

Daylight in interiors

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ABSTRACT: One for your healthy and full life needs natural light, which affects the biological rhythm of man. Design of daylight should therefore be well thought out, to arrange visual comfort for the user according to the predominant visual activity inside the room. Therefore we try to bring daylight into the interior to a sufficient extent and quality, through window openings or light guides, which must be designed not only to the adequate size, but also must be properly positioned. Quantitative criterion for day light is daylight factor D , which is expressed in percentage. Daylight factor D is defined as the ratio of daylight illumination at a given point of the plane $E_{\text{intr}} [\text{lx}]$ on the present outdoor illuminance levels $E_{\text{extr}} [\text{lx}]$ for known or expected sky brightness distribution. Direct sunlight is excluded in both measurements. Quantitative criterion is the uniformity of daylighting $r [-]$, which indicates the ratio between the maximum and minimum values of daylight factor. Another quantitative criterion is the distribution of light, preventing glare, light reflectivity and color of surfaces. With decreasing the possibilities of new construction are currently being used in less attractive locations for the construction and much more likely to approach various types of reconstruction. Reconstruction will help us as saving energy for heating or other aspects of improve interior, we must be careful to the negative influence of daylight inside a room. Also, existing dense development gives us a big limitation for appropriate design of the interior with the qualifying conditions for a visual activity. In places not directly neighbouring on the exterior environment a suitable means of lighting are daylight guidance systems which may transmit light over long distances. Their installation belongs to investments with high financial demands; therefore, adequate attention should be paid to the optimisation of their design with respect to the interior environment resulting in the maximum effectiveness of the designed installation even without any contact with the exterior environment.

1 DESCRIPTION OF ONE OF THE SELECTED ROOMS

Due to the fact that the investigated lighting system is not very common in practice and sets high financial demands, it was necessary to visit a large number of spaces where day light guidance systems have been installed to select the most universal implementations in terms of the defined boundary conditions and light guide structural designs used that will, at the same time, comply to the maximum possible extent with the regulations of the codes on which the boundary conditions are based. Out of all selected and measured rooms the one chosen for this presentation is located in the premises of the Institute of Geology of the Academy of Sciences of the Czech Republic in Prague 6 - Lysolaje. The selected room is situated on the first underground storey and serves as a library. The room is shaped like an orthogonal trapezoid $12.3(9.57) \times 6.85$ m with a clearance of 3.08 m and bookshelves occupy a room largely. The daylight in the room is provided by only three light guides with a diameter of 400mm and a length of 800mm. The polycarbonate domes of the light guides are fitted onto the flat green roof of the atrium of

the building being thus partially shaded by the whole complex. The light guide diffusers, which function as the light source for the interior, are located at the ceiling level of the room being circular shaped.

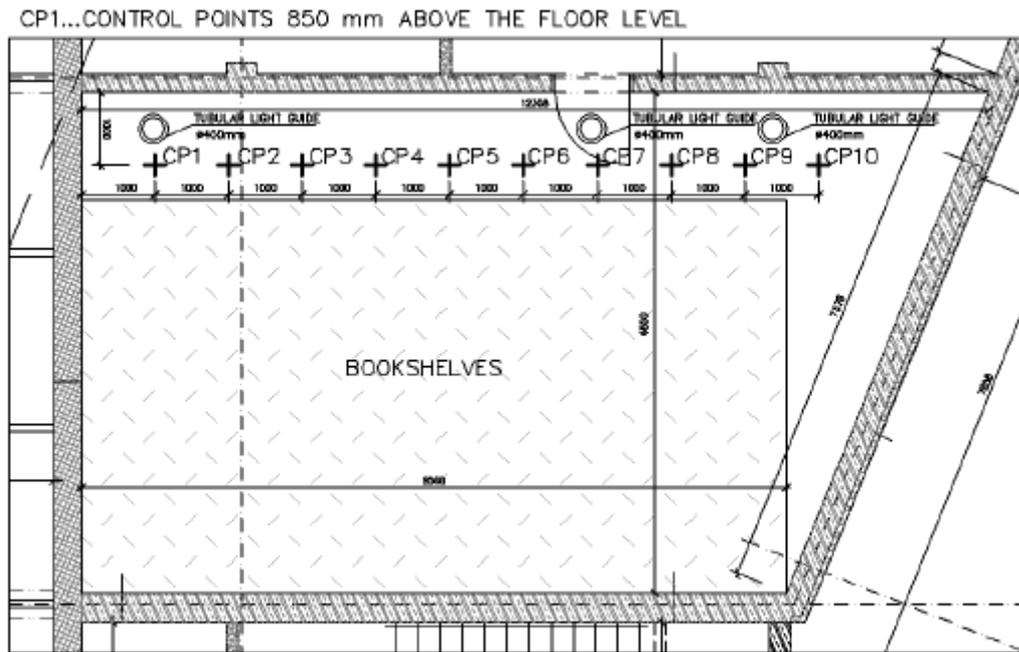


Figure 1: The floor plan of the selected room

2 BOUNDARY CONDITIONS AND CONTROL POINTS

One of the most important conditions for the measurement and also for the computational method is the processing of results for uniformly overcast sky conditions which should correspond to the brightness distribution pursuant to ČSN 73 0580-1.

The considered outside terrain is always dark unless the investigated object is situated at an elevation of over 600 m above sea level, with an average light reflection coefficient ranging between 0,05 and 0,20.

The illumination and its distribution were identified at control points at a distance of 1 m from each other, in aisle between wall and bookshelves. The height of the comparative reference plane was 850 mm above the floor level.

3 COMPUTATIONAL METHODS

Prior to the very selection and application of individual computational methods the light guide shape factor, the AR (Aspect Ratio), needed to be defined, which is specified for a direct light guide as the length ($l=0,80\text{m}$) to the diameter ($d = 0,40\text{ m}$) ratio of the light guide.

$$AR = l/d = 0,80/0,40 = 2,0 \quad (1)$$

The computation of the light flow Φ_e entering the light guide further depends on the light guide cross sectional area ($A = 0,196\text{m}^2$) and the total outside illumination $E_e = 25000\text{ lux}$.

$$\Phi_e = A \times E_e = 0,196 \times 25000 = 4900\text{ lm} \quad (2)$$

Then, three computational methods described below were selected.

3.1 CIE Computational and Table Method

A group of international experts specialised in the light passage through tubular light guides published the CIE 173 -2006 (Tubular Daylight Guidance Systems) document containing a computational method for the light passage through light guides. The method is used for obtaining rough results of illumination in an investigated room lit by a daylight guidance system. The shape factor affects the light transmission through the TTE light guide tube:

$$TTE = \frac{e^{-\frac{l}{d} \tan \Theta \ln \rho}}{1 - \frac{l}{d} \tan \Theta \ln \rho} = \frac{e^{-\frac{0,8 \tan 30 \ln 0,60}{0,4}}}{1 - \frac{0,8}{0,4} \tan 30 \ln 0,60} = 0,349 \quad (3)$$

Θ ... represents the sky segment around the zenith with the most efficient effects of sky brightness, this angle is objectively considered as 30°

ρ ... is the light reflection factor on the inside light guide surface, for the computation it was estimated as 60%

The light transmission efficiency EG is affected not only by the light transmission efficiency through the TTE light guide tube, but also by the loss due to the diffuser and the light guide dome, which pursuant to the CIE recommendation equals 0,63. Another loss coefficient is the effect of the outside environment pollution, typical of the urban development. The room utilisation relies on the MF value (MF = 0,76).

$$EG = TTE \times 0,63 \times MF = 0,349 \times 0,63 \times 0,76 = 0,167 \quad (4)$$

The light flow exiting the light guide Φ_i depends on the light transmission coefficient of a light guide EG and the light flow entering the light guide:

$$\Phi_i = \Phi_e \times EG = 4900 \times 0,167 = 818 \text{ lm} \quad (5)$$

The calculation of the illumination E_i at a distance of $V = 0,50$ m below the light guide along its axis equals: [1]

$$E_i = 0,494 \times \frac{\Phi_i}{V^2} = 0,494 \times \frac{818}{0,5^2} = 1616 \text{ lux} \quad (6)$$

3.2 Luxplot Package Model

The authors of the second selected model are Jenkins and Muneer, who described light by the difference between the light entering the light guide and the light exiting the light guide. The result is the light permeability coefficient τ_t , which also relies on the light loss due to the diffuser and the light guide dome permeability. [2]For this case, the value defined was 0,63:

$$\tau_t = 0,82 \times e^{-0,11AR} = 0,63 \times e^{-0,11 \times 2,0} = 0,506 \quad (7)$$

Thus, the light flow exiting the light guide equals:

$$\Phi_i = \tau_t \times \Phi_e = 0,506 \times 4900 = 2479 \text{ lm} \quad (8)$$

The resultant illumination at a distance $V = 0,50$ m below the light guide along its axis, which again was modelled by means of measurements and computations made in Great Britain, including the coefficient of 0,494, is:

$$E_i = 0,494 \times \frac{\Phi_i}{V^2} = 0,494 \times \frac{2479}{0,5^2} = 4894 \text{ lux} \quad (9)$$

3.3 Tsangrassoulis Method

The last of the evaluated methods was again published by Jenkins and Muneer in 2004[3] where perfect light dispersion from the diffuser inside the interior is assumed. To identify the diffuser brightness L the method departs from the light flow value as follows:

$$L = \frac{E_e \tau_T}{\pi} = \frac{25000 \times 0,506}{\pi} = 4027 \text{ cd/m}^2 \quad (10)$$

Then, illumination at a distance $V = 0,50$ m below the light guide long its axis equals:

$$E_i = \frac{\pi L r^2}{V^2 + r^2} = \frac{\pi \times 4027 \times 0,2^2}{0,5^2 + 0,2^2} = 1745 \text{ lux} \quad (11)$$

4 MEASURING DEVICES

Lux meter: two autonomous calibrated lux meters are used for the measurement of inside and outside illumination since it is important to measure the inside and outside illumination at the same moment for the reason of the changeability of exterior light conditions.

Luminance meter: Uniformly overcast sky is controlled by the brightness measurement using a luminance meter. If a luminance meter is not available, a lux meter is used instead with a brightness adapter with a black matte surface inside whose length equals minimally twenty times the distance of its inside diameter.

5 DAY ILLUMINATION INSIDE A ROOM

The day illumination level inside a room is described by the Daylight Factor D . It is the inside illumination to the outside illumination ratio expressed as a percentage.

$$D = \frac{E_i}{E_e} \cdot 100 = [\%] \quad (12)$$

6 COMPARISON OF RESULTS

Results that compare computational methods and real measuring are given in Tab.1

Table 1. Daylight Factor D in Control Points

Method	Control Points									
	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	CP9	CP10
CIE	0,5	0,4	0,2	0,1	0,2	0,4	0,5	0,5	0,6	0,5
Luxplot Package	1,6	1,1	0,6	0,4	0,6	1,2	1,6	1,6	1,7	1,4
Tsangrassoulis	0,6	0,4	0,2	0,1	0,2	0,4	0,6	0,6	0,6	0,5
Measuring	0,2	0,1	0,0	0,1	0,2	0,3	0,2	0,2	0,2	0,2

7 CONCLUSION

Computational models describe light transmission through a light guide allowing us to imagine the day illumination level inside a room where the daylight source is the light guide itself. [4] Results evidently show the comparability of the measurement results with the mathematical modelling using the CIE or Tsangrassoulis method where the differences are minimal, according to Luxplot Package are the differences very noticeable. Next rooms are presently being investigated by means of measurements and comparative analysis is made for individual computational models. The final solution of our research project will be not only the selection of the method which will best copy the actually measured values thus simulating correctly and optimally the selected boundary conditions for a specific design and computation, but, above all, the modification and adjustment of this method, to the maximum possible extent, to real conditions and requirements of standards for the design of the optimum interior environment. The methods will be further modified to describe the behaviour of light guides in the Czech Republic, including the possibility of defining the surface reflectivity and material permeability values to be used for the light guide. [5]

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