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Sky type determination using vertical illuminance

***Abstract**. The modelling of daylight in buildings requires also information about exterior daylight conditions. The regularly measured horizontal and vertical illuminances offer data applicable in daylight research as well as in practical daylight design and energy simulations in buildings. Daylight illuminances are continually changing during days within a year and some of their classification is needed. It seems that new possibilities for determination of daylight conditions based on the measured vertical illuminances exist. This paper presents the concept of the standard sky type determination based on vertical illuminances with orientation to cardinal points and documents its application in case of overcast skies.*

***Streszczenie.** Modelowanie światła dziennego w budynkach wymaga informacji o zewnętrznych dziennych warunkach oświetleniowych. Regularne pomiary poziomego i pionowego natężenia oświetlenia dają podstawę do badań oświetlenia dziennego i zastosowania praktycznego w projektowaniu oświetlenia dziennego i symulacji energetycznych w budynkach. Dzienne natężenie oświetlenia nieustannie zmienia się w ciągu dnia i roku, co wymusza potrzebę jego klasyfikowania. Wydaje się, że możliwe staje się nowe opisanie warunków dziennych na podstawie pomiarów pionowego natężenia oświetlenia. W artykule przedstawiono koncepcję określenia standardowego nieboskłonu opartą na pionowym natężeniu oświetlenia zorientowanym względem podstawowych stron światowych i zaprezentowano jej wykorzystanie dla warunków nieboskłonu pokrytego. (**Określenie rodzaju nieboskłonu na podstawie pionowego natężenia oświetlenia**)*

Keywords: Daylight vertical illuminance, solar azimuth, plane orientation, daylight parameters
Słowa kluczowe: Pionowe natężenie oświetlenia dziennego, azymut Słońca, orientacja przestrzenna, parametry światła dziennego

Introduction

In the daylight theory and measurements were determined exterior daylight conditions especially on the availability of horizontal illuminance levels in various localities and under different cloudiness situations. Now more specific relative sky luminance patterns or sky types were standardised [1, 2] and realistic illuminance on vertical surfaces, such as house windows can be calculated in differently oriented interiors.

This paper tries to coordinate calculated and measured illuminance data within the parameterisation system based on oriented fluxes of sunray and sky luminance influence arbitrary vertical planes. Under clear sky conditions the position between the orientation of the vertical plane and the momentary solar azimuth is of primary importance as evident from measured vertical illuminances and has to be taken into account in calculation programs. Otherwise, outdoor vertical illuminance measured regularly on vertical planes with their orientation to four cardinal points can be used to approximate sky types present during the measurement period [3, 4]. Common used sky type classification method [5, 6] applies the identification ratio of zenith luminance to horizontal diffuse/sky illuminance L_{vz}/D_v. However, if vertical illuminance data are available in several CIE IDMP stations [7], then the sky type differences in four cardinal point directions can be studied and specified.

Derivation of vertical sky illuminance

Usually vertically placed sensors oriented to cardinal point towards North, East, South and West are measuring global illuminances, thus total global values G_{vI} include:

- sunlight, i.e. parallel sunbeam illuminance P_{vI} in accordance with the momentary sun position and turbidity and/or cloudiness shading,
- skylight, i.e. diffuse illuminance from the sky vault D_{vI},
- reflected daylight illuminance R_{vI} from obstructions and the terrain above and/or under the horizon.

To exclude the sunlight influence it is important to identify the presence of sunlight due to the sun position with respect to the orientation of the vertical plane as well as to the sun-shading by clouds. The momentary sunlight effect is easily identified by the difference between the measured horizontal global and diffuse illuminance. The absence of sunlight is also caused by the orientation of the vertical plane in respect of the momentary sun position. Therefore it is necessary to calculate the solar azimuth in the moment of the measurements A_s and compare it with the azimuths of each vertical sensor, i.e. A_{IN}, A_{IE}, A_{IS}, and A_{IW}

Thus can occur following situations:

- The North facing sensor can be reached by direct low sunbeams only during early morning or late afternoon from the spring to autumn equinox days.
- The East facing sensor can be illuminated by direct sunbeams from sunrise hours to noon, i.e. to 12 a.m. true solar time TST.
- The Southern sensor can be reached by sunbeams almost the whole day except the morning hours before 6 a.m. and afternoon hours after 6 p.m.
- The Western sensor can register sunlight from noon until sunset.

Evidently the sunlight component in the global measured value is present only during intervals when the Sun is unshaded by clouds, then $G_{vI} = P_{vI} + D_{vI} + R_{vI}$. If Sun is shaded then $G_{vI} = D_{vI} + R_{vI}$ is valid and such occasions can be simply selected from the measured data.

During overcast or foggy situations, when sunlight is missing, L_{vz}/D_v is relatively stable within the interval 0.293 - 0.433 or in a more restricted range 0.32 – 0.42, where L_{vz} is the zenith luminance and D_v is the horizontal diffuse illuminance. Under ideal homogeneous atmospheric conditions with dense cloud cover three ISO/CIE sky types can be identified:

A. *Sky type 1, ISO/CIE Overcast Sky with luminance gradation 1:3* in the characteristic range of L_{vz}/D_v:

(1) $$L_{vz} / D_v = 0.408 \pm 2.5\% = 0.408 \pm 0.025$$

while the zenith luminance can be approximately expressed in kcd/m^2 as:

(2) $$L_{vz} = (D_v / E_v)[54.65 \sin \gamma_S]$$

where: E_v - extraterrestrial horizontal illuminance, γ_S - the momentary solar altitude.

Because of the uniform azimuth luminance the influence on any vertical plane for all D_{vI} are equal and can be calculated after:

(3) $$D_{vI} = \int_{A_P=0}^{\pi} \int_{\varepsilon_P=0}^{\pi/2} L_P \cos i_P \cos \varepsilon_P \, d\varepsilon_P \, dA_P$$

where: L_P - luminance of the sky element, ε_P - elevation of the sky element, A_P - azimuth of the sky element, i_P - the incidence angle, i.e. the spherical angle of the sky element to the normal of the vertical surface.

Instead of the tedious integration can be used a numerical summation of elemental sky luminance in solid angles which can yield approximately the same results [8] as:

(4) $$D_{vI} = \sum_{i=1}^{n} \sum_{j=1}^{k} L_{ij} \cos i\,(ij)$$

where: L_{ji} - the luminance of the sky element (ij), n - number of bands in the sky hemisphere, k - number of elements in each band of the sky hemisphere, ij - the spherical area of the sky element which is equal to $ij = \frac{\pi/2}{n} \cos \frac{\varepsilon_P \pi}{k}$, while in the integration formula it is expressed as $dA_P\, d\varepsilon_P \cos \varepsilon_P$.

To increase the accuracy of the numerical integration a division of the sky hemisphere in very small elements is crucial, in [9] is recommended for 145 circular sky patches dimension of diameter 0.2 radians. However, the error of this matematical operation has to be tested.

If the D_{vI}component is defined by the above calculation, then the reflected components, i.e. R_{vN}, R_{vE}, R_{vS} and R_{vW} can be derived from the measured G_{vI} illuminance. In case of overall diffuse reflecting surfaces in the downward half-space approximately illuminated as a horizontal plane by D_v these reflected components assuming Lambertian diffuse reflection could have the value $R_{vI} = D_v\, \rho_g/\pi$, i.e. the ground reflectance will be $\rho_g = R_{vI}\pi / D_v$.

Sometimes the ground reflectance is approximated by the value 0.2, but using the IDMP five year measurements in Bratislava during 1994 - 1998 could be detected also seasonal changes in R_{vN}, R_{vE}, R_{vS} and R_{vW} with variations during winter snow cover, spring fresh greenery or bare trees in winter with dark ground.

B. *Sky type 3, ISO/CIE Overcast Sky with luminance gradation roughly 1:2* is characterised by L_{vz}/D_v in the range:

(5) $$L_{vz} / D_v = 0.361 \pm 2.5\% = 0.361 \pm 0.025$$

with typical zenith luminance in kcd/m^2

(6) $$L_{vz} = (D_v / E_v)\left[\, 48.3 \sin \gamma_S \right]$$

C. *Sky type 5, ISO/CIE Overcast Sky with uniform gradation* represents the simplest Lambert sky with unity luminance and with the L_{vz}/D_v characteristic range:

(7) $$L_{vz} / D_v = 0.318 \pm 2.5\% = 0.318 \pm 0.025$$

and typical zenith luminance in kcd/m^2 will be:

(8) $$L_{vz} = (D_v / E_v)\left[\, 42.59 \sin \gamma_S \right]$$

Under all these three skies the modelled luminance patterns is independet on solar altitude and azimuth angles so these can be used for testing homogeneity of measured real skies. Then the difference in measured four vertical global illuminances should be also similar as well as the ratios D_{vI}/D_v which should be approximately under the unobstructed ISO/CIE sky type 1 D_{vI}/D_v = 0.39, under sky type 3 D_{vI}/D_v = 0.47 and under sky type 5 D_{vI}/D_v = 0.50.

The value D_{vI}/D_v is also called the Vertical Daylight Factor *VDF* which is used in some light flux methods after [10] divided into sky and ground reflected components as *VDF* = $(D_{vI} + R_{vI})/D_v$. It is also to be noted that this ratio corresponds to the C values in %, i.e $C = 100 \times D_{vI}/D_{vI}$. Similarly in [4] Vertical Sky Components *VSC* in % were derived for the ISO/CIE standard sky types and types 1, 3 and 5 are constant for all scattering angles or solar altitudes under the unobstructed skies.

Even under overcast skies with relatively thinner cloud layers allowing slight brightening towards the sun position (as determined by ISO/CIE sky types 2 and 4) these can cause different illuminance on various vertical planes due to different scattering angle influences as noted also in [4]. It is evident that under these skies the ratio D_{vI}/D_v will rise in cases when the vertical plane faces the sun position. As the scattering angle on any sky element is dependent on its spherical distance from the momentary sun position, the sky luminance pattern is integrated with respect to the cosine of the incidence angle of each sky element within the half-space of the particular vertical plane. Such an integration is in fact included in the measured vertical illuminance if sunlight is absent. While in presence of sunlight the indicatrix influence is strongest around the solar corona its effects are small on the level of horizontal illuminance in the sun-rising hours under low solar altitudes. Contrary this the level of vertical illuminance is increasing markedly under sky types 2 and 4. Of course, this phenomenon is even more evident under all cloudy and clear sky conditions when the vertical plane is facing the momentary sun position. Such circumstances will occur clearly in the measured values of global vertical illuminance on differently oriented planes G_{vI}^m and the exact diffuse component D_{vI}. Then D_{vI}/D_v is determined respecting all possible components (global, direct and reflected) after:

(9) $$D_{vI} = G_{vI}^m - P_{vI} - R_{vI} \text{ ...or...}$$

$$D_{vI} / D_v = G_{vI}^m / D_v - P_{vI} / D_v - R_{vI} / D_v$$

As in the case of overcast skies the reflected component from the ground or downward space R_{vI} is relatively small, thus it can be approximated easier. Considering the diffuse reflectance of the ground illuminated by the global horizontal illuminance G_v the reflected component can be:

(10) $$R_{vI} = G_v \rho_g \omega_{pv} / \pi$$

where roughly ρ_g could be either derived form measurements under overcast sky conditions or approximated by its mean value 0.2 or an approximation of reflected component $R_{vI} = C_2 = 0.5\, G_v\, \rho_g$ with ρ_g = 0.1 can be applied with the so called "ground configuration" of a vertical window is ω_{pv} = 0.5 (which represents the projected solid angle on a vertical plane).

A computer program Skyfinder evaluating sky types from measured vertical illuminance

Skyfinder is the evaluating software written in C language which constists of two parts with various additional functions. The first part of the program imports raw dataset files containing data measured at the CIE IDMP station ICA SAS located in Bratislava, Slovakia. As a basic input, solar altitude γ_S is imported from the data file and solar azimuth A_S for a given date and time of measurement is calculated in as:

(11) $$A_{S,H\le 12} = \arccos\left[\frac{\cos\delta}{\cos\gamma_S} \left(\cos\varphi \tan\delta + \sin\varphi \cos\left(15°H\right)\right) \right]$$

while for hours $H > 12$ of True Solar Time is valid:

(12) $$A_{S,H>12} = 360° - A_{S,H\le 12}$$

Thereafter, the theoretical values of the zenith luminances L_{vz} and horizontal diffuse illuminances D_v are calculated for 15 standardized sky types in according to [1]. Integration over the hemisphere to obtain diffuse illuminances were performed using double Simpson's rule with the adequate integration step for sufficient accuracy. Each theoretical value of L_{vz}/D_v is compared with the measured/calibrated value for the given solar altitude and the most proximate sky type is determined. Deviation of the measured value from the theoretical is also calculated and written into the output file (table 1 and 2).

The second part of the program computes diffuse vertical illuminance in accordance with (3). Subsequently, the ratio of the diffuse vertical illuminance to the diffuse horizontal illuminance is calculated for 15 ISO/CIE sky types and four sensors oriented to the appropriate cardinal points. Therefore, the integration boundaries for the azimuth in the (3) depend on the orientation of the sensor, so for East is A_P = (0; π), South is A_P = (π /2; 3π /2), West is A_P = (π ; 2π) and for North is A_P (3π /2; π /2). The program reads the measured global vertical illuminances, calculates theoretical diffuse vertical illuminances on the same orientated surface and ratio D_{vI}/D_v. Finaly measured data are compared with the theoretical values.

However, the sensors at the CIE IDMP station are influenced by the systematic errors due to the reflection from the ground, therefore the correction coefficients for each sensor had to be determined. The reflectance of the ground is calculated in according to (10) and the measured data are adapted to the theoretical ideal values by the correction coefficient for each sensor separately. The ideal theoretical values are selected in accordance to the L_{vz}/D_v criterion with the sky determination error less than 0.1%.

CIE sky types evaluated from the measurements for each vertical sensor serve as the output of the Skyfinder program. For every specified sky type, the error of its determination is included into the output file and also the exact values of theoretically computed and measured calibrated data are attached. As the additional function, Skyfinder separates overcast, clear and partly cloudy situations from the input dataset obtained at the CIE IDMP station. Output files are in the standard ASCII format.

Analysis of measured vertical illuminances from Bratislava dataset

The vertical illuminance availability or their ratios to horizontal illuminance were sporadically analysed and published before e.g. in [11 - 13]. Now, more detail analysis was carried out documenting almost perfect overcast conditions identical with the CIE Overcast Sky [1] or ISO standard sky type 1 [2] from measurements taken in Bratislava during November 11th, 1995 already published in the book [6].

For the sake of comparison and analysis of these Bratislava measurements showing perfectly overcast day changes of L_{vz}/D_v are shown in figure 1. The morning course is very fluent and stable with sky conditions very close to the CIE standard type 1, i.e. $L_{vz}/D_v \approx 0.41$ with the D_v /E_v ratio in the range 0.08 – 0.2 while the afternoon course is more variable.

It seems that the optimal conditions are under the solar altitude range 18° - 20° (between 9.30 and 10.00 a.m.). The test of dependence of vertical to horizontal diffuse illuminance on solar altitude has slight differences of G_{vI}^m / D_{vI} values with any dependence on the solar altitude. The lowest values were measured at the southern and western orientated sensor and the highest at the northern orientated sensor, figure 2. Both these figures document that luminance levels of sky patches were differed in azimuth directions and real sky conditions can cause various light exposition on vertical windows.

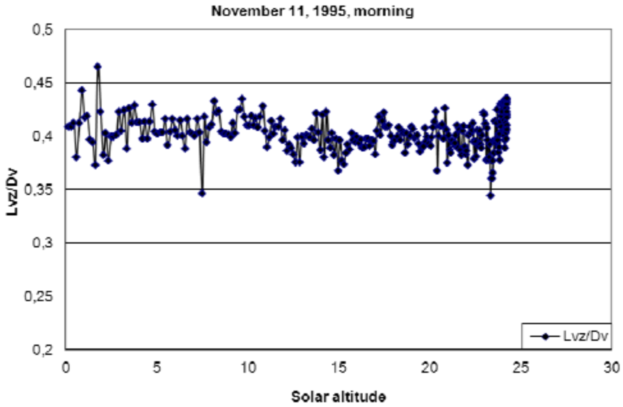

Fig. 1 Occurrence of L_{vz}/D_v, Bratislava at November 11th, 1995, morning overcast day

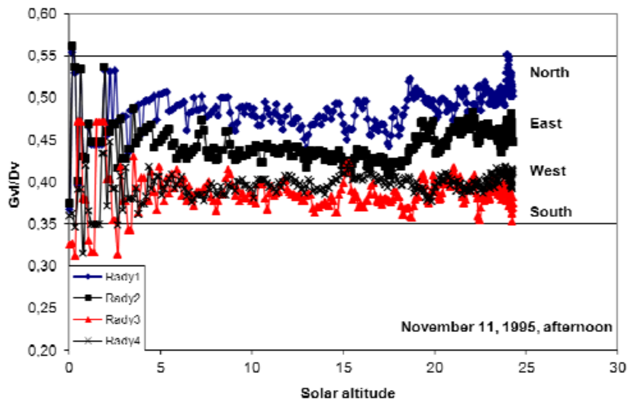

Fig. 2 Occurrence of G_{vI}^m / D_{vI} , Bratislava at November 11th, 1995, afternoon overcast day

When sky classification parameter L_{vz}/D_v was analysed with associated vertical G_{vI}^m / D_{vI} there were found also small differences in sky type classification. Findings in table 1 confirm results presented in figure 2. The perfectly homogeneous overcast sky type 1 was identified at 9:36, when differences between measured and theoretical parameters were very close to zero. While the sky type 1 was identified in all parts of sky hemisphere using parametrisation of vertical illuminances, only six situations were classified to sky type 2 after the parameter L_{vz}/D_v. These cases document higher sensitivity of the L_{vz}/D_v parameterisation to momentary luminance levels in the zenith. The highest classification differences between measured data and theoretical assumptions occur on the eastern and southern sensors.

Similar analysis of data measured on January 28th, 1996 was carried out. This day, the daylight conditions were classified to sky type 5 "Overcast, foggy or cloudy with overall uniformity" when classification parameter L_{vz}/D_v was applied (table 2, column 2). The evaluation of measured and calculated vertical illuminances shows that also can occur azimuthally depended sky luminance distributions classified into several overcast sky categories.

For instance the western orientated sensor documents sky conditions associated with sky type 5, but on the northern side the sky type 3 and on the southern orientation the sky type 2 were dominant while the eastern part of hemisphere looks like the sky type 1.

Table 1 Sky classification after L_{vz}/D_v and G_{vI}^m / D_{vI} parameters. Bratislava, November 11, 1995, overcast day, type 1

Time	L_{vz}/D_v		G_{vN}		G_{vE}		G_{vS}		G_{vW}	
	Sky type	Difference	Sky type	Difference	Sky type	Difference	Sky type	Difference	Sky type	Difference
9:32	2	2.9%	1	7.6%	1	7.0%	1	9.6%	1	8.9%
9:33	1	3.3%	1	7.2%	1	5.3%	1	6.7%	1	7.1%
9:34	1	3.0%	1	6.7%	1	4.9%	1	6.3%	1	8.0%
9:35	1	2.1%	1	5.2%	1	4.4%	1	5.8%	1	3.4%
9:36	1	0.0%	1	0.0%	1	0.0%	1	0.0%	1	0.0%
9:37	1	3.0%	1	7.1%	1	6.3%	1	0.5%	1	3.7%
9:38	1	0.7%	1	15.1%	1	11.6%	1	3.9%	1	7.6%
9:39	1	1.3%	1	19.1%	1	17.5%	1	10.9%	1	11.7%
9:40	2	1.0%	1	21.3%	1	21.8%	1	15.0%	1	14.2%
9:41	1	1.4%	1	18.4%	1	22.4%	1	15.5%	1	14.7%
9:42	2	3.0%	1	14.0%	1	22.9%	1	12.4%	1	7.7%
9:43	1	2.0%	1	8.5%	1	17.7%	1	6.2%	1	3.2%
9:44	1	0.1%	1	1.1%	1	6.5%	1	1.9%	1	3.8%
9:45	1	0.3%	1	5.3%	1	1.3%	1	6.6%	1	9.7%
9:46	1	2.5%	1	8.0%	1	0.9%	1	8.5%	1	11.8%
9:47	1	2.2%	1	9.6%	1	4.2%	1	12.5%	1	13.6%
9:48	1	1.8%	1	12.9%	1	7.2%	1	14.1%	1	15.4%
9:49	2	3.1%	1	14.3%	1	8.0%	1	13.8%	1	17.1%
9:50	2	1.1%	1	14.8%	1	8.7%	1	13.4%	1	16.8%
9:51	2	2.2%	1	13.6%	1	9.4%	1	17.0%	1	16.4%
9:52	2	2.4%	1	14.1%	1	11.1%	1	18.4%	1	16.1%
9:53	1	0.2%	1	14.6%	1	10.8%	1	18.1%	1	17.8%
9:54	1	3.3%	1	13.5%	1	9.5%	1	19.6%	1	18.4%
9:55	1	2.2%	1	13.1%	1	11.2%	1	19.3%	1	18.1%
9:56	2	2.9%	1	14.5%	1	13.7%	1	19.0%	1	16.9%

Table 2 Sky classification after L_{vz}/D_v and G_{vI}^m / D_{vI} parameters. Bratislava, January 28th, 1996, overcast day, type 5

Time	L_{vz}/D_v		G_{vN}		G_{vE}		G_{vS}		G_{vW}	
	Sky type	Difference	Sky type	Difference	Sky type	Difference	Sky type	Difference	Sky type	Difference
8:13	5	1.0%	2	6.8%	1	18.1%	5	5.0%	5	14.1%
8:14	5	1.0%	2	4.1%	1	15.7%	5	2.1%	5	13.6%
8:15	5	4.3%	2	4.1%	1	17.0%	5	0.5%	5	11.3%
8:16	5	4.3%	2	1.5%	1	14.6%	5	1.8%	5	11.0%
8:17	5	3.1%	2	1.4%	1	12.3%	2	0.2%	5	10.8%
8:18	5	1.3%	2	1.0%	1	10.1%	2	2.4%	5	8.6%
8:19	5	1.3%	2	3.5%	1	7.7%	2	5.1%	5	6.2%
8:20	5	1.7%	2	3.2%	1	9.4%	2	7.7%	5	6.1%
8:21	5	1.7%	3	3.4%	1	7.2%	2	5.1%	5	6.0%
8:22	4	0.8%	3	1.2%	1	5.1%	2	7.5%	5	3.9%
8:23	5	0.5%	3	1.3%	1	6.5%	2	10.1%	5	3.8%
8:24	5	0.5%	3	1.6%	1	4.5%	2	7.5%	5	3.8%
8:25	5	0.7%	3	0.5%	1	2.5%	2	9.8%	5	3.9%
8:26	4	2.0%	3	0.3%	1	4.0%	2	7.5%	5	3.8%
8:27	4	2.0%	3	0.0%	1	2.0%	2	5.2%	5	3.8%
8:28	5	1.1%	3	2.0%	1	3.7%	2	7.3%	5	3.9%
8:29	4	0.7%	3	1.9%	1	1.7%	2	9.6%	5	3.8%
8:30	5	0.0%	3	3.8%	1	3.3%	2	7.2%	5	3.9%
8:31	4	0.2%	3	3.4%	1	1.5%	2	9.3%	5	4.0%
8:32	5	2.5%	3	5.3%	1	0.3%	2	11.4%	5	2.2%
8:33	5	1.0%	3	4.9%	1	1.2%	2	9.1%	5	2.2%
8:34	5	1.5%	3	4.5%	1	0.5%	2	11.1%	5	0.5%
8:35	4	2.5%	3	2.1%	1	1.0%	2	13.1%	5	2.5%
8:36	4	0.2%	3	3.8%	1	0.7%	2	10.8%	5	0.8%
8:37	4	1.0%	3	3.5%	1	0.9%	5	12.7%	5	0.9%
8:38	5	2.8%	3	5.2%	1	0.7%	3	14.1%	4	0.6%
8:39	5	1.9%	3	4.9%	1	2.3%	3	12.7%	4	0.8%
8:40	4	1.7%	3	4.5%	1	0.9%	5	14.0%	4	1.0%
8:41	4	0.5%	3	4.0%	1	0.7%	3	13.3%	5	0.3%
8:42	4	0.2%	3	3.7%	1	0.9%	5	13.4%	5	0.1%
8:43	5	2.2%	3	3.4%	1	0.6%	5	11.3%	5	0.0%

Conclusions

Predetermination of representative daylight conditions is crucial for correct design and evaluation of daylighting in buildings. The sky luminance distribution and sun radiation are basic sources of daylight. Their intensities are continually changing, but the reference/typical situations can be classified and applied in practice. The study of sky type classification after parameters L_{vz}/D_v and G_{vI}^m / D_{vI} results in the following guidance:

- the L_{vz}/D_v parameter is expressing the simplest method for sky type classification and the overall effect of the sky pattern on horizontal surfaces, but it requires sky instantaneous luminance measured values very sensitive to cloud changes in the zenith. However, this parameter cannot distinguish influences of various sky luminance distributions on those half hemispheres facing different cardinal points.

- the G_{vI}^{m} / D_{vI} parameter allows to classify sky types in the cases when no sky luminance measurements are available. The azimuth effects of sky luminance distribution irregularities can be identified applying the method Skyfiner, which can study sky standard conditions on the half hemisphere in relation to vertical windows with different orientations. However, various directional sky patterns influence also daylight levels in interiors simulated by standard patterns valid only for particular orientation.

Further studies considering the non-homogeneous distribution of cloudiness and sky luminance distribution have to be elaborated to determine more real daylight conditions.

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REFERENCES

[1] CIE – Commission Internationale de l´Éclairage: Spatial distribution of daylight – CIE Standard General Sky. CIE Standard S 011/E:2003, CB CIE Vienna 2003.

[2] ISO – International Standardisation Organisation: Spatial distribution of daylight – CIE Standard General Sky. ISO Standard 15409:2004.

[3] Alshaibani, K., Determination of CIE standard general sky from horizontal and vertical illuminance/irradiance. Proc. World Renew. Energy Congress X, Glasgow, July 2008.

[4] Li, D.H.W., Cheung K.L., Tang, H.L., Cheng, Ch.C.K., Identifying CIE standard skies using vertical sky component. *J. Atmosph. Solar-Terrestr. Physics*, 73, (2011), No. 13, 1861–1867.

[5] Kittler, R., Darula, S., Perez, R., A set of standard skies. Bratislava: Polygrafia, 1998.

[6] Kittler, R., Kocifaj, M., Darula, S., Daylight science and daylighting technology. Springer, N.Y., 2012.

[7] http://idmp.entpe.fr.

[8] Alshaibani, K., Finding frequency distributions of CIE Standard General Skies from sky illuminance or irradiance. *Light. Res. Technol.*, 43, (2011), No. 4, 487-495.

[9] Tregenza, P. and Sharples, S., Daylighting algoritms. Report ETSU, Univ. Of Sheffield, 1993.

[10] Longmore, J., Daylighting: a current view. *Light and Lighting*, 68, (1975), No. 3, 113-119.

[11] Perradeau, M., Climat lumineux à Nantes. Analyse des mesures effectuées en 1991-1994. EN-ECL 94-14L Report. Nantes : CSTB, 1994.

[12] Dumortier, D., Daylight availability in Lyon, Proc. of the European Conference on Energy .Lyon: Ecole Nationale des Travaux de l´Etat Lyon, 1315–1320, 1994.

[13] Darula S., Availability of vertical illuminance in Bratislava. *Building Res. Journal*, 46, (1998), No. 3, 211-225.

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