studies on the light transmission is the transmission coefficient. It determines the amount of light that the given centre will let through. Knowledge of the value of this factor allowed the selection of the suitable location of the fibre optic cable head in relation to the concentrator's focus, as the right positioning of the fibre optic head has a significant impact on the quality of light that will reach the darkroom. The studies aimed to indicate the location, where the fibre optic end will get the highest possible amount of light, at the same time so that it will not be damaged as a result of high temperatures.

In order to compare the amount of transported light regardless of weather conditions the luminous flux was calculated for the external light falling on the fibre optic head φ_2 and emitted by the end of the fibre optic located in the darkroom φ_1. The calculations of the luminous flux falling on the head included the combined area of all wires of the fibre optic *S*, while the calculations of the flux inside the darkroom used the knowledge of the distance of the fibre optic end to the sensor *d* [1]:

$$\varphi_1 = I_{1,śr} \cdot d^2 \ [\mathrm{lm}] \tag{1}$$

$$\varphi_2 = I_{2,śr} \cdot S \ [\mathrm{lm}] \tag{2}$$

where:

- $I_{1śr}$ – the average light intensity measured in the darkroom lux,
- $I_{2śr}$ – the average light intensity measured outside lux,
- d – the distance of the optical fibre from the light intensity sensor m,
- S – the surface area of the fibre optic cable m^2.

Due to the lack of knowledge of the characteristics of the light distribution by the fibre optic the (1) expression is approximate. The adopted simplification means that the emission of light takes place with a constant intensity in a stable angle equal to one radian. Using the fluxes defined from the formulas (1) and (2) the light transmission through the fibre coefficient was determined [1]:

$$\alpha = \frac{\varphi_1}{\varphi_2} = \frac{I_{1,śr} \cdot d^2}{I_{2,śr} \cdot S} \tag{3}$$

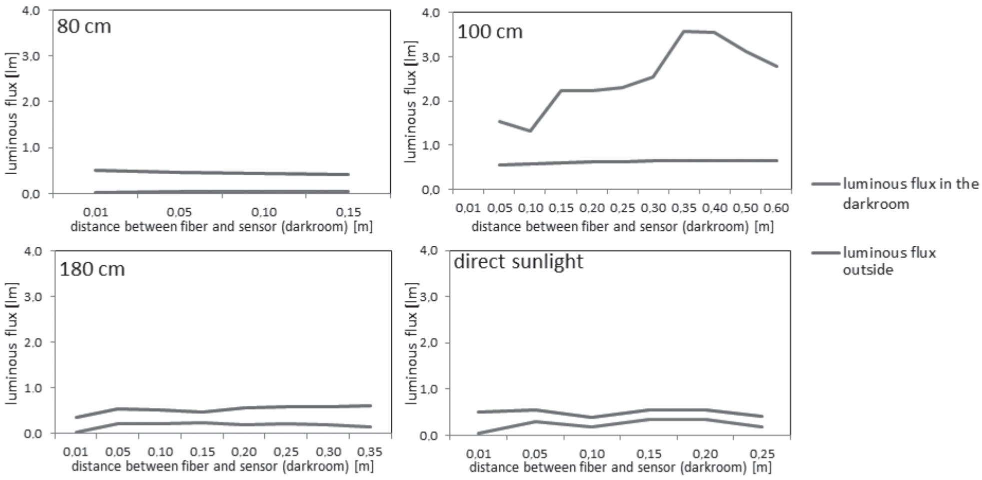

Fig. 3. Dependence of the luminous flux input to the darkroom and external (sensor lighted by direct solar radiation in a horizontal plane)

Values of the flux φ_1 and φ_2 are presented in Fig. 3, which shows flux values for different distances of the head from the concentrator surface. In addition, the flux values were presented for the fibre optic end in accordance to the orientation of the lighting intensity sensor outside. This allows the determination of the fibre optic quality – the higher the α coefficient, the better the fibre optic from the point of view of performance properties in the lighting system of rooms with daylight.

What results from chart 3 is that the location of the head at a distance of 100 cm from the mirror surface is the most effective solution. In this setting we have observed almost a 6-time higher flux of the transmitted light compared to the light falling on the external sensor in the horizontal plane ($\alpha > 100\%$). Therefore, the strengthening of the light – η created as a result of the use of the concentrated solar radiation took place.

In subsequent studies the spectral characteristics were performed on the assessment of the light quality. The first element that could affect the spectrum of the light radiation in the discussed system is the solar radiation concentrator. The performed measurements showed that the spectrum of the reflected light from the concentrator is continuous. Only minor deviations have been observed, which did not affect the qualitative features of the transmitted light (slight shift towards shorter wavelengths). Another element of the installation, which may cause distortion of the spectral characteristics is the transmitting medium. In Fig. 4 it can be seen that the spectrum of the transmitted light changes depending on the length of the used fibre. In order to test this feature, the analysis of the daylight transmission used the fibre optic with the diameter of 85 mm and lengths: 1, 4, 10 and 17 m. The studies calculated the degree of light passage in the wavelength for the selected lengths of the fibre. It can be seen in Fig. 4a, that for the length up to approx. 5 m the light loss is relatively small – approx.

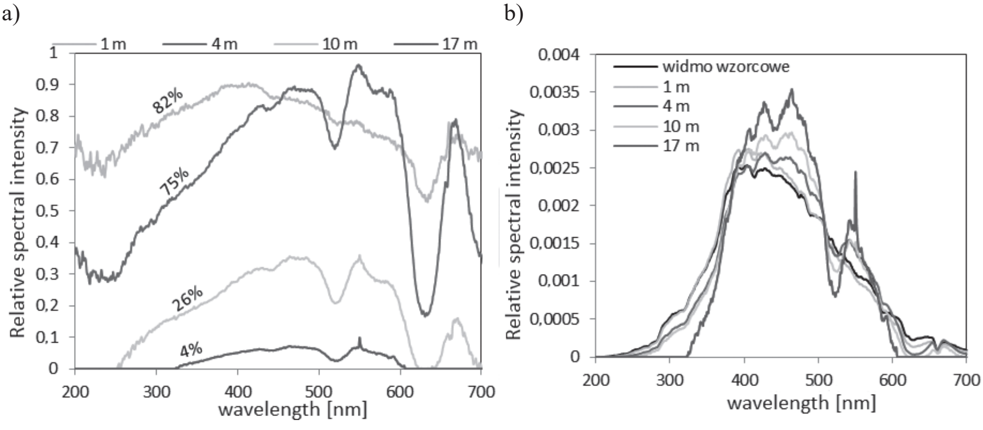

Fig. 4a) degree of light transmission, b) normalised spectrum for fibre

70% of light introduced to the fibre optic passes through. While for greater lengths – approx. 10 m, this loss is almost 3/4 of the introduced light, and for the length of 17 m only 4% of light was passed through the fibre optic. The conducted analysis and obtained results allow to conclude that the best length for this fibre optic type is approx. 5 m. Lengths between 5 and 10 m are still possible for use, while fibre optic with lengths of ca. 15 m are the border of the transportation of useful (for lighting purposes) amounts of light [PES].

The results listed in Fig. 4a clearly indicate that the light distortion increases with the length. The invisible ultraviolet light is poorly passed throughand the light with the length of approx. 630 nm, is damping, however, it includes a narrow scope, so it is not very relevant for lighting purposes. Though, an important feature is that for the fibre optic length over approx. 10 m the cutting of the red light is observed, what will result in the fact that the light after getting out of the fibre optic will give an impression of the cold light, with the colour slightly

Fig. 5. The propagation of radiation inside the fibre: a) flexion, b) a straight line

more bluish than the sunlight. In Fig. 4b (normalised spectrum) we can observe the distortions created as a result of light transmission. For waves with the length of approx. 600 nm we can observe absorption, yet, it is not a substantial distortion. The presented spectrum still has the character of the sunlight spectrum and it is continuous. The analysis of Fig. 4b confirms that good light parameters for the transmission to the distance up to 10 m and satisfactory to the maximum studied of 17 m [1].

Also computer simulations were performed as part of the research, which allowed to detect places of radiation loss in the waveguide. Below, in Fig. 5 we can see the way to propagate the rays inside the fibre. On a straight line (Fig. 5b) rays are reflected from the boundary of two materials having different refraction index. While on the bend the rays go to the shell, where some of them pass outside – they are lost. Based on the simulations it was calculated that in the case of the optical fibre bent by the 1cm ray, light losses were as high as 90%. They decreased with the growth of the bending ray: for r = 5 cm losses were 81%, and for r = 10 cm 71%. Thus, it can be seen that the bend of the fibre optic has a significant effect on the system efficiency. Other power degradations in the system are calculated via ray tracing simulations and described in [4].

4. Conclusions

The best way to reduce the demand for energy for illumination while retaining good qualitative light parameters is to maximally use the sunlight. High costs of optical fibres, however, force the search of new solutions, such as solar radiation concentrators. It has been proven that the light from the concentrator system has parameters close to the daylight, if the fibres cables not longer than 10 m are used – especially due to great quantitative losses in transmission. However, it is important to remember about the potentially smallest degree of fibre bending, as this has an adverse effect on the efficiency of the transmission.

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