The Influence of Photometric Coating on Spectral Reflectance of Artificial Sky Dome.

Evaluation of new surface´s spectral properties

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Abstract — The artificial sky has been in operation at the Institute of Constructions and Architecture of Slovak Academy of Sciences in Bratislava since 1970´s. This artificial sky provides lighting simulations in conditions of overcast sky mainly for daylighting measurements in physical scaled models. It has been used for wide spectrum of photometric measurements ranging from scaled building interiors to light distribution using tubular light guides. The sky dome was made of reinforced concrete and is suspended to loadbearing structure of the surrounding building on steel ropes. It is hemispherically shaped with diameter of 8 meters. Thanks to support of grant scheme APVV the lighting system in artificial sky is undergoing the total reconstruction. The part of this reconstruction contains the renewal process of the dome´s surface through applying special photometrical coating, developed especially for this purpose in cooperation with company Chemolak a. s. Smolenice, Slovakia. The other part of reconstruction consists of new LED lamp installation in combination with the new electrical installations and new controlling and calibration programming system.

This paper deals with comparison of spectral reflectance of dome´s surface before and after application of new photometrical coating to determine inputs for simulation of CIE Standard General Sky in laboratory conditions. The experimental results show the quite high rate reflectance values and uniform - spectrally neutral reflectance properties. The surface also meets the desired requirements regarding the diffuse light reflectance. The aim of lighting system reconstruction is to improve spectral rendering of new lighting system, to decrease consumption of electricity and enable to simulate of all 15 types of the CIE Standard General Sky, which are adopted by ISO and CIE in ISO 15409:2004/CIE S 011/E:2003.

Keywords— Daylight, Artificial sky, CIE Standard General sky

INTRODUCTION

The artificial sky in the Lighting laboratory at the Institute of Constructions and Architecture of Slovak Academy of Sciences in Bratislava (ICA SAS) has been in operation for more than 40 years. A special light diffusing coating material was applied to the inner surface of the hemispherical dome. Altogether with the setup of incandescent spotlights, the unit generated diffuse light and it was possible to simulate sky luminance distributions of CIE overcast sky, unity and clear sky, [1-3]. Under these daylight conditions the measurement of illuminance or other photometric variables could be performed in models of buildings´ interiors according to conditions defined by the Slovak standard [6] or similar foreign documents.

Since 2004 a new standard [7] has defined the parameters of daylight sources and terms for modelling of 15 homogenous sky types providing different luminance distribution patterns. Because of high consumption of energy during operation times, when heavy 500 W spotlights produce also a notable amount of heat, the aim is also to use modern lighting devices based on the LED technology. This new lighting system should not only reduce the energy consumption and heat gains under the dome, but also provide the better spectral composition of the light for measurements and ability to illuminate the hemisphere to comply all the 15 types of skies, [4].

To make this retrofitting process the most effective, the inner coating had to be renewed. The hemispherical dome was treated 2 times by coating material based on cellulose and barium sulphate, roughly 20 years ago. Last experiments in the ICA SAS artificial sky were carried out under incandescent lamps with non-renovated coating in 2014. Real status of old coating surface is illustrated in the fisheye, Fig. 1.

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Fig. 1. View on the old coating surface of the sky dome illuminated by incandescent lamps

Reflectance of the old coating material was $\rho_V = 0.85$. The composition of white coatings with high value of reflectance and high light diffusivity is required by the standard [6] for photometrical devices. This coating has to be applied in three layers: base layer consists of synthetic coating. Middle layer is white underlay coating based on dispersion of titanium oxide. Third layer is based on barium sulphate with matte finish. The coating prepared according to [8] can be applied only on non-absorptive surfaces. Because the surface of the ICA SAS artificial sky hemisphere is made of reinforced concrete, this procedure could not be applied. A new coating, named "Photometric coating", was developed in cooperation with company Chemolak a. s. Smolenice to provide better spectral reflectance properties of the surface and to enable the application on the absorptive materials.

METODOLOGY

The old coating significantly decreased reflectance within low wavelengths. It was necessary to renovate the dome`s surface for designing spectrally unselective coating, Fig. 2. Measurements [5] resulted in maximum reflectance $\rho = 0.85$ of the old ICA SAS artificial sky surface.

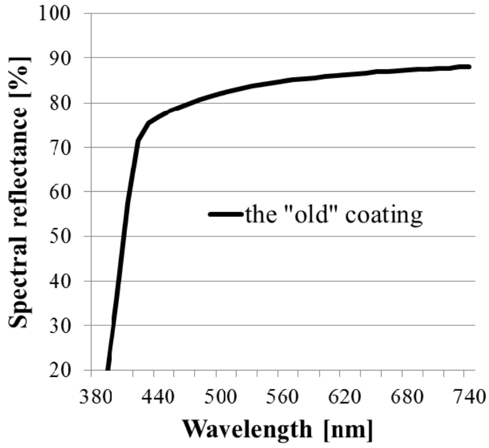

Fig. 2. Spectral reflectance of the old coating, [5].

The base of the "Photometric coating" consists of the suspension of barium sulphate in an aqueous solution of carboxymethyl cellulose with high water retention, together with special additives. During the process of selection of the barium sulphate supplier, the purity of the filler, the light reflectance and the fineness of the particles was taken into account. Listed additives provide complete wetting of the solids and eliminate foaming during application. Insufficient wetting and foaming of barium sulphate coating would result in non-uniformity of the finished coating, which could adversely affect the directional characteristics of light reflectance. The consistency of the coating is slightly thixotropic and rheology is set in the way to provide easy application by roller without further dilution in water, while developing a uniform film. Since barium sulphate has a high light reflectivity, but a low covering power, the optimum properties could be reached by application of minimum 3 layers.

In 2014 tests of different technology in terms of coating application were realized [5] directly in the sky dome. There were 3 various samples 1m × 1m of coating applied on the dome surface. Sample marked as 3 resulted the highest reflectance, therefore it was proposed for coating application to use 3 layers of the "Photometric coating" as optimal for photometric measurements. Finally, the technology of application of 3 layers was used on the whole surface of the sky dome. Since the aim of the dome`s renovation is to simulate ISO/CIE General Sky [7] in laboratory conditions, the reflectance of the new coating must be experimentally verified also after its application. One of the parameters used in calculations of the sky luminance distribution of the artificial sky surface is the reflectance and its spectral properties. This is important especially in the case of the use of LED light sources.

Material of the coating was produced in standard manufacturing conditions for the standard interior applications

- stainless tank with a powerful dissolver. Coating quality parameters were assessed in the analytical laboratory of company Chemolak a. s. Smolenice and reflectance was checked using the X-rite device. The "Photometrical coating" delivered in the plastic buckets was applied using roller to cover the whole surface of the dome according to prescribed procedure.

Fig. 3. Spectrophotometer Konica Minolta CM-5

The spectral reflectance of the old coating and also the “Photometric coating” was measured in the dome using spectrophotometer Konica Minolta Spectrophotometer CM – 5, Fig. 3. This device has a built-in standard light source type A and D65. Since the artificial sky will be utilized under daylight conditions, the device was set to the light source of D65 type. The colour temperature of new LED sources is 5000 K more close to daylight like is colour temperature of the incandescent light sources. The measuring range of the spectrophotometer is 360-740nm with resolution of 10nm.

The spectral reflectance measurements were made 3 times at the three points on each of the seven positions from which the average value was calculated to get the reflectance factor of the surface. Positions of the points were selected circa regularly around the dome perimeter in its lower 1/3 part because of access possibility. Locations of these positions are shown in Fig. 4. Reflectance of light coefficient ρ of the material surface is defined as the ratio of the reflected luminous flux to luminous flux entering the surface. When examining the spectral reflection of light, the radiant flux is assessed in the visible region 380-780 nm, as is documented in formula (1).

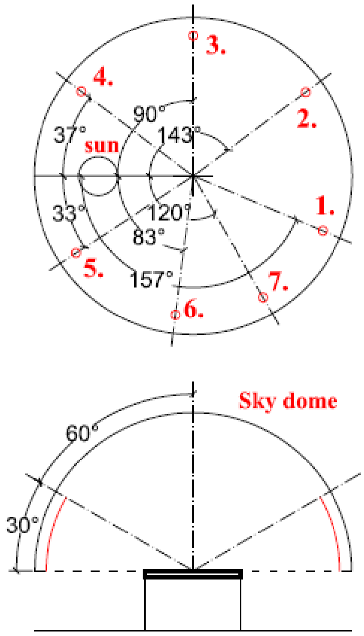

Fig. 4. Positions of the measurement points

$$\rho = \frac{\Phi_\rho}{\Phi} = \frac{\sum_{380}^{780} \Phi_{e,\lambda}\, \rho_\lambda\, V(\lambda) d\lambda}{\sum_{380}^{780} \Phi_{e,\lambda}\, V(\lambda) d\lambda} \quad (-;\mathrm{lm}) \qquad (1)$$

where:

- ρ_λ – spectral coefficient of reflectance [-],
- Φ – incident luminous flux [lm],
- Φ_ρ – reflected luminous flux [lm],
- $\Phi_{e,\lambda}$ – radiant flux at wavelength λ [W.nm^{-1}],
- $V(\lambda)$ – luminous efficiency function [-].

In the case of practical measurements for the determination of light reflectance coefficient, measuring instruments utilize standardized light sources with the ability to generate radiant flux at different wavelengths. Then for determination of the light reflectance coefficient, in the case of our “Photometric coating”, formula (1) can be modified as follows (2).

$$\rho_V = \frac{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda \rho_{(\lambda)} V_{(\lambda)} \Delta_\lambda}{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda V_{(\lambda)} \Delta_\lambda} \quad (-;-) \qquad (2)$$

where:

- $\rho_{(\lambda)}$ – spectral coefficient of reflectance [-],
- $D_{(\lambda)}$ – relative spectral power distribution of standardized light source D65 [-],
- $\Delta_{(\lambda)}$ – measured range of wavelengths [nm],
- ρ_V – coefficient of reflectance of the “Photometric coating” [–].

The measured data were evaluated by formula (2) in this study.

RESULTS

In the past, the artificial sky dome was illuminated by scenic spotlights which were equipped by 500 W incandescent lamps. During operation the artificial sky's surface recorded reduction of light reflectance of existing coating due to degradation effects of materials and dust cover. The illustration of the spectral reflection of the old surface of the dome is shown in Fig. 2. It can be seen, that significant decrease and reduction in spectral reflectance is in the lower part of the measuring range 380-500 nm. When using incandescent light sources, the decrease has the minimal effect on the illuminance measurements in the models. For light sources with spectral composition closer to daylight, e.g. LED sources, this decrease in spectral reflectance can lead to additional errors and should be considered in calculations of uncertainties.

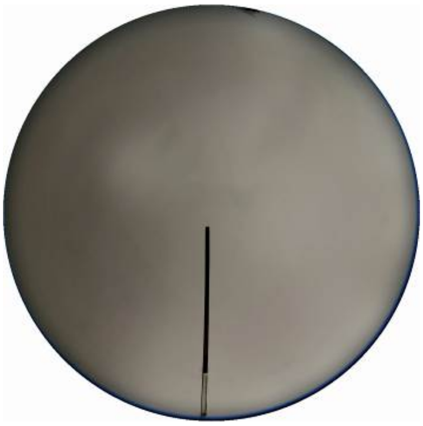

Fig. 5. View on the inner surface of the sky dome illuminated by new LED lamps

The measurements of the new photometric coating show improvement of the spectral reflectance properties of sky dome surface, as can be seen in Fig. 5. The new „Photometric coating" leads to higher light reflectances, resulting in averaged value ρ_V = 86 %, Fig. 6 and Tab. 1, with a minimum effect of the spectral selectivity, Fig. 7. The improvement in lower part of the visible spectrum is notable from the diagram in Fig. 7. The variation of the data is less than 10 % around the average values of the spectral course.

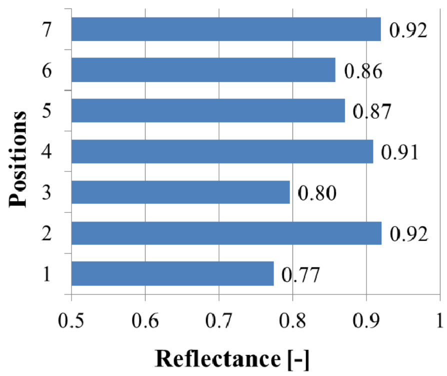

Fig. 6. Averaged reflectance in seven positions.

TABLE 1. AVERAGED REFLECTANCE ρ_V

Position	1	2	3	4	5	6	7
ρ_V	0.77	0.92	0.80	0.91	0.87	0.86	0.92
Average	0.86						

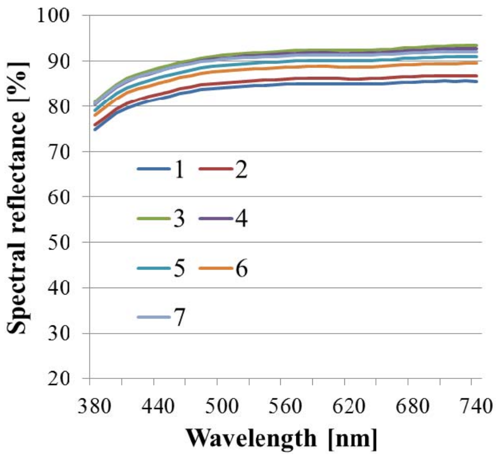

Fig. 7. Spectral reflectance of the new coating

Recorded reflectance in new dome was lower than in old dome´s coating in two assessed positions. This could be caused by the manwork errors during coating procedure of the new material on the dome´s surface. Another cause can be the utilization of measuring device - spectrophotometer, which is mainly designed to work with flat surfaces, and could produce some errors on curved surfaces by inaccurate handling due to its weight..

CONCLUSION

Modernization process or design of laboratory equipment for measuring of photometric quantities often deals with request for ensuring high value of diffuse reflectance of its surfaces. The formulation for the composition of suitable coating for non-absorptive surfaces can be found in standard [8]. In the lighting laboratories many various surfaces that have absorptive properties could be found, for example, concrete domes of artificial skies, gypsum or cement surfaces used in large-scale integrators. In these cases, the standard´s recommendation [8] cannot be used. This study shows the possibility to design and manufacture a coating with very good reflectance and spectral properties throughout the visible spectrum, which can be applied on the non-absorptive large surfaces.

The measurements determine reflectance coefficient ρ = 0.86 of the inner surface of the ICA SAS artificial sky and this value can be used in the simulation of the ISO/CIE General sky luminance distributions and adjustments of dimming LED sources in the new lighting system.

After reconstruction of the dome, lighting system and retrofitting of a new LED sources with its controlling mechanism, there is assumption, this artificial sky will become to be the device of international importance. It is expected that examination of lighting conditions in the interior of building models and daylight transmitting devices such as light pipes or light shelves will get to the higher level. Also verification of different calculation methods under daylight standard boundary conditions will be more effective.

Acknowledgement

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