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Full Length Research Paper

The challenge of all sky luminance modeling and its availability for electric light saving in interior spaces at Mahasarakham, Thailand

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The purposes of this paper are to present the results of a study on all sky conditions for zenith luminance modeling and daylight availability for the central region of the Northeastern part of Thailand (16°14'N, 103° 15'E). The data for zenith luminance estimation were taken for one year from a station at the Mahasarakham University (MSU), the required components of sky quantities, namely, zenith luminance for saving energy used in buildings, are estimated. The zenith luminance models for all sky conditions are determined and developed to become a new function in the polynomial function. The accuracy of the validated model is determined in terms of the mean bias deviation (MBD), the root mean square deviation (RMSD) and the coefficient of correlation (R^2) values. Comparison of the estimated zenith luminance values and the observed values revealed a small error slide as well. The estimated values of zenith luminance in daytime at Mahasarakham, Thailand is presented in terms of light source efficacy and integrated with electric lighting in commercial buildings that could reduce energy and power consumption.

Key words: Daylight, sky luminance, zenith luminance, solar energy.

INTRODUCTION

Daylight has great potential for energy conservation in buildings. Energy savings from daylight means not only lower power consumption for electric lighting, which reduces the cooling load, but reduced peak demand as well. In commercial buildings, one of the major consumers of electricity is lighting. A number of reports have confirmed that artificial lighting accounts for 20 to 30% of the total building electricity consumption (Li and Lam, 2000). The utilisation of daylight is a design approach with great energy saving potential. The objective in designing a building to integrate daylight and electric lighting is to acquire not just the total amount of outdoor illuminance, but also the distribution of sky luminance.

Daylight and solar radiation data are important parts of building design. However, many of the fundamental daylight and solar research studies used by architects and engineers are based upon data taken in other parts of the world (Alfonso and Pilar, 1997). Using locally observed data would substantially improve the relevance of the information as well as provides more useful results from more appropriate local observations.

In 2001, for subtropical regions, all sky models as standard skies for simulation of daylight environments was proposed (Igawa and Nakamura, 2001). This model is expressed as functions of solar altitude and global illuminance. Chirarattananon et al. (2002) proposed daylight availability and models for all sky type in tropical regions, with measured data from North Bangkok, Thailand in an annual form. Alfonso and Kannam (2002) proposed daylight availability and models for cloudless

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Figure 1. MSU daylight measurement station Mahasarakham University, Mahasarakham, Thailand.

skies at Madrid, Spain with measured data in an annual form (Soler and Gopinathan, 2002). Zain-Ahmed et al. (2002) proposed daylighting as a passive solar design strategy for tropical region. Pattanasethanon et al. (2008), proposed an accuracy assessment of a model in different function and application for forecasting illuminance/irradiance on horizontal plane at Mahasarakham, Thailand. Danny (2003) proposed the analysis of zenith luminance data at Hong Kong.

A Mahasarakham University (MSU) daylight measurement station with solar irradiance measuring equipment and some weather measuring equipment was established on the flat roof of the five story Faculty of Engineering building at Mahasarakham University, Mahasarakham, Thailand and the data were proved for modeling.

This paper presents the model of zenith luminance using sky ratio and solar altitude angle at Mahasarakham, Thailand. An error evaluation for the models is reported and there characteristics of the findings are discussed.

METHODOLOGY

Experiment data and statistical assessment

The MSU daylight measurement station is as shown in Figure 1. During an annual measurement period from January 6, 2007 to December 31, 2007, the data were proved for modeling. This meteorological station would be classified as a general station in accordance with the International Daylight Measurement Program (IDMP) of the Commission International de l'Eclairage (CIE). All data were recorded at 1 min intervals. The data were verified in accordance with the IDMP quality assurance procedures and archived as 5 min data. About 8% of the data were lost due to short term electricity outages. The site is at latitude 16°14'N and longitude 103° 15'E. The center of the Northeastern part of Thailand, is sometimes called the Isan region.

The humidity around the Isan region is dry for long periods during the winter (November to February) and summer months (March to June). The mean temperature and relative humidity in winter and summer are 20°C, 50% Rh and 35°C, 60% Rh, respectively. The rainy season occurs from July to October. The mean temperature and relative humidity are 29°C and 70% Rh, respectively. The area can be described as countryside.

Daylight availability

Daylight availability for 2005 at the center of the Isan region was published in an earlier study. In the current study, daylight availability for 2007 in the Isan region is presented. The local time at the MSU station is delayed from the standard local time zone of Thailand from 6.5 to 8 min. The maximum sky quantities, global and diffuse radiation on a horizontal plane and zenith luminance on a horizontal plane are 1,469.4 W/m^2, 513.4 W/m^2 and 127.6 kcad, respectively. Annual means of zenith luminance on horizontal plane quantities are 442.51 W/m^2, 161.7 W/m^2 and 149.82 kcad, respectively. The hourly averaged values from the annual measured data of zenith luminance are exhibited as shown in Figure 2.

Sky classification

Sky conditions have been chosen from the values of a sky ratio (Reas, 2000). The sky ratio computed from irradiance values, is divided into 10 ranges from 0.0 to 1.0. The frequency distribution of each sky type will determine the classification.

In this study, for the frequency distribution of sky ratio and variability of sky condition, we used the sky ratio to classify measured data for each sky type (Chirarattananon and Limmechokchai, 1996). The ratio is defined as:

$$SR = E_{ed} / E_{eg} \quad (1)$$

where E_{ed} is diffuse horizontal irradiance (W/m^2) and E_{eg} is global

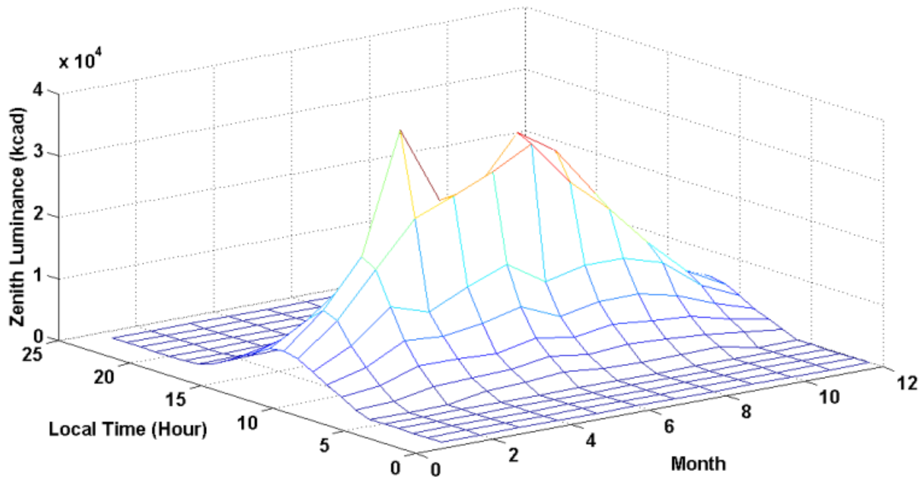

Figure 1. The hourly averaged values of zenith luminance in 2007.

Table 1. Classification of sky condition and frequency of occurrence of each of sky types at MSU according to the values of sky ratio.

Frequency of occurrence of each sky type at MSU station		
Clear sky (SR ≤0.3)	Inter-mediate sky (0.3<SR<0.8)	Cloudy sky (0.8≤SR)
33.83%	58.18%	3.49%

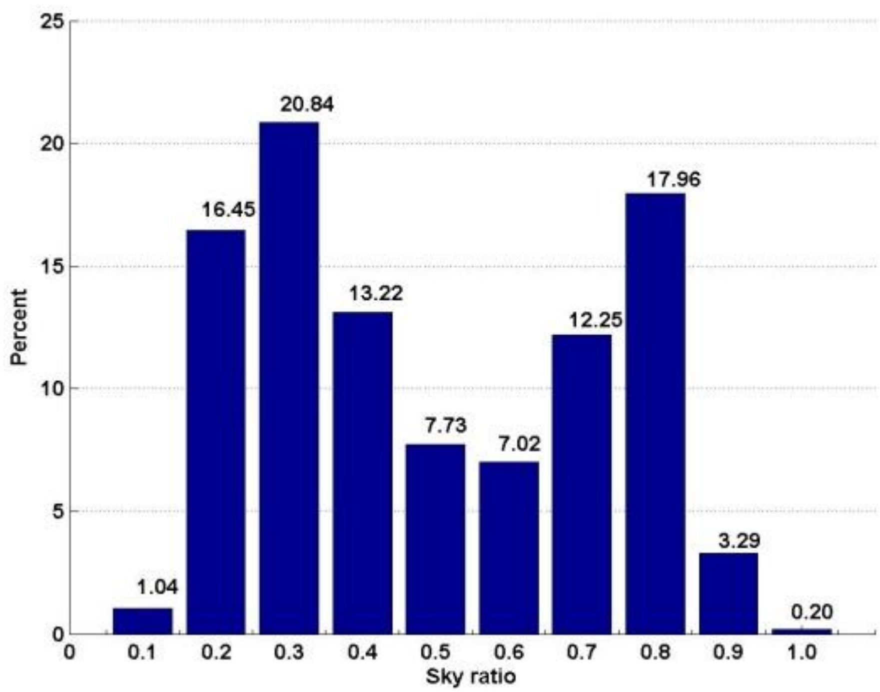

Figure 2. Frequency occurrence of sky ratio (SR) from observed data at MSU station.

horizontal irradiance (W/m^2). The IESNA classified the sky into three sky types according to the values of the sky ratio as shown in Table 1. The frequencies of occurrence of sky ratio at MSU in Mahasarakham are illustrated in Figure 3.

Mathematical analysis

The two most widely used statistical indicators for dealing with the evaluation of solar radiation estimation models are the mean bias deviation (MBD), root mean square deviation (RMSD) and coefficient of determination (R^2). They are defined as stated in Equations 3, 4 and 5 (Pattanasethanon et al., 2007).

$$RMSD = \left(\frac{1}{E_{mean}}\right) \cdot \left[\frac{\sum_{i=1}^{N}(E_{model} - E_{meas})^2}{N}\right]^{1/2} \quad (3)$$

$$MBD = \left[\frac{\sum_{i=1}^{N}(E_{model,i} - E_{meas,i})}{N \cdot E_{mean}}\right] \cdot 100 \quad (4)$$

where $E_{meas,i}$ is the measured value of the dependent variable corresponding to a particular set of values of the independent variables. $E_{model,i}$ is the predicted dependent variable value for the same set of independent variables (these values are obtained from the model). E_{mean} is the mean value of the dependent variable testing data set. *N* is the number of records data in the testing set.

$$R^2 = \frac{\sum(E_{model} - E_{mean})^2}{\sum(E_{meas} - E_{mean})^2} \quad (5)$$

where E_{meas} is the measured values of zenith luminance, E_{model} is the predicted *E* values from the regression equation and E_{mean} is the mean of the E_{meas} values.

Modeling zenith luminance on horizontal plan for Mahasarakham

The validation process of zenith luminance models for the annual data from the MSU station is presented. The polynomial functions can be expressed as Equation 6:

$$P(s) = a_n s^n + a_{n-1} s^{n-1} + \cdots + a_1 s + a_0 \quad (6)$$

where *P(s)* is polynomial function of the zenith luminance, *s* is solar altitude angle, $a_n, \ldots, a_0$ is polynomial coefficients and *n* is the degree of the polynomial.

The parameters in polynomial functions can be determined by least squares surface fitting, by using the curve fitting toolbox of Matlab, programming version 7.8, in the fit.

RESULTS AND DISCUSSION

The plot of zenith luminance against solar altitude angle is as shown in Figure 4 to 13, respectively. Determinations of the optimum error and coefficient values of the polynomial function in the fits for the results of the model discrepancies, such as MBD, RMSD and coefficient of correlation (R^2) are as shown in Table 2.

We compared the polynomial models and coefficient values from Table 2 with the measured data in the sky ratio cases. Figures 14, 15 and 16 are plots of the polynomial model versus measured data with the best linear fit to the data for clear sky (SR= 0.0 - 0.1), intermediate sky (SR = 0.4 - 0.5) and overcast sky (SR = 0.8 - 0.9), respectively.

The values of zenith luminance characteristics for tropical region at Mahasarakham, Thailand from 2007 measured data, is classified by sky ratio in 10 ranges. In Figures 4 to 13, we have found that the value of zenith luminance that characterizes the zenith luminance is increased to a maximum value at the solar altitude angle 90° for clear sky and the inter-mediate sky. In the case of overcast sky, the zenith luminance is increased in the initial stage and then decreased until 90° of the solar altitude angle. This recent model is a model for calculating sky quantities, namely, the zenith luminance on a horizontal plane if the solar altitude angle and global illuminance are known.

Light source efficacy

In the previous work of subtropical regions, natural daylight does not have great potential for energy conservation in buildings.

Here, the light source efficacy (η) is presented. The light source efficacy can be expressed as Equation 7:

$$\eta = lumen/watt \quad (7)$$

Equation 7 can be determined in terms of global illuminance and global irradiance defined as Equation 8:

$$\eta = \frac{\text{global illuminance}}{\text{global irradiance}} = \frac{lumen}{m^2} \cdot \frac{m^2}{watt} = \frac{lumen}{watt} \quad (8)$$

The hourly averaged values from the annual measured data of global illuminance divided by global irradiance at Mahasarakham is exhibited as shown in Figure 17.

The averaged value of light source efficacy in daytime is 133.84 lumen/W, which is about three times the value of light source efficacy from a 36 W fluorescent lamp. Therefore, the daylight integrated electric lighting in commercial buildings could reduce energy and power consumption.

Conclusion

This paper introduced concepts for estimating the zenith luminance on a horizontal plane. Parameters in a polynomial

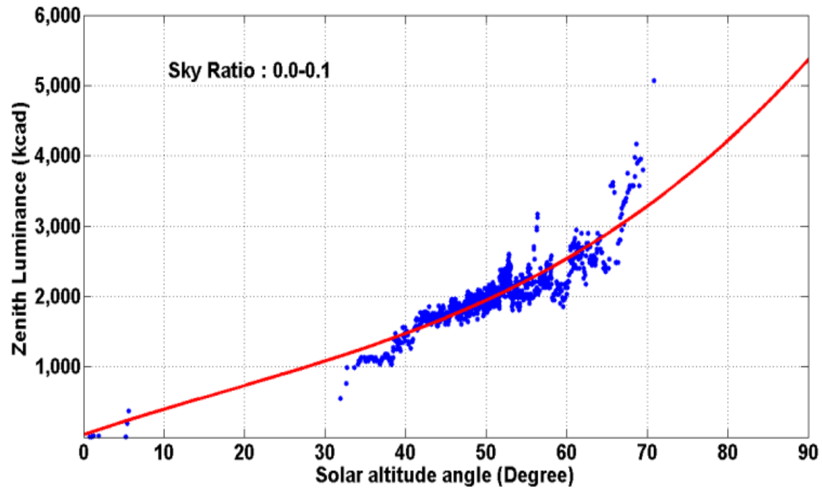

Figure 4. Plots of zenith luminance against solar altitude angle, overcast (0.0<SR≤0.1).

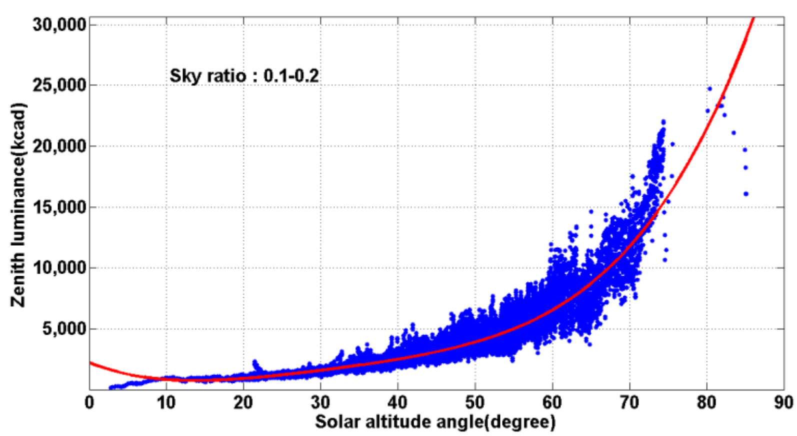

Figure 5. Plots of zenith luminance against solar altitude angle, overcast (0.1<SR≤0.2).

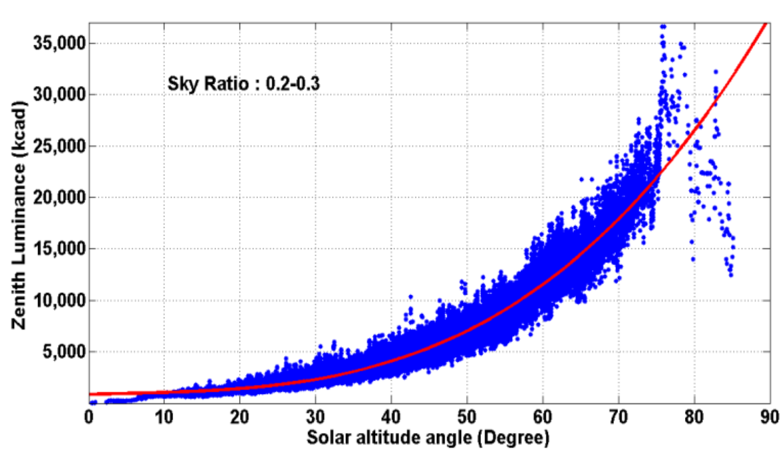

Figure 6. Plots of zenith luminance against solar altitude angle, overcast sky (0.2<SR≤0.3).

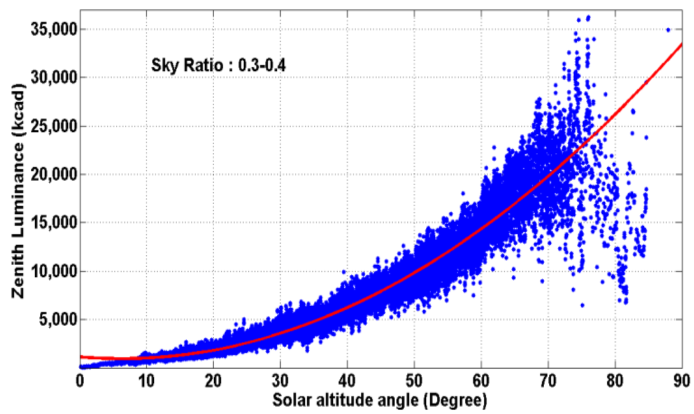

Figure 7. Plots of zenith luminance against solar altitude angle, inter-mediate sky (0.3<SR≤0.4).

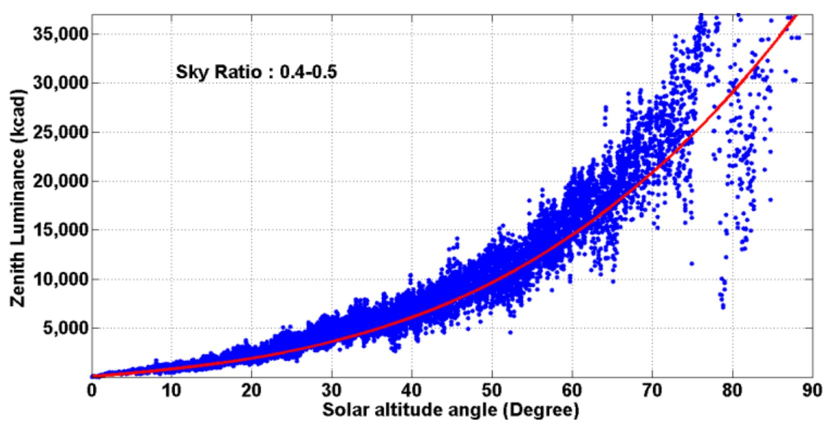

Figure 8. Plots of zenith luminance against solar altitude angle, inter-mediate sky (0.4<SR≤0.5).

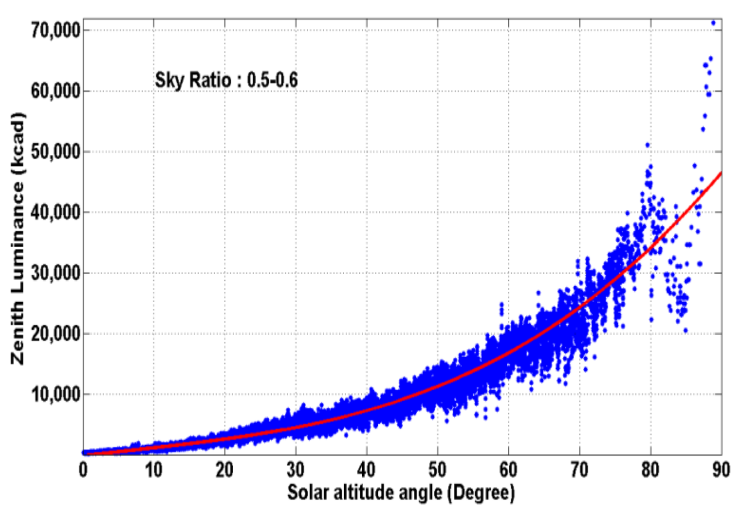

Figure 9. Plots of zenith luminance against solar altitude angle, inter-mediate sky (0.5<SR≤0.6).

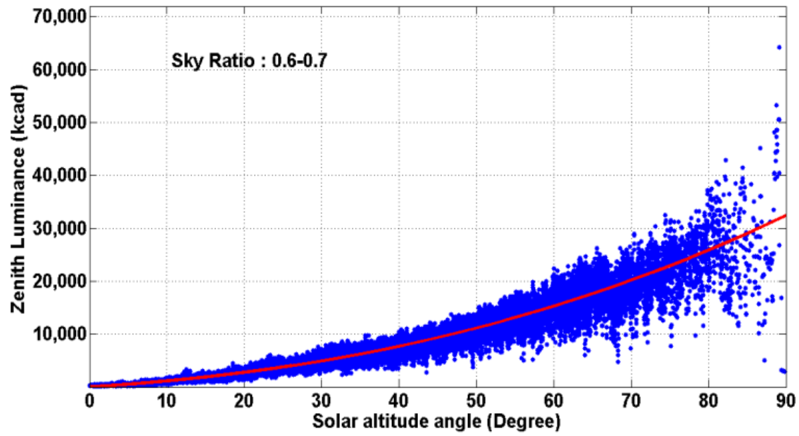

Figure 10. Plots of zenith luminance against solar altitude angle, inter-mediate sky (0.6<SR≤0.7).

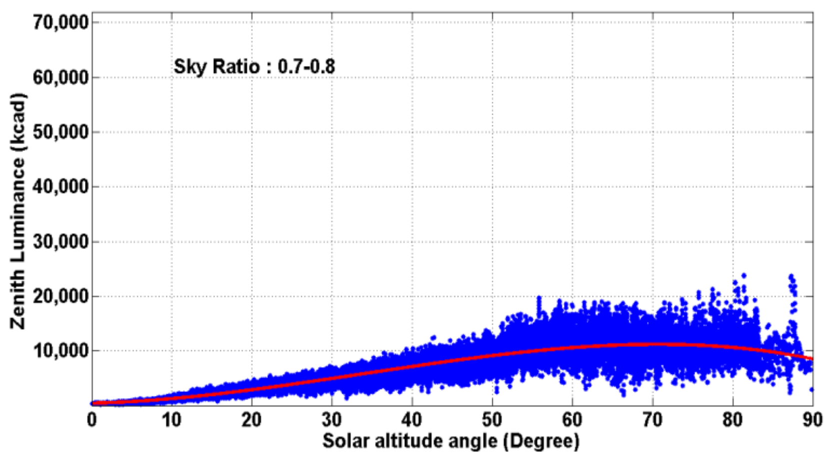

Figure 11. Plots of zenith luminance against solar altitude angle, inter-mediate sky (0.7<SR≤0.8).

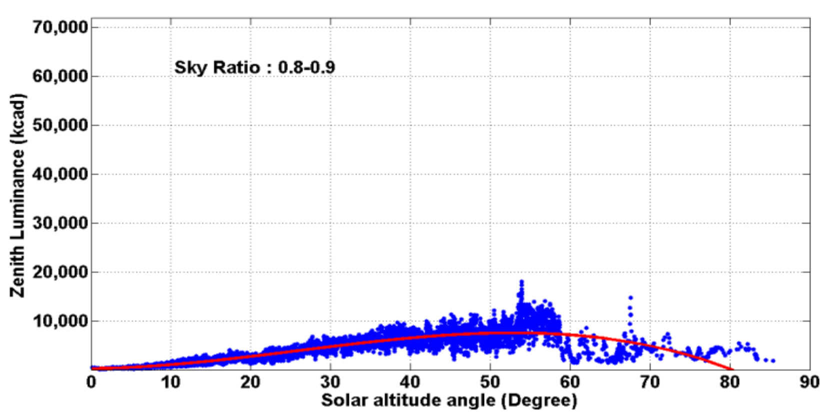

Figure 12. Plots of zenith luminance against solar altitude angle, clear sky (0.8<SR≤0.9).

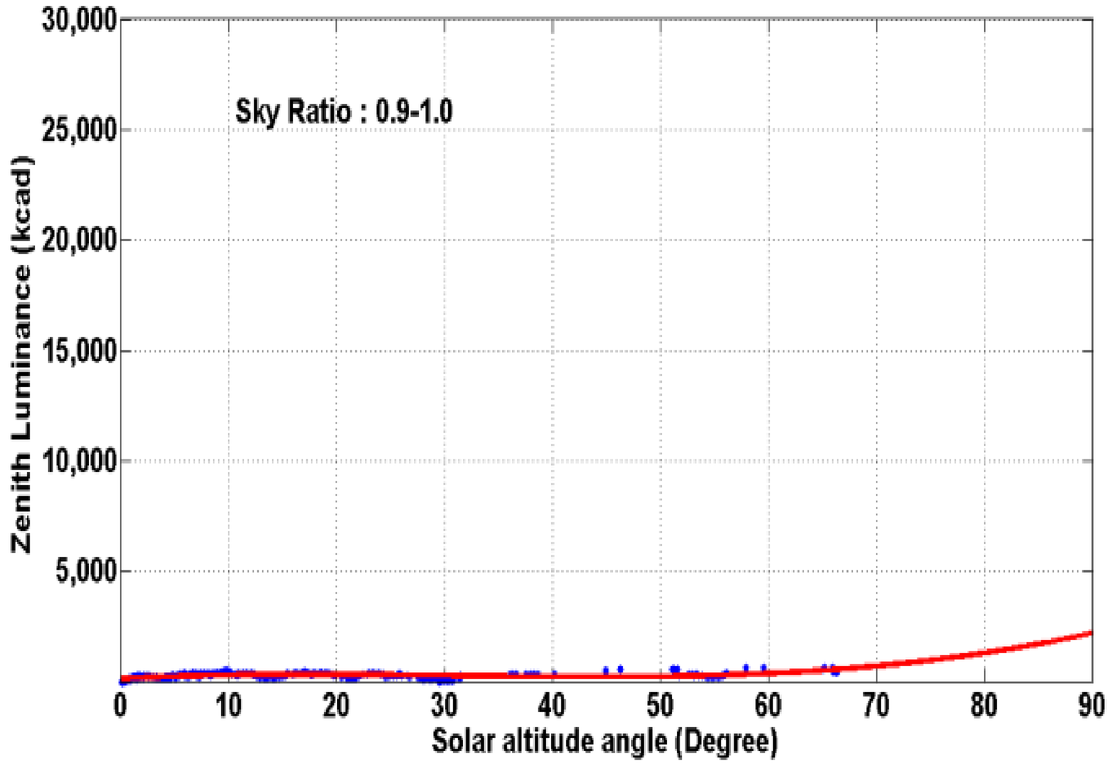

Figure 13. Plots of zenith luminance against solar altitude angle, clear sky (0.9<SR≤1.0).

Table 2. Summary of polynomial coefficient of zenith luminance on horizontal for all sky condition.

Data	Sky ratio									
	0.0-0.1	**0.1-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.8**	**0.8-0.9**	**0.9-1.0**
MBD (%)	0.0570	0.0014	-2.9298	4.1339	6.3472	1.7236	5.8661	0.8926	7.4616	-10.669
Poly. fit RMSD (%)	25.8096	2.7689	5.4642	6.4280	7.5623	1.9465	8.7996	1.6497	5.9210	-0.9420
R^2	0.8845	0.9629	0.9756	0.979	0.9697	0.9622	0.979	0.9252	0.9365	0.4569
Coeff. of polynomial										
a_4	0	0.002317	0	0	0	0	0	0	0	0
a_3	0.005959	-0.2874	0.09274	0	0.0709	0.06073	0.0091	-0.05396	-0.0928	0.01101
a_2	-0.3085	14.37	-5.155	4.635	-2.772	-1.233	2.177	5.461	7.207	-1.015
a_1	38.63	-255.8	176.9	-57.89	189.1	138.5	90.91	35.98	16.35	25.22
a_0	31.18	2200	-746	1125	-807.3	-216.7	9.444	405.9	249.7	129.7

Poly.: Polynomial; coeff.: Coefficient.

model are fitted in 10 ranges of the sky conditions (sky ratio). The polynomial functions of all sky conditions of sky ratio are validated. This recent model is a model for calculating sky quantities, namely the zenith luminance on a horizontal plane if the solar altitude angle and the sky conditions are known.

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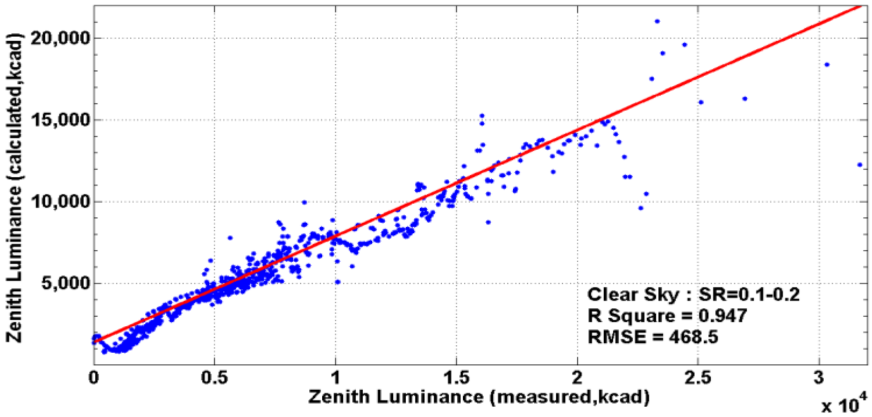

Figure 14. Plot of zenith luminance model with polynomial function versus measured zenith luminance with best linear fit to the data for clear sky (SR=0.1-0.2).

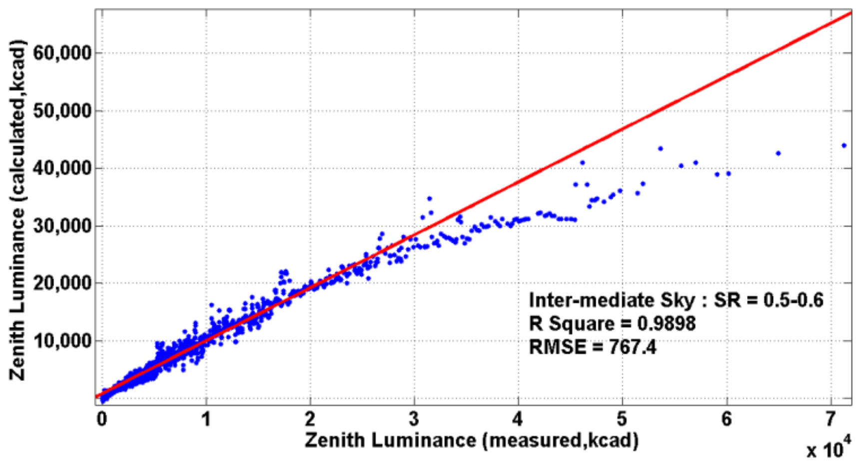

Figure 15. Plot of zenith luminance model with polynomial function versus measured zenith luminance with best linear fit to the data for inter-mediate sky (SR=0.5-0.6).

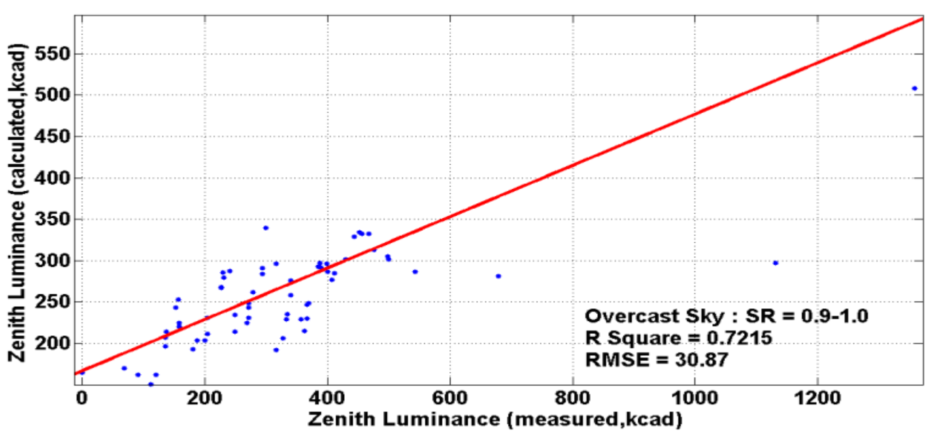

Figure 16. Plot of zenith luminance model with polynomial function versus measured zenith luminance with best linear fit to the data for overcast sky (SR=0.9-1.0).

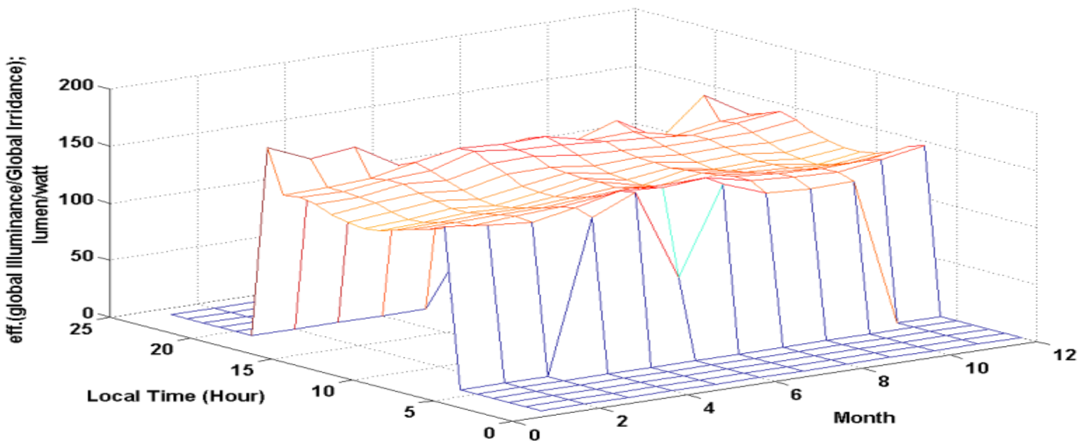

Figure 17. The hourly averaged values of light source efficacy.

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REFERENCES

Alfonso S, Kannam KG (2002). Modeling zenith luminance on Madrid cloudless skies from illuminance on a horizontal surface. Renew. Energy J., 43(16): 2145-2155.

Alfonso S, Pilar O (1997). Light shelf performance in Madrid, Spain. Build Environ. J., 32(2): 87-93.

Chirarattananon S, Chaiwiwatworakul P, Pattanasethanon S (2002). Daylight availability and models for global and diffuse horizontal illuminance and irradiance for Bangkok. Renew. Energy J., 26(1): 69-89.

Chirarattananon S, Limmechokchai B (1996). Daylighting potential in Thailand. Energy Sources J., 18(8): 875-883.

Danny HW (2003). An analysis of all-sky zenith luminance data for Hong Kong. Build. Environ. J., 38(5): 739-744.

Igawa N, Nakamura H (2001). All sky model as a standard sky for the simulation of daylight environment. Build. Environ. J., 36(6): 763-770.

Li DHW, Lam JC (2000). Measurement of solar radiation and illuminance on vertical surfaces and daylighting applications. Renew. Energy J., 20(4): 389-404.

Pattanasethanon S, Lertsatitthanakorn C, Atthajariyakul S, Soponronnarit S (2007). All sky modeling daylight availability and illuminance/irradiance on horizontal plane for Mahasarakham, Thailand. Energy Convers. Manage. J., 48(5): 1601-1614.

Pattanasethanon S, Lertsatitthanakorn C, Atthajariyakul S, Soponronnarit S (2008). An accuracy assessment of an empirical sine model,a novel sine model and an artificial neural network model for forecasting illuminance/ irradiance on horizontal plane of all sky types at Mahasarakham, Thailand. Energy Convers. Manage. J. 49(8): 1999-2005.

Reas MS (2000). Lighting handbook: reference and application. Daylighting illuminating engineering society of North America (IESNA). Chapter 8.

Zain-Ahmed A, Sopian K, Othman MYH, Sayigh AAM (2002). Daylighting as a passive solar design strategy in tropical buildings: a case study of Malaysia. Energ Convers Manage J., 43(13): 1725-1736.