Revista Română de Inginerie Civilă, Volumul 6 (2015), Numărul 1 © Matrix Rom

Daylight in retrofiting office building design*

[1]Alexandru Mircea Iatan–PhD
[2]Angel Madalin Dogeanu–PhD Student

[1]Technical University of Civil Engineering of Bucharest, Faculty of Building Services, Romania
e-mail: alex_iatan@yahoo.fr
[2]Technical University of Civil Engineering of Bucharest, Faculty of Building Services, Romania
e-mail: angeld_ro@yahoo.com

Abstract*:* *Understanding the specifics of sustainable building and determining effective sustainable practices can be confusing. Daylighting analysis is an important component towards creating accurate simulations for sustainable design and visual health. Daylight has been utilized as a design element in buildings throughout history. One of the main reasons for using daylight in recent years is its benefit in reducing energy consumption through its use as a main or secondary illumination source in order to replace the use of electrical lighting. Daylight not only replaces artificial lighting, reducing lighting energy use, but also influences both heating and cooling loads. Planning for daylight therefore involves integrating the perspectives and requirements of various specialties and professionals. Daylighting design starts with the selection of a building site and continues as long as the building is occupied.*

This paper presents a numerical method based on Dialux to predict daylight factors and daylight uniformity factor into a retrofit office building in order to comply green and sustainability standards requirements.

Keywords: daylight factor, daylight uniformity ratio, green building, sustainability development.

1. Introduction

For centuries, daylight was the only efficient source of light available. Architects ware dominated by the goal of creating openings large enough to distribute daylight to building interiors. Efficient artificial light sources and fully glazed facades have liberated designers from these constraints of the past. Advanced daylighting systems and the new control systems are another step forward in providing daylight in an user-friendly, energy-efficient manner. These systems need to be integrated into a building's overall architectural strategy and incorporated into the project from the early design stage. The design considerations will be associated with enhancing a building's daylight utilization while achieving maximum energy efficiency anduser acceptance.[1]. The energy efficiency and sustainability become a common subject these days increasing the important issues in the field of architecture. Daylighting is recognized as the first step in reducing the energy consumption. A coherent design is reducing the amount of electrical lighting in a building. In addition to reducing the

---

* Lucrare inclusă în programul conferinţei EENVIRO 2014

carbon footprint of buildings, daylighting is known to have positive effects on human health and productivity. All energy standards and green building rating systems have strongly recommended that designers incorporate daylighting strategies into building design. However, this recommendation is all too frequently ignored due to the complexity of daylighting design and to concerns of the potential for thermal and visual discomfort caused by excessive sunlight penetrations and glare. [2]

2. The concept of daylight coefficients

The concept of daylight coefficients, originally proposed by Tregenza and Waters (1983) [3], is to theoretically divide the celestial hemisphere into disjoint sky segments, and to calculate the contribution of each sky segment to the total illuminance at various sensor points in a building,
based on each sensor's position within a given environment and orientation.[4]
Although the sky is changing every minute of a day, typically average sky conditions are used for daylighting calculations. Different models of virtual skies have been developed by the CIE. CIE has mathematically developed 15 different sky conditions, two of which are shown in Figure 1[5],

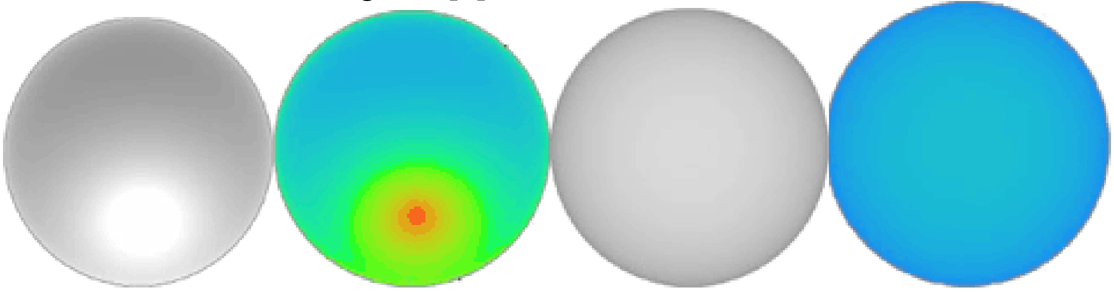


Figure1. CIE sky conditions [6].

where CIE Overcast Sky - completely cloudy sky (100% covered), represent the most widely used sky model for daylight factor calculation and CIE Clear Sky is defined by having less than 30% of clouds covering the sky or no clouds, being useful when visual glare and thermal discomfort studies are performed. [5]

In the past because the computational resources were limited, the luminance of the entire overcast sky was taken as uniform. This type of sky is termed as uniform sky and under this condition the illuminance at a point on a horizontal surface due to an unobstructed hemisphere of overcast sky can be given by:

$$E = L \times \pi \text{ (lux)} \qquad (1)$$

Where

L represent the sky luminance in Cd/m^2.

Nowadays, when the standardized CIE sky was widely adopted and implemented in the simulation software, the diffuse light from a completely overcast sky is calculated when ground is free of snow. The luminance distribution of the CIE sky is not uniform. The relative luminance L_q depends on the angle θ of elevation q measured with respect to the horizon, and is given by:

$$L_q = L_z \frac{1+2\sin\theta}{3}, \qquad (2)$$

Where

L_z represent the sky luminance at the zenith.

This equation shows that :

(a) Zenith ($q = 90^0$) is the brightest region,

(b) The luminance decreases to 1/3 of that of the zenith towards the horizon

(c) The luminance is independent of the position of the sun, and therefore the orientation of the windows has no effect on the illumination of the room.

There are two ways to handle daylight quantitatively:

(a) by using luminous quantities (flux, illuminance), by a set of outdoor conditions and calculating the resulting interior illumiances;

(b) by using relative values (the daylight factor) which compare indoor to outdoor illuminance.This factor is constant under widely varying outdoor lighting conditions for a given position.

The daylight factor is defined as :

$$DF = \frac{E_i}{E_0} \times 100 \ \ (\%) \qquad (3)$$

where:

E_i = illumiance due to daylight at a point on the indoors working plane,

E_0 = simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.

In figure 2 we presented all possible paths along which light can reach a point inside a room through glazed windows. [4] As following:

(a) light from the sky visible at the point considered, this component is named as the sky component (SC),

(b) light that is reflected from opposing exterior surfaces and then reached the point, this component is known as the externally reflected component (ERC),

(c) light entering through the window but reaching the point after it reflect from internal surfaces, this component is known as the internally reflected component (IRC).

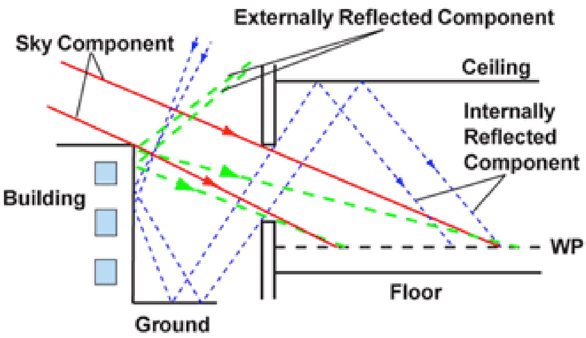


Figure 2. Components of the Daylight Factor. [4]

The sum of the three components gives the daylight factor:

$$DF = SC + ERC + IRC \qquad (4)$$

3. Daylight Factors Target

In temperate climates, choosing the value for the daylight factor can have a crucial impact on the energy efficiency of a building. This is mainly for two reasons. First of all the impact is because of the low thermal insulation of glazing that carries a heavy penalty in heating energy consumption matching the minimum of glazed area sufficient to provide adequate day lighting is an important target. Secondly, the short day lit hours of the winter mean that the transition to artificial lighting will occur during the working day and this transition point will be sensitive to the daylight factor and the light level required for functional purposes [7]. There are many methods for finding the components for a specific given point, though they are checking procedures rather than ones, which generate a daylighting design. In order to reach this goal an average daylight factor must be proposed as a design parameter. To determine the factor all three comoponents are calculated simultaneously based on window sizing, enabling daylighting to take a place in the overall design process. [8]Technical recommendations and Standards defining daylighting design parameters and minimum values have been drawn up independently for each country. For example, British Standards settle minimum average daylight factors related to different activities and to supplementary electric lighting as presented in table 1. [9]

Table 1.

Daylighting recommendations in some workplaces. [9]

Activity/ Spaces	Type of daylighting(*)	DF (%)
Teaching	A B	5 2
General offices	A B	5 2
Laboratories	A B	5 2
Drawing offices	A B	5 1 (in supplemented area)

(*) A - Full daylighting / B - Supplemented daylighting

There are also recommendations for checking daylight uniformity in table 2 [10]

Table 2.

Recommendation on daylight uniformity. [10]

BS CP 3/64	$DF_{\max} / DF_{\min} < 2$
BS 8206/92	- no significant part of the working planes shall lie beyond the no-sky line; -in an interior with one or more windows on one wall only room depth shall not exceed window height and width; - in an interior with rooflights, the spacing/height ratio should not be too great; - in an interior with rooflights, ceiling and floor reflectance should be high enough

In practice is recommended to use the following expression for estimating average daylight factor [11],[12]:

$$DF_m = \frac{A_w \cdot t \cdot \theta}{A_{tot}(1 - r_m^2)}, \qquad (5)$$

where:

DF_m=average Daylight Factor,

A_w=total glazed area of windows,

t=glass transmittance,

θ=angle of visible sky,

A_{tot}=total area of all the room surfaces,

r_m=area-weighted average reflectance of room surfaces.

It is also inadequate to use standard average daylight factor because it only provide recommended values that can be used as a partial checking of daylighting quantitative aspects and does not provide natural light distribution, luminance ratio and view. The average daylight factor is a single, broad measure of daylightfor the whole room and does not provide any detailed information about distribution and punctual value in different points.[8]

The average daylight factor has other limitations such as not being able to predict glare and luminance ratio and often it is necessary to make use of further daylight control elements to satisfy user visual comfort requirements.

During the design stage it is necessary to take into consideration the different performances of a daylighting system with respect to light distribution and uniformity ratio as they play an important role in architectural daylighting, in this case we are talking in particular case of an office buildings.

Based on a relationship between source and background luminance, the degree of glare caused by any individual light source can be expressed as a glare constant [13]:

$$G_i = k\frac{L_s^{1.6}\Omega^{0.8}}{L_b + 0.07\omega^{0.5}L_w}, \qquad (6)$$

where:

G_i=glare coefficient for each of the component parts of the view through the window (sky, obstruction, ground);,

L_s=luminance in Cd/m^2 of the patch of visible sky, of the obstructions and of the ground seen through the window,

Ω=solid angle subtended by the source, with weighting factors for different areas de pending on their direction with respect to the occupant line of sight,

L_b=average luminance in Cd/m^2 of the interior surfaces of the room which contribute to the visual field of an occupant of the room,

ω=total solid angle in steradians subtended by the window,

L_w=average luminance of the window weighted according to the relative areas of sky obstructions and ground,

k=constant depending on measurement units and source.

The glare constants for all sources are then summed to determine the Daylight Glare Index [13]:

$$DGI = 10\log\sum_{i=1}^{n} G_i \; . \qquad (7)$$

The glare is a comfort sensation, the DGI is based on how groups of people have responded to various levels of brightness, the DGI is influenced by daylight and artificial light, with the glare sensation scored as each individual perceived it. Being a subject test there was created an satisfaction scale at different glare index obtained in different conditions. The scale is having intervals ranging from “just imperceptible” to “just intolerable”. Daylight glare criteria have been defined and compared to those ones for classical electric lighting sources in table 3. [8],[14]

Table 3.
Comparison between artificial source glare indices (IES GI), daylight glare index (DGI) and glare criteria.

MEAN SUBJECTIVE ASSESSMENT OF GLARE	IES GI	DGI
just imperceptible	10 13	16 18
just acceptable	16 19	20 22
just uncomfortable	22 25	24 26
just intolerable	28	28

All the above considerations require for an numerical study showing lighting performances of different rooms based on window options in order to evaluate the relationship between window shape, position and light distribution [8]. When sizing windows should be take into account qualitative aspects such as view out.

4. The case study

The building used in this study is a single floor building built to mid 1980. The building hasn’t been finalized, remaining at foundation stage for more then 30 years. Foundations surface is 1800 square meters. On those foundations a new building will be designed as open space business center. The plan view with the new space layout is represented in figure 3.

The virtual room was 64 meters long, 45 meters wide, and 3.2 meters high. On the south orientation the walls was entirely glass with an 89% transmittance value. Light meters were added into work plane area situated at 0.75 meters above floor. The properties of all the elements are given here: ceiling: 80% reflectance walls: 50% reflectance, floor: 20% reflectance, glass wall: 89% transmittance. This virtual space has been tested under CIE overcast skies. From the base case model described above, a 3D model has to be created.

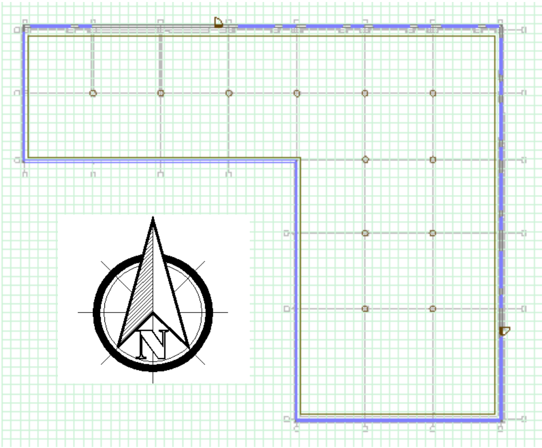


Figure 3. Building new layout plan view.

The computer simulation need a 3D drawing reproducing the material characteristics of which the model was realized so that the model drawing was made with the DIALux software assigning to each geometrical component the properties used in the real model is presented in Figure 4.

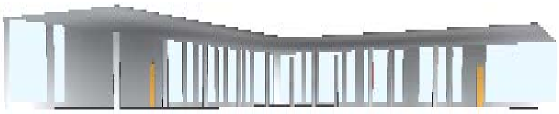


Figure 4. Building 3D model view.

The daylight calculation capabilities within DIALux make use of German standard DIN 5043 and CIE Publication 110. Geometric input is limited to certain shapes. Sky choices are somewhat limited but acceptable for diverse ranges of weather conditions. There is an external radiosity and ray-tracing model, POV-Ray (Persistence of Vision 2010).

The geometry of the model and the finishing touches are very simple to have a base model avoiding any influence on the analysis of particular material or geometrical element and deferring the study of single specific case to a separate evaluation. The room building parameters analyzed were the geometry, its glazing system, the reflectance of the room walls and floor, the dimensions of the adjoining spaces and the reflectance of the materials that finish the interior spaces. The study was based on preliminary design hypothesis such as a simple finishing touches, as mentioned above.

5. Simulation results

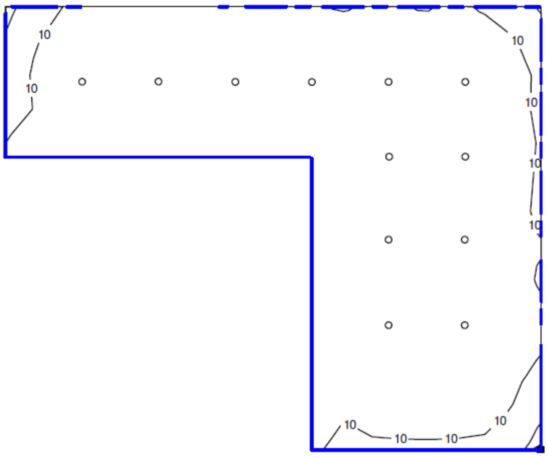


Figure 5. Daylight workplaneisolines.

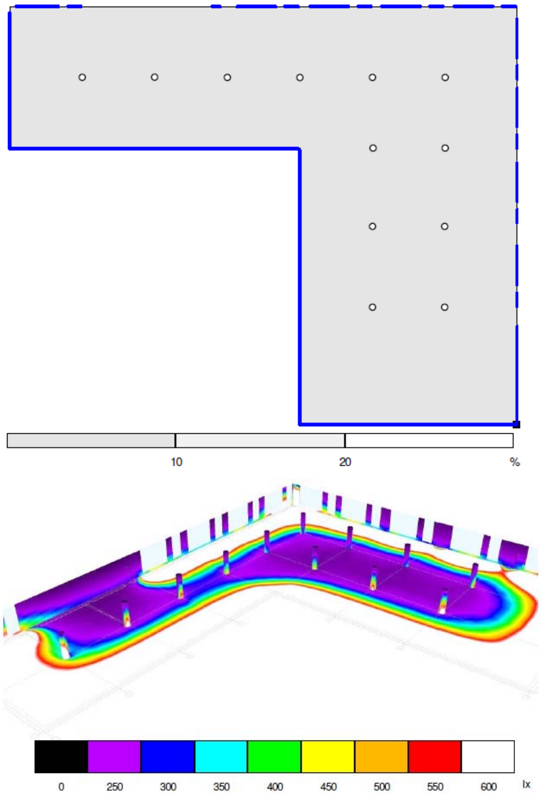
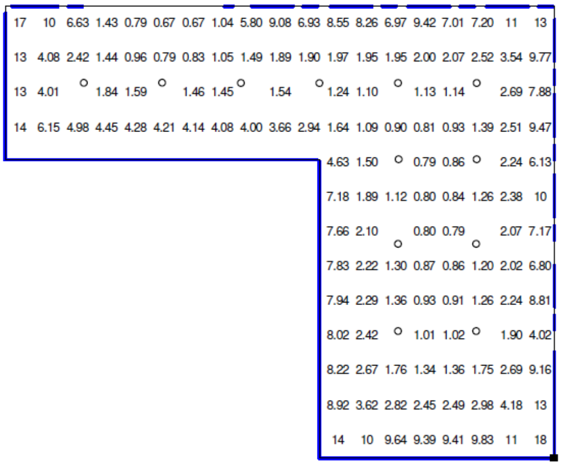


Figure 6. Daylight workplanegreyscale(a), 3D rendering colors (b).



17	10	6.63	1.43	0.79	0.67	0.67	1.04	5.80	9.08	6.93	8.55	8.26	6.97	9.42	7.01	7.20	11	13
13	4.08	2.42	1.44	0.96	0.79	0.83	1.05	1.49	1.89	1.90	1.97	1.95	1.95	2.00	2.07	2.52	3.54	9.77
13	4.01		1.84	1.59		1.46	1.45		1.54		1.24	1.10		1.13	1.14		2.69	7.88
14	6.15	4.98	4.45	4.28	4.21	4.14	4.08	4.00	3.66	2.94	1.64	1.09	0.90	0.81	0.93	1.39	2.51	9.47
											4.63	1.50		0.79	0.86		2.24	6.13
											7.18	1.89	1.12	0.80	0.84	1.26	2.38	10
											7.66	2.10		0.80	0.79		2.07	7.17
											7.83	2.22	1.30	0.87	0.86	1.20	2.02	6.80
											7.94	2.29	1.36	0.93	0.91	1.26	2.24	8.81
											8.02	2.42		1.01	1.02		1.90	4.02
											8.22	2.67	1.76	1.34	1.36	1.75	2.69	9.16
											8.92	3.62	2.82	2.45	2.49	2.98	4.18	13
											14	10	9.64	9.39	9.41	9.83	11	18

Figure 7. Daylight workplane value chart.

The following parameters have been measured: illuminance outdoors, illuminance indoors on horizontal working plane, and luminance for glazing and adjacent room surfaces seen from a top point of view. A 19x13 points grid, 52m wide and 43m large, coincident with the working plane, has been used for carefully measuring indoor illuminance (figures 5, 6 and 7).

Figures 5, 6 and 7 show rendered images for the study case illuminance and luminance measurements for 2 hours interval between 11 AM and 13 PM at 21 march 2014 in overcast sky conditions. These images are exported from DIALux.

The window wall (south side) is facing the sun but the direct sunlight is not visible in these images since the sun is completely covered by clouds.

The numerical simulation shows that:

$DF_m[\%] = 4,95$, $DF_{\min}[\%] = 0,56$, $DF_{\max}[\%] = 32$, $DF_{\min} / DF_{\max} = 0.114$, $DF_{\max} / DF_{\min} = 0.017$

Simultaneously, in conformity to daylight factor formula, external illuminance, without direct solar radiation, has been measured in the horizontal plane seeing the sky dome:

$$E_0 = 13461 \text{ lx}.$$

Under the overcast sky, changing building orientations does not affect indoor illuminance levels. Changing time settings under overcast sky condition causes slightly different results but the difference is too small to be considered as an important design variable.

It is generally considered that the overcast sky provides the worst daylight condition; selection of more nuanced sky models will provide better designers better predictive simulations.

As can be seen in Figure 6b the lighting level in the adjacent windows area is so close to the corresponding “just intolerable” glare criteria, surpassing 700 lx in 80% of the corresponding area. It is obvious that to achieve a tolerable degree of glare criteria, additional measures are to be taken:

a) reducing windows area by limiting the windows height,
b) introduction of automatic shading elements,
c)changing the glass composition to decrease the degree of transparency
d) changing the glass composition to increase the reflectance.

Thus it follows that the attempt to use the maximum level given by daylight does not necessarily lead to an efficient energy solution, nor in terms of comfort.

Additional measures to be taken are chosen such so there is a balance between the use of day lighting luminance level and interior comfort (regarding energy efficiency of building facilities, with particular reference to HVAC systems and artificial lighting).

6. Conclusions

Today, a large number of buildings are refurbished because of:
a) a poor indoor environment,
b) high power level or energy consumption,
c) the need for a new floor layout.

Daylight design is an important component of building retrofitting components that affect the building performance. Most common retrofit measures are referring to the replacement of windows or of the whole facade.

Building refurbishment is an opportunity to redefine the functional concept in order to meet today's requirements.

Selection of the right glazing is of major importance for a building's daylighting strategy. The combined application of new glass and new daylighting systems, particularly those that provide solar shading, glare control, and the redirection of light, can increase daylightand decrease cooling loads.

Combining daylighting and artificial lighting systems through is a design option in retrofits as well as new construction.

The aim of this study has been to undertake a more comprehensive analysis of daylighting in interior spaces, and to verify the performances of daylighting systems with respect to the luminous environment.

An overall analysis of the luminous environmental quality and its effects on psychological and emotional aspects needs for a subjective survey.

7. References

[1] Daylight in Buildings, A report of IEA SHC Task 21/ ECBCS Annex 29, July 2000;

[2]Kensek K., Suk J.Y., "Daylight Factor (overcast sky) versus Daylight Availability (clear sky) in Computer-based Daylighting Simulations", Journal of Creative Sustainable Architecture & Built Environment, CSABE Vol. 1, November, 2011

[3] Tregenza, P., Waters, "Daylight coefficients. Lighting Research and Technology.", Vol. 15, No. 2, pp. 65 – 71. I. M. 1983;

[4] Bourgeois D, Reinhart CF, Ward G, "A Standard Daylight Coefficient Model for Dynamic Daylighting Simulations" Building Research & Information 36:1 pp. 68-82, 2008;

[5] Norvasuo, Markku,"The new CIE general sky standard: daylighting experiences and implications.", The European Council for an Energy Efficient Economy, 2002

[6] Sky Illuminance. Retrieved March14, 2010 from www.naturalfrequency.com/wiki/Sky_Illuminance

[7] Comfortable Low Energy Architecture, website,http://www.new-learn.info/packages/clear/index.html;

[8] C. Aghemo, A. Pellegrino," Indoor daylighting: assessment of the performances of different window options",Dipartimento di Energetica - Politecnico di Torino, Torino, Italy, 2010;

[9] BS DD73:Basic data for the design of buildings: Daylight, (British Standards Institution), 1982;

[10] Torricelli M.C., Sala M., Secchi S., "Daylight - La luce del giorno. Tecnologie e strumenti per la progettazione", AlineaEditrice, Firenze, 1995;

[11] CIBSE (The Chartered Institution of Building Services Engineers), "Code for interior lighting", 1994;

[12] CIBSE (The Chartered Institution of Building ServicesEngineers), "Applications Manual, Window Design", 1987;

[13] Chauvel P., Collins J.B., Dogianux, Longmore J., "Glare from windows: current view of the problem", Lighting Research &Technology, Vol.14 (1), 1982;

[14] N. Baker, A. Fanchiotti, K., Commission of the European Communities,Directorate General XII for Science,Research and Development, Daylighting in Architecture, a european reference book,1stedition, Brussels and Luxembourg, Steemers, 1993.