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ILLUMINANCE OF THE WORKING PLANE IN ATTIC SPACES UNDER DIFFERENT EXTERIOR DAYLIGHT CONDITIONS

NATĘŻENIE OŚWIETLENIA NA PŁASZCZYŹNIE ROBOCZEJ W PODDASZU POD RÓŻNYMI ZEWNĘTRZNYMI WARUNKAMI ŚWIATŁA DZIENNEGO

Abstract

The assessment of interior daylight conditions, under the current Slovak standards, is based on the Daylight Factor concept. It means that the worst exterior daylight conditions are reflected in calculations, represented by the CIE overcast sky. Since this evaluation criterion was adopted, several decades have passed. Because the overcast sky is not the only sky type observable in nature, the development of a new criterion, based on photometric variables, e.g. illuminance in lux, became necessary. This article presents a study which investigates the relation between relative and absolute illuminance, in specified points on the working plane illuminated by the standard overcast and clear sky.

Keywords: daylighting, attic room, illuminance, overcast sky, clear sky

Streszczenie

Ocena oświetlenia wnętrz światłem dziennym, w ramach obowiązujących słowackich standardów, opiera się na koncepcji współczynnika oświetlenia dziennego. Oznacza to, że najgorsze warunki oświetlenia światłem dziennym występują przy zachmurzonym niebie, co znajduje odzwierciedlenie w obliczeniach. Od przyjęcia tego kryterium za obowiązujące minęło kilka dekad. Ponieważ niebo zachmurzone nie jest jedynym, obserwowanym w przyrodzie rodzajem nieba, rozwój nowego kryterium opierającego się na zmiennych fotometrycznych, takich jak natężenie oświetlenia w luksach, stał się konieczny. W artykule przedstawiono badania, które określają związek między względną i bezwzględną iluminacją oświetlenia, w określonych punktach na płaszczyźnie roboczej, przy standardowo pochmurnym i bezchmurnym niebie.

Słowa kluczowe: światło dzienne, pokój na poddaszu, natężenie oświetlenia, zachmurzone niebo, jasne niebo

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Denotations

a_v – luminous extinction coefficient
E_v – extraterrestrial illuminance
$E_{v,d}$ – diffuse external illuminance
$E_{v,g}$ – global external illuminance
$E_{v,o}$ – luminous solar constant, 133800 lux
$E_{v,s}$ – direct external illuminance, recalculated on the horizontal plane
J – day of the year
m – relative optical air mass
T_v – luminous turbidity factor
γ_s – solar altitude
ε – factor of eclepticity

1. Introduction

Sunlight plays a very important role in our daily lives. In addition to being associated with the basic processes of the contemporary life on the Earth, as a natural factor it has a significant impact on the physiological functions of the human organism and thus on the quality of the environment in which we are living and working. On the other hand, the uncontrolled amount of direct sunlight may cause thermal or visual discomfort, in some cases both at the same time.

According to the currently applicable standards, all kinds of spaces with permanent occupancy (i.e. work-, school-, residential spaces) have to be illuminated by daylight [1–3]. Daylight in buildings is assessed according to light conditions represented by overcast sky conditions, respecting the CIE overcast sky model. Recently, several models of the sky luminance distribution have been developed. They allow simulating conditions of the clear and also cloudy daylight situations [4–6]. Hence interiors are illuminated by each of them during the 365 days of the year, the Daylight Factor method seems to be at least a non-representative criterion.

The aim of this study is to provide a discussion about the differences of the working plane illuminance levels after CIE overcast- and subsequently CIE clear sky pattern. For this purpose a sample attic room with South orientation has been chosen and the time 12 a.m. on 21st March has been set as default for demonstration of sunlight penetration.

2. Methodology

The task was performed with a simple computer program Velux Daylight Visualizer. Unfortunately the program calculates only the diffuse illuminance under both – overcast and sunny sky condition, so the direct component has to be determined additionally. For this purpose the formulas were used – working on the solar altitude, diffuse ratio $E_{v,d}/E_v$ and luminous turbidity factor.

Generally, the horizontal illuminance on the ground can be expressed as:

$$E_{v,g} = E_{v,s} + E_{v,d} \quad (1)$$

where:

$E_{v,g}$ – global external illuminance,
$E_{v,s}$ – direct external illuminance, recalculated on the horizontal plane,
$E_{v,d}$ – diffuse external illuminance.

To calculate the direct component of the external illuminance the next exponential formula should be used:

$$E_{v,s} = E_v \cdot e^{\left(-a_V \cdot m \cdot T_Y\right)} \quad (2)$$

where:

E_v – extraterrestrial illuminance,
a_v – luminous extinction coefficient,
m – relative optical air mass,
T_v – luminous turbidity factor, for clear sky ISO/CEI Type12 can be used value: $T_v = 4$.

The extraterrestrial illuminance represents a solar illuminance incident on the outer limit of the Earth's atmosphere, and in order to calculate its value, the luminous solar constant (illuminance produced by the extraterrestrial solar radiation on a surface perpendicular to the Sun's rays at mean Sun-Earth distance), the factor of eclepticity and the value of the solar altitude are needed.

$$E_v = E_{v,o} \cdot \varepsilon \cdot \sin \gamma_s \quad (3)$$

where:

$E_{v,o}$ – luminous solar constant, 133800 lux,
ε – factor of eclepticity,
γ_s – solar altitude.

The factor of eclepticity can be calculated after the [ISES, 1984] as follows:

$$\varepsilon = 1 + 0.034\left[360 \cdot \frac{(J - 2°)}{365}\right] \quad (4)$$

where:

J – day of the year.

Thus, to determine the direct component of the external illuminance only two unknowns are left. The first is the luminous extinction coefficient (of the atmosphere) a_v (Clear, 1982) after the formula (5), which expresses the attenuation of the direct illuminance when the sun rays cross vertically the pure and dry atmosphere (Rayleigh atmosphere).

$$a_v = \frac{1}{(9.9 + 0.043 \cdot m)} \quad (5)$$

The second one is the relative optical air mass m (Kasten–Young, 1989) weighed to take account of the relative spectral transmittance characteristics of the atmosphere.

$$m = \frac{1}{\sin\gamma_s + 0.50272\left(\gamma_s + 6.07995°\right)^{-1.6364}} \tag{6}$$

Now, the last step, in order to determine the internal illuminance on the working plane, is to sum up the reduced direct component of the external illuminance (by the factor of light transmission, dirt reduction and directional light transmission) and the indirect component of internal illuminance obtained by means of VELUX computer program.

3. The tested room and the location

A sample room was designed as follows: rectangular floor plan, whose dimensions are 4.0 × 6.0 m, where the first measure corresponds to the windows wall (see Fig. 1). The height of the room was adjusted to 2.6 m, whereas the height of the 45° pitched roof's "roofwall" is 0.6 m. The floor has the reflectance of 30%, the ceiling 80% and the average reflectance of the walls is 50%.

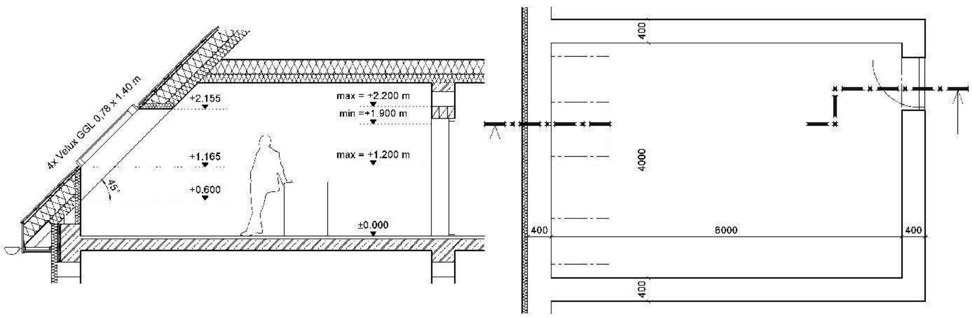

Fig. 1. The section and the floor plan of the tested room

The room is illuminated from one side by four roof windows with dimensions 0.78 × 1.4 m, the glazed area of each window is 0.69 m^2. The position of the windows was proposed in accordance to the current architectural rules and Slovak standards [4–6]. Thus, the total area of the window glazing is approximately equal to 1/10 of the floor area and their bottom and top edges were proposed within the allowable limits (see Fig. 1).

To calculate the required values of illuminance, the information about the location of the investigated room is also needed. For this purpose the city of Košice with the geographical coordination: latitude 48°43′ N, longitude 21°15′ E was chosen. The best study of sunlight influence on the interior illuminance levels is in an orientation where windows are placed towards the sun, i.e. along the solar meridian. Therefore the time 12 a.m. on 21st March and the orientation of the windows to South was chosen.

4. Test calculations and results

The levels of illuminance for both overcast and clear sky (without the direct component) were calculated by means of the computer program as it is shown in Fig. 2. Spacing between the points of the grid is generated automatically by the program. In our case it is created by the group of 24 points (4 points along the window wall and 6 points along the side wall).

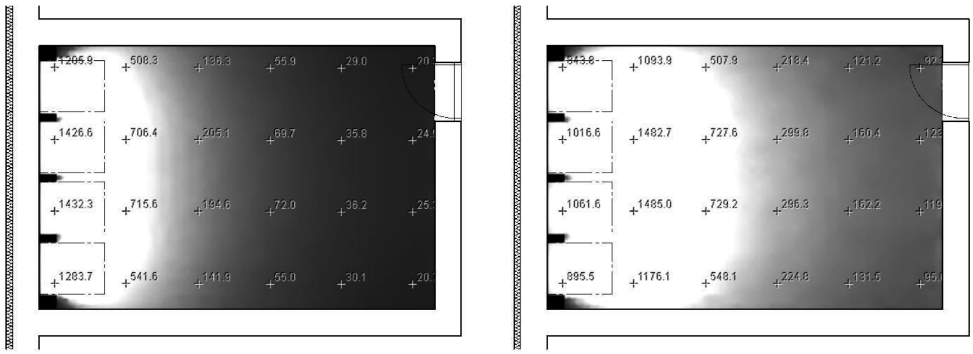

Fig. 2. Values of illuminance for overcast and clear sky (without the direct component)

The levels of global illuminance under clear sky conditions, including the direct component, have to be additionally determined. The positions of points, which are directly illuminated, were determined by calculations (basing on solar altitude) and subsequently by simulation. Fig. 3 leads to a conclusion that considerations were correct, and only the 2nd row of the points is directly illuminated by sunlight.

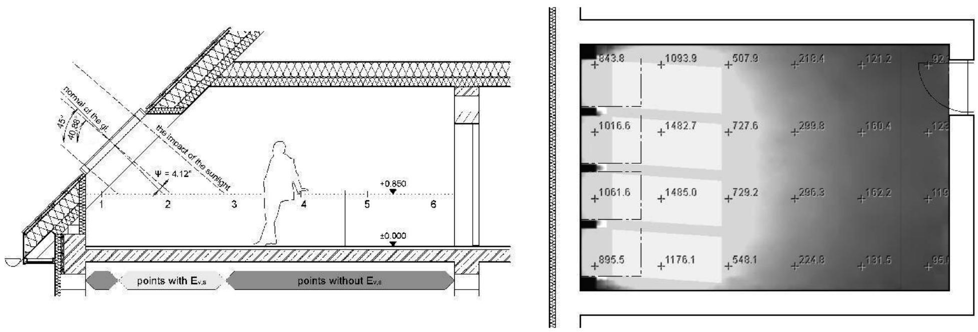

Fig. 3. The positions of directly illuminated points (calculated from the section and simulated in the floor plan)

The value of the factor of light transmission in normal direction for the double glazed window is 0.92^2, the factor of dirt reduction for the outer side of the glass is 0.7 for semi-polluted exterior air and 0.95 for the inner side of the glass for light-polluted interior air.

All results are summarized in the Table 1.

Table 1

Values of illuminance *E*[lux] on the working plane

	Points	1	2	3	4	5	6
Overcast sky	1	1205.9	508.3	136.3	55.9	29.0	20.3
	2	1426.6	706.4	205.1	69.7	35.8	24.9
	3	1432.3	715.6	194.6	72.0	36.2	25.3
	4	1283.7	541.6	141.9	55.0	30.1	20.7
Clear sky without $E_{v,s}$	1	843.8	1039.9	507.9	218.4	121.2	92.1
	2	1016.6	1482.7	727.6	299.8	160.4	123.6
	3	1061.6	1485.0	729.2	296.3	162.2	119.9
	4	895.5	1176.1	548.1	224.8	131.5	95.6
Clear sky with $E_{v,s}$	1	843.8	27961.0	507.9	218.4	121.2	92.1
	2	1016.6	28403.8	727.6	299.8	160.4	123.6
	3	1061.6	28406.1	729.2	296.3	162.2	119.9
	4	895.5	28097.2	548.1	224.8	131.5	95.6

5. Conclusions

Sunlight has a significant effect on the human well-being and on the work productivity. In interiors it can also cause disability glare and overheating. The aim of this contribution was to provide a study about the effects of using different sky pattern on interior daylight conditions. The main finding is that the levels of illuminance in points illuminated by direct sunlight are an order of magnitude greater than in other points of the grid, which are illuminated only by diffuse skylight. This finding demonstrates the fact that in nature not only overcast sky conditions occur, but also other sky situations, which should be taken into account in the daylight design.

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