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Effect of directional reflectance in lighting

Abstract. *This article describes the influence of directional reflectance for the lighting calculations. Also compares the difference between the calculations of materials ideally diffuse and real materials. For real material applies that indicatrix of reflected light and reflecting material are not behaving as an omni directional diffusor, but under certain angles are starting to behave almost like a mirror. This contributes to an erroneous calculation of lighting, because the existing computer programs allow for real reflective materials as ideal. This error has resulted in unnecessary over-lighting certain places, and ultimately a waste of electricity.*

Streszczenie. *Artykuł opisuje wpływ odbicia kierunkowego na wyliczenia oświetlenia, porównuje różnicę pomiędzy wyliczeniami dla materiałów dyfuzyjnych i materiałów rzeczywistych. W przypadku materiałów rzeczywistych pojawia się zakrzywienie światła odbitego i materiał odblaskowy nie zachoruje się już jako rozpraszacz ogólnokierunkowy, ale pod pewnymi kątami zaczyna się zachowywać prawie jak zwierciadło. Wspomniana sytuacja może być powodem błędnych obliczeń oświetlenia a to dlatego, że dotychczasowe programy kalkulacyjne traktują rzeczywiste materiały odblaskowe jako idealne. Następstwem tego błędu może być zbyt intensywne oświetlenie niektórych miejsc a w efekcie i zbyteczne zużycie energii elektrycznej.* ***(Wpływ odbicia kierunkowego w oświetleniu).***

Keywords: directional reflectance, Lighting, BRDF, safe energy.
Słowa kluczowe: odbicie kierunkowe, oświetlenie, BRDF, oszczędność energii.

Introduction

Presently rising energy prices press on the reducing its consumption. If we consider that the global annual electricity consumption in 2009 was approximately 2 600 TW·h, implies even lower power consumption enough to significantly lessen the negative impact on the environment. Worldwide, approximately 19% of electricity consumed for lighting [1]. Therefore the design of high-quality illuminating system with low power consumption is more than desirable and globally, we can contribute to lower growth in electricity.

One of the steps how proposed a friendly lighting system is to comprehend the inclusion of directional reflectance of the material to the calculation. It can be assumed that such proposed lighting system will make better use component reflected from the walls, which is undoubtedly in some locations will increase the overall level of illumination. In these places, then you will not need to increase the contribution from the direct illumination component, which in turn will lead to lower electricity consumption.

Reflectance model

The main aspect of this calculation is the definition of an appropriate mathematical model of reflectance materials. Currently known computer programs operate almost always ideal diffuse reflection (Lambert's emitter), which brings the one hand, faster computation, but on the other hand, an inaccurate result of calculated surface illuminating.

Almost all mathematical descriptions of reflective materials are empirically derived relations, which have no direct relationship to the physical nature of light reflection. They are quite often used especially in computer graphics because of its simplicity.

One such relationship is called Phong's lighting model (1) Report of Vietnamese scientist Bui Tuong-Pong in 1975 [2].

(1)
$$I_v = I_d + I_s$$
$$I_d = I_0 \cdot r_d \cdot \cos(\Theta)$$
$$I_s = I_0 \cdot r_s \cdot \cos^h(\Theta + \Theta_0)$$

This relationship represents the reflected light (luminous intensity), with the components of diffuse I_d and spectacular reflection I_s. Where I_0 is the luminous intensity of the incident beam, r_d is a coefficient representing the measure of representation of diffuse reflectance, and r_s is a coefficient representing the measure of representation of specular reflection. Exponent h reflects the measure of variance specular reflection. Θ_0 parameter expresses the angle of incidence and reflection angle Θ beam. The following figure shows Phong's lighting model graphically.

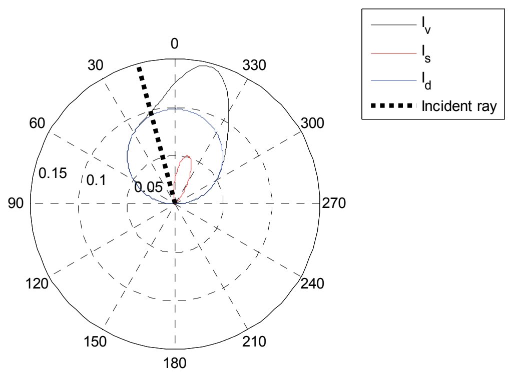

Fig.1. Phong's lighting model

This model is based on more sophisticated models. For our calculation, it was necessary to derive a model that respects bidirectional impact angle and the angle of reflection bidirectional called BRDF function. Graphical representation is shown on the figure below.

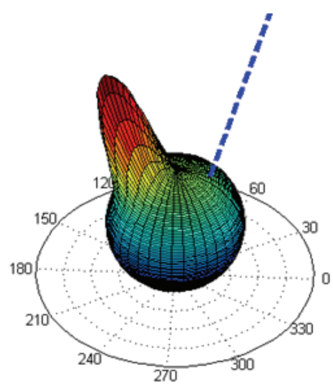

Fig.2. Phong's lighting model in 3D (BRDF)

Calculation of illuminance

When calculating the illuminance one assumes (2)

$$E = \frac{I}{r^2} \cdot \cos\alpha \tag{2}$$

where I represents the luminous intensity of the incident beam, r is the photometric distance between the luminaire and point of impact, and α is the angle of the incident beam, representing a departure from the normal correlation plane. In the first step of calculating the illuminance calculated from the direct component, and the next step is to calculate the contributions of illumination of all reflections (3)

$$E_{xyz} = E_{Axyz} + \sum E_{Rxyz} \tag{3}$$

In our case, we will consider only one reflection from the wall and of course the direct component. If we are looking for illuminance in xyz coordinates of the point, we must to sum the direct component with the reflected component, which is formed from all points of the reflective walls. If we describe reflection as the ratio of intensities of the infinitely small point, letting the errors in calculating the indirect component from the infinite number of points reflecting surface, the illuminance at point xyz grow over all bounds. That is why is necessary to include the coefficient to the calculation, (4) the coefficient is representing the ratio of the size of the elemental reflecting surfaces with the size of surfaces for which the data was acquired by directional reflectance. Than we multiply the luminous intensity of the reflected light with this coefficient.

$$k = \frac{S_0}{dS_R} \tag{4}$$

Thus we approach as close to real conditions.

Results of calculation

In our calculation, we were thinking about the correlation plane, the size of 4x4 m, 2 m over its center was located spotlights with cosine luminous intensity curve. Furthermore, on the one side was white perpendicular reflecting wall (4x2 m), which in the first case showed a directional reflection and second case reflection of purely diffusion. Directional reflection of such wall was measured in the light laboratory, and its course is shown on the screenshot below.

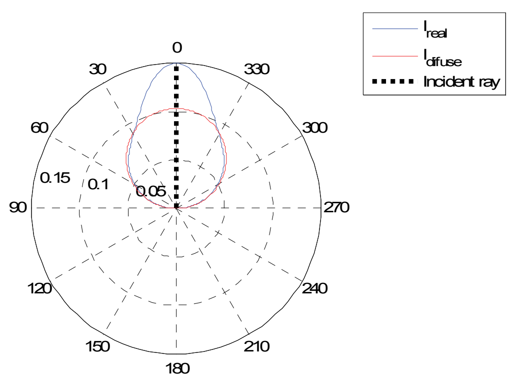

Fig.3. Directional reflectance (real) and diffuse reflectance (ρ=0,8; S=0,00113m^2)

Equivalent diffuse reflection shown in red was calculated from the real reflectance method of zonal flux. Maximum luminous intensity of the equivalent diffuse reflection will be described by Eq. (5)

$$I_{dif\,\max} = L \cdot S$$

$$L = \frac{M}{\pi}$$

$$M = \frac{\phi_{refl.}}{S}$$

$$I_{dif\,\max} = \frac{\Phi_{refl.}}{\pi \cdot S} \cdot S$$

$$I_{dif\,\max} = \frac{\Phi_{refl.}}{\pi} \tag{5}$$

So if we compare the resulting illuminance including directional reflection Fig. 4.

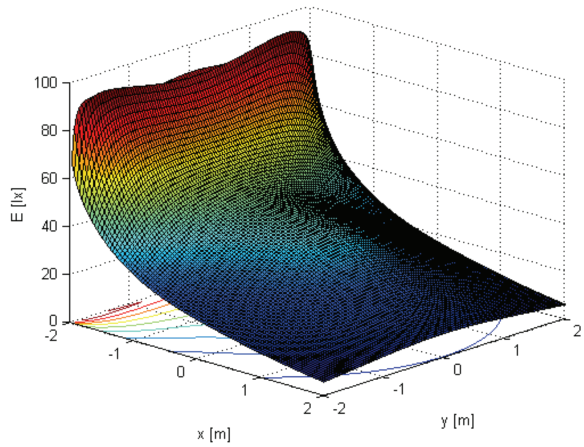

Fig.4. Illuminance including directional reflection

and illuminance including diffuse reflection spare Fig. 5

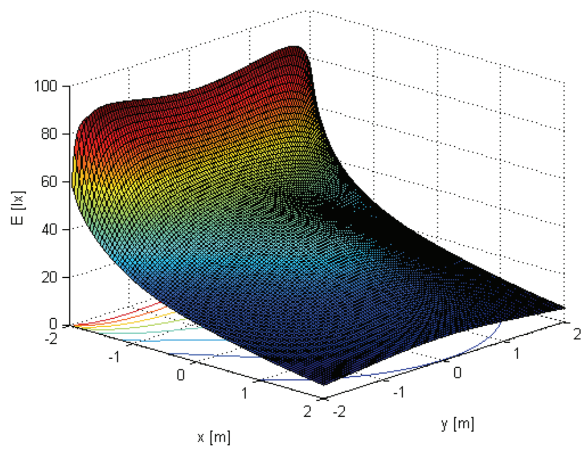

Fig.5. Illuminance including correlated diffuse reflection

we get an error due to disregard of directional reflectance of materials in accordance with

$$\Delta E = \frac{E_{dif} - E_{real}}{E_{real}} \quad (6)$$

E_{dif} where illuminance comprehensive replacement and diffuse reflection and $E_{real,}$ which is illuminance involving real directional reflection.

In the same way we compare each point on the correlation plane, we get the expression of three-dimensional errors, the result is shown in Fig.6.

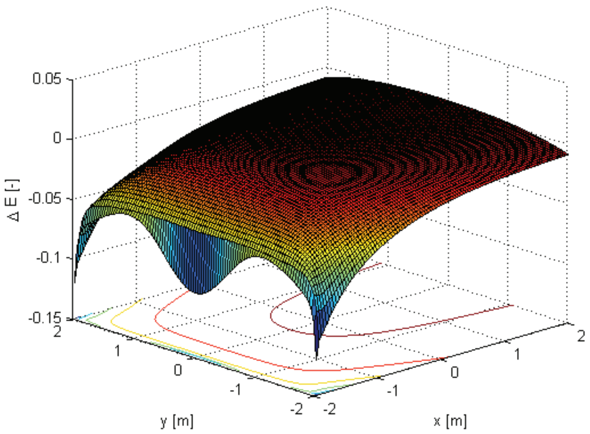

Fig.6. Absolute error of illuminance

We can see on the picture above that this problem can be achieved in our case the average error to -5%. This means that if we consider directional reflection material, no need to increase illuminance in places that previously seemed to be poorly lighted. This will ultimately lead to higher operational costs, and naturally to greater electricity consumption.

Conclusion

This article was supposed to compare the illuminance on the desktop in the calculation with respect directional reflection from the walls. In the computer programs are now considering the reflection from the walls as purely diffusion, which introduces some error into the calculation. Today the resulting calculation can then show that some places are poorly lighted, so the designer tries to put more ligtening to this place. But if we involve directional reflection, we find that places which previously seemed like poor lighting, are lighting good and other light level leads to unnecessary over-lighting and hence to unnecessary demands for electricity. The former procedure of calculation for the case of a reflection and direct components, it can be concluded that the errors inflicted, may be in this case the average of up to -5%, the peak to -13%. If we thought more than one reflection may be error of illuminance and higher.

The overall rate of errors resulting also depends on many aspects such as to consider real luminaires as a point luminaires, directional reflection from walls and so on.

If we can simulate the real parameters of all components for calculate. It is possible to calculate more precise and in some cases to reduce energy intensity lighting system.

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REFERENCES

[1] Kubes, Karel. Budova osvětlená výhradně diodami LED. *Světlo. 2010, 1,* s. 33. ISSN 1212-0812

[2] Malek, Jan, Habel Jiří. Model činitele odrazu světelně činných materiálů. In *Světlo 2004*., 2004. s. 211-214. ISBN 80-238-8928-1.

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