Optimisation of The Design of Daylight Guidance Systems Including Measurement Methodology

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Keywords: light guide, daylight, lighting measurement, interior environment

Abstract. Daylight is important for a human organism mainly in the physiological and psychological respect. These days, however, the economic aspect is also becoming a non-negligible parameter. Due to the lack of daylight eye strain occurs that may lead not only to eyesight damage, but also to various related health disorders studied by numerous experts. 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. At the same time, a light guide should be designed to eliminate thermal bridges and thus undesirable manifestations of condensation on the inside surfaces of structures.

Intorduction

The first half of the research project in its introductory part was focused, in particular, on literature search and the definition of boundary conditions that will lead to the universal application of daylight guidance systems in the design optimisation. With respect to these conditions the task was to select several suitable interiors where the main sources of daylight are, in particular, light guides. The selected rooms will serve as reference rooms for the defined boundary conditions and for successive measurements. In the next phase, measuring devices verified by calibration were selected and described. The selected rooms and individual types of daylight guidance systems were simulated in several versions of computational models under the above boundary conditions. The current phase involves the measurements and processing of the results. The methods are compared against each other and evaluated. The final output will be the definition of not only boundary conditions for measurements, but also a specific and the most precise within the allowable range of errors methodology of measurement based on the computational models available.

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) x 6.85 m with a clearance of 3.08 m. 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.

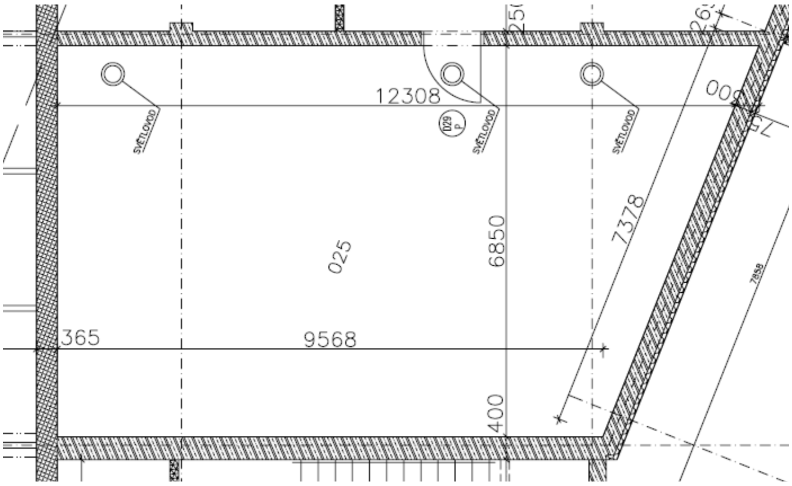

Fig. 1: The floor plan of the selected room

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 0.2.
The illumination and its distribution were identified at control points at a distance of 1 m from side walls situated in a regular rectangular grid with 1m spacing across the whole comparative plane. The height of the comparative reference plane was 850 mm above the floor level.

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=0.80m) to the diameter (d = 0.40 m) ratio of the light guide.

$$AR = l/d = 0,80/0,40 = 2,0 \tag{1}$$

The computation of the light flow Φ_e entering the light guide further depends on the light guide cross sectional area ($A = 0.196m^2$) and the total outside illumination E_e= 25000 lux.

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

Then, three computational methods described below were selected.

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.
He shape factor affects the light transmission through the TTE light guide tube:

$$TTE = \frac{e^{\frac{l}{d}\tan\Theta\ln\rho}}{1-\frac{l}{d}\tan\Theta\ln\rho} = \frac{e^{\frac{0,8}{0,4}\tan 30 \ln 95}}{1-\frac{0,8}{0,4}\tan 30 \ln 0,95} = 0,890 \tag{3}$$

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 95%

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).

$$EG = TTE \times 0{,}63 \times MF = 0{,}89 \times 0{,}63 \times 0{,}76 = 0{,}426 \qquad (4)$$

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:

$$\Phi_i = \Phi_e \times EG = 4900 \times 0{,}426 = 2087 \text{ lm} \qquad (5)$$

The calculation of the illumination E_i at a distance of V = 0.50 m below the light guide along its axis equals: [1]

$$E_i = 0{,}494 \text{x} \frac{\Phi_i}{V^2} = 0{,}494 \text{x} \frac{2087}{0{,}5^2} = 4124 \text{ lux} \qquad (6)$$

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 0.82:

$$\tau_t = 0{,}82 \times e^{-0{,}11AR} = 0{,}82 \times e^{-0{,}11x2{,}0} = 0{,}658 \qquad (7)$$

Thus, the light flow exiting the light guide equals:

$$\Phi_i = \tau_t \times \Phi_e = 0{,}658 \times 4900 = 3224 \text{ lm} \qquad (8)$$

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:

$$E_i = 0{,}494 \text{x} \frac{\Phi_i}{V^2} = 0{,}494 \text{x} \frac{3224}{0{,}5^2} = 6371 \text{ lux} \qquad (9)$$

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:

$$L = \frac{E_e \tau_T}{\pi} = \frac{25000 \text{ x } 0{,}658}{\pi} = 5236 \text{ cd/m}^2 \qquad (10)$$

Then, illumination at a distance V = 0.50 m below the light guide long its axis equals:

$$E_i = \frac{\pi L r^2}{V^2 + r^2} = \frac{\pi \text{x} 5236 \text{x} 0{,}2^2}{0{,}5^2 + 0{,}2^2} = 2269 \text{ lux} \qquad (11)$$

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.

$$D = \frac{E_i}{E_e} 100 = [\%] \tag{12}$$

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.

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. Partial results evidently show the comparability of the measurement results with the mathematical modelling using the CIE method where the difference accounted for less than 15% along the light guide axis, while in the Luxplot package model and the method according to Tsangrassoulis the differences account for around 50%. Other 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. [4]

Currently we still make control measurements, we adapt and evaluate the results. The measurement results will be presented after the completion of a research project.

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