DE GRUYTER OPEN

DOI: 10.2478/sspjce-2014-0004

Daylighting on the working plane in oriented attic rooms under overcast and clear sky

Kristián Kondáš, Stanislav Darula[1]

Technical University of Košice
Civil Engineering Faculty, Institute of Architectural Engineering
e-mail: kristian.kondas@tuke.sk
[1]Slovak Academy of Sciences, Bratislava
Institute of Construction and Architecture
e-mail: usardar@savba.sk

Abstract

The evaluation of daylight conditions in building interiors is based on the Daylight Factor concept after current Slovak standards. Criteria and requirements determined in these standards consider the worst daylight exterior conditions which are described by CIE overcast sky model. The sky luminance distribution of overcast sky is centrical to the zenith, so independence of window orientation to cardinal points is characteristic in daylighting calculations. The sky luminance distribution modelling is one of the main task of the daylight source research more than 50 years. It is evident that also other types of sky conditions exist in nature. An introduction of a new criterion based on photometric variables, which also consider sunlight influence, is expected. This article represents a study of the influence of the interior orientation on distribution of daylighting in attic spaces under an overcast and clear sky.

Key words: illuminance, attic spaces, overcast sky, clear sky, orientation

1 Introduction

The loft is defined according to Slovak standard [1] as interior space of a house accessible from the last storey, which is placed within by the structure of the roof and other building structures and is intended to purposeful use. A loft can be considered only in the upper storey, which has sloped roof structure above the 1/3 of its floor area and the “roof-walls” are not higher than the half of the height of a common storey. These spaces in past, without heating and lighting, were considered a less lucrative parts of the building, while at present, their utilization is becoming popular and often the necessary part of housing or work place. There are a lot of reasons to live under a pitched roof because of efficient utilization of the land, lower costs of utility connection, better contact with environment and life in attic spaces has a very positive impact on the human well-being [2]. A few years ago this way of living was a relatively new trend. The technical standards did not determine the optimum of work area in offices or living area in residential buildings. Currently, Slovak standard [1] determines dimensions of these spaces with flat ceilings which can be also applied in attics rooms. The minimum room height of 2.3 m is possible to design, but height above 2.4 m is recommended and has to cover more than the half of the floor area. The height of the point of inclination (i.e. the height of the “roof-wall”) has to be at least 0.6 m above the floor, while the usable floor area of the rooms is counted only for spaces with ceilings above 1.3 m. These rules are recommended also for the design of family houses [2]. In case of determination of workspaces the typological requirements for the design are defined by the Building Act and relevant regulations. All interior spaces must be designed and constructed so that requirements for the human safety and healthy environment have to be satisfied [3] – [5]. Daylighting is one of the most important components of the environmental design also in attic rooms [6].

According to currently valid Slovak standards [7] and [8], all kinds of spaces with permanent occupancy (i.e. work-, school-, residential spaces) have to be illuminated by daylight. Daylight in buildings is assessed according to light conditions represented by overcast sky situations, respecting the CIE overcast sky model. Recently several models of the sky luminance distribution were developed, which allow simulating also conditions under clear and quasi cloudy sky situations [6] – [12].

Experiences with exploitation of attic spaces show that the minimum lighting requirements for interior illuminance are associated with the worst exterior daylight conditions seldom occurring during the whole year. There are many situations in which effects of glare appearance and overheating due to the direct sunlight during transitional and summer seasons are present. In terms of lighting, windows of the attic spaces can create discomfort in the indoor workplaces on a larger working plane area and control devices are needed.

The presented study provides a discussion about the differences and the effects of building orientation on interior daylight illuminance during overcast and clear sky situations in one sample attic room. For this purpose the time at 12 a.m. on 21st March was chosen.

2 Methodology

To investigate influences of direct sunlight and diffuse skylight on the size of insolated working area, the computer program VELUX Daylight Visualizer 2 (version 2.6.0) [13] was applied. This is a simple tool for daylighting design and analysis of daylight situations under various standard conditions. It is intended to promote the use of daylight in buildings and to aid professionals by predicting and documenting daylight levels and appearance of a space prior to realization of the building design. This program offers following outputs: luminance of surfaces, values of illuminance and the Daylight Factor distribution on the working plane, as well as daylight/sunlight animation [13].

As it is mentioned in [14] this program unfortunately calculates only sky/diffuse illuminance under sunless and sunny sky situations and the direct sunlight has to be determined additionally. Therefore, the form for calculation of all, global, direct and diffuse, exterior illuminance components was elaborated in Excel program [13]. For this purpose formulae working on the solar altitude γ_v, diffuse ratio $E_{v,d}/E_{voh}$ and luminous turbidity factor T_v were used. Generally, horizontal illuminance on the ground can be expressed as:

$$E_{v,g} = E_{v,s} + E_{v,d} \tag{1}$$

where

$E_{v,g}$ - is the global external horizontal illuminance [lx],

$E_{v,s}$ - is the direct external illuminance, recalculated on the horizontal plane [lx],

$E_{v,d}$ - is the diffuse external horizontal illuminance [lx].

To calculate the direct component of the external illuminance the next exponential formula, recommended also by [15] can be used:

$$E_{v,s} = E_{voh} \cdot e^{(-a_V \cdot m \cdot T_V)} \tag{2}$$

where

E_{voh} - is the extraterrestrial illuminance expressed on the horizontal plane [lx],

a_V - is the luminous extinction coefficient [-],

m - is the optical relative air mass of the atmosphere [-],

T_V - is the luminous turbidity factor ($T_V = 4$ representing ISO/CIE Type 12 clear sky standard conditions and the environment in common cities areas. Thisvalue was taken into account in calculations).

The room with windows orientated to East, South and West was chosen to demonstrate changes of maximum size of insolated working area. At time 12 a.m. (noon) the direct sun beams enter a room trough the windows only if they have South orientation. In all other investigated cases the working plane is illuminated only by diffuse skylight. If we want to find out the total internal illuminance on the working plane, we need to sum direct illuminance with the indirect internal illuminance obtained by the means of computer program VELUX. Direct illuminance was calculated from the external direct illuminance reduced by light transmission losses through the glazing material and dirt on the inner and outer glazing surfaces.

The formula for calculation of the sunlight contribution to the internal illuminance E_i on the working plane for α orientation is as follows:

$$E_{v,si} = E_{v,s} \cdot \left(\frac{\tau_{s,\psi}}{\tau_{s,nor}} \right) \cdot \tau_{s,nor} \cdot \left(\tau_{z,e} \cdot \tau_{z,i} \right) \tag{3}$$

where

$\tau_{s,\psi}$ - is the factor of light transmission at angle ψ from the window normal [-],

$\tau_{s,nor}$ - is the factor of light transmission in normal direction [-],

$\tau_{z,e}$ - is the factor of dirt reduction for the outer side of the glass [-],

$\tau_{z,i}$ - is the factor of dirt reduction for the inner side of the glass [-].

Then can be described and evaluated influences of the window orientation on interior daylight conditions during overcast and clear sky situations.

3 Description of the tested room

For the test calculation a sample room with dimensions 4.0 m width and 6.0 m depth of the room was chosen (i.e. width corresponds to the window wall). The maximum depth of 6 m for the side-lit room and the height 2.6 m of the room was chosen the same in all cases. The slope roof with angle 45° has a thickness 0.4 m while the height of the point of its inclination is 0.6 m above the floor, as is shown in Fig. 1.

The room is illuminated from one side by four roof windows VELUX GGL with dimensions 0.78 x 1.4 m, while the glazed area of each window is 0.69 m^2. The sill of the windows is 1.17 m, and the top edge is 2.16 m above the floor.

The following reflectance of the interior surfaces was considered: the floor 20 %, the ceiling and linings of the windows 70 % and walls 50 %. The grid of the measured points on the working plane is automatically generated by the computer program. The height of the working plane was set to the level 0.85 m above the floor. In our case this grid is created by the group of 24 points (4 points along the window wall and 6 points along the side walls).
The room is located on the last storey and can be assumed that windows will be not shaded by external obstructions, therefore this effect was neglected in interior illuminance calculations.

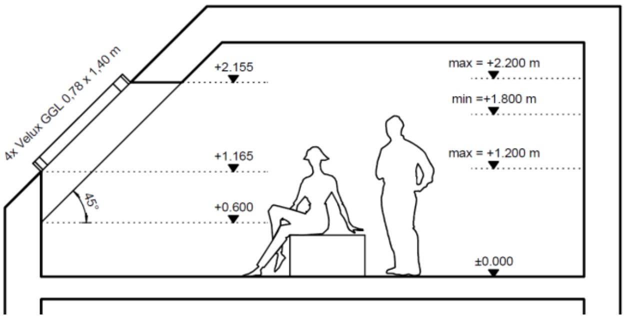

Figure 1: Section of a sample room

To calculate values of illuminance under sunny conditions, the information about the location of the investigated room is also needed. For this purpose the city of Košice with the geographical coordination: latitude 48°43´ N, longitude 21°15´ E was chosen. The best study of sunlight influence on the interior illuminance levels is at the time, when the sun is in the highest position during equinox, therefore time 12 a.m. on 21st March with the orientation of windows to cardinal points East, South and West was investigated.

4 Results

The values of illuminance for overcast sky and for the clear sky to different orientations without the direct component were calculated directly from the program VELUX Daylight Visualizer 2, as is shown in Fig. 2. to Fig. 4. Due to symmetrical sky luminance distribution of overcast sky model the illuminance distribution on the working plane is independent on the window orientation.
Values of the illuminance under the overcast sky can be read directly in this program and can be used in daylighting evaluations as reference. Thus we are able to compare influence of the

building orientation on the interior illuminance of the working plane also under sunny situations.

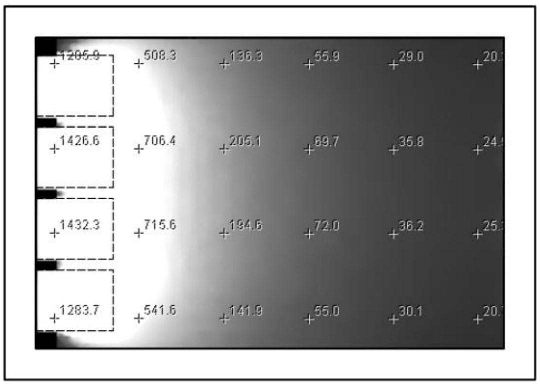

Figure 2: Values of interior illuminance for overcast sky to arbitrary window orientations

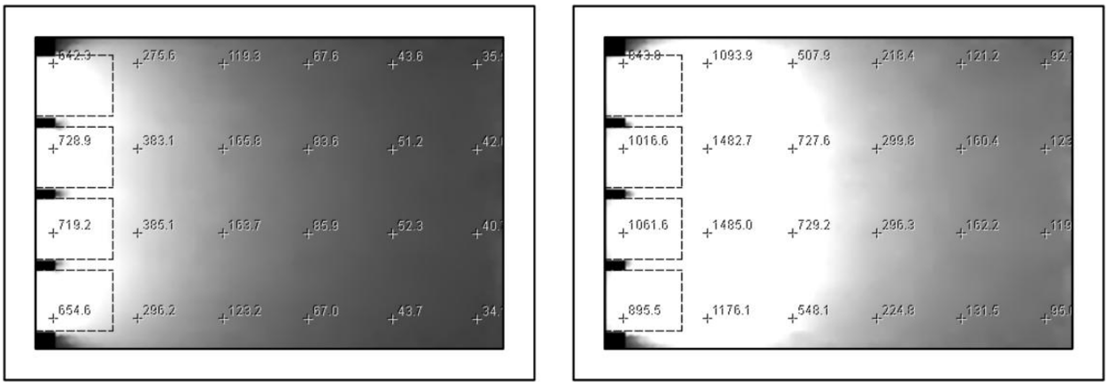

Figure 3: Values of interior illuminance for clear sky to North and South window orientations

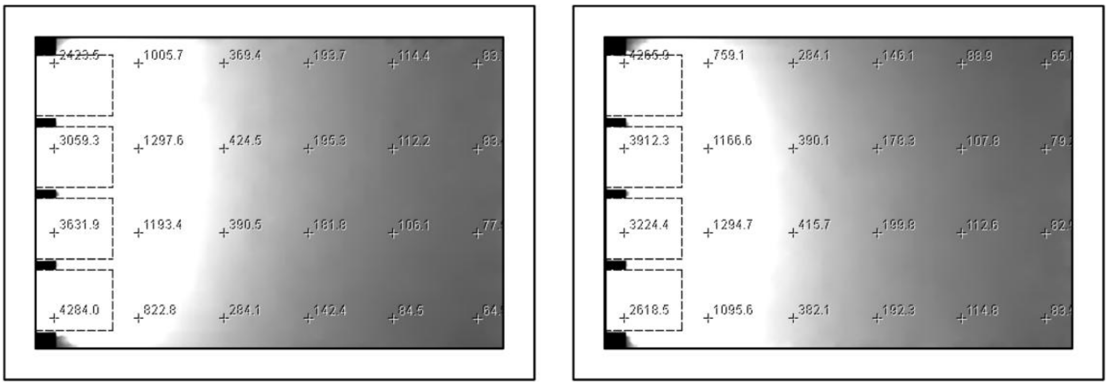

Figure 4: Values of interior illuminance for clear sky to East and West window orientations

The values of global illuminance representing clear sky situation include also direct component in the case of South orientation because of chosen noon time. This component has to be additionally calculated and summed with sky component taken from processing of the computer program. Small symmetry differences of illuminance in the net points can be observed. These are caused by small shift position of the sun from the South - North direction. The program Velux Daylight Visualizer requires as an input of investigation Local Clock Time - *LT* and this shift reflects difference between *LT* and True Solar Time - *TST* at 12:00 in

Košice. Symmetry of illuminance distribution on the working plane will be evident when results will be presented in *TST* at 12:00.

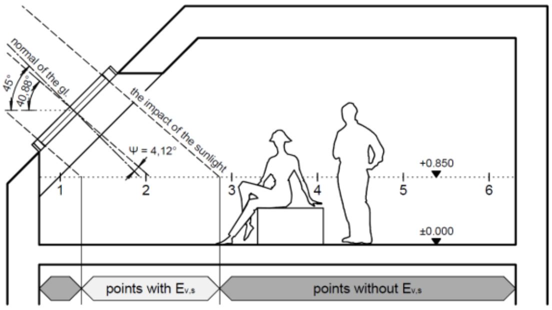

Figure 5: Points of the grid with and without the direct component

To calculate the global interior illuminance at a given point of a working plane according to formulae (1) it is necessary to determine the factor of light directional transmission at angle ψ from the window normal. The selection of the points which are illuminated by sunlight, according to the solar altitude for the chosen date was graphically checked, as is shown in Fig. 5. Therefore the direct component was calculated for the 4 points of the 2nd row from the window wall.

Table 1: Values of the illuminance in lx

Type	Orientation	Points	1	2	3	4	5	6
Overcast sky	N,S,E,W	1	1205.9	508.3	136.3	55.9	29.0	20.3
		2	1426.6	706.4	205.1	69.7	35.8	24.9
		3	1432.3	715.6	194.6	72.0	36.2	25.3
		4	1283.7	541.6	141.9	55.0	30.1	20.7
Clear sky	North	1	642.3	275.6	119.3	67.6	43.6	35.5
		2	728.9	383.1	165.8	83.6	51.2	42.6
		3	719.2	385.1	163.7	85.9	52.3	40.7
		4	654.6	296.2	123.2	67.0	43.7	34.1
	South	1	843.8	27961.0	507.9	218.4	121.2	92.1
		2	1016.6	28403.8	727.6	299.8	160.4	123.6
		3	1061.6	28406.1	729.2	296.3	162.2	119.9
		4	895.5	28097.2	548.1	224.8	131.5	95.6
	East	1	2423.5	1005.7	369.4	193.7	114.4	83.7
		2	3059.3	1297.6	424.5	195.3	112.2	83.4
		3	3631.9	1193.4	390.5	181.8	106.1	77.5
		4	4284.0	822.8	284.1	142.4	84.5	64.9
	West	1	4265.9	759.1	284.1	146.1	88.9	65.0
		2	3912.3	1166.6	390.1	178.3	107.8	79.2
		3	3224.4	1294.7	415.7	199.8	112.6	82.9
		4	2618.5	1095.6	382.1	192.3	114.8	83.5

In accordance with [4] the value of the factor of light transmission in normal direction for the double clear glazed window is 0.92^2, the factor of dirt reduction for the outer side of the glass with 45° slope is 0.7 for the middle polluted atmosphere and 0.95 for the inner side of the glass in the small polluted interior environment. Achieved results are summarized in the Table 1, where values of illuminance under clear sky in the South oriented room include also direct component, column 2. In the Table 2 are documented values of ratios representing relation between illuminance under clear to overcast sky conditions for different orientations of the windows. It is important to notice, that external illuminance under overcast and clear sky are different but in interiors oriented to sunless part of hemisphere can be similar.

Table 2: Relation between illuminances under overcast and clear sky conditions

Type	Orientation	Points	1	2	3	4	5	6
Clear sky / Overcast sky	North	1	0.533	0.542	0.875	1.209	1.503	1.749
		2	0.511	0.542	0.808	1.199	1.430	1.711
		3	0.502	0.538	0.841	1.193	1.445	1.609
		4	0.510	0.547	0.868	1.218	1.452	1.647
	South	1	0.700	55.009	3.726	3.907	4.179	4.537
		2	0.713	40.209	3.548	4.301	4.480	4.964
		3	0.741	39.696	3.747	4.115	4.481	4.739
		4	0.698	51.878	3.863	4.087	4.369	4.618
	East	1	2.010	1.979	2.710	3.465	3.945	4.123
		2	2.145	1.837	2.070	2.802	3.134	3.349
		3	2.536	1.668	2.007	2.525	2.931	3.063
		4	3.337	1.519	2.002	2.589	2.807	3.135
	West	1	3.538	1.493	2.084	2.614	3.066	3.202
		2	2.742	1.652	2.070	2.558	3.011	3.181
		3	2.251	1.809	2.136	2.775	3.111	3.277
		4	2.040	2.023	2.693	3.496	3.814	4.034

5 Conclusion

Presented results of this study show significant variation of interior illuminance distribution to different orientation of the windows under various skies. The main finding is that the values including the direct component (Table 1) are an order of magnitude greater than any other. It is interesting, that values of the ratio of illuminance under clear to overcast sky conditions (Table 2) increase sequentially only to North orientation. On any other orientation the 2nd row from the window wall shows some shift. It is also remarkable, that values of the illuminance in the 1st row close the window wall to East and West orientation, under clear situation are markedly higher than the illuminance at other points of the grid and that values increase in the opposite direction than the others. This reflects two aspects of the attic spaces. The first is influence of inclination of window on the dimension of solid angles of apertures. The second is specific sky luminance distribution seen from investigated points due to difference between Local Clock Time and True Solar Time. These findings demonstrate the fact that in nature occur not only overcast sky conditions but there are other sky situations too and in these cases the building orientation plays an important role which should be taken into account in the daylight design and strategy of effective utilization of daylight. Also, the possible insolated area in the attic spaces will be deeper than in side-lit rooms so a risk of glare occurrence is higher in the larger space.

Acknowledgements

This study was supported under the project ITMS 26220120037, VEGA 2/0117/14 and MVTS IEA – SHC – Task 50.

References

[1] STN 73 4301. (2005). Budovy na bývanie. (Dwelling buildings). Bratislava: SÚTN.

[2] Duboisová Petroffová, M. P. & Selcová, Ľ. (2005). *Podkrovia*. Bratislava: Jaga.

[3] van Bommel, W.J.M & van den Beld, G.J. (2004). Lighting for work: a review of visual and biological effects. *Lighting Research and Technology. Volume 36* (4), 255 – 269.

[4] Rybár, P., Šesták, F., Juklová, M., Hraška, J. & Vaverka, J. (2002). *Denní osvětlení a oslunění budov (Daylighting and insloation of buildings).* Brno: Era group.

[5] Veitch, J.A. (2005). Light, lighting, and health: issues for consideration. *Leukos. Volume 2* (2), 85 – 96.

[6] Mohelníková, J. (2007). Daylighting of Attic Rooms by Dormers. *Leukos*. *Volume 3* (4), 249 – 258.

[7] STN 73 0580-1. (1987). Denné osvetlenie budov. Časť 1: Základné požiadavky. (Daylighintg in buildings. Part 1: Basic requirements). Praha: ÚNM.

[8] STN 73 0580-2. (2000). Denné osvetlenie budov. Časť 2: Denné osvetlenie budov na bývanie. (Daylighting in buildings. Part 2: Daylighting of residential buildings). Bratislava: SÚTN.

[9] Perez, R., Seals, R. & Michalsky, J. (1993). All weather model for sky luminance distribution – preliminary configuration and validation. *Solar Energy. Volume 50* (3), 235 – 245.

[10] Kittler, R., Darula, S. & Perez, R. (1997). A new generation of sky standards. In LuxEuropa, 1997 (359 – 373). Amsterdam: Office NSVV.

[11] Igawa, N., Koga, Y., Matsuzawa, T., & Nakamura, H. (2004). Models of sky radiance distribution and sky luminance distribution. *Solar Energy. Volume 77* (2), 137 – 157.

[12] ISO 15409:2004/ CIE S 011/E:2003. (2004). Spatial distribution of daylight – CIE Standard General Sky.

[13] Velux. *Daylight Visualizer*. July 9, 2013, from http://viz.velux.com/daylight_visualizer/about.

[14] Kondáš, K. (2012). Influence of exterior daylight conditions on daylighting in the attic space. In Young Scientist 2012: 4th PhD. Student Conference of Civil Engineering and Architecture, 2012 (1 – 6). Košice: Civil Engineering Faculty, Technical University of Košice.

[15] Tregenza, P. & Sharples, S. (1993). *Daylight algorithms.* Sheffield: School of Architecture Studies, University of Sheffield.

[16] Kittler, R. & Pulpitlová, J. (1988). *Základy využívania prírodného svetla* (*Basis of the utilization of daylight*). Bratislava: Vydavateľstvo VEDA.