VPLYV OBLOHOVÝCH TYPOV NA PODMIENKY SVETELNEJ KLÍMY

THE INFLUENCE OF SKY TYPE ON DAYLIGHT CLIMATE CONDITIONS

Darula, S., Kittler, R.
Ústav stavebníctva a architektúry SAV

Abstract

Current daylighting inside buildings in Slovakia is designed according to the national standard STN 73 0580. Exterior illuminance is defined only for the overcast sky with the same azimuthal luminance and gradation conditions as specified by the standard. Real daylight conditions change considerably throughout the year and include also sunny and partly cloudy periods. To calculate the resulting exterior illuminance by integrating the luminace of sky elements in a solid angle of a window (i.e. looking at the sky from a particular place inside) it is very important to know the luminance distribution under different conditions. Luminance distribution can be modelled by indicatrix and gradation functions for different sky patterns as shown by the research carried out within the US-SK grant No. è.92 052. The parametrisation of long-term measured illuminance data in relation to luminance of the sky patterns can define the daylight climate in a specific location.

Introduction

The human dependence on daylight is evident more or less in all activities. Therapeutic and biological aspects of daylight or its necessity for visual perception of details on the working plane was described by a lot of authors, e.g. [1], [2], [3]. Generally interiors are illuminated by vertical or inclined windows and skylights respectively. Vertical windows are used in the majority of rooms. The quantity of illuminance on the working plane depends on the solid angle from any point through apertures in the building envelope extended to the sky and exterior obstructions respectively. Daylight penetrated into interiors usually comes from sky patches close to horizon up to 35 degree above it.

Because sunheight is changing continually as well as characteristics of the atmosphere, the daylight conditions are different and varied in time too. The results of older researches have presented mostly daylight conditions under homogeneous states, i.e. overcast and clear sky respectively, rarely measurements confirm the theoretic relative luminance distribution for both skies standardised by CIE [4], [5] and the mutual ISO/CIE [6] standard published in 1996.

The present study is considering continual changes of daylight during the whole year describing daylight occurrence frequencies and also typical daylight climate.

Sky types

After the adoption CIE Overcast and Clear skies by the ISO/CIE code the CIE activities were concentrated on finding models which could describe prevailing daylight condition in different regions. The Technical Committee TC 3.15 „Sky luminance models“ was created in 1987 and researchers from Japan and Slovakia have proposed three different sky luminance models [7], [8], [9]. Finally the model of US-SK 92 052 grant [10] was accepted and is now under review and approval procedures in the CIE community.

Because exterior daylight changes depend mainly on actual sunlight and skylight, the new system is using gradation and indicatrix functions dependent on the sun position and the placement of the sky element on the vault. Therefore the general formula for the luminance of an arbitrary element (L) relative to zenith luminance (Lz) is :

$$\frac{L}{Lz} = \frac{f(\chi)\,\varphi(Z)}{f(Zs)\,\varphi(0°)} = F(Z, Zs, \chi) \qquad (1)$$

where the partial formula for the relative gradation φ is :

$$\varphi(Z)/\varphi(0°) = [1 + a \exp(b/\cos Z)]/(1 + a \exp b) \qquad (2)$$

when Z is the angle of the sky element from zenith,

φ(0°) is the gradation function for the zenith, i.e. Z = 0°.

The relative scattering indicatrix can be modelled by an exponential formula :

$$f(\chi) = 1 + c[\exp(d\chi) - \exp(d\pi/2)] + e \cos^2\chi \qquad (3)$$

where χ is the scattering angle, i.e. the smallest angular distance of an arbitrary sky element from the sun position.

For every different sky type the gradation functions are modelled by parameters a, b whereas the indicatrix functions by parameters c, d and e [10]. The different parameters provide formulae not only for homogeneous cases, i.e. overcast and clear skies, but also for quasihomogeneous irregular and partly cloudy skies. The analysis of measured luminance distribution by scanners in Berkeley, Tokyo and Sydney tested several similar patterns during year [7], [8], [9]. Typical gradation and indicatrix functions were derived by the best fit method in [11]. Combinations of the six standard gradation and six indicatrix functions were chosen to standardise fifteen typical luminance distributions. The first five standards (I.1, I.2, II.1, II.2 and III.1) model daylight conditions under various overcast skies, the second group of five standards (III.2, III.3, III.4, IV.2 and IV.3) reflect stronger influence of sunlight with some clouds on the sky, the last group (IV.4, V.4, V.5, VI.5 and VI.6) describes sunny states with various turbidities.

Further parametrisation and classification of regularly measured data by zenith luminance to diffuse illuminance (Lz/Dv) with solar altitude and by ratio Dv/Ev for cases without sunlight (where Ev is horizontal extraterrestrial illuminance) and by luminous turbidity (Tv similar to Linke) for cases with sunlight, permit to cover almost all daylight situations encountered in the exterior. In this respect note the importance of situations with sunlight and without it which are related to relative sunshine duration.

Table 1. Monthly averages of relative sunshine duration in Bratislava, 1994 - 1998, after IDMP measurements.

Month	Year					5-year average
	1994	1995	1996	1997	1998	
January	0.296	0.184	0.159	0.104	0.309	**0.210**
February	0.359	0.338	0.438	0.435	0.560	**0.426**
March	0.304	0.307	0.329	0.465	0.465	**0.374**
April	0.430	0.387	0.482	0.441	0.419	**0.432**
May	0.436	0.529	0.417	0.547	0.539	**0.494**
June	0.473	0.408	0.575	0.488	0.520	**0.493**
July	0.668	0.700	0.519	0.410	0.474	**0.554**
August	0.587	0.535	0.481	0.689	0.587	**0.576**
September	0.498	0.426	0.194	0.695	0.339	**0.430**
October	0.388	0.475	0.423	0.519	0.295	**0.420**
November	0.220	0.114	0.298	0.280	0.284	**0.239**
December	0.245	0.090	0.244	0.113	0.138	**0.166**
Average	**0.409**	**0.374**	**0.380**	**0.432**	**0.411**	**0.401**

Table 2. Monthly averages of relative sunshine duration in Athens, 1992 - 1996 after information by NOA.

Month	Year					5-year average
	1992	1993	1994	1995	1996	
January	0.499	0.554	0.516	0.477	0.210	**0.451**
February	0.526	0.417	0.476	0.609	0.370	**0.479**
March	0.417	0.584	0.654	0.661	0.265	**0.516**
April	0.599	0.681	0.668	0.637	0.628	**0.643**
May	0.585	0.599	0.748	0.738	0.662	**0.666**
June	0.672	0.781	0.856	0.808	0.866	**0.797**
July	0.770	0.880	0.873	0.807	0.891	**0.844**
August	0.890	0.874	0.884	0.765	0.858	**0.854**
September	0.816	0.844	0.870	0.661	0.725	**0.783**
October	0.528	0.742	0.591	0.682	0.484	**0.506**
November	0.476	0.287	0.518	0.415	0.593	**0.458**
December	0.382	0.543	0.481	0.263	0.332	**0.400**
Average	**0.597**	**0.649**	**0.678**	**0.627**	**0.554**	**0.625**

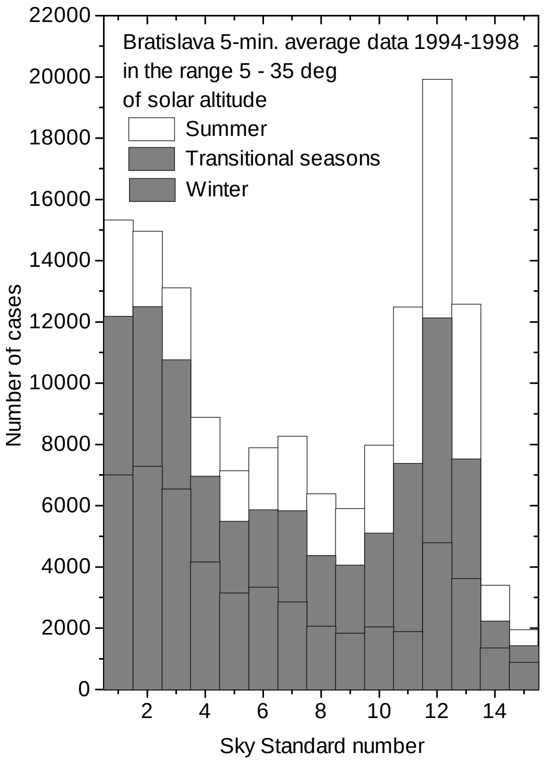

Figure 1 Seasonal number of cases of Sky Standard in Bratislava 1994-1998

Methodology and results

In Europe there are different daylight climates. The climate in the Central Europe is characterized by periodical changes of four seasons whereas in the Mediterranean there are dominant summer and winter seasons with weak transitional periods. The differences between climates can be adequately characterised by sunshine duration. The comparison of Bratislava to Athens data can specify significant situations with sunlight and skylight. The relative sunshine durations s_m at Bratislava (1994 - 1998) and at Athens (1992 - 1996) are given in Table 1 and Table 2. These were calculated after [12] with

Table 3 Occurrence of 5-minute average cases, Bratislava 1994-98, within solar altitude 5° - 35° for situations with and without sun

Sky Standard		Winter season (I +II+XI +XII)				Summer season (V+VI+ VII+VIII)			
		Number of cases			%	Number of cases			%
Code	No.	Without sun	With sun	Sum		Without sun	With sun	Sum	
I.1	1	6998		6998	13,25	3156		3156	7,45
I.2	2	7289	368	7289	13,81	2462	198	2462	5,81
II.1	3	6548	scarce	6548	12,40	2351	scarce	2351	5,55
II.2	4	4159	cases	4159	7,88	1927	cases	1927	4,55
III.1	5	3148	omitted	3148	5,96	1650	omitted	1650	3,90
III.2	6	3124	212	3336	6,32	1822	196	2018	4,76
III.3	7	2402	453	2855	5,41	1961	473	2434	5,75
III.4	8	1506	562	2068	3,92	1390	634	2024	4,78
IV.2	9	1167	661	1828	3,46	1152	695	1847	4,36
IV.3	10	1009	1033	2042	3,87	1305	1556	2861	6,76
IV.4	11		1877	1877	3,56		5106	5106	12,06
V.4	12	1946	4792	4792	9,08	2862	7789	7789	18,39
V.5	13	scarce	3617	3617	6,85	scarce	5042	5042	11,90
VI.5	14	cases	1354	1354	2,56	cases	1174	1174	2,77
VI.6	15	omitted	887	887	1,68	omitted	512	512	1,21
Sum		37350	15448	52798	100,00	19176	23177	42353	100,00

Table 3 Continued

Sky Standard		Spring + Autumn (III+IV+ IX+X)				Whole year			
		Number of cases			%	Number of cases			%
Code	No.	Without sun	With sun	Sum		Without sun	With sun	Sum	
I.1	1	5179	394 scarce cases omitted	5179	10,15	15333	960 scarce cases omitted	15333	10,49
I.2	2	5210		5210	10,21	14961		14961	10,24
II.1	3	4220		4220	8,27	13119		13119	8,98
II.2	4	2801		2801	5,49	8887		8887	6,08
III.1	5	2339		2339	4,59	7137		7137	4,88
III.2	6	2220	307	2527	4,95	7166	715	7881	5,39
III.3	7	2312	663	2975	5,83	6675	1589	8264	5,65
III.4	8	1540	755	2295	4,50	4436	1951	6387	4,37
IV.2	9	1257	971	2228	4,37	3576	2327	5903	4,04
IV.3	10	1251	1814	3065	6,01	3565	4403	7968	5,45
IV.4	11	2081 scarce cases omitted	5505	5505	10,79	6889 scarce cases omitted	12488	12488	8,54
V.4	12		7339	7339	14,39		19920	19920	13,63
V.5	13		3915	3915	7,68		12574	12574	8,60
VI.5	14		867	867	1,70		3395	3395	2,32
VI.6	15		544	544	1,07		1943	1943	1,33
Sum		28329	22680	51009	100,00	84855	61305	146160	100,00

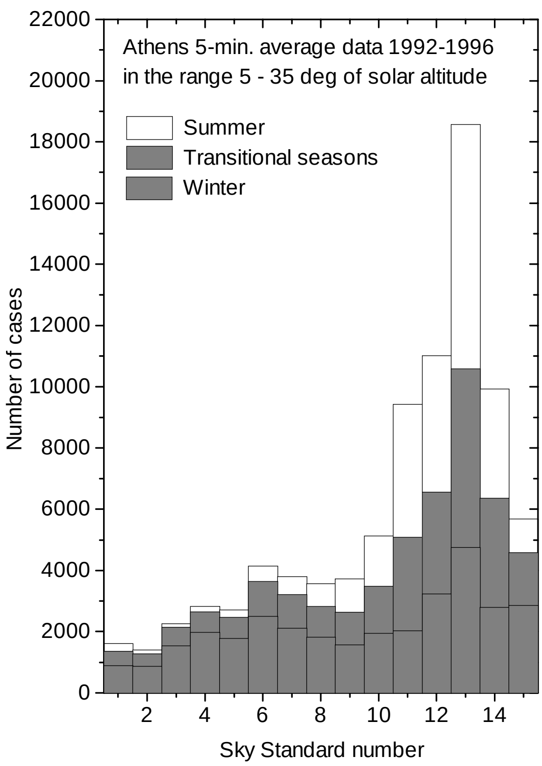

Figure 2 Seasonal number of cases of Sky Standard in Athens 1992-1996

border direct irradiance Ees>120 W/m^2. In tables 1 and 2 can be observed big differencies between the daylight climate in Bratislava and in Athens. While in Bratislava the winter period is evidently very cloudy ($s_m < 0.3$) there are many sunny situation in Athens. There is a transitional spring/autumn season in Bratislava with $s_m = 0.3$ to 0.5. Long and dominant sunny situations have to be expected in Athens during summer ($s_m > 0.7$).

The Standard Sky Luminance Distribution model [10], [11], allowed to investigate characteristic daylight climate conditions using the mentioned parametrisation system of Lz/Dv, Dv/Ev and Tv. After agreement with Greek colleaques from NOA Athens the 5-minute averages were calculated and

Table 4 Occurrence of 5-minute average cases, Athens 1992-96, within solar altitude 5° - 35° for situations with and without sun

Sky Standard		Winter season (I +II+XI +XII)				Summer season (V+VI+ VII+VIII)			
		Number of cases			%	Number of cases			%
Code	No.	Without sun	With sun	Sum		Without sun	With sun	Sum	
I.1	1	885		885	2,71	248		248	0,92
I.2	2	875	462	875	2,68	125	381	125	0,46
II.1	3	1534	scarce	1534	4,69	131	scarce	131	0,49
II.2	4	1977	cases	1977	6,05	179	cases	179	0,66
III.1	5	1786	omitted	1786	5,46	231	omitted	231	0,86
III.2	6	2177	321	2498	7,64	367	139	506	1,88
III.3	7	1355	767	2122	6,49	231	348	579	2,15
III.4	8	868	955	1823	5,58	195	553	748	2,77
IV.2	9	600	977	1577	4,82	212	883	1095	4,06
IV.3	10	478	1468	1946	5,95	245	1406	1651	6,12
IV.4	11		2035	2035	6,23		4345	4345	16,12
V.4	12	1183	3235	3235	9,90	1179	4465	4465	16,56
V.5	13	scarce	4754	4754	14,54	scarce	7989	7989	29,63
VI.5	14	cases	2790	2790	8,53	cases	3565	3565	13,22
VI.6	15	omitted	2853	2853	8,73	omitted	1102	1102	4,09
Sum		12535	20155	32690	100,00	2164	24795	26959	100,00

Table 4 Continued

Sky Standard		Spring + Autumn (III+IV+ IX+X)				Whole year			
		Number of cases			%	Number of cases			%
Code	No.	Without sun	With sun	Sum		Without sun	With sun	Sum	
I.1	1	476		476	1,82	1609		1609	1,87
I.2	2	407	304	407	1,56	1407	1147	1407	1,64
II.1	3	603	scarce	603	2,30	2268	scarce	2268	2,64
II.2	4	668	cases	668	2,55	2824	cases	2824	3,29
III.1	5	689	omitted	689	2,63	2706	omitted	2706	3,15
III.2	6	880	260	1140	4,36	3424	720	4144	4,83
III.3	7	616	479	1095	4,18	2202	1594	3796	4,42
III.4	8	417	586	1003	3,83	1480	2094	3574	4,16
IV.2	9	304	758	1062	4,06	1116	2618	3734	4,35
IV.3	10	366	1167	1533	5,86	1089	4041	5130	5,98
IV.4	11		3047	3047	11,65		9427	9427	10,99
V.4	12	840	3318	3318	12,68	3202	11018	11018	12,84
V.5	13	scarce	5829	5829	22,28	scarce	18572	18572	21,64
VI.5	14	cases	3569	3569	13,64	cases	9924	9924	11,56
VI.6	15	omitted	1726	1726	6,60	omitted	5681	5681	6,62
Sum		5426	20739	26165	100,00	20125	65689	85814	100,00

data for five year periods at Bratislava and Athens were studied by the statistical methods. For each Sky Standard the occurrence of cases in four seasons and the whole year were derived. Results presented on figure 1 and in the table 3 document occurrence in Bratislava where the CIE Clear Sky No. 12 or code V.4 and No.1 or code I.1, i.e. CIE Overcast Sky, seem to be most significant. The occurrence of these opposite situations is prevailing in each season.
Another situation can be expected in Athens. The occurrences of cases documented in table 4 and presented on figure 2 show dominant abundance of clear skies during each season. The movement of the peak to predominant Standard V.5, turbid CIE Clear Sky, signalizes a higher pollution content of the atmosphere which confirms higher turbidity.

Conclusions

The statistical evaluations of long-term measured data can show differences in daylight conditions in any climate zone. The comparison of two different climates in Bratislava and in Athens demostrate evident differences. While overcast sky standards occur from 12,40 % to 13,81 % in Bratislava during winter, these represent only 2,68 % - 4,69 % in Athens. The marked differences can be found in summer when the occurrence of overcast skies in Bratislava is 5,55 % - 7,45 % contrary to 0,46 % - 0,92 % in Athens. Fewer sunny situations can expected in Bratislava than in Athens, in winter it is 9,08 % in summer about two times, i.e. 18.39 %. In Athens CIE Clear Sky with turbidity around Tv = 4 can appear 9.9%, while polluted clear skies can rise to 14.54 % in winter. Very high occurrence of clear skies was observed in summer, i.e. around 16.56 % for CIE and up to 29.63 % for clear polluted situations. This coincides with the high summer sunshine duration. The occurrence of typical daylight conditions is characterised by U distribution in Bratislava not only during winter but in summer too. The first peak represents overcast skies the second clear skies. Different conditions are in Athens with one peak frequency distribution to clear skies.
The study of standard skies for maritime climates was recently published by Tregenza [13] aimed at the prediction daylight in interiors. After a best-fit analysis of scanning measured luminance distribution data collected in Singapore (2272 scans), Fukuoka (151 scans) and Garston (12025 scans) the number of prevailing skies could be restricted to four types with the most frequency of occurrence. These are:

- type I.1, CIE Overcast Sky standard,
- II.1, overcast sky with a less steep gradation than the CIE Overcast Sky,

- III.4, rather uniform with an obvious solar corona,

- V.5, CIE Clear turbid clear sky.

The studies of daylight climates after standardised luminance distribution conditions [9] could be useful for predicting daylight climate in different regions. The advantage of this method is the utilisation of data collected in the International Daylight Measurement Programme CIE/WMO. Relevant and compatible data collected at the IDMP stations can show comparisons such as those from Bratislava and Athens published in this paper.

Acknowledgement Authors are grateful to the Ministry of Education SR and ICA SAS for the support of the grant VEGA no. 2/6050/99 and grant GR-SK no.13/98 under which reported results were obtained.

Keywords daylight climate, sky types, illuminance, luminance distribution, sunshine duration

References

1. Ne´eman E.(1974) : Visual aspects of sunlight in buildings. Light. Res. and Technol., 6, 3, 159-164.
2. Steck B.(1982) : Effects of optical radiation on man. Light. Res. and Technol., 14, 3, 130-1141.
3. Muneer T.(1997): Solar radiation and daylight models, Architectural Press,Oxford.
4. CIE Commission Internationale de l´Eclairage (1955): Natural Daylight, Official Rocommendation. Compte Rendu CIE 13 Session, 2 part 3.2, 2-4.
5. CIE Commission Internationale de l´Eclairage (1973): Standardisation of luminance distribution on clear skies, CIE Publ. 22, Paris.
6. ISO/CIE 15469 (1997) Spatial distribution of daylight - CIE standard overcast sky and clear sky
7. Igawa N., Nakamura H., Marsuzawa T., Koga Y., Goto K. and Kojo S.(1997): Sky luminance distribution between two CIE standards skies1.2. Proc. Lux Pacifica, E7-E18.
8. Nakamura H., Oki M. and Hayashi Y. (1985): Luminance distribution of intermediate sky. J. Light and Vis. Envir., 9, 1, 6-13.
9. Kittler R., Perez R. and Darula S.(1997) : A new generation of sky standards. Proc. Lux Europa Conf., 359-373.
10. Kittler R., Perez R. and Darula S. (1998) : A set of standard skies. Polygrafia SAV Bratislava.
11. Kittler R. (1997): A new exterior daylight standardisation system for all future design needs. Proc. Lux Pacifica Conf. E1-6.
12. CIE 108-1994 Guide to recommended practice of daylight measurement. Pub. CIE Central Bureau, Vienna, 1994.
13. Tregenza P.R. (1999): Standard skies for maritime climates, Light. Res. and Technol., 31, 3, 97-106.

Ing. Stanislav Darula, CSc, Ing. Richard Kittler, DrSc, Ústav stavebníctva a architektúry SAV, Dúbravska 9, 842 20 Bratislava, e-mail : usarsdar@savba.savba.sk