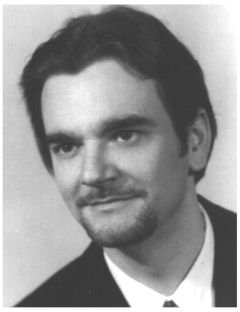
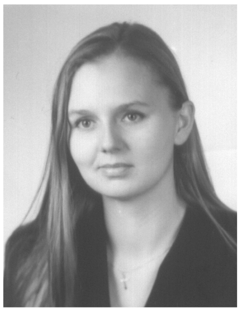
GUIDELINES ON SUPPLEMENTARY LIGHTING RELATED TO THE TOTAL DAYLIGHT INDEX (TDI)

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Summary

Spatial daylight illuminance in building interiors is a function of daylight transmission, distribution and utilisation. All the factors mentioned above, decide on the amount of daylight entering from the outside and migrating to a given point in the room. This amount is determined by glazing/opaque ratio, glazing properties, interior shapes, finishing materials, etc. Proposed indicator – Total Daylight Index (TDI) is a function of transmission (T) and distribution (D) and changes between 0 and 1 depending on the different distance from the daylight source (e.g. window). The values of TDI determined the required level of illuminance (lx) at working plane in a distance (m) from the light source.

The main purpose of our study was to developed TDI methodology and find the amount of supplementary light essential for providing required level of illuminance for assumed TDI value. The analyses were done using advanced numerical techniques based on Backward Ray Tracing Method, for Overcast sky conditions. Obtained results show the energy efficient of supporting system and electric power of luminaries. On the other hand the final results will be guidelines for designers, who would like to estimate the visual comfort and energy efficient aspects of the building.

Keywords: Supplementary lighting, visual comfort, energy efficiency, daylight utilisation

1 Introduction

Daylight utilization in a sustainable building design is a crucial point, not only from the point of view of indoor environment quality but energy as well. Present recommendations mainly depend on a building type, function, occupation etc. They are based on visual criteria and three of the main parameters are [1, 2]: daylight factor, horizontal illuminance on the working plane, luminance ratio (contrast).

A great amount of daylight coming into the buildings is determined mainly by architectural ideas and vision. Usually, the first part of a design process is oriented towards esthetic requirements and deprived of technical analysis. It is almost impossible to apply advanced engineering techniques at such an early design level. Any simulation tools based on **split-flux** method, **radiosity** or **ray tracing** methods required detailed descriptions of the building (geometry, construction and materials) and the system (shading, light leading and transport devices). Therefore, at this stage any technical adjustments using accurate methods are difficult to obtain, laborious and strongly approximated. The second part of the project is more often supported by advanced numerical techniques to estimate precisely the features of the project and apply final corrections. However, first estimation at the initial design step can often determine further characteristics of a building and its components. It must be done as precisely as possible but in a relatively easy way. The initial guidelines (at the conceptual design phase) should be formulated clearly, explicitly and comprehensively. They should be based on and determine only the main features of the building (e.g. geometry, material properties) taking into consideration the character of external environment, localization, obstructions etc. They should be functionally diverse according to the type of the building and its occupation.

A friendly, general and initial methodology for daylight utilization in buildings is proposed in the paper. It is based on the total amount of daylight getting to the working plane inside the rooms. Daylight illuminance inside the building is changeable and depends on external conditions (weather, time, season and urban development) and internal factors (surface properties – transmission and reflection characteristics, architectural design).

On the other the obtained results should give the quantitative information to the designers about possibly energy saving by daylight. Therefore, it is essential to developed TDI methodology for indicator representing additional, supplementary illuminance from artificial lighting.

2 Total Daylight Index (TDI)

Total Daylight Index (TDI) is the first step indicator for architects and engineers at the conceptual design phase to consciously create the buildings and building interiors at an early design stage. TDI is a dimensionless product of daylight transferring (T) and distribution (D) on the way from the sky to the point on the working plane and it ranges from 0 to 1. TDI should be individually estimated for one localization, standard climatic parameters (weather, time and season) but without any urban and architectural obstructions. Further particularities are realized by the correction factor (C) taking into account remaining external and internal conditions.

The methodology required only general information about the building, usually available at this leg. It is based on the concept of exterior envelope, building function and basic dimensions.

2.1 Transferring factor

First part of the information concerns the properties of exterior envelope. This characteristic is described by the daylight transferring factor (T). It is defined as an amount of daylight entering the building interior space to the amount of daylight falling on the building envelope. The T factor is a glazing daylight transmission. Boundary partial coefficient C_b (p.2.3) takes into account the glazing/opaque ratio (window area) and window position. For a single indoor space, bounded by *n* external, transparent daylighting openings it is estimated according to the equation (1):

$$T = \sum_{i=1}^{n} g_{\mathrm{i}} \times \frac{A_{\mathrm{ti}}}{A} \qquad (1)$$

g_{i} is the total daylight transmission of surface *i*
A_{ti} is the area of transparent surface *i*
A is the total area of external transparent surfaces bounding the analysed space
T factor changes from 0 to 1 and in extreme cases it can be:
T = 1 for a fully glazed external façade and daylight glazing transmission equals 1 (only in theory);
T = 0 for a fully opaque façade or daylight glazing transmission equals 0

2.2 Distribution factor

The second part of the information concerns the properties of interiors. This characteristic is described by the daylight distribution factor (D). It is defined as an amount of daylight coming from the window to the assumed working plane. On the other hand, the distribution factor also determines the weakness of the daylight inside the building space. The D factor is always described by the average reflectance of the surfaces in the room. For a single indoor space, bounded by *m* internal surfaces it is estimated according to the equation (2):

$$D = \sum_{i=1}^{m} S_i \times R_i \times \frac{A_{si}}{A_i} \qquad (2)$$

A_{si} is the area of surface *i* in the analysed space ;
A_i is the total area of the surface in the analysed indoor space;
R_i is the daylight reflection of surface *i* ;
S_i is the surface coefficient [3];
D ranges from 0 to 1 and in extreme cases it can be:
D = 1 for ideally reflected surfaces and no other internal obstructions (only in theory);
D = 0 for no reflected surfaces (100 % of daylight is absorbed).

2.3 Correction factor

The values of Total Daylight Index calculated according to the procedure presented in paragraph 3 are valid only in some particular cases. Firstly, the daylight that reaches the building is not disturbed by the elements of external environment. It means that the analysed building and the glazing elements are fully exposed. The second assumption is that the daylight spreads out symmetrically to the interior space (the window is placed centrally in the external surface). It means that the daylight is distributed symmetrically from the outdoors to the building space. Finally, the third limitation concerns building interiors. It is assumed that the daylight is reflected in the same way by the floor, the ceiling and the walls except the wall opposite the window. This assumption does not delimit the depth of the room, but in reality the daylight reflected on the surface at the rear of the room changes the illuminance level in the deepest areas. Also, individual surfaces have different properties, reflect dissimilar amount of daylight inside the building space.

The correction factor C should be used in order to generalize the proposed methodology. It is a product of three partial coefficients: exterior (C_{e}), interior (C_{i}) and boundary (C_{b}) factors.

$$C = C_e \times C_b \times C_i \tag{3}$$

The exterior correction factor C_e includes the mitigation of the daylight caused by urban development, building geometry and any other obstructions around the transparent parts at building envelopes. The boundary correction factor C_b takes into account the size and the position of the window in relation to the reference case, when the façade is fully glazed and placed centrally in the external surface. Any vertical movement of the sill above the level of the working plane changes the daylight distribution inside the building. The third component of the correction factor (C_i) concerns the influence of the light reflected by the opposite (to the window) wall. It can cause various intensity of light transfer through reflectance by the ceiling, the walls or the floor. As it is well known, the amount of light reflected by the ceiling is crucial for the illuminance at the upper side of the horizontal plane.

The correction factor ranges from 0 to 1 and:

C = 1 is for ideal conditions: no external obstructions, centrally fixed window and identical properties of all internal surfaces;

C = 0 when one of the factors (outside, inside or at boundary layer) presents total barrier for daylight transportation (only in theory).

2.4 Supplementary lighting

Proposed methodology bases on two parameters described above: transferring (*T*) and distribution (*D*). Additional two, devoted to supplementary artificial lighting: power input (*P*) and general efficiency (η) was also considered. The final form of TDI is presented below:

$$TDI_y^x\left(P,\eta\right) \tag{4}$$

x is distance from light source in meters;
y is required level of illuminance in lx;
P is the power input of supplementary light in watts;
η is the general efficiency of supplementary light;

The utilization of artificial light is determined by general efficiency η but also depends on distribution factor *D*. The relation between illuminance at the level of working plane and distribution factor is presented in **Fig. 1**. The assumed power output was 150 W and general efficiency 100 %. The presented results show the greatest impact of surface properties on spatial artificial lighting distribution. Finally, the daylight utilisation depends on both: transferring and distribution factors [3] while the amount of supplementary light depends only on distribution factor.

Fig. 2 represents illuminance distribution for ideally reflective surfaces (D = 100 %) and luminairies located at each meter from the daylight source (at 0 m). Decreasing values of supplementary lighting intensity close to the daylighting surface results due to low reflectance of the glass. In the middle of the room (at about 4 m) the artificial light utilisation is determined by two walls and ceiling, while in the end of the room (at 8 m) there is additional third wall opposite to the window face. In **Fig. 3** the illuminance level achieved from luminaires with different power input is presented.

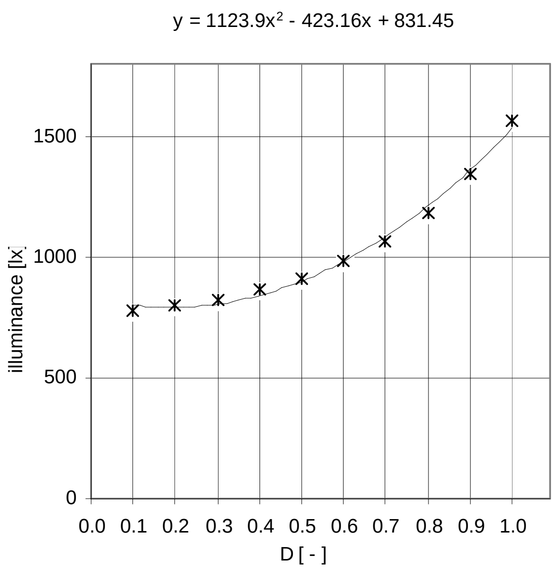

Fig. 1 Relation between illuminance and distribution coefficient D for 150 W luminaries

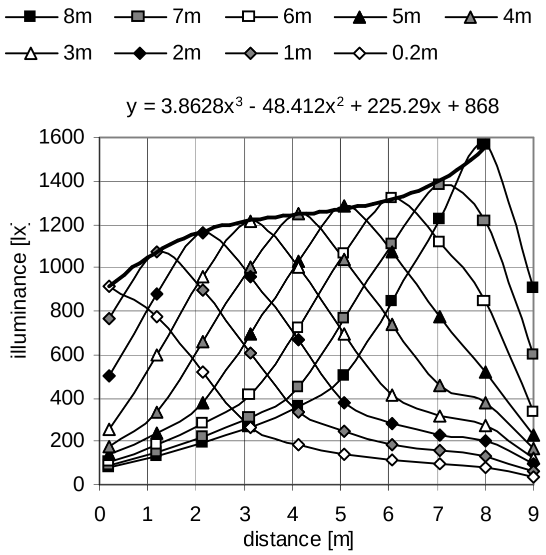

Fig. 2 Illuminance distribution of supplementary light for 100 % of efficiency and D = 1,0

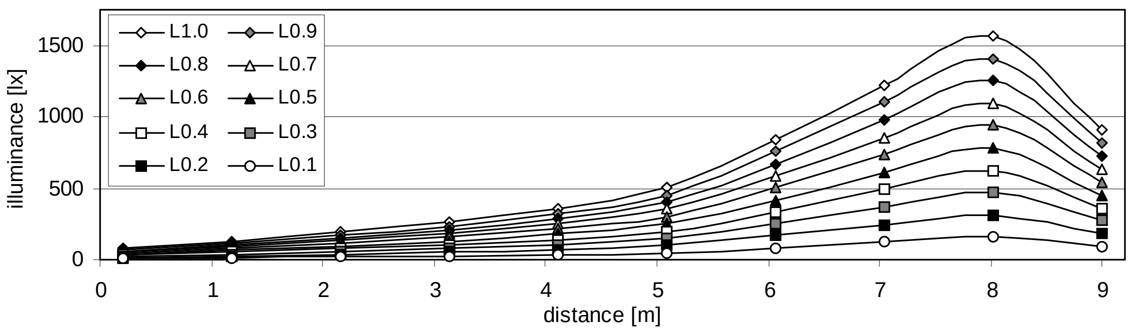

Fig. 3 Illuminance distribution at 8th meter for selected efficiency of luminaires, from 10 to 100 %.

Power input for supplementary lighting with 100% efficiency at the depth of 8 m.

Required power input [W]		**Distribution *D* [-]**									
		1,0	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1
Supplementary lighting [lx]	1000	105	120	135	150	165	165	180	180	195	195
	900	90	105	120	135	150	150	165	165	180	180
	800	90	90	105	120	135	135	150	150	150	165
	700	75	90	90	105	120	120	135	135	135	135
	600	60	75	90	90	105	105	105	120	120	120
	500	60	60	75	75	90	90	90	105	105	105
	400	45	45	60	60	75	75	75	75	75	90
	300	30	45	45	45	60	60	60	60	60	60
	200	30	30	30	30	45	45	45	45	45	45
	100	15	15	15	30	30	30	30	30	30	30

The exemplar results were obtained for single luminair mounted at deepest part of the room (at 8 m from the window). Based on relations for luminaries located at different depth required power input was estimated due to distribution factor D (see **Tab. 1**). The power requirement is necessary to provide supplementary (to daylight) lighting illuminance. The whole procedure how to find the level of supplementary illuminance was presented in [3].

3 Conclusions

The required TDI index relates to the illuminance level inside the building was proposed and can be easily used as the first guideline during the architectural design process. The index give information about illuminance distribution due to construction solution and also energy saving by daylight can be easily determined.

The initial results show that the Transferring factor (the amount of daylight entering the building space) determined the daylight illuminance distribution in the whole room space. On the other hand Distribution factor (the amounts of light reflected and transfer to the surroundings) determines efficiency of supplementary, artificial lighting.

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