Optimization of daylight use in building for Mild composite climate(Indore)

Umesh Namdev
IPS, Indore
umesh.namdev@gmail.com

Abstract-India exhibits a vast variety of climates. The climate ranges from warm and humid in the coastal areas, hot and arid deserts of Rajasthan and there is dry and cold at the higher altitudes of Ladhakh and Leh region. However, the composite climate, which is a dominant factor in most of the mid latitudes of India, where no single season predominates, poses a challenge to the designer as it has to meet both heating requirements during the winter and cooling requirements during summers with weak driving force of natural energies. Traditional architecture in some form or the other had taken into account the climatic diversity in the form of building materials use, orientation, fenestration etc.

The thermal energy flow in a passive building is wholly through natural means of heat transfer i.e. natural conduction, convection and radiation. The term solar architecture means buildings whose design amasses the thermal directional and seasonal aspects of the sun. Solar gain through windows, walls and skylight clerestory and roof sections use the opportunity to reduce the total heating energy requirements of a building.

Daylight

Daylight is the visible part of the solar radiation as perceived by the eye. Daylight is composed of a spectral power distribution (SPD) of electromagnetic radiation in the visible wavelength range (380 to 780 nm). Basically, the daylight has two components viz. sunlight and skylight. Sunlight is the direct component of light coming from the sun, which is variable in nature and creates glare and shadow. On the other hand, skylight is a diffuse component of light coming from the sky dome. Sky light is quite steady and does not create glare and shadow. The spectral distribution and efficacy of skylight and sunlight are found to be somewhat different. The beam and diffuse solar irradiance values, obtained as a part of meteorological weather data, give the total solar radiation (from the sun and the sky) hitting the earth at a particular place. This contains visible, and also the invisible portions of the solar radiation. The luminous efficacy

Energy is now considered as one of the important dimensions in building design. The major components of a building include:

i. The walls and roof which protect man from the extremities of the environment outside.
ii. The windows and ventilators for daylight, solar heat gain and ventilation and
iii. The doors that cause infiltration.

Major consumption of conventional energy in buildings is for cooling, heating, and lighting purposes. For understanding these aspects of the window in a mild composite climate, Indore (latitude 22.720N, longitude 75.90E, altitude 567m above mean sea level) was chosen as a representative city for our study. A normal size room 6m x 4.5m x 3m with a centrally installed window in one of the cardinally oriented wall was used to study the effect of various window parameters on the quantity of light, quantity of heat and luminance distribution at the task level in the entire room.

(lm/W) of a light source, which is defined as the ratio of luminous flux to the radiant flux, can be estimated through luminous efficacy models that are used to convert the portion of the irradiance into the illuminance.

Daylight is found essential for all the basic needs of a human being. It has been established that the people working in a day-lit environment are less susceptible to illness and fatigue as compared to when they work under artificially lighted indoor spaces. In contrast to artificial lighting systems which give a fixed intensity, color rendering and texture, daylight is characterized by time varying properties but is available only during the daytime.

Mathematical Models

-Illuminance data records are seldom available and therefore, designers have to rely on various models for estimation of daylight. Beam and diffuse solar irradiance values which are available from meteorological stations and are commonly used for estimation of illuminance values using efficacy models. If no measured data sets of irradiance values are available it is also a practice to use the irradiance models based on other available meteorological data as an alternative.

Using the horizontal illuminance values thus obtained the daylighting performance of a building is evaluated in terms of daylight factor, which by definition is the ratio of interior illuminance and that of the illuminance outdoors on horizontal surface under overcast-sky conditions [1.5]. For overcast sky, there are two patterns viz. thin and heavily covered sky [1.6]. The thin overcast-sky may include a circumsolar component and the sky luminance pattern is azimuth and altitude independent. The overcast-sky model is applicable only to a heavy overcast sky, in which sky luminance has only altitude dependence and is often considered to provide the worst design conditions for daylighting.

The Irradiance models –

In this section method used for estimation of beam component and diffused component of solar irradiance received by an inclined surface from the measured or estimated beam and diffused components received on horizontal surfaces has been described. Various models for estimation of diffused component on horizontal surface have also been reviewed.

An inclined plane surface is specified in terms of its tilt

$$\cos\theta_i = \sin\alpha_s \cos\beta + \cos\alpha_s \sin\beta\cos(\gamma_s - \gamma_i)$$

angle β, orientation angle (azimuth angle) γi and area of the surface. The surface receives direct radiation from the sun (also known as beam radiation) and diffuse radiation from the sky and reflected diffuse radiation from the ground visible to the surface.

The total irradiance on an inclined surface, G_i, is defined as the sum of beam, diffuse, and ground reflected

$$G_{b,i} = G_b \cos\theta_i / \sin\alpha_s = R_{b,i} G_b$$

components of solar irradiance i.e.

$$G_i = G_{b,i} + G_{d,i} + G_{r,i}.$$

The beam irradiance on inclined surfaces ($G_{b,i}$) may be calculated from the equation given below

Where α_s is solar altitude angle and G_b is the measured beam irradiance on the horizontal surface generally available from recorded meteorological data on hourly basis, R_{bi} is the tilt factor defined by the expression: ($\cos\theta_i / \sin\alpha_s$).

The solar altitude angle, α_s angle of

incidence, θ_i, on a surface may be calculated from the following relations [1.7]:

$$\sin\alpha_s = \cos\phi_L \cos\delta\cos\omega + \sin\phi_L \sin\delta$$

Where γ_s is the solar azimuth angle, γ_s for a given hour of the average day of a month at a given location can be calculated from the relation:

$$\cos\gamma_s = (\sin\alpha_s \sin\phi_L - \sin\delta) / \cos\alpha_s \cos\phi_L$$

Where ϕ_L is the latitude of place, and δ is the solar declination, which can be estimated from:

δ=23.45° sin [360(284+J)/365]

Where J is the average Julian day (starting from Jan1) for each month. For design purposes ,the yearly performance of the building systems ,are evaluated in terms of their monthly performance. To reduce the number of calculations the monthly performance is evaluated in terms of the average day of each month. Average day of each month and corresponding Julian day values are given in Table 1.1

ω is the hour angle expressed as:

ω= (ST-12)*15° (see table 1.1)

Diffuse radiation generally may consist of three components

i) Isotropic radiation from the sky dome,

ii) Circumsolar diffuse radiation (Figure 1.1), and

iii) Horizon brightening.

The isotropic component is received uniformly from the entire sky dome (Fig. 1.2).

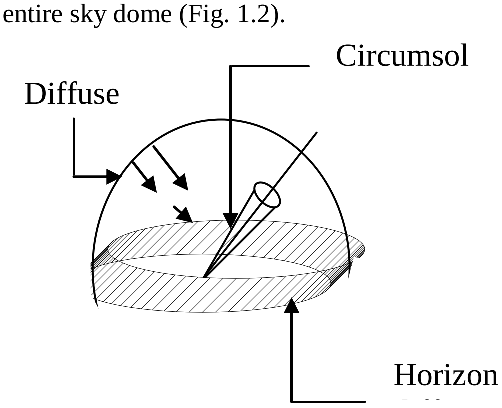

Figure1.1 The circumsolar and horizon brightening components

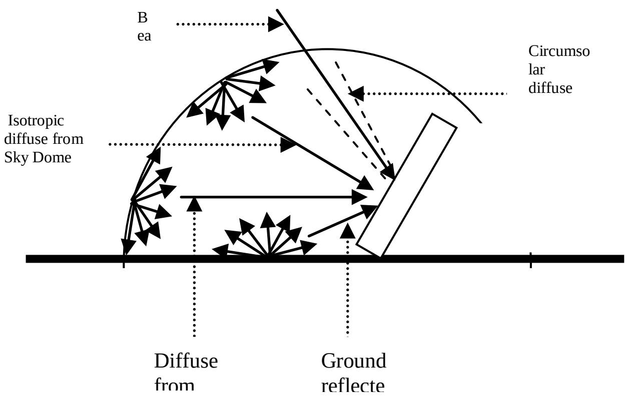

Figure1. 2. The isotropic diffuse radiation from sky dome

In a simple case of isotropic sky, the diffuse irradiance on

$$G_{d,i} = G_d (1 + \cos\beta)/2$$

inclined surface ($G_{d,i}$)can be expressed as.

Where G_d is the measured diffuse irradiance on the horizontal surface and is also generally available from recorded meteorological data on hourly basis.

Assuming isotropic reflection for the beam and the diffuse components of solar irradiance, the ground reflected irradiance on inclined surface ($G_{r,i}$) may be calculated from the following relation:

$$G_{r,i} = \rho_g G (1 - \cos\beta)/2$$

Where $G=G_b+G_d$ is the global irradiance on the horizontal surface and ρ_g is the diffuse reflectance of the ground surface in front of the surface.

However, in actual practice the radiance distribution of the sky is not isotropic. In view of this, an anisotropic diffuse sky model may be used to accurately estimate irradiance on an inclined surface.

The circumsolar component results from forward scattering of solar radiation and gets concentrated in the sky around sun. The horizontal brightening is usually concentrated near the horizon and is seen most pronounced in clear skies. The circumsolar component of solar irradiance is defined as the amount of solar radiation coming from a circle in sky centered on the sun's disk having a radius of 2.5° to 3.5°. This area of the sky is brighter than other areas of the sky especially under clear sky conditions. To account for this circumsolar anisotropy and horizon brightening, models have been proposed which are discussed below.

Perez et al. Model

In irradiance model of Perez et al. [1.1], the circumsolar and the horizon/ zenith anisotropy are controlled by two coefficients F_1 and F_2, respectively. The diffuse irradiance on an inclined surface in this model is given by

$$G_{d,i} = G_d \begin{bmatrix} (1 - F_1)(1 + \cos\beta)/2 \\ + F_1 a/b + F_2 \sin\beta \end{bmatrix}$$

............(1.1)

Where a = max [0, cos(θi)] and b = max [cos 85°, cos(θ_z)]. The coefficients F_1 and F_2 are defined as the functions of sky's clearness (ε), sky's brightness (Δ), and solar zenith angle (θ_z). These may be evaluated using the following expressions:

F_1=max [0, {F_{11}+ F_{12} Δ + θ_z F_{13}}] ……..... (1.2)

F_2=max [0, {F_{21}+ F_{22} Δ+ θ_z F_{23}}………..... (1.3)

The values of F_{11}, F_{12}, F_{13}, F_{21}, F_{22} and F_{23}, as determined experimentally by Perez et al. [1.12], are given in table 1.2 as a function of sky clearness index. The ε and Δ may be evaluated using the following expressions:

$$\varepsilon = \left[\left(G_{b,n} + G_d \right) / G_d + 1.041\theta_z^3 \right] / \left(1 + 1.041\theta_z^3 \right)$$

$$\Delta = G_d m_a / G_{o,n}$$

Where $G_{b,n}$ is ground level beam irradiance at normal incidence, $G_{o,n}$ is extraterrestrial irradiance at normal incidence and m_a is optical air mass.

Table 1.2 Experimental coefficients for estimating irradiance on sloping surface

ε (bin)	1	2	3	4	5	6	7	8
F_{11}	-0.008	0.129	0.329	0.568	0.873	1.132	1.060	0.677
F_{12}	0.587	0.6826	0.486	0.187	-0.3	-1.2	-1.5	-0.3

					92	36	99	27
F_{13}	-0.062	-0.1514	-0.221	-0.295	-0.361	-0.411	-0.358	-0.250
F_{21}	-0.059	-0.0189	0.055	0.108	0.225	0.287	0.264	0.156
F_{22}	0.072	0.0660	-0.064	-0.151	-0.462	-0.823	-1.127	-1.376
F_{23}	-0.022	-0.028	-0.026	-0.014	0.001	0.055	0.131	0.250

Estimation of diffuse irradiance on a surface inclined at an angle β

Researchers have investigated the relation between solar radiation and daylight and have proposed various mathematical models The model proposed by Perez et al. is usually considered to be most accurate and therefore, selected to predict hourly.

CALCULATION:-

Perez et al. Model

- Where a = max [0, cos(θi)] and b = max [cos 85°, cos(θ_z)].
- The coefficients F_1 and F_2 are defined as the functions of sky's clearness (ε),
- sky's brightness (Δ),
- and solar zenith angle (θ_z).
- These may be evaluated using the following expressions:

F_1=max [0, {F_{11}+ F_{12} Δ + θ_z F_{13}}]

F_2=max [0, {F_{21}+ F_{22} Δ+ θ_z F_{23}}]

- Where G_d is the diffuse horizontal irradiance,
- $G_{b,n}$ is the normal beam irradiance;
- θ_z is the solar zenith angle in radians.
- θ_z and $G_{b,n}$ for a given location and time of the year can be estimated from the relations:

$$G_{d,i} = G_d \left[\begin{matrix} (1-F_1)(1+\cos\beta)/ \\ 2 + F_1 a/b + F_2 \sin\beta \end{matrix} \right] ...(1.1)$$

- Where ϕ_L is the latitude of place, and δ is the solar declination, which can be estimated from:
- δ=23.45° sin [360(284+J)/365]
- *Cos* θ_z =*cos*ϕ_L *cos*δ *cos* ω+*sin*ϕ_L*sin*δ
- $G_{b,n}$= G_b /cos (θ_z) , Where G_b is the beam irradiance.
- The sky brightness (Δ) is given by:
- Δ=(G_d/G_o). cos (θ_z)
- G_o is the extraterrestrial irradiance
- G_o =1367[1+0.033cos (360/365) n] cosθz w/m2
- Gd=C.Gb w/m2
- Gb=A.exp.(-B/cosθz) w/m2

Conclusions

Using established models the monthly mean of hourly Luminous Efficacy and then the exterior illuminance (diffuse, direct and global) on horizontal and for all the four walls (N-S-E-W) of any building in Indore has been computed.

For almost all the cases, the optimum height of the sill is higher than the desk level and there is a considerable amount of reduction in daylight if the sill height increases from the desk level of 0.75 meters.

With an increase in overhang width, the decrease in daylight is significant in south facing window in December, while in all the other cases, the decrease is minimal. A uniform spread of daylight is achieved through north window in both the months of June and December months indicating that this orientation is optimum for daylight design of buildings. It is also seen that the effect of overhang width on skylight and sunlight is more prominent near to the window.

ST is the Solar Time.

Month	Date	Day of the Year
January	17 Jan	17
February	16 Feb	47
March	16 March	75
April	15April	105
May	15 May	135
June	11 June	162
July	17July	198
August	16 Aug	228
September	15 Sep	258
October	15 Oct	288
November	14 Nov	318
December	10 Dec	344

Table 1.1 Average Julian day of each month [1.8]

Reference

[1]. Estimation of Illuminance efficacy of daylight and exterior luminance for composite climate of Indore city in Mid Western India, Renewable Energy, July 2007, Pages 1363-1378.
[2]. Mathematical models for Estimation of Daylighting in Buildings: A review, Journal of the Solar Energy Society of India (2006) Pages 45-67.
[3]. Parametric Studies of Internal Illuminance of Daylight through Window Location and Orientation for composite climate of Indore city in Mid Western India (communicated.)
[4]. Studies on Solar Heat Gain through Window Location and Orientation for composite climate of Indore city in Mid Western India (communicated).
[5]. Optimization of the working plane for daylight use in winters through the South façade with overhang width variation (communicated).
[6]. Experimental and Theoretical Performance Evaluation of SEES Building: A Solar Passive Featured Envelope (communicated).