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Calculation methods and programs for daylighting and comparison of their use

Abstract. *Lighting status of an interior and effect of lighting on humans and their eyes does not depend solely on the amount of light, but also on other factors (spatial distribution of light, the dynamics of changes of lighting with time etc.). The design must maintain good lighting quality in case of sunny, cloudy and overcast sky, and also in case of direct illumination by the Solar. To maintain good lighting quality, sufficient lighting level does not suffice; it is also necessary to maintain good lighting quality. The article below presents a short analysis of evaluation of daylight lighting and related calculation programs, their possibilities and possible uses.*

Streszczenie. *Stan oświetlenia wnętrza jak również wpływ oświetlenia na cyłowieka i jego oczy nie zależy tylko od ilosci światła, ale także od innych czynników (przestrzenne rozłożenie światła, dynamika zmian oświetlenia wywołana upływem czasu, itd.) Projekt musi brać pod uwagę konieczność dobrej jakości oświetlenia w przypadku wysokiej intensywności nasłonecznienia, ale także w sytuacjach mniejszego czy większego zachmurzenia, jak również bezpośredniego oświetlenia Solar. Dobra jakość oświetlenia to nie tylko dostateczny poziom oświetlena, ale konieczna jest także dbałość o dobrą jakość oświetlenia. Poniższy artykuł przedstawia krótką analizę oceny oświetlenia dziennego, związanych z nim programów obliczeniowych a także ich możliwości i zastosowań.* ***(Metody obliczeniowe i programy światła dziennego a także porównanie ich wykorzystania*****).**

Keywords: daylight, calculation programs and methods for daylight lighting.
Słowa kluczowe: oświetlenie światłem dziennym, programy obliczeniowe, metody oświetlenia światłem dziennym.

Introduction

Lighting status of an interior and effect of lighting on humans and their eyes does not depend solely on the amount of light, but also on other factors (spatial distribution of light, the dynamics of changes of lighting with time etc.). The design must maintain good lighting quality in case of sunny, cloudy and overcast sky, and also in case of direct illumination by the Solar. To maintain good lighting quality, sufficient lighting level does not suffice; it is also necessary to maintain good lighting quality.

1. Evaluation of daylight lighting

1.1 Quantitative criterion

To evaluate illuminance from quality point of view, daylight factors D [%] is used; it expresses the ratio of interior illuminance E [lx] at the point at working plane relative to illuminance E_H [lx] outdoors from the standard unobstructed sky.

(1) $$D = \frac{E}{E_H} \cdot 100\,[\%]$$

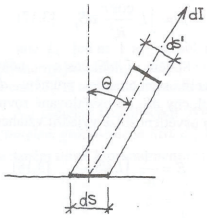


Fig.1 Illuminance defined

Resulting daylight factor composes of the sky component, the externally reflected component from exterior obstacle, and the internally reflected component from interior surfaces.

(2) $$D = D_s + D_e + D_i$$

Sizing of windows must allow sufficient lighting of the room. Windows in one perimeter wall sometimes does no suffice; use of lighting from multiple directions may improve lighting of the room; sometimes, roof lighting may be added as long as the position of room within the building allows it. It is necessary to assess the quality of lighting, e.g. in some cases, lighting from opposite windows may actually worsen the situation.

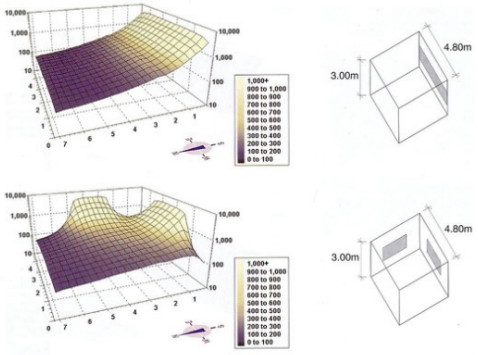


Fig.2 Daylight factor and its spatial distribution depending on window location. [4]

1.2 Qualitative criteria

Qualitative criteria express the quality of interior lighting; they include uniformity, flux distribution, brightness distribution in one's field of vision, prevention of dazzle, and color finish of interior surfaces. Provision of sufficient light intensity does not guarantee visual comfort at all.

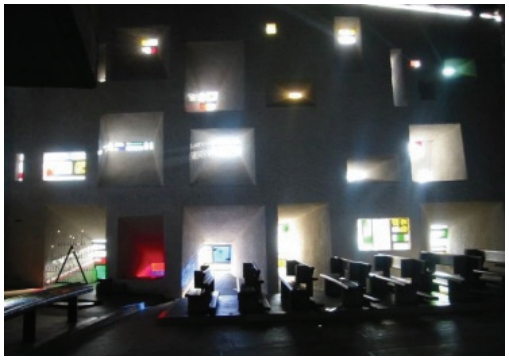


Fig.3 Le Corbusier – RONCHAMPS chapelle

1.2.1 Uniformity of daylight lighting

This is the ratio of minimum and maximum coefficient of daylight illuminance at level working area in interior or its functional part.

1.2.2 Dazzle

One of visual disturbances, where differences in brightness exceed the adaptability of human eye, namely its contrast sensitivity. Dazzle is the more extensive the closer to field of vision's axis it occurs, and also when it impacts the eye from below, e.g. a reflection from desk or floor surface. The source of dazzle must not be in the field of vision, i.e. no shiny objects nor windows/skylights may be installed in the field of vision, depending on user's work position/orientation. Dazzle can be prevented by suitable positioning of windows/skylight, or by suitable light intensity controls (blinds, sunbreakers, seasonal painting).

1.2.3 Brightness distribution

Relates to phototropic reflex, dazzle must be prevented at all times.

Between observed object and its background:

a)Between observed object and distant dark areas

b)Between observed object and distant light areas

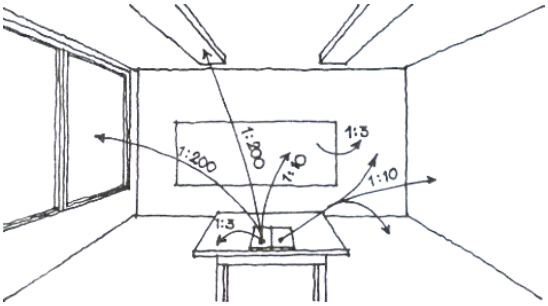


Fig.4 Brightness distribution in an interior [1]

1.2.4 Color perception

Humans relate colors in space with certain functions of their living and work environment. Colors influence psychical condition. Emotion-oriented persons are more sensitive to colors, while the mind-oriented are less sensitive. Colors provoke feelings and emotions commonly described as the joy of color sight. Color has three functions within spatial perception:

1. Distance perception (perception of length and depth) .
2. Temperature perception (perception of different temperatures)
3. Overall spatial impression (the effect of color on general space perception)

Fig.4 Seasonal depression syndrome

1.2.5 Seasonal depression syndrome

Seasonal depression syndrome (SAD - Seasonal Affective Disorder) may develop in sensitive persons who suffer from insufficient light. Insufficient lighting of working and living quarters may increase fatigue and also lead to loss of work motivation and absenteerism [2]. Approx 5% of population are affected in this way. Statistic data show that 50-80% of patients can be successfully treated with strong light.

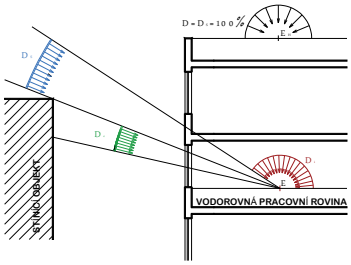
2. Calculation

2.1 Calculation methods

To calculate daylight factor, several methods may be used, which differ in suitability and complexity; some are more suitable than other for specific conditions, e.g. design and evaluation or design of various lighting systems, under different conditions of exterior shading, also depending on dimensions and shapes of the room being assessed, etc. All methods share the basic principle – determination of daylight illuminance factor as a sum of three components:

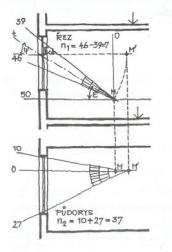
Sky component, reflected component from exterior obstacle, and reflected component from interior surfaces.

Calculation of sky and exterior reflected components [1]



Daniljuk method,

Sky component (SC)

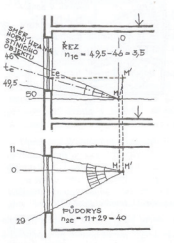


$$D_s = D_{sr} \cdot q \cdot \tau_{0,\psi} \quad (3)$$

$$D_{sr} = \frac{n_1 \cdot n_2}{100} \quad (4)$$

$$\tau_{0\psi} = \tau_{S,\psi} \cdot \tau_k \cdot \tau_z \cdot \tau_b \quad (5)$$

Externally reflected component (ERC)



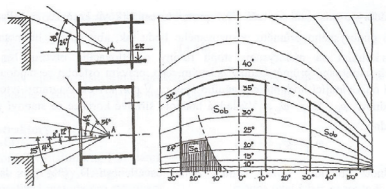
$$D_e = D_{er} \cdot k \cdot \tau_{0,\text{nor}} \quad (6)$$

$$D_{er} = \frac{n_{1e} \cdot n_{2e}}{100} \quad (7)$$

$$k = \frac{L_e}{L_s} \quad (8)$$

Waldram method

Sky + externally reflected component (ERC)



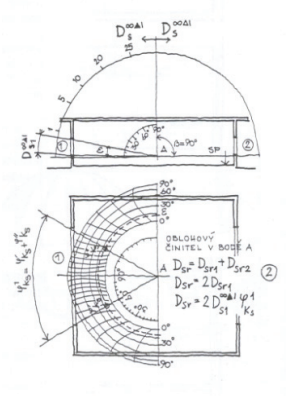
$$D_s = \frac{S_s}{S_o} \cdot \tau_{0,nor} \quad (9)$$

$$D_{we} = \frac{S_e}{S_o} \cdot k \cdot \tau_{0,nor} \quad (10)$$

$$\tau_{0,nor} = \tau_{s,nor} \cdot \tau_k \cdot \tau_z \quad (11)$$

Protractors

BRS, England, 1946, and Kittler invented an improvement for various inclinations of windows. [1,4]



(12) $$D_s = D_S^{\infty \Delta I} \varphi_{k_s} \cdot \tau_{0,\mathrm{nor}}$$

2.2 Calculation programs

Calculation programs are used worldwide to assess the quality and quantity of daylight illumination. Simpler ones calculate the daylight illuminance coefficient only (e.g. Wall, Wdls), while the more complex ones can also evaluate brightness contract (Ecotect, Radiance), or even temperature behaviour of an interior. In simple instances, graphs can be used even today, for quick assessment and to validate the output from calculation programs.

2.2.1 WAL (M. Pelech)

User-friendly and intuitive DOS application for calculation of daylight illuminance coefficient in interiors. Evaluation of points, areas, and spaces is possible. This program, however, does not work with skylights and inclined windows. Working with coordinates may be lengthy when bigger complexes are being evaluated. This program uses Waldram method combined with BRS.

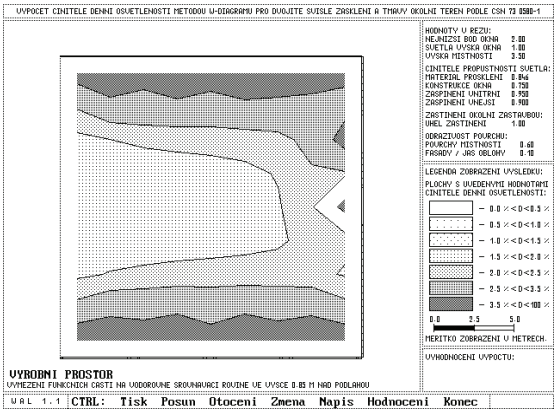


Fig. 11 WAL

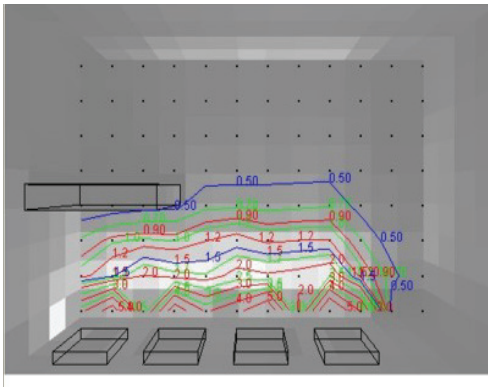


Fig. 12 Wdls , sample output

2.2.2 Wdls (P. STANĚK)

Intuitive Windows application, CAD compatible, which speeds up data entry and also calculation speed. Evaluation of points and areas is possible. However, the room cannot be turned, which sometimes complicates data entry. Working with skylights and inclined windows is a great advantage of this program. The algorithm used for calculation has not been published.

2.2.3 Eurodial

Very simple program for preliminary evaluation during design of building with relation to exterior lighting, artificial lighting, and proposal of NWSE orientation for the purpose of heating technology design. It provides first impression of thermal characteristics of a room. (E.g. the number of days when AC will have to be switched on, or blinds activated, or a ledge over a window installed because of excess Solar irradiation).

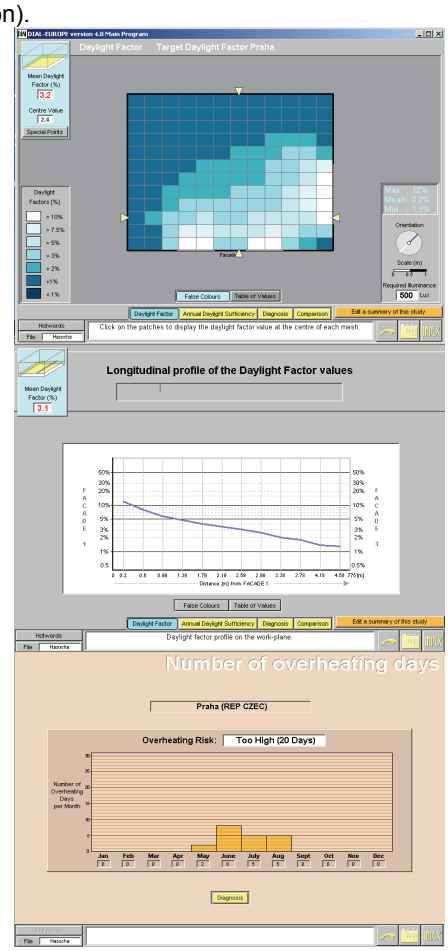


Fig. 13 Eurodial, sample output

2.2.4 Radiance (Ecotect-Dr. A. J. Marsh, IES)

A program simulating not only lighting situation, but also thermal-technical. Radiance method can be categorized as a generalized raytracing method. This method takes all areas as ideal diffusion primary or secondary light sources or a combination thereof. Advantages of his method include simple implementation of visualization and calculation algorithm, as the surface illuminance is being calculated regardless of the direction of viewing of the scene being visualized. When changing this direction, there is no need to recalculate (on the contrary to classical raytracing), which improves the performance tremendously, especially when animating walk-throughs in architectonic CAD etc. This program evaluates daylight illuminance and also brighness contrast in an interior and when combined with IES, it is possible to evaluate thermal behaviour as well, and ECOTECT program allows to simulate solar irradiance and to perform acoustical calculations.

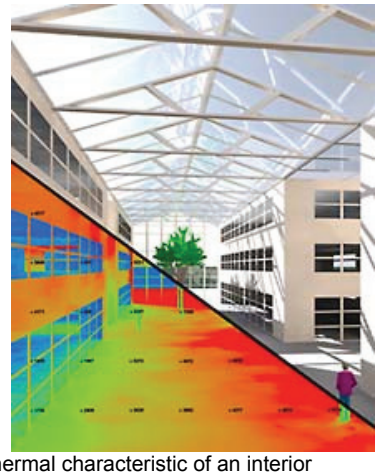


Fig. 14 IES thermal characteristic of an interior

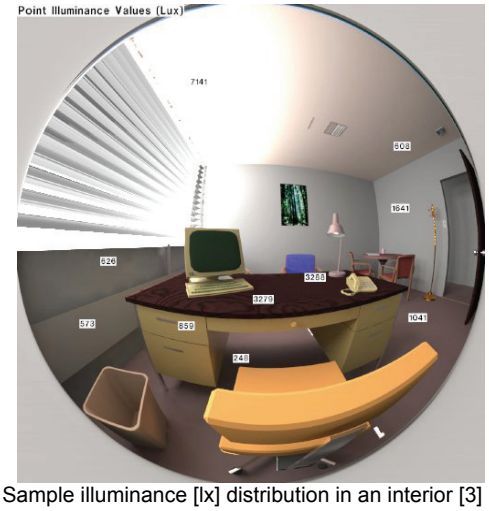


Fig. 15 Sample illuminance [lx] distribution in an interior [3]

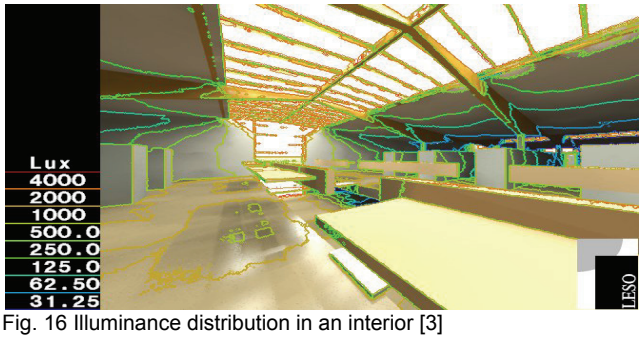
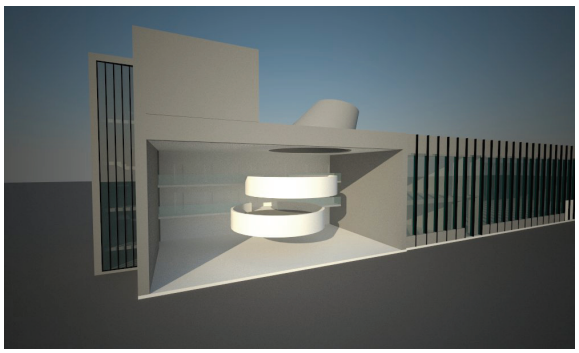
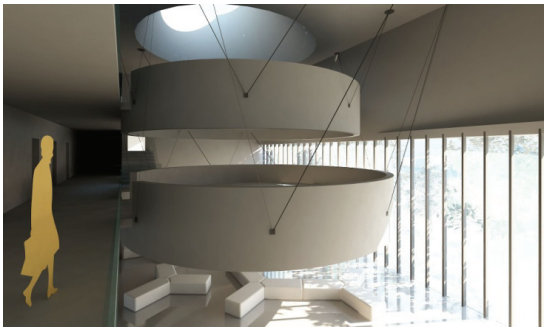


Fig. 16 Illuminance distribution in an interior [3]

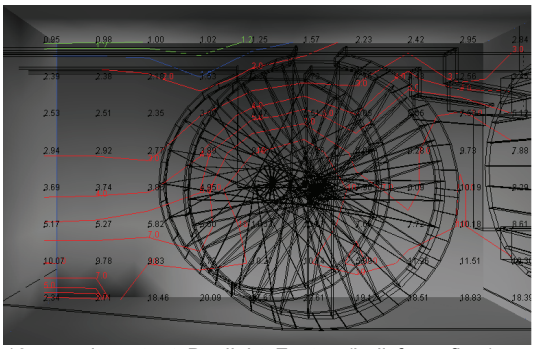
The interior depicted below has special lighting system, including glazed façade and inclined lighting tube with "pills", which is designed and installed to allow early morning and morning sunlight, while preventing excess thermal load at the noon.



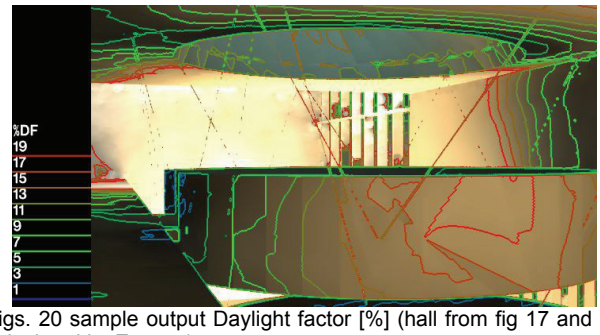
Figs. 17 Design of hall and meeting area [5]



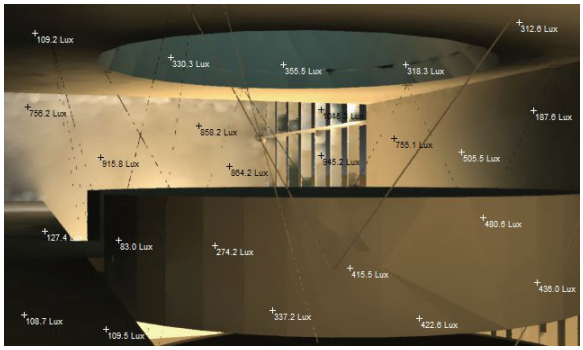
Figs. 18 Design of hall and meeting area [5]



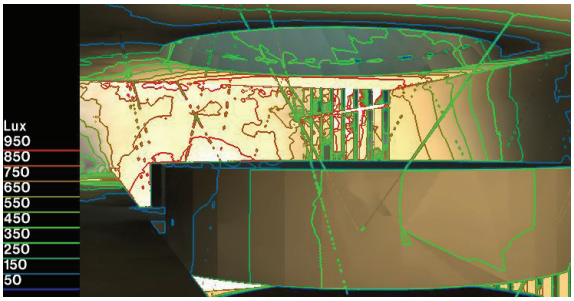
Figs. 19 sample output Daylight Factor (hall from fig 17 and 18 calculated by Wdls)



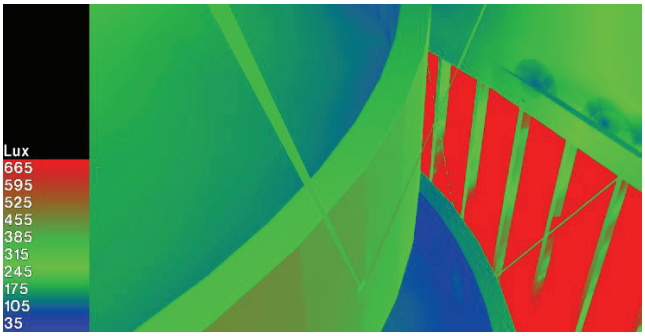
Figs. 20 sample output Daylight factor [%] (hall from fig 17 and 18 calculated by Ecotect)



Figs. 21 sample output Illuminance image [lx] (hall from fig 17 and 18 calculated by Ecotect)



Figs. 22 sample output Illuminance image[lx] (hall from fig 17 and 18 calculated by Ecotect)



Figs. 22 sample output Illuminance [lx] (hall from fig 17 and 18 calculated by Ecotect)

Conclusion

Daylight may be utilized in many different ways - architects and light technicians must ensure that resulting light effects are suitable from quality and quantity point of view. To assess this, we may use calculation programs. Different methods of light reflection or directing of sunlight should be used to solve the needs for lighting of complex interiors, even if the situation and resulting solution may seem complicated.

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