METHODS FOR DAYLIGHT ESTIMATION IN BUILDINGS

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Abstract

The current paper discusses the problem of daylight penetration in buildings and the different methods for its estimation. The results, obtained by experimental studies of the daylight factor for different geographical exposures are compared to calculation results, obtained by means of several methods for estimation of the average daylight factor. The results are analyzed and show that the experimental data follows more closely the tendencies of change of the Daylight factor on daily and yearly basis.

Keywords: daylight factor, calculation methods for daylight availability estimation

Introuction

The first step for estimation of the lighting conditions and energy efficiency in buildings is to make accurate assessment of the daylight penetrating the building. Often the illuminance from natural light sources is estimated by means of daylight coefficients. At first daylight coefficients are estimated by means of experimental studies or through point to point methods and have proved their efficiency and potential for energy savings through better use of natural light [1]. Later on, Longmore follows another conception – estimation of one average value of the daylight coefficients – daylight factor, which shows the adequacy of the natural lighting of a given space as a whole instead of that in predefined points. [2]. This approach is subsequently further developed and simplified by a number of researchers [3, 4]. The average daylight factor can be calculated by means of less detailed information, that that needed for estimation of the daylight coefficients in different points on the working plane.

Different calculation methods and standards exist, that recommend different values of daylight coefficients for different types of rooms. For example in [5] an average value of 5% for the daylight factor is recommended for rooms in which the natural lighting is not completed by artificial lighting through the day. Similarly in [6] it is assumed that a given space is well lit with natural lighting when the average daylight factor is 5% or more, while when the value of this parameter is less than 2%, the interior space seems dimly lit.

Although the average daylight factor play a main role in the current norms and standards, a lot of researchers are still trying to introduce another measure, that will successfully replace this parameter. A lot of researches are made about the possibility to use climate based modeling of the natural light, taking in consideration the local climate conditions, the illumination requirements and the use of the premises concerned [7].

There are three basic methods for modeling of the daylight. The first of them is by means of protractors and diagrams for quick analysis of the natural light – the BRE protractor, the Waldram diagram. The second method is by means of physical models for analysis of the natural light. And the third method for climate based daylight estimation is by means of simulation models in specialized software like Radiance, Daysim, Ecotect etc. [8].

Daylight Calculation Methods

The ratio in percent of the illumination on the working plane in a specific point and the diffuse horizontal illuminance outside, measured at the same time is defined as daylight coefficient (Figure1):

$$DC = \left(\frac{E_i}{E_o} \right).100,\% \tag{1}$$

where:

E_i is the natural illuminance in a specified point on the working plane,

E_o is the diffuse horizontal illuminance outside, measured simultaneously with E_i.

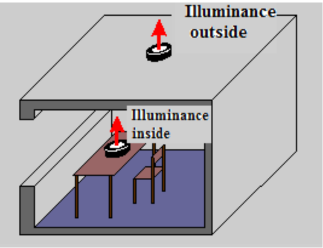

***Figure 1** E_i and E_o measurement*

The illumination E_i can be defined as a sum of three different components

- Direct illuminance, in case that the sky is seen from the specified point (E_D);
- Illumination due to reflections from the external enviroment (E_{ER});
- Illumination due to reflections from the surfaces inside the room (E_{IR}).

Thus it is possible to represent the DC (daylight coefficient) as a sum of three components:

$$DC = DirectC + ERC + IRC \tag{2}$$

where DirectC is the direct component, ERC is the externally reflected component and IRC is the internally reflected component of the natural light.

DC can be measured in predefined points in the premises or can be calculated as an average value. The average DC or the daylight factor (DF) is the arithmetic mean of the sum of values, obtained by measurements in a network of predefined points from the room profile. DF can be defined as an average value not only by means of experimental measurements, but also through different empirical expressions. Some of the most common expressions for evaluation of the DF are the following:

- IES formula

$$DF_{IES} = \frac{(A_w.\varepsilon.U.100)}{A_F} \tag{3}$$

- BRE formula

$$DF_{BRE} = \frac{(A_w.\alpha.M.t)}{A_t(1-\rho_m{}^2)} \tag{4}$$

- Sumpner formula

$$DF_{Sumpner} = \frac{(A_w.\alpha.M.t)}{2A_t(1-\rho_m)} \tag{5}$$

- Italian legacy formula

$$DF_{Italy} = \frac{(A_w.\varepsilon.\psi.t)}{A_t(1-\rho_m)} \tag{6}$$

where:

A_w is the area of the glazing without the frames or other obstructions, [m²];

A_F – the area of the floor [m²];

A_t – the total internal area of the room, [m²];
ε - factor taking into account the availability of external obstructions;
U – utilization factor;
α - angle at which the sky is visible from the middle of the window area [°];
M – maintenance factor of the windows;
t – factor taking into account the transparency of the glazing;
ρ_m - average reflectance of all internal surfaces;
ψ - factor taking into account the thickness of the window glass.

After calculating the DF for a given premises by some of the methodologies shown above, the obtained value can be estimated as it is shown in Table 1.

Table 1

DF	Exposition of the room	There is a need of complementary artificial lighting
< 2%	The room seems dimly lit	A complementary artificial lighting is needed through most of the day
2% to 5%	The room seems quite light	The need of complementary artificial lighting is decided individually
> 5%	The room seems very light	No complementary artificial lighting is needed

A similar estimation method of the natural lighting is used in the EN 15193 standard [9]. The formula for the DF, given in this standard for estimation of the energy efficiency of the lighting systems in buildings is the following:

$$DF = (4.13 + 20.I_T - 1.36.I_{De}).I_o, \% \quad (7)$$

where:

I_T is the transparency index of the part of the building, which can benefit from daylight;

I_{De} is the depth index of the space, which can benefit from natural lighting;

I_O is the obstruction index that accounts for effects reducing light incident onto the façade.

Results from the experimental measurements and calculations

The aim of the current paper is to make comparison between experimentally obtained value of the DF for a particular room, and those obtained using the different computational approaches described above.

The room taken in consideration is a laboratory, situated on the third floor ob the building of the Electrotechnical faculty of Technical University – Sofia. The laboratory is with west geographical exposure, the area of its glazing is 14 m^2 and the area of the floor is 52.5 m^2 (Fig. 2).

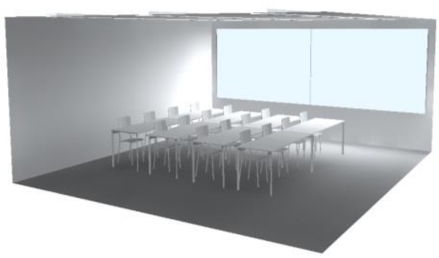

Figure 2. *Profile of the considered laboratory*

The values of the factors needed in expressions 3, 4, 5, and 7 are considered as follows:

A_W = 14 m²;
A_F = 52.5 m²;
A_t = 192 m²;
ε = 0.9, there is only a low building as an obstruction [9];

U =0.15, according to [6];
α = 70° according to[9];
M = 0.8 according to [9];
t =0.85 for single glass windows [9];
ρ_m = 0.5;

The results for the DC, obtained by means of an yearlong experimental studies in the considered laboratory are given in Table 2 and Table 3 accordingly for the morning and evening hours.

Table 2

DC row1	DC row2	DCav
4.11	1.51	2.81
3.67	1.27	2.47
5.75	1.40	3.58
4.94	1.18	3.06
Average value of the DC in the morning		2.99

Table 3

DC row1	DC row2	DCav
6.46	2.65	4.56
5.2	1.48	3.34
6.77	1.69	4.23
7.65	2.07	4.86
Average value of the DC in the evening		4.26

In order to compare the results obtained by the experiment to those obtained by the empirical expressions, the average value of the DC for all the points considered is taken for the morning and evening values of this parameter. As a result a single value of the DC is obtained, which is compared to the calculation results. Summary of the obtained values of DF using the different methods of evaluation of this indicator are summarized in Table 4.

Table 4

Values of the DF, obtained by means of different evaluation methods					
IES	BRE	Sumpner	EN 15193	Experiment	Dialux
3.60	4.63	3.47	4.38	3.63	4.31

Except experimental and calculation results, the value of DF is obtained by means of simulation of the natural light in Dialux [10]. The results, obtained are shown on Fig. 3

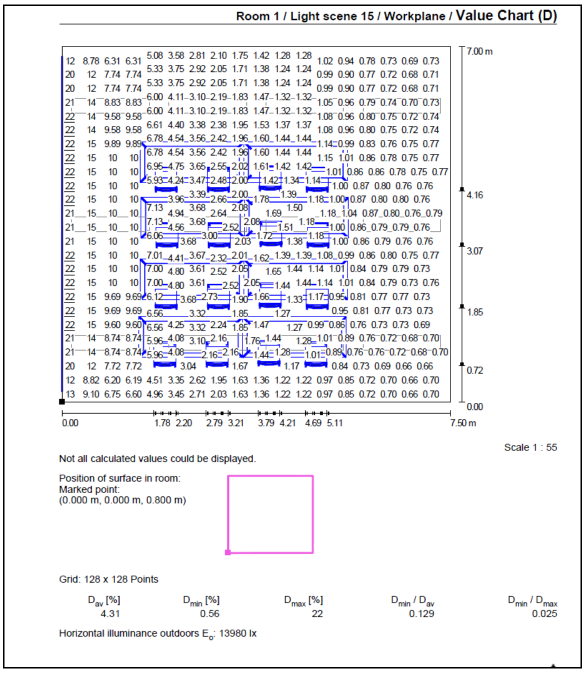

Figure 3 *Results for the DF, obtained by Dlalux*

Conclusions

From the research made, it is obvious that closest to the experimental value are the results for the DF, obtained by means of IES and Sumpner methodologies. Despite this, however, all the calculation methods for the assessment of the rate of natural lighting in buildings are approximate and lead to some uncertainty, since it does not take into account the change of the atmospheric conditions in the different seasons, and the geographical orientation of the premises.

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