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Comparative Study of summer, Winter and Quinox Sky Type of India Using Daylight Coefficient Method and Cie Standard General Sky Model

Sutapa Mukherjee, M.Tech.
Assistant Professor, Electrical Engineering Department
B. P. Poddar Institute of Management & Technology, Kolkata-700052. INDIA

Abstract:- Energy efficiency provided by daylight requires an accurate estimation of the amount of daylight entering a building. The actual daylight illuminance of a room is mainly influenced by the luminance levels and patterns of the sky in the direction of view of the window at that time. The daylight coefficient concept, which considers the changes in the luminance of the sky elements, offers a more effective way of computing indoor daylight illuminances. Recently, Kittler et al. have proposed a new range of 15 standard sky luminance distributions including the CIE (International Commission onIllumination) standard clear sky. Lately, these 15 sky luminance models have been adopted as the CIE Standard General Skies.This paper aims to find out representative CIE (International Commission on Illumination) Standard Clear Sky model(s) for three different seasons-winter solstice, equinox, and summer solstice applicable for prevailing clear sky climatic conditions in India [Roorkee]. Indian measured sky luminance distribution database is available only for Roorkee[$29^0 51^{'}$N; $77^0 53^{'}$E]. To find out the best match between Indian measured sky luminance distribution and each of five CIE Standard Clear sky models, only sky component of spatial illuminance distribution over the working plane of a room was simulated by MATLABfor three different seasons. Daylight Coefficient method has been applied for the simulation using Indian sky luminance database.The simulation has been done for the room with eight different window orientations ranging from 0^0 to 315^0 with an interval of 45^0 to generate data for the entire sky vault. To find out the best fit CIE model(s)Indian measured sky luminance distribution data is taken as reference. Analysis revealed that CIE Standard General Clear sky type 15 described as *"White-blue sky, turbid with a wide solar corona effect"*is the best-fit clear sky model for both summer and equinox seasonsand sky type 11 described as *"White blue sky with a clear solar corona"* is the best-fit clear sky model for winter seasonat Roorkee.

Keywords:- Daylight Coefficient method, CIE Standard general sky models, Daylight factor.

I. INTRODUCTION

Daylighting is an important issue in modern architecture.The evaluation of visual comfort and energy efficiency due to daylighting requires an accurate estimation of the amount of daylight for any pointwithin the internal space.Conventionally, the illuminance from natural sources is often determined in terms of daylight factor (DF) with the calculations being based on an overcast sky [1], which is often considered to provide the worst design condition for daylighting. Actually it has been found, from simultaneous measurements of daylight that the ratio of internal to external illuminance varies greatly under real skies. This means that it is inaccurate to predict the illuminance at a point in a room by just multiplying the level of external available daylight by the daylight factor or by any other constant ratio.Prediction of daylight availability in an interior space at different seasons throughout a year is important for daylighting design.This prediction of daylight availability is made either in absolute illuminance or in relative illuminance with respect to external illuminance. In either case sky luminance distribution model or data is required. CIE(International Commission on Illumination) proposed its homogeneous sky types with the understanding that the 15 sky luminance distributions represent the sky type at any location all over the world for different seasons. Out of 15 sky types, five types represent overcast skies, five types represent intermediate skies and the rest five types represent clear skies**[2]**. Attempts have been made earlier to utilize CIE 15 General Sky models for daylight predictions **[3]** and also to correlate these Standard models with measured sky luminance data **[4]**. So to utilize the CIE Standard general sky model for the prediction of daylight illuminance at a particular location, the relevant sky type representing the prevailing sky luminance distribution for different seasons throughout the yearmust be known.At present, Daylight Coefficient technique is the commonly used tool for daylighting design using sky luminance distribution **[5,6]**. Under IDMP(International Daylight Measurement Program) monthly averagedhourly sky luminance distribution data was available in India at Roorkee(latitude $29^0\ 51^{'}$ (N), longitude(E) $77^0 53^{'}$) at three different seasonal conditions-summer solstice,winter solstice and equinox**[7]**.

In this paper attempt was made to find out the best fit CIE Standard General Sky type(s) which represents sky pattern at Roorkeeduring above three different seasonal conditions.The performance of the Indian sky model was also evaluated along with CIE Standard skies. To do this one sample room with single-sided window was considered for prediction of available daylight distribution on working plane and subsequent comparison. Two MATLAB programs were written to compute absolute illuminance in Lux at different station points over working plane. In one program, measured clear sky luminance data was takenusingDaylight Coefficient method and in the other program five types of CIE clear sky models were used. The predicted data obtained from Daylight Coefficient method were taken as reference and percent illuminance deviation were computed for each clear sky type to find outbest fitCIE sky type prevailing at Roorkee.

II. CIE STANDARD GENERAL SKY MODELS

In 2003 CIE published spatial luminance distribution data for fifteen CIE Standard General Skies. The relative sky luminance distribution was modeled based on the theory of sunlight scattering within the atmosphere and expressed by the product of two different exponential functions viz, gradation function $\phi(\frac{\pi}{2}-\gamma)$ and indicatrix function f(χ) as **[2]**

$$\frac{L_{\gamma\alpha}}{L_z}=\frac{f(\chi)*\varphi(\frac{\pi}{2}-\gamma)}{f(\frac{\pi}{2}-\gamma_s)*\varphi(0)}\cdots\cdots(1)$$

$L_{\gamma\alpha}$ = Luminance (cd/m^2) of any sky element specified by altitude angle γ and azimuth angle α
L_z = Luminance (cd/m^2) of sky at zenith, i.e. at $\gamma = \pi/2$
χ = scattering angle between the sun and sky element
γ_s = altitude angle of sun
Here γ and α angles are in radian.
The direction of altitude angle is measured from horizon (0^0) upward up to zenith (90^0) and the direction of azimuth angle is taken due north (0^0) and clockwise.
Now the gradation function is given by,

$$\varphi(\frac{\pi}{2}-\gamma)=1+a*\exp(\frac{b}{Cos(\frac{\pi}{2}-\gamma)})\cdots\cdots(2)$$

For zenith $\gamma = \pi/2$, and gradation function becomes

$$\varphi(0)=1+a*\exp(b)\cdots\cdots(3)$$

The indicatrix function is given by,

$$f(\chi)=1+c*[\exp(d*\chi)-\exp(d*\frac{\pi}{2})]+e*Cos^2\chi\cdots\cdots(4)$$

The scattering angle (χ) can be calculated from the following formula

$$\chi=Cos^{-1}[Sin\gamma*Sin\gamma_s+Cos\gamma*Cos\gamma_s*Cos(\alpha-\alpha_s)]\cdots\cdots(5)$$

where α_s = solar azimuth angle (radian).

The indicatrix function for zenith

$$f(\frac{\pi}{2}-\gamma_s)=1+c*[\exp(d*(\frac{\pi}{2}-\gamma_s)-\exp(d*\frac{\pi}{2})]+e*Cos^2(\frac{\pi}{2}-\gamma_s)\cdots\cdots(6)$$

wherea,b,c,d,e are standard parameters used to represent CIE 15 Standard General skies. The values of these parameters are tabulated in **Table 1**.

2.1 Indian Measured Sky Luminance Distribution Data:

The sky luminance distributions of sunny clear sky condition during three seasons (summer solstice, winter solstice and equinox) which were measured at Central Building research Institute [CBRI] with a sky-scanner from M/S EKO Japan, having a field of view of 11^0 and the total measurements were completed for the whole sky vault in three minutes [7]

III. COMPUTATION OF SPATIAL ILLUMINATION DISTRIBUTION

The spatial illuminance distribution has been computed on 150 station points over working plane of a room having dimension 30m x 20m x 4m with a centrally placed single-sided clear window opening of 28m long and 3m height. The working plane has been considered at height of 1m from the floor. The reflectances of ceiling, walls and floor are taken as 80%, 70% and 20%.
The sky illuminance [E] at any horizontal station point is computed by

$$\mathrm{E}=\int_{\alpha_1}^{\alpha_2}\int_{\gamma_1}^{\gamma_2}\mathrm{L}_{\gamma\alpha}*\mathrm{Sin}\gamma*\mathrm{Cos}\gamma*\mathrm{d}\gamma*\mathrm{d}\alpha\cdots\cdots(7)$$

where α_1, α_2 and γ_1, γ_2 represent lower and upper limits of horizontal and vertical acceptance angles with respect to station point.

3.1 With five CIE Standard clear skies:

Spatial illuminance distribution over the working plane was computed for five CIE Standard Clear Skies using Eqn.(7) by including the values of $L_{\gamma\alpha}$ from Eqn.(1). Now for clear sky condition $L_{\gamma\alpha}$ depends on sun position specified by solar altitude [γ_s] and solar azimuth [α_s]. To compute sun position during winter, equinox and summer, three months viz. January, March and June were considered respectively. The values of Julian day were taken as 15, 74 and 166 for the above three months respectively. The computation was done for eight window orientations as mentioned earlier through developed MATLAB program for three seasonal sky conditions. For computation of sun position and related parameters, algorithms were taken from Daylight Algorithms **[10]**. The values of Zenith Luminance(L_z) at 12 noon is taken from measured sky luminance data as given in **Table 2**.

Table - 1: Values of Standard parameters for five CIE Standard Clear Sky types **[2,4]**

No.	Type of CIE Standard Clear sky	For gradation		For indicatrix		
		a	b	c	d	e
11	White blue sky with a clear solar corona	-1	-0.55	10	-3	0.45
12	Very clear/unturbid with a clear solar corona	-1	-0.32	10	-3	0.45
13	Cloudless polluted with a broader solar corona	-1	-0.32	16	-3	0.3
14	Cloudless turbid with a broader solar corona	-1	-0.15	16	-3	0.3
15	White-blue sky, turbid with a wide solar corona effect	-1	-0.15	24	-2.8	0.15

Table - 2: Values of Zenith Luminance at Roorkee at12 noon **[7]**

Season	Value of L_z in kcd/m^2
Summer	25.5
Equinox	5.8
Winter	4.1

3.2 With Indian Measured sky luminance data:

As there is no analytical expression for Indian sky luminance distribution Eqn.(7) can not be used directly. Here Daylight Coefficient method was applied to use discrete sky luminance data available from measured iso-luminance contour

3.2.1 Daylight Coefficient Method:

Daylight illuminances inside a room are not in general proportional to the external illuminance, but depend on the exact sky luminance distribution at that time. This is because a point in a room will receive direct light only from certain areas of the sky and the illuminance within a room is not equally sensitive to changes in the luminance of different parts of the sky.Daylight Coefficient method **[10]** utilizes the sky luminance data of the portion of the sky as seen from the station point through the window to predict point-specific indoor illuminance. The Daylight Coefficient [$\Delta D_{\gamma\alpha}$] is defined by the ratio of total illuminance at a particular point to the product of luminance of that sky element and the solid angle subtended by sky element at that point.and mathematically expressed

$$D_{\gamma\alpha} = \frac{\Delta E_{\gamma\alpha}}{L_{\gamma\alpha} * \Delta S_{\gamma\alpha}} \quad \text{…………(8)}$$

where,

$\Delta E_{\gamma\alpha}$= illuminance at any station point for the sky element specified by angles γ,α

$L_{\gamma\alpha}$ = luminance of that sky element

$\Delta S_{\gamma\alpha}$ = solid angle subtended by above sky element at the station point.

To compute point-specific horizontal illuminance on working plane of a room the expression for Daylight Coefficient is

$$D_{\gamma\alpha} = sin\gamma \quad \text{…………..(9)}$$

Hence the Eqn.(7) is modified as

$$E = \sum_{\alpha_1}^{\alpha_2} \sum_{\gamma_1}^{\gamma_2} \Delta L_{\gamma\alpha} * Sin\gamma * \text{Cos}\gamma * \Delta\gamma * \Delta\alpha \quad \text{……..(10)}$$

IV. ROOT MEAN SQUARE DEVIATION COMPUTATION

To find out the similarity between two sets of spatial illuminance distribution over the working plane, Root Mean Square of percentilluminance deviation value was calculated. Theilluminance distribution obtained from Daylight Coefficient method was taken as Referencevaluewhereas that obtained from five types of CIE General Standard Clear skies andIndian Clear Design sky were taken as Test value.The minimum RMS value ofilluminance deviation was taken as an indicator for the closest matching.

4.1 Results and conclusion:

It is important to mention here that available Indian measured sky luminance data **[6]** are hour-wise monthly averaged data. Sky Luminance distribution data measured in January,March and June represent winter solstice, equinox and summer solstice respectively.Moreover, linear interpolation was done to pick up sky luminance values for 145 skyelements from iso-luminance contours which is one of the sources of deviation. On the other hand, the CIE sky models are mathematical models with which day and time specific skyluminance distribution can be simulated. The Indian Design Clear sky model assumes axiallysymmetric sky luminance distribution which is far from the real sky distribution.The computed RMS values of percentilluminance deviation for eight window orientations and for three seasonswere tabulated in **Table 4**. The average values ofpercent RMS deviations for the three seasons were graphically shown in **Fig.1**

Table - 4:RMS values of percentIlluminance deviations for Local solar time 12noon

W_{nom}(Deg) Window Orientation	0 N	45 NE	90 E	135 SE	180 S	225 SW	270 W	315 NW	Average % RMS Deviation
Sky Type	**Percent RMS deviation for Summer Solstice**								
CIE_11	78	60	44	33	40	59	76	83	59
CIE_12	100	80	60	44	53	76	97	105	77
CIE_13	57	40	29	25	29	43	58	63	43
CIE_14	74	55	38	27	35	56	75	81	55
CIE_15	52	34	26	25	28	41	56	60	40
Sky Type	**Percent RMS deviation for Equinox**								
CIE_11	46	33	27	31	32	29	30	38	33
CIE_12	66	48	28	24	27	26	27	55	39
CIE_13	29	23	26	32	32	28	26	27	28
CIE_14	46	33	22	24	27	26	30	40	31
CIE_15	17	22	28	31	30	27	24	22	25
Sky Type	**Percent RMS deviation for Winter Solstice**								
CIE_11	57	43	26	27	29	26	27	40	34
CIE_12	83	64	33	23	27	24	32	59	43
CIE_13	47	35	22	27	34	31	25	34	32
CIE_14	72	55	30	31	42	38	33	53	44
CIE_15	21	18	17	33	47	42	26	21	28

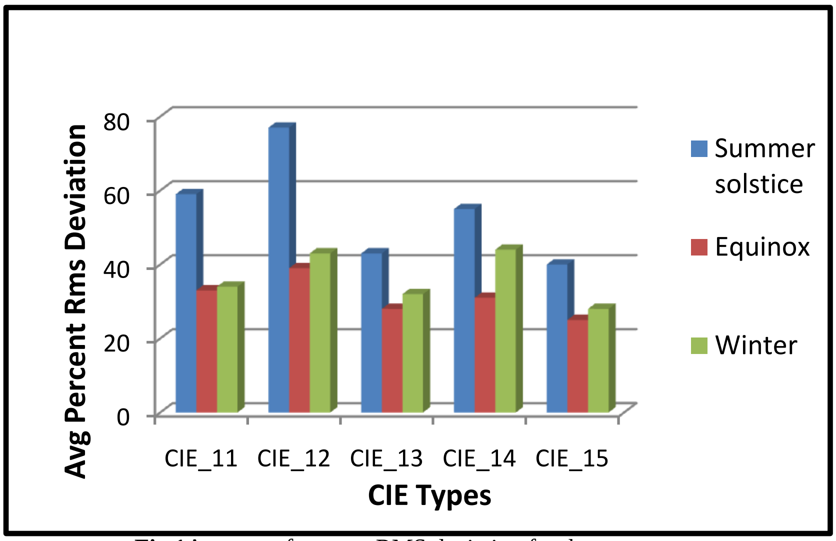

Fig.1 Average of percent RMS deviation for three seasons

It is important to mention here that available Indian measured sky luminance data **[6]** are hour-wise monthly averaged data. Sky Luminance distribution data measured in January, March and June represent winter solstice, equinox and summer solstice respectively.

This study may be done by comparing iso-luminance contours of measured sky luminance distribution and CIE mathematical models or by comparing sky luminance values of 145 sky elements. In this approach entire sky vault would be taken into account. But in our approach sky illuminance distribution on working plane of a room was considered for comparison because for the prediction of indoor illuminance the contribution from the visible portion of sky is much more effective than the entire sky vault. The contributions from the entire sky come through reflection from external obstructions and ground. In this study window height 3m was taken to include the effect of sky portions from horizon to well above horizon about 70^0.

However, this comparison was done based on the daylighting distribution only for local time 12 noon when solar azimuth is 180^0. Similar hour-wise study for complete duration of day will be effective to draw more comprehensive conclusion.

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