Trends in

Applied Sciences Research

ISSN 1819-3579

Academic
Journals Inc.

www.academicjournals.com

Trends in Applied Sciences Research 4 (3): 158-166, 2009
ISSN 1819-3579

Evaluation of Horizontal and Vertical Illuminance Models against Measured Data in Iran

S. Shekari. S and R. Golmohammadi
Department of Occupational Health, Public Health School,
Hamadan University of Medical Sciences, Hamadan, Iran

Abstract: This study was undertaken to evaluate performance of three models of horizontal and two models of vertical illuminance based on measured data in Iran. Measurement of horizontal and South oriented vertical illuminance was carried out at three stations of Eshtehard, Hamadan and Kerman over 15 days at one hour intervals between 12 July and 1 August 2007 from 9 a.m. to 3 p.m. Synchronically calculation of solar altitudes and global horizontal illuminance carried out utilizing equations proposed by Illuminating Engineering Society of North America (IESNA) for measuring period. Two localized models entitled Solar altitude model and IESNA model in conjunction with the model of Robledo was adopted to predict horizontal illuminance. Also for predicting of South oriented vertical illuminance, a localized model based on IESNA equations in conjunction with a model of Ruiz were taken in to account. Mean measured and predicted horizontal values by three models found to be 96 KLx and 107.3-108.7 KLx, respectively. Among three horizontal models the model of IESNA (MBD = -1.26, RMSD = 10.25) performed best and the model of solar altitude performed worst. Mean measured and predicted values of vertical illuminance by two vertical models found to be 33.59 and 25.71-32.19, respectively. The IESNA model (MBD = -1.4, RMSD = 0.2) performed better than the model of Ruiz. Respective mean monthly predicted horizontal and vertical illuminance exceeded 63 KLx for 50 and 0.96% of working year indicating high daylight availability on horizontal and vertical planes in Iran.

Key words: Daylight availability, vertical illuminance, mean bias difference, root mean square difference

INTRODUCTION

It has long been recognized that light has a direct effect on the functioning of the brain. Effect of high intensity light is said to stimulate the brain in a manner similar to caffeine. Studies have found that bright light will raise hormones, such as Cortisol, associated with alertness in the morning (Stephenson, 2005) and in the offices (2500 Lx) can boost alertness and mood, especially in the afternoon. It also seems to promote melatonin secretion and fall in body temperature at night, changes that should improve the quality of sleep (Webb, 2006). Moreover, natural lighting provides both a more pleasant and attractive indoor environment that can foster higher productivity and performance (Ihm *et al*., 2009).

Presently, most of industrial buildings in Iran, a country located in subtropical region, rely only on electric lighting for day and night even though daylight is abundant throughout the year. The lack of simplified evaluation tools, capable of providing information on the suitability and the cost-effectiveness of daylighting, is considered as one of the major reasons for the reluctance of building professionals in incorporating daylighting features in their design (Ihm *et al*., 2009).

Corresponding Author: Rostam Golmohammadi, Department of Occupational Health, Public Health School, Hamadan University of Medical Sciences, P.O. Box 4171, Hamadan, Iran
Fax: +98 811 8255301

Daylighting is recognized as an important and useful strategy in energy-efficient building designs. Research studies showed that daylight-integrated electric lighting in commercial buildings could reduce more than 50% of energy and power use due to lighting (Chirarattananon *et al*., 2007).

Daylight availability defined in terms of the external skylight illuminance available on an unobstructed horizontal plane for a certain percentage of daytime working hours or for specified periods (Rahim and Mulyadi, 2000). Over the years, many mathematical models have been proposed by different researchers to estimate daylight availability on horizontal or inclined surfaces. For instance, models proposed by Vazquez and Bernabeu (1997) and Robledo and Soler (2000) for horizontal illuminance and models proposed by Klucher (1979), Li and Lam (2000), Perez *et al*. (1990) and Ruiz *et al*. (2002) for inclined surfaces. Most of these models are based upon irradiance and luminance data. Since, the launch of International Daylight Measurement Program (IDMP) by the International Commission on Illumination (CIE, Commission Internationale de l'Eclairage) in 1991, measurement of daylight illuminance has been undertaken and reported from various parts of the world (Chirarattananon *et al*., 2007). Since, any reliable measurement of irradiance and sky luminance has not yet been undertaken for Iran, most of above mentioned models are not applicable for the country.

This study was undertaken to develop proper models of illuminance on horizontal and inclined surfaces in the country based on measured horizontal and vertical data. Also, a comparative study on performance of three horizontal and two inclined models has been presented.

MATERIALS AND METHODS

This study was based upon following stages:

- Measurement of global outdoor horizontal and South oriented vertical illuminance in three stations
- Developing of two experimental models and evaluation of their performance by comparison with a model proposed by Robledo and Soler (2000) in predicting of outdoor horizontal illuminance
- Developing of an experimental model based on horizontal data and evaluating of it?s performance by comparison with a model proposed by Ruiz *et al*. (2002) in predicting vertical illuminance

Measurement of Outdoor Horizontal and Vertical Illuminance

Measurement of horizontal and South oriented vertical illuminance was carried out at three different stations of Eshtehard (E50°C 19.538′, N35°C 41.944′), Hamadan (E48°C 29.340′, N34°C 47.406′) and Kerman (E56°C 43.782′, N29°C 56.973′) over 15 clear days at one hour intervals between 12 July and 1 August 2007 from 9 a.m. to 3 p.m. The daylight measurement station in Hamadan, Eshtehard and Kerman was established on the roof of Health School of Hamadan University of Medical Sciences, on the roof of a factory in Eshtehard Industrial Park and at the yard of a factory respectively. Details on measurement periods have been given by Golmohammadi *et al*. (2009). Totally 105 sets of horizontal also vertical illuminance were taken at three stations. Synchronically calculation of horizontal and vertical illuminance was carried out utilizing equations proposed by Illuminating Engineering Society of North America IESNA (Rea, 2000) for measuring period.

In respect to more common clear skies in the measuring period (88%) only data associated with clear skies were taken in to account. This measured data was adopted to develop horizontal and vertical illuminance models as well as to validate fitted models.

Comparison of Three Models in Prediction of Horizontal Illuminance

Since, any parameter of daylight climate has not yet been defined in Iran, there are no reliable data on horizontal and vertical illuminance in the country. Therefore, estimation of horizontal illuminance was carried out utilizing three experimental models. Calculation of solar altitudes and global horizontal illuminance carried out utilizing IESNA equations (Rea, 2000).

All of the collected data were entered in statistical sheet of SPSS software. Multiple regression models were applied to develop two models: a model between solar altitudes and measured horizontal illuminance (Solar altitude model) and other regression model (IESNA model) between calculated and measured values of horizontal illuminance. Additionally, simple model Robledo and Soler (2000) was taken in to account for predicting horizontal illuminance for working year using Eq. 1:

$$E_G = 109.19(\sin\alpha)^{1.076} \tag{1}$$

where, E_G and α are the global horizontal illuminance in KLx and the solar altitude angle in radian, respectively.

The accuracy of applied models was determined using statistical estimators, the Mean Bias Deviation (MBD) and the Root Mean sQuare Deviation (RMSD).

$$\text{MBD} = \sum (y_i - x_i)/N \tag{2}$$

$$\text{RMSD} = \sqrt{\sum (y_i - x_i)^2/N} \tag{3}$$

where, y_i is the predicted *i*th value, x_i is the ith measured value and N is the number of values.

The two parameters are different in nature. The value of RMSD is always positive, while MBD can be positive or negative. Positive value of MBD implies an overestimation of the model (Chirarattananon *et al*., 2007). The units for both quantities above are KLx.

Comparison of Two Models in Prediction of Vertical Illuminance

South oriented vertical illuminance were calculated for measuring period utilizing the selected model of horizontal illuminace. Values of South facing vertical illuminance were predicted utilizing two models based on IESNA equations (Rea, 2000; Shekari *et al*., 2008) and a model proposed by Ruiz *et al*. (2002). In IESNA method vertical illuminance is equal to sum of diffuse, direct and ground reflected illuminance in which direct component could be obtained by Eq. 4:

$$Ed_V = Ed_n \times \cos a_i \tag{4}$$

where, Ed_v, Ed_n and α_i are direct illuminance on vertical surface in KLx, direct normal solar illuminance in KLx and incidence angle in radian, respectively.

In Ruiz and Soler model, vertical illuminance could be obtained by following equations:

$$E_\psi = E_H \exp\left(-k_V\left(\psi^2 - {\psi_H}^2\right)\right)F_C \tag{5}$$

$$F_C = 1 + \rho\sin^2(\psi/2) \tag{6}$$

$$\begin{aligned}\cos\psi = {} & \sin(90° - \upsilon)\sin(90° - \upsilon_S) + \\ & \cos(90° - \upsilon)\cos(90° - \upsilon_S)\cos(\alpha_S - \alpha)\end{aligned} \tag{7}$$

where, E_ψ and E_H are the global inclined and horizontal illuminance respectively, K_v is the luminous clearness index defined as the ratio of global to extraterrestrial illuminance, taking this last one as 133.8 KLx, ψ expressed in radians, is scattering or incidence angle, that is the angle between the normal to inclined surface and the sun-earth vector. ψ_H is the angular distance ,expressed in radians, between the normal direction to the horizontal plane and the sun, s position. F_C is the surface albedo for illuminance. ρ is the albedo of underlying surface. υis the zenith angle or slope of inclined surface. α represents the azimuth of inclined surface. and υ_S and α_S are solar zenith angle and solar azimuth, respectively.

RESULTS

Regression analysis between measured horizontal illuminance and corresponding calculated values as well as calculated solar altitude angles resulted in two simple experimental models with following equations:

$$E_{hm} = 0.841E_{hc} + 6.65, r^2 = 0.80 \tag{8}$$

$$E_{hm} = 1.027\alpha + 26.573, r^2 = 0.786 \tag{9}$$

where, E_{hm} and Ehc are predicted and calculated horizontal illuminance in KLx respectively and α is calculated solar altitude angle in degree.

Maximum, minimum and mean values of field measured global horizontal illuminance exceed 129, 53 and 96 KLx, respectively. Statistical analysis of predicted illuminance and solar angles is exhibited in Table 1. In respect to (Table 1) maximum predicted values by two fitted models and model of Robledo ranged from 107.3 to 108.7 KLx. Minimum predicted values ranged from 60.7 to 71.9 KLx also mean values found to be in range of 89.8 to 94.9 KLx. Figure 1 shows comparison of mean hourly measured and predicted horizontal values by three models. Mean hourly measured values ranged from 79 to 109 KLx. Mean hourly values of IESNA model found to be closer to measured values which ranged from 78 to 107 KLx.

Values of MBD and RMSD for three models ranged from -1.26 to -6.35 KLx. Values of MBD and RMSD obtained for fitted models of horizontal and South facing vertical illuminance are given in Table 2. The IESNA model with smaller MBD and RMSD values (MBD = -1.26, RMSD = 10.25) had more performance rather than two other models hence this model was considered more suitable to predict horizontal illuminance.

Table 1: Descriptive analysis of illuminance and solar angles for measuring period

Illuminance parameter	Minimum	Maximum	Mean	SD
Ehmeasured (KLx)	53.90	129.90	96.17	14.29
EhmodelIESNA2000 (KLx)	71.93	108.73	94.91	10.82
EhmodelRobeldo (KLx)	60.70	107.31	93.17	11.31
Ehmodelat (KLx)	62.95	108.41	89.81	11.65
Evsmeasured (KLx)	10.50	79.60	33.59	15.05
EvsmodelIESNA2000 (KLx)	8.21	52.14	32.19	11.21
EvsmodelRuiz (KLx)	18.21	31.49	25.71	3.16
Incidence angle (degree)	73.41	89.96	81.33	4.62
Solar altitude (degree)	35.42	79.75	61.58	11.34
Solar azimuth (degree)	2.60	89.95	60.10	25.89

All illuminance are in KLx and solar angles are in degree

Table 2: Values of MBD and RMSD for adopted models

Applied model	MBD (KLx)	RMSD (KLx)
IESNA for horizontal illuminance	-1.26	10.25
Solar altitude model	-6.35	11.81
Robledo model	-3.00	10.54
IESNA for vertical illuminance	-1.40	0.20
Ruiz model	-7.88	0.433

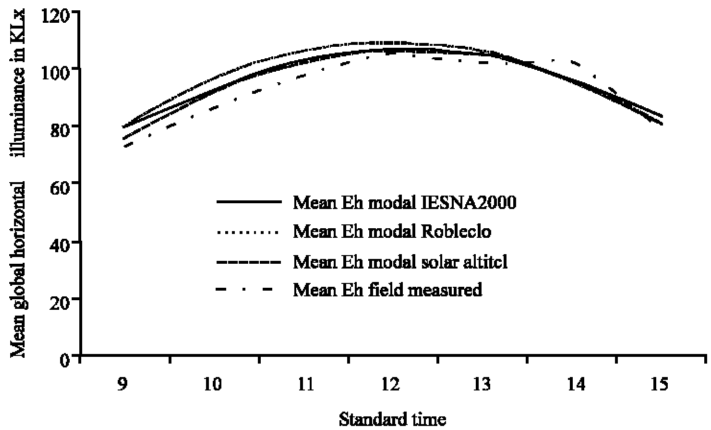

Fig. 1: Comparison of mean hourly measured and predicted horizontal Illuminance by three models

Table 3: Frequency of horizontal and vertical illuminance in different ranges

	Horizontal illuminance (KLx)			South facing vertical illuminance (KLx)		
	Frequency (%)			Frequency (%)		
Category	Range	Measured Eh	Eh model of IESNA	Range	Measured Evs	Evs model of IESNA
1	<76	29(10.5)	15(5.4)	<13.09	7(2.5)	14(5.1)
2	76.01-80.09	15(5.4)	15(5.4)	13.1-17.97	44(15.9)	26(9.4)
3	80.1-84.18	17(6.2)	41(14.9)	17.98-22.85	34(12.3)	29(10.5)
4	84.19-88.27	21(7.6)	0(0)	22.86-27.73	22(8)	22(8.0)
5	88.28-92.36	23(8.3)	26(9.4)	27.74-32.61	29(10.5)	41(14.9)
6	92.37-96.46	28(10.1)	53(19.2)	32.62-37.50	42(15.2)	42(15.2)
7	96.47-100.55	21(7.6)	2(0.7)	37.51-42.38	30(10.9)	43(15.6)
8	100.56-104.64	41(14.9)	70(25.4)	42.39-47.26	24(8.7)	39(14.1)
9	>104.64	81(29.3)	54(19.6)	>47.26	44(15.9)	20(7.2)
Total		276(100)	276(100)		276(100)	276(100)

Values in brackets are percentage

Review of different ranges of horizontal illuminance suggested that maximum frequency of occurrence for measured vlues (29.3%) was in associated with values more than 104.64 KLx whereas for predicted illuminance by model of IESNA, this frequency (25.4%) was related in range of 100.56 to 104.64 KLx. Table 3 shows the frequency of occurrence of measured and predicted values on horizontal and vertical surfaces.

Field measured South oriented vertical illuminance found to be in range of 10.5 to 79.6 KLx. While developing a localized model, measured vertical illuminance exhibited a better agreement with those calculated by IESNA equations for corresponding daylight time (one hour later). So for vertical IESNA model, calculated values related in one hour later, were taken in to account.

Regression model was fitted between measured and calculated vertical values using following equation:

$$E_{vsm} = 0.919Evs_c + 1.661, \ r^2 = 0.806 \quad (10)$$

where, E_{vsm} and E_{vsc} are measured and calculated South facing vertical illuminace in KLx, respectively.

Statistical analysis of measured and predicted vertical values by two models of IESNA and Ruiz are exhibited in Table 1. Mean predicted value by IESNA model (32.19 KLx) was closer to corresponding measured value (33.59 KLx).

In respect to (Fig. 2), predicted values by model of IESNA exhibited a better agreement with corresponding measured values by comparison with Ruiz model. Also Examining the statistical parameters as measures of performance of models (Table 2), revealed that this model (MBD = -1.4, RMSD = 0.2) performs better than the model of Ruiz hence model of IESNA was selected to predict vertical illuminance based on horizontal data during working year.

Review of different ranges of vertical illuminance revealed that maximum frequency of occurrence for measured illuminance (15.9%) was associated with range of 13.1 to 17.97 KLx also more than 47.26 KLx whereas this frequency (15.6%) was related in range of 37.51 to 42.38 KLx for predicted values by the model of IESNA (Table 3).

In respect to Table 4, maximum and minimum predicted mean monthly vertical illuminance were related in January (73.37 KLx) and June (28.63 KLx), respectively whereas for horizontal illuminance, respective maximum and minimum values were associated with June (91.61 KLx) and December (38.33 KLx). Table 4 illustrates mean predicted hourly and monthly vertical and horizontal illuminance for different months of the year. A similar pattern for distribution of vertical illuminance has been reported in San Francisco by Navvab *et al.* (1984).

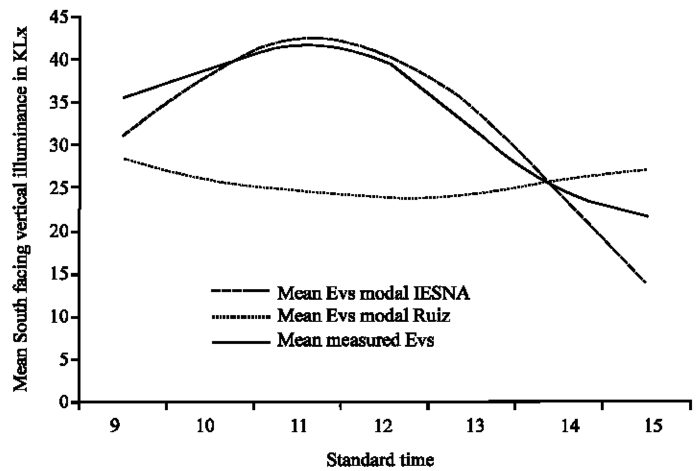

Fig. 2: Comparison of mean measured and predicted South facing vertical illuminance at different standard times

Table 4: Prediction of mean hourly and monthly vertical and horizontal illuminance for a working year in Iran

	Mean hourly South facing vertical illuminance (KLx)							Meanmonthly illuminance (KLx)	
Month	9	10	11	12	13	14	15	Vertical	Horizontal
January	64.18	78.37	86.11	87.81	83.47	72.90	40.77	73.37	41.50
February	62.06	75.22	82.86	84.92	81.32	72.12	45.54	72.01	51.87
March	55.91	67.39	74.11	75.66	71.91	63.10	39.48	63.94	63.35
April	42.86	52.76	58.29	59.01	54.82	46.03	23.93	48.24	78.97
May	20.06	38.39	43.41	43.82	39.59	39.91	13.95	34.16	85.56
June	23.92	29.83	35.18	35.88	32.03	23.51	20.03	28.63	91.61
July	24.76	32.77	38.47	39.57	36.07	28.00	15.86	30.79	87.95
August	36.14	46.21	51.99	53.03	49.25	40.89	19.07	42.37	82.76
September	53.27	63.37	68.78	69.11	64.29	54.68	30.84	57.76	71.96
October	66.93	79.63	84.75	84.18	77.78	65.65	33.03	70.27	57.46
November	70.84	82.16	87.43	86.76	80.12	67.25	31.11	72.24	44.35
December	67.92	81.10	87.62	87.91	81.93	69.22	31.21	72.42	38.33

Predicted illuminance are related in one hour later for each standard time

DISCUSSION

An evaluation of the predicted horizontal illuminaces was undertaken based on two localized model in conjunction with an other model as well as performance of one localized model in conjunction with an other experimental model was evaluated for South oriented vertical illuminance. All three horizontal models overestimated in minimum values. The explanation of this difference is that models of solar altitude and Robledo are independent from sky cover also Model of IESNA has restricted ability in identification of real sky conditions. In IESNA method there are just three sky conditions of clear, partly cloudy and cloudy and one distinct constant is considered for each sky condition solely. So a wide range of sky covers with different sky luminance are taken in to account in group of clear skies hence predicted values may tend to higher levels than measured values.

Comparison of mean hourly measured and predicted horizontal illuminance revealed that however all three models underestimate horizontal illuminance, IESNA and Robledo models give more accurate data whereas solar altitude model underestimates by a wide margin. Indeed evaluation of horizontal and vertical experimental models revealed that among horizontal models, the model of IESNA (MBD = -1.26, RMSD = 10.25), performs best and the model of solar altitude performs worst. Also vertical model of IESNA (MBD = -1.4, RMSD = 0.2) performs better than the model of Ruiz. Mean hourly measured and predicted horizontal illuminance at midday touch higher values than morning and afternoon due to variation of solar altitude α and solar azimuth α_Z. As it is shown in Fig. 3, at midday solar altitude and solar azimuth angles are in higher and lower values, respectively therefore sin (α) and cos α_Z and hence horizontal illuminance would be higher than other times.

In this study, the model of South oriented vertical illuminance was different from fitted vertical model in previous study (Shekari *et al*., 2008). Two reasons could be explained for this difference: 1) in previous study older equations of IESNA were applied (Rea, 1993) whereas in present study new "equation of time" was adopted based on new equations of IESNA (Rea, 2000). 2) In prior study prediction of vertical illuminance at a given standard time was based on calculated illuminance for the same time whereas in the new vertical IESNA model, for predicting of vertical illuminance at a given standard time, calculated values related in one hour later, are taken in to account. The vertical IESNA model underestimated vertical illuminance with wide margin in hours 9, 14 and 15. The reason of this difference could be variation of incidence angle α_i with different slope during working hours.

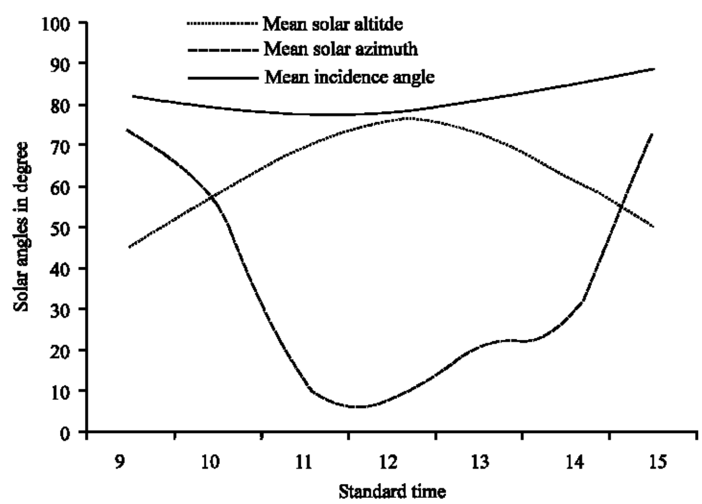

Fig. 3: Comparison of mean solar angles at different standard times

Review of Excel calculating sheets of vertical illuminance suggested that however there is no significant difference for two component of diffuse and ground reflected illuminance, direct vertical illuminance has great variation during working year. In accordance with Eq. 4, increase of incidence angle results in decrease of cos α_i hence smaller direct vertical illuminance. In respect to Fig. 3, since incidence angles in hours of 9, 14 and 15 were more than other times, predicted direct illuminance and subsequently global vertical illuminance were considerably less than measured values.

Contrary to expectation, mean monthly South facing vertical illuminance in late fall and winter were higher than the rest of year. Variations of incidence angles during year justifies this phenomenon so that while increasing of incidence angle α_i, the cosα_i decreases in late spring and summer which results in decrease of direct vertical illuminance hence diminish in global vertical illuminance.

Mean monthly values of horizontal and South facing vertical illuminance found to be in range of 28-74 KLx and 38.33-91.61 KLx, respectively. Additionally mean monthly horizontal and vertical illuminance exceed 63 KLx for 6 months (50% of working year) and 8 months (0.96% of working year), respectively. These findings reinforced earlier expectation of high daylight availability on horizontal and vertical planes in subtropical region of Iran.

ACKNOWLEDGMENTS

This study is based on the first author Mscthesis which was conducted in Hamadan University of Medical Sciences, Iran in 2008.

REFERENCES

Chirarattananon, S., P. Rukkwansuk., P. Chaiwiwatworakul and P. Pakdeepol, 2007. Evaluation of vertical illuminance and irradiance models against data from North Bangkok. Build. Environ., 42: 3894-3904.

Golmohammadi, R., S. Shekari and H. Mahjub, 2009. Estimation of horizontal illuminance for clear skies in Iran. J. Applied Sci., 9: 2144-2149.

Ihm, P., A. Nemri and M. Krarti, 2009. Estimation of lighting energy savings from daylighting. Build. Environ., 44: 509-514.

Klucher, T.M., 1979. Evaluation of models to predict insolation on tilted surfaces. Solar Energy, 23: 111-114.

Li, D.H.W. and J.C. Lam, 2000. Evaluation of slope irradiance and illuminance models against measured Hong Kong data. Build. Environ., 35: 501-509.

Navvab, M., M. Karayel, E. Neeman and S. Selkowitz, 1984. Daylight availability data for San Francisco. Energy Build., 6: 273-281.

Perez, R., P. Ineichen and R. Seals, 1990. Modeling daylight availability and irradiance components from direct and global irradiance. Solar Energy, 44: 271-289.

Rahim, R. and R. Mulyadi, 2000. Priliminary study of horizontal illuminance in Indonesia. http://www.fab.utm.my/download/ConferenceSemiar/SENVAR52004SPKN03.pdf.

Rea, M.S., 1993. Lighting Handbook Reference and Application. 8th Edn., Illuminating Engineering Society of North America, New York.

Rea, M.S., 2000. The IESNA Lighting Handbook Reference and Application. 9th Edn., Illuminating Engineering Society of North America, New York, ISBN: 0-87995-150-8.

Robledo, L. and A. Soler, 2000. Estimation of global illuminance for clear skies at Madrid. Energy Build., 31: 25-28.

Ruiz, E., A. Soler and L. Robledo, 2002. Statistical assessment of a model for global illuminance on inclined surfaces from horizontal global illuminance. Energy Convers. Manage., 43: 693-708.

Shekari, S., R. Golmohammadi, H. Mahjub, I. Mohammadfam and M. Motamedzadeh, 2008. Estimation of illuminance on the South facing surfaces for clear skies in Iran. J. Res. Health Sci., 8: 46-55.

Stephenson, P., 2005. Artificial daylight as ergonomic lighting. http://www.virtualdaylight.com/downloads/ArtDayErgoLight.pdf.

Vazquez, D. and E. Bernabeu, 1997. Quantitative estimation of clear sky light in Madrid. Energy Build., 26: 331-336.

Webb, A.R., 2006. Considerations for lighting in the built environment: Non-visual effects of light. Energy Build., 38: 721-727.