Journal of Energy Research and Environmental Technology (JERET)
p-ISSN: 2394-1561; e-ISSN: 2394-157X; Volume 3, Issue 4; October-December, 2016; pp. 244-247

http://www.krishisanskriti.org/Publication.html

Study of Daylight and Luminous Efficacy Models

M. Jamil Ahmad

Department of Mechanical Engineering Aligarh Muslim University, Aligarh-202002, India
E-mail: jamil.amu@gmail.com

Abstract—*Daylight is found to be essential for all the basic needs of a human being. It has been established that people less susceptible to illness and fatigue when they work in a daylight environment as compared to when they work under artificially lighted indoor spaces. The utilization of daylight in buildings helps to reduce electricity consumption considerably. Therefore, daylight investigations have been conducted in a number of countries. To design an efficient daylight-integrated building, the local distribution of daylight is necessary.*

Luminous efficacy models are important prediction tools that allow the estimation of daylight illuminance in regions where only measured irradiance values are available. There are several mathematical models given by various scientists to calculate luminous efficacy. These models have been developed for the climatic condition of UK, Norway, New York and Hong Kong. In this article, these models have been tested for composite climate of New Delhi. A new model has also been developed for composite climate of New Delhi.

1. 1. INTRODUCTION

Daylight is the visible part of solar radiation as perceived by the eye. It is composed of a spectral power distribution (SPD) of electromagnetic radiation in the visible wavelength range (380-780nm). Basically, 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 Skylight is a diffuse component of the light coming from the sky dome, which is quite steady and does not create glare and shadow. The solar irradiance values, obtained as a part of meteorological weather data, describe the total solar radiation (from sun and sky) hitting the earth at a particular place. This contains visible and, also, invisible portions of the solar radiation. The luminous efficacy (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 visible portion of irradiance in to luminance.

Daylight is found to be essential for all the basic needs of a human being. It has been established that people less susceptible to illness and fatigue when they work in a daylight environment as compared to when they work under artificially lighted indoor spaces. In contrast to artificial lighting systems that give a fixed intensity, color rendering and texture daylight is characterized by time varying properties. An intelligent mix of the daylight and artificial lights is essential to obtain best results from energy conservation point of view.

Form and orientation of a building play a key role in determining the quality and quantity of daylight inside them. It is usually preferred to have larger side of the building elongated along East-West axis to admit daylight from north and south apertures. It may be noted that that the daylight from the east and west apertures is highly variable in nature from first half of the day to second half. The daylight from the north aperture is found to be steadier than that from south aperture. However the contribution of sunlight to daylight from the south aperture is more as compared to that from the north aperture.

Generally daylight from north aperture is preferred from that of south aperture for interior illumination. Overhangs and blinds can be used to control direct sunlight from the south. Higher placement of windows allows deeper penetration of daylight in buildings. It is considered beneficial to have an extended plan for a building, rather than a compact plan from the viewpoint of day lighting. Once the building form, orientation and placement of windows have been decided, Mathematical models may be used quantifying daylight performance of the building at the design state itself. Advanced technology for energy efficient windows may also be used to further improve day lighting in to the buildings. Glazing, shading systems and indoor materials modify the day lighting aspects through large variations of color.

The benefits of day lighting on the building sector are well known. Most important are the energy savings derived from minimizing or eliminating the need for artificial light. Day lighting can also increase the comfort of building occupants. Although difficult to quantify, day lighting generally improves occupant satisfaction and visual comfort, leading to better overall performance of any working environment. Day lighting is provided through windows, clerestories, roof monitors, skylights, saw- tooth roofs or light-pipe systems. The proper design of these systems requires accurate information on daylight availability, and hence external solar illuminance.

The utilization of daylight in buildings helps to reduce electricity consumption considerably. Therefore, daylight investigations have been conducted in a number of countries.

To design an efficient daylight-integrated building, the local distribution of daylight is necessary. One of the most important daylight variables is sky luminance. The sky luminance can be measured using sky scanners, which are designed to measure visible light in small zenith and azimuthal steps following an incremental viewing angle. However, the sky scanner is costly and requires qualified people for maintenance, making luminance measurements extremely limited, especially in developing countries. Hence, luminance models have been developed and applied to building design in many developed countries around the globe.

1.1 Luminous efficacy

Solar radiation is the major source of radiant energy on earth and investigations indicate that all solar radiant energy falls in the short wavelength region from 0.2 to 5 µm. However, the human eye can only sense part of the radiant energy spectrum from 380 to 780 nm. Illumination is the luminous effect caused by the radiant energy as sensed by the human eye. The luminous efficacy of solar radiation is defined as the ratio between illuminance and irradiance and can be expressed in lm/W. Continuous measurements of illuminance on horizontal surfaces are not so common as irradiance measurements. When irradiance measurements are available, corresponding illuminance values can be obtained if reliable luminous efficacy models are used.

The luminous efficacy at a given wavelength is the ratio of the illuminance caused by the radiation in that wavelength to the radiant energy in that wavelength. This is a function of the wavelength as the sensitivity of the human eye depends on the wavelength of the radiation.

The luminous efficacy of daylight, K, is defined as the ratio between daylight illuminance E and solar irradiance G, expressed in lumens per watt and is given by the following mathematical expression:

$$K = \frac{E}{G} = \frac{K_m \int_{380}^{780} G_\lambda V_\lambda d\lambda}{\int G_\lambda d\lambda} \quad (1)$$

where, Km = 683 lm/w is defined as the maximum luminous efficacy for photopic (daytime) vision. It means that luminous efficacy can be 683 lm/w for monochromatic light of wavelength 555 nm. However, solar radiation is not monochromatic.

Values of luminous efficacy are obtained by simultaneously measuring the illuminance and irradiance on a specified surface, and then computing their ratio. Alternatively, the luminance and radiance of particular sky elements can be measured to calculate the luminous efficacy. It is a convenient quantity in the calculation of daylight availability and lighting energy use in building and, in principle allows for most of the climate and latitude related variations.

There are several mathematical models given by various scientists to calculate daylighting parameters. Some models are discussed in this work and luminous efficacy models are particular of our interest.

2. LUMINOUS EFFICACY MODELS

Luminous efficacy models are important prediction tools that allow the estimation of daylight illuminance in regions where only measured irradiance values are available. As illuminance measurements are farther rarer than irradiance measurements and the characterization and analysis of daylight availability is therefore, less developed than irradiance characterization.

Luminous efficacy models are used to convert solar radiation data in to horizontal illuminance, which is further used as input to estimate illuminance at inclined surfaces. These data may, subsequently, be used in estimating illuminance levels inside a building.

The luminous efficacy of solar radiation would depend on its atmospheric absorption, which increases as its path in the atmosphere increase. As the atmosphere absorption is more for infrared radiation than visible light, the luminous efficacy can vary greatly depending on the irradiance levels and weather conditions.

2.1 Muneer and kinghorn Model

Muneer and Kinghorn measured five locations in the United Kingdom (UK) and devised the following expression for global luminous efficacy

$$K = 136.6 - 74.541k + 57.3421k^2 \quad (2)$$

where k, the clearness index is defined as

$$k = G / G_0 \quad (3)$$

The diffuse luminous efficacy is given by

$$K_d = 130.2 - 39.828k + 49.979k^2 \quad (4)$$

2.2 Littlefair Model

Littlefair devised a model for luminous efficacy after measuring beam and diffuse radiation in UK. The expression suggested for luminous efficacy for beam radiation was

$$K_b = 51.8 + 1.64\alpha_s - 0.0151\alpha_s^2 \quad (5)$$

The actual measurements indicated average values of global luminous efficacy to be 109 ± 5 lm/w. For clear and totally overcast skies, diffuse luminous efficacy was found to be 144 ± 7 and 155 ± 8 lm/w, respectively. Since the sky is neither totally clear nor totally overcast, Littlefair suggested the following expression for diffuse luminous efficacy based on interpolation between clear and overcast skies

$$K_d = 115 + 29\sigma \quad (6)$$

where, σ is refers as sunshine probability. It is defined, according to World Meteorological Organization (WMO) criterion for bright sunshine, as the fraction of time when direct normal irradiance exceeds values of 120 w/m^2.

The luminous efficacy of global radiation may be estimated as

$$K = (K_b G_b + K_d G_d) / G_b G_d \quad (7)$$

2.3 Skartveit and Olseth Model

Skartveit and Olseth developed a luminous efficacy model based on measurements in Norway and validated the model for measured data corresponding to Albany, New York. According to their model, the beam luminous efficacy may be evaluated using

$$\begin{aligned} K_b &= (107\{1-\exp[2-(\alpha_s+2)^{0.475}]\} \\ &+[2+13\exp(-0.064\alpha_s)] \\ &\times\cos[360(J-288)/365]) \end{aligned} \quad (8)$$

where, α_s is in Degree.

For diffuse luminous efficacy, three types of sky conditions have been suggested viz., totally clear sky, overcast sky and bright cloud.

The diffuse luminous efficacy for these three conditions may be evaluated from

$$K_{d,cl} = (137 + 40\exp(-0.08\alpha_s)) \quad (9)$$

$$\begin{aligned} K_{d,oc} &= (102 - 48k + 21\exp(-10k) \\ &+16\alpha_s^{0.22}) \end{aligned} \quad (10)$$

$$K_{d,br} = c_w K_{d,oc} + (1-c_w) K_b \quad (11)$$

and c_w is known as cloud weight factor and is expressed as

$$c_w = 0.3 + 0.7\exp(-0.08\alpha_s) \quad (12)$$

The overall diffuse luminous efficacy can be expressed as

$$\begin{aligned} K_d &= (K_{d,cl} G_{d,cl} + K_{d,oc} G_{d,oc} \\ &+K_{d,br} G_{d,br}) / G_d \end{aligned} \quad (13)$$

2.4 Chung Model

Chung measured luminous efficacy in Hong Kong and formulated the following expressions for beam and diffuse luminous efficacies in terms of the altitude angle

$$K_b = 48.5 + 1.67\alpha_s - 0.0098\alpha_s^2 \quad (14)$$

$$K_d = (135.3 - 25.7CR) lm / W \quad (15)$$

where CR is the cloud ration defined as

$$CR = G_d / G \quad (16)$$

3. PROPOSED MODEL:

$$K = 176.0905 - \frac{21.87855}{k} + \frac{4.31224}{k^{\frac{3}{2}}} \quad (17)$$

where k, the clearness index is defined as

$$k = G / G_0 \quad (18)$$

4. CONCLUSIONS:

Luminous flux has been calculated by Muneer and Kinghorn model, Littlefair model, Chung model, Skartveit and Olseth model and our proposed model. Results demonstrate that all models present the same variation of luminous flux with time but calculated values of luminous flux are not so approachable to measured values. Among these models Muneer and Kinghorn model furnishes closest values of luminous efficacy to measured values.

We have developed a model on the basis of Muneer and Kinghorn model to calculate luminous efficacy and results show that it produces the best results for our location.

Statistical analysis also shows minimum values of root mean square percentage error and mean bias percentage error and maximum value of correlation coefficient for our model on each day calculations among all the models. Our model provides almost same variation as measured flux and offers the closest values of calculated luminous efficacy as shown in tables in appendix.

REFERENCES

[1] Mahendra Joshi, R. L. Sawhney and D. Buddhi 2006, "Mathematical models for Estimation of Daylight in Buildings: A Review"; Jour. of solar eng. society of India 16(1): pp 45-67.

[2] Duffie, J.A. and Beckman. W.A. 1991, "Solar Engineering of Thermal Processes", John Wiley & Sons, Inc.

[3] Reindl, D.T., Beckman, W.A. and Duffie, J.A., 1990, "Evaluation of Hourly Tilted Surface Radiation Models", Solar Energy, 45, pp.9-17.

[4] Skartveit, A. and olseth, J.A., 1994, "Luminous Efficacy models and their application for calculation of Photosynthetically Active Radiation", Solar Energy, 52, pp. 391-399.

[5] Muneer T. and Kinghorm D., 1998, "Luminous Efficacy Models: Evaluation Against UK Data", Jour. of Illuminating Engg. Soc., 27, pp. 163-170.

[6] Chung, T.M., 1992, "A study of Luminous efficacy of Daylight in Hong Kong", Energy and Buildings, 19, pp. 45-50.

[7] Littlefair, P. J., 1994, “A Comparison of Sky Luminance Models with Measured Data from Garston, UK”, Solar Energy, 53, pp.315-322.

[8] Joseph C. Lam and Danny H.W.LI ,1995; "Luminous Efficacy of Daylight Under Different Sky Conditions”; Energy Convers. Magmt. 37(12) pp. 1703-1711.

[9] Eero Vartiainen, 1999, "A comparison of luminous efficacy models with illuminance and irradiance measurements” Renewable Energy 20, p.p265-277

[10] Roberta G. de Souzaa, Luis Robledo, Fernando O.R. Pereira, Alfonso Soler, 2006, “Evaluation of global luminous efficacy models for Floriano´ polis, Brazil” Building and Environment 41, p.p. 1364–1371.