Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 9 (11): 2144-2149, 2009
ISSN 1812-5654

Estimation of Horizontal Illuminance for Clear Skies in Iran

[1]R. Golmohammadi, [1]S. Shekari and [2]H. Mahjub
[1]Department of Occupational Health, Public Health School and Center for Health Research,
Hamadan University of Medical Sciences, Hamadan, Iran
[2]Department of Biostatistics, Hamadan University of Medical Sciences, Iran

Abstract: In this study, illuminance on horizontal surface based on a proper method was estimated. In respect to no available data regarding irradiance, sky luminance and illuminance in Iran, computing horizontal illuminance by the IESNA method could be the viable alternative. An illuminance measuring set was designed for measuring horizontal illuminance for standard times over 15 days in 1 h intervals from 9 am to 3 pm at three measuring stations (Hamadan, Eshtehard and Kerman). These data were used to confirm calculated data. Minimum, mean and maximum values of measured illuminance in clear sky were found to be 53, 96 and 129 Klx, respectively. Results showed a good correlation between measured and calculated data (r = 0.703).

Key words: Illuminance, daylight, sky, modeling

INTRODUCTION

Daylight is considered as the best source of light for good color rendering and its quality is the one light source that most closely matches human visual response. It does make an interior look more lively and attractive (Li and Lam, 2003). Daylight is part of energy spectrum of electromagnetic radiation emitted by the sun within the visible wave-band that is received at the surface of the earth after absorption and scattering in the earth's atmosphere. Sunlight is the direct component of light, while daylight is the total light from the sky dome (Ahmed *et al*., 2002). Daylight consists of direct (or beam), diffuse and ground-reflected components. Illumination is the cumulative energy incidents on a surface in a certain time whereas Illuminance (1 m m^{-2}) is the instantaneous incident energy. The solar height angle determines the thickness of the atmospheric layer through which direct light has to travel and distribution of sky luminance (Robledo and Soler, 2000). Thus daylight directly is affected by the solar high angle.

Whilst there are no absolutely conclusive studies that correlate daylighting provision or occupant satisfaction with workers productivity, there is mounting evidence that workers do appreciate offices that provide daylight and a view of the outside (Nabil and Mardaljevic, 2006).

Apart from visual effects of daylight it has observed to elicit powerful non visual effects. It controls the circadian rhythm of hormone secretions and body temperature with implications for sleep/wake states, alertness, mood and behavior (Webb, 2006). Additionally it is widely known that electrical lighting in office interiors can make up for 30% of the total building energy consumption (Wittkopf *et al*., 2006). Recently there has been an increasing interest in incorporating daylight in building designs to save building energy consumption (Li and Lam, 2003). Therefore, the increased use of daylight and careful tailoring of the lighted environment has potential for both health benefits and increased safety and productivity (Webb, 2006).

The phrase daylight availability refers to the amount of light from the sun and the sky for a specific location, time, date and sky condition. The performance of daylight technologies depends on the dynamic nature of the external illuminance (Rea Mrks, 2000). This could be represented by an hourly, daily or monthly data. Such data can be obtained either by measurements or by calculation from other meteorological quantities (Alshaibani, 2001). In some measurement stations external illuminance has been measured regularly for several years but in Iran there are no recorded data associated with daylight levels so it was obtained by established models.

MATERIALS AND METHODS

The daylight measurement station: Three daylight measurement stations were established in three cities having different climatic conditions in Iran. Table 1 shows geographical coordinate and climatic condition of measurement stations and demonstrates measuring standard times in Julian date.

Corresponding Author: Shamsi Sekari, Department of Occupational Health, Public Health School, Hamadan University of Medical Sciences, P.O. Box 4171, Hamadan, Iran

Table 1: Characteristics of daylight measuring stations

Stations name	Location	Climatic condition	Longitude	Latitude	Measuring time (Julian date)
Hamadan	West of Iran	Predominantly cold weather	E 48°29.340′	N 34°47.406′	195-200,202-206, 210-213
Eshtehard	Central near the West	Moderate	E 50° 19.538′	N 35°41.944′	194-208
Kerman	East of Iran	Hot and dry	E 56°43.782′	N 29°56.973′	194-208

Fig. 1: Illuminance measuring set

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.

A simple illuminance measuring equipment supplied by a measuring set were used for monitoring the horizontal surface. The designed set was consisted two adjustable plans to support and keep the photosensor of measuring equipment in a horizontal or vertical position. Figure 1 shows an illuminance measuring set. Illumination monitoring was carried out over 15 days at 1 h intervals between 12 July and 1 August 2007 from 9 am to 3 pm.

It must be noted that sky conditions were determined experimentally and data related to partly cloudy and cloudy sky conditions are eliminated and solely data related to clear sky are considered.

Estimation of horizontal illuminance using IESNA method: In respect to inadequate access to developed daylight monitoring system, for monitoring luminance and irradiance, it was imperative that external illumination be estimated using a proper method. Thus daylight data were obtained by a calculating model proposed by illuminating Engineering Society of North America (IESNA). These equations do not express instantaneous values of illuminance. In the other word they give mean values and provide best fits to data averaged over time and measurement sessions. Based on IESNA equations basic data and beam normal illuminance and solar altitude were calculated for each station and subsequently two components of daylight (beam or sunlight, diffuse or skylights) were calculated using following equations:

$$\mathrm{ET} = \left[7.637\sin\left(\frac{2\pi(J-2.5)}{365.25}\right) - 9.836\sin\left(\frac{2\pi(J-81.6)}{365.25}\right)\right]\frac{1}{60} \tag{1}$$

$$t_s = td - 1 \tag{2}$$

$$t = t_s + \mathrm{ET} + \frac{12(\mathrm{SM}-\mathrm{L})}{\pi} \tag{3}$$

$$\delta = 0.4093\sin\left[\frac{2\pi(J-81)}{368}\right] \tag{4}$$

$$a_t = \arcsin\lfloor \sin l.\sin\delta\text{-}\cos l.\cos\delta.\cos(\pi t/12)\rfloor \tag{5}$$

$$E_{xt} = E_{SC}\left[1 + 0.034\cos\frac{2\pi(J-2)}{365}\right] \tag{6}$$

$$m = \frac{1}{\sin a_t} \tag{7}$$

$$E_{dn} = E_{xt} \,.\, e^{-cm} \tag{8}$$

$$E_{dh} = E_{dn} \,.\, \mathrm{sinat} \tag{9}$$

$$E_{kh} = A + B\sin^{C} a_t \tag{10}$$

Where:

ET : Equation of time (the difference between solar time and clock time) expressed in decimal hours (for example, 1:30 pm = 13.5)

J : Julian date, a number between 1 and 365

t_s : Standard time in decimal hours

t_d : Daylight time in decimal hours

t : Solar time in decimal hours

SM : Standard meridian for the time in rad

L : Site longitude in rad

δ : Solar declination in rad

l : Site latitude in rad

α_t : Solar altitude in rad

E_{xt} : Extraterrestrial solar illuminance in Klx

E_{sc} : Solar illumination constant in Klx(current standard 128 Klx)

m : Optical air mass (dimensionless)

c : Atmospheric extinction coefficient (0.21 for clear, 0.8 for partly cloudy and very high for cloudy sky so Edn = 0)
E_{dn} : Direct normal solar illuminance in Klx
E_{dh} : Direct horizontal solar illuminance in Klx
E_{kh} : Horizontal illuminance due to unobstructed skylight in Klx
A : Sunrise/sunset illuminance in Klx (0.8 for clear, 0.3 for partly cloudy and 0.3 for cloudy sky)
B : Solar altitude illuminance coefficient in Klx (15.5 for clear, 45 for partly cloudy and 21 for cloudy sky)
C : Solar altitude illuminance exponent (0.5 for clear, 1 for partly cloudy and 1 for cloudy sky)

Virtually illuminance on horizontal surfaces was simply achieved by following equation:

$$Eh = E_{dh}+E_{kh} \tag{11}$$

Where:
Eh = Horizontal illuminance in Klx

RESULTS AND OBSERVATIONS

Measurement of illuminances carried out to confirm calculated illuminances. Respective frequency of occurrence of clear, partly cloudy and cloudy skies found to be 96, zero and 9 at hamadan. The corresponding values were 96, 3 and 6 at Eshtehard also 85, 3 and 17 at Kerman. Generally from 315 times measurement of horizontal illuminance, respective frequency of occurrence of clear, partly cloudy and cloudy skies found to be 277, 6 and 32 at stations. Frequencies of occurrence of each sky condition are shown in Table 2.

Table 2: Sky condition frequency at stations

	Sky cover			
Stations name	Clear	Partly cloudy	Cloudy	Sum
Hamadan	96	-	9	105
Eshtehard	96	3	6	105
Kerman	85	3	17	105
Total	277	6	32	315

Table 3: Descriptive results of field measured Eh and calculated Eh (Klx) in stations

Stations	Eh	N	Minimum	Maximum	Mean	SD
Hamadan	Measured	96	67.70	118.00	93.36	13.37
	Calculated	96	85.32	120.05	105.14	12.09
Eshtehard	Measured	95	68.40	114.50	93.39	11.69
	Calculated	95	86.02	119.64	104.80	11.76
Kerman	Measured	85	53.90	129.90	102.45	16.02
	Calculated	85	77.62	121.38	104.85	14.91
Total	Measured	276	53.90	129.90	96.17	14.30
	Calculated	276	77.62	121.38	104.94	12.87

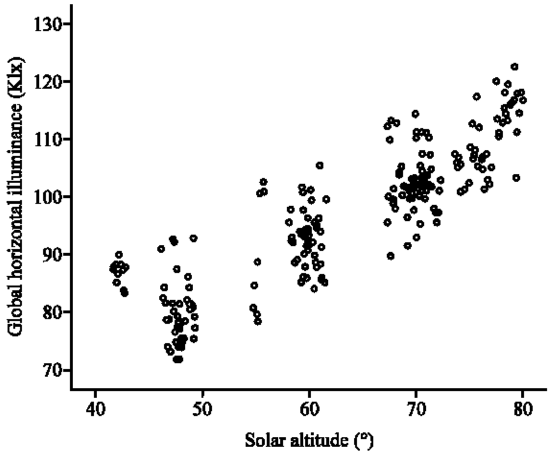

Fig. 2: Relation between measured values of Eh and solar altitude

Descriptive analysis of field measured and calculated illuminance on horizontal surface, at Hamadan station exhibits that the peak values exceed 118 and 120 Klx, respectively and corresponding mean values exceed 93 and 105 Klx. Also minimum values exceed 67 and 85 Klx, respectively. At Eshtehard station the peak values of measured and calculated data exceed 114 and 119 Klx and associated mean values exceed 93 and 104 Klx and minimum illuminances exceed 68 and 86 Klx, respectively. At Kerman station, the peak values of measured and calculated data exceed 129 and 121 Klx and corresponding mean values exceed 102 and 104 Klx and minimum illuminances exceed 53 and 77 Klx, respectively. Results of total data at all stations, reveals that the peak values of measured and calculated illuminances, exceed 129 and 121 Klx, respectively. Also corresponding total mean values exceed 96 and 104 Klx and corresponding minimum values exceed 53 and 77 Klx, respectively. Table 3 demonstrates these results.

Measured values of total stations consist of a wide range from 53 to 129 Klx and standard deviation of 14.30 whereas corresponding calculated values have a smaller range (79-121 Klx) and smaller standard deviation (12.87). Solar altitude decreases from 79.75° in 194th day to maximum of 41.69° in 208th day of the year. Global illuminance was plotted related solar altitude in Fig. 2, indicating a good linear regression between Eh and the solar altitude angle ($r = 0.866$, $r^2 = 0.75$).

In respect to Table 4, mean values of horizontal illuminance in Iran for solar altitude of 194th day (near 80°) reach to 110.5 Klx and for 208th day (more than 40°) exceed 88.5 Klx. These values compared with a period of

Table 4: Comparison of mean global illuminance in different locations for corresponding solar altitudes

Solar altitude (degree)	Mean global horizontal illuminance (Klx)			
	Iran	Spain	Spain	Thiland
40	88.62	70	40	70
50	80.15	82	58	90
60	94.14	92	75	100
70	104.94	102	96	110
80	110.58	-	118	118

Table 5: Categories of measured and calculated horizontal illuminances and solar altitude at

Category	Range of measured Eh	Range of calculated Eh	Range of calculated at
1	Lower-55	Lower -78	Lower -42
2	55.01-64.36	78.01-83.42	42.01-46.72
3	64.37-73.73	83.43-88.84	46.73-51.44
4	73.74-83.09	88.85-94.27	51.45-56.15
5	83.1-92.45	94.28-99.69	56.16-60.87
6	92.46-101.82	99.70-105.11	60.88-65.59
7	101.83-111.18	105.12-110.53	65.60-70.31
8	111.19-120.54	110.54-115.95	70.32-75.03
9	120.55-higher	115.96-higher	75.04-higher

Table 6: Frequency and percent of categories of measured and calculated values and solar altitudes at stations

Category	Measured Eh (%)	Calculated Eh (%)	Solar altitude (%)
1	1(0.4)	3(1.1)	4(1.4)
2	1(0.4)	12(4.3)	16(5.8)
3	18(6.5)	35(12.7)	51(18.5)
4	37(13.4)	21(7.6)	26(9.4)
5	48(17.4)	24(8.7)	45(16.3)
6	66(23.9)	35(12.7)	10(3.6)
7	62(22.5)	22(8)	47(17)
8	37(13.4)	60(21.7)	37(13.4)
9	6(2.2)	64(23.2)	40(14.5)
Total	276(100)	276(100)	276(100)

measuring in this research, June 1994-May1995 for Spain (Robledo and Soler, 2000), June 1993- January1994 for Spain (Vazquez and Bernabeu, 1997) and 1998-2000 for Thailand (Chirarattananon *et al.*, 2002).

Frequency analysis of total data of measured and calculated horizontal illuminance and solar altitude were performed by dividing them in to 9 categories. Table 5 and 6 exhibit categories and frequencies of measured and calculated horizontal illuminances and calculated solar altitudes. In accordance with Table 6, maximum frequency of measured and calculated illuminances and solar altitudes found to be 66(23.9%), 64(23.2%) and 51(18.5%), respectively. These maximum frequencies range from 92 to 101 Klx and from 115Klx to higher and from 46 to 51°, respectively.

Measured values of Eh plotted related calculated values, exhibit a good regression as it is shown in Fig. 3. Estimation of mean values of field measured and calculated illuminances on horizontal surface over 15 days at measuring stations, reveals that maximum and minimum measured values of mean hourly illuminances exceed 109 and 79 Klx, respectively. Other results are shown in Table 7. the average of mean hourly values in Iran, Thailand (Chirarattananon *et al.*, 2002), Turkey (Hasdemir, 1984), Malaysia (Ahmaed *et al.*, 2002) and India (Li and Lam, 2003; Joshi *et al.*, 2007) are 96.46, 73.59, 61, 56.7 and 56.7 Klx, respectively. It must be noted that values are recorded in a period of July 2007 in this research, July months of 1978-1980 for Turkey, solar times of 1998-2000 for Bangkok, months of March, August and December 1975-1995 for Malaysia and year 2005 for India. Table 8 exhibits the results of various locations.

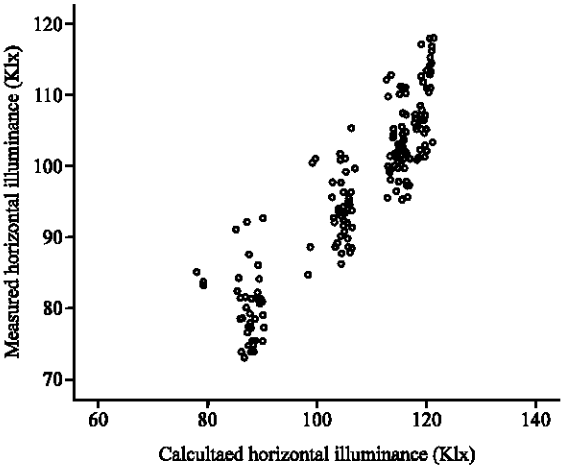

Fig. 3: Relation between measured and calculated values of Eh

In respect to coefficient of determination, the correlation appears to be reasonable for horizontal illuminances at Hamadan (r = 0.806) and Eshtehard (r = 0.826) and Kerman (r = 0.629) therefore correlation of measured values against calculated values appears to be reasonable for all stations (r = 0.703). Figure 4 exhibits the comparison of measured and calculated values of Eh in standard times.

Finally, a simple regression model fitted between measured and calculated values of horizontal illuminance. This model suggested for predicting Eh by calculated values using following equation: ($r = 0.89$, $r^2 = 0.80$):

$$E_{hm} = 0.841E_{hc} + 6.65 \qquad (12)$$

Where:

E_{hm} = Predicted horizontal illuminance in Klx

E_{hc} = Calculated horizontal illuminance in Klx

Table 7: Mean values of measured and calculated Eh at different standard times

		Standard time						
Mean illuminance (Klx)	Measuring stations	9	10	11	12	13	14	15
Eh	Hamadan	70.95	88.13	100.66	106.27	106.94	97.77	84.48
		89.42	105.85	115.98	119.15	115.10	104.12	86.94
	Eshtehard	77.80	93.26	101.35	103.89	103.54	94.39	81.78
		87.31	104.20	114.94	118.93	115.82	105.72	89.46
	Kerman	88.62	107.00	118.24	118.00	109.22	99.13	75.09
		78.66	99.06	113.50	120.94	120.80	113.28	98.66
	Total	79.34	96.46	106.22	109.23	106.49	96.67	80.87
		84.98	102.91	114.87	119.65	117.14	106.82	91.15

Data written in upper rows and lower rows at stations are related to mean measured illuminances and calculated illuminances, respectively

Table 8: Mean hourly values of Eh in various locations

	Mean hourly values (Klx)				
Time	Iran	Turkey	Malaysia	Thailand	India
9	79.34	55	40.0	61.05	45.0
10	96.46	62	54.0	75.07	57.0
11	106.22	70	65.0	82.81	65.0
12	109.23	70	73.0	83.65	68.0
13	106.49	68	73.0	82.38	60.0
14	96.67	57	67.0	74.75	57.0
15	80.87	46	53.0	55.42	45.0
Mean	96.46	61	60.7	73.59	56.7

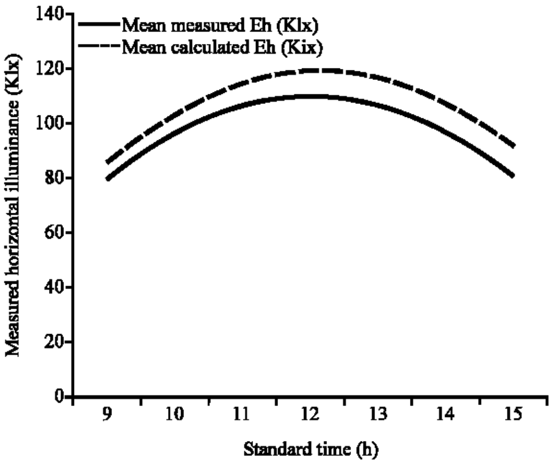

Fig. 4: Comparison between measured and calculated values of Eh at standard times

DISCUSSION

The objective of this study was to estimate horizontal illuminance on horizontal surface based on IESNA method in Iran. Measurement of horizontal illuminance carried out from 12 July and 1 August 2007 from 9 am to 3 pm Frequency of partly cloudy and cloudy skies may be equal at Eshtehard and Hamadan (8.6%) whereas at Kerman it found to be two times higher than other two stations (19%). Clear sky is predominant sky type (88%) for most of measuring period among total data. Maximum, mean and minimum values of measured global illuminance exceed 129, 96 and 53 Klx, respectively also 23.9% of measured values range from 92 to 101 Klx. These values are high as further expectation for a subtropical location as Iran. It obvious that IESNA equations estimate horizontal illuminances a little higher than measured illuminances at corresponding standard times. The maximum measured illuminances in Iran (129 Klx) is similar to monthly average amount of mean hourly illuminance (120 Klx) in Saudi Arabia (Alshaibani, 2001).

Comparison of measured and calculated values shows that calculated values tend to higher levels especially in minimum values also they have smaller standard deviation. The reason of this difference could be restricted ability of IESNA method in identification of real sky conditions. These 15 sky illuminance model have been adopted as CIE (international commission on illumination) General Standard Skies (Li and Cheung, 2006) and completely described by Kambedezidis *et al*. (2002). Whereas in IESNA method there are only three sky conditions of clear, partly cloudy and cloudy and one distinct constant is considered for each sky condition so this limitation results in calculating concentrated horizontal illuminances rather than measured illuminances.

Solar altitude which varies from 41.69° in 208th day to maximum 79.75° in 194th day of the year, has a maximum frequency of 18.5% between 46 and 51° at measuring stations. Mean global illuminances in Iran are higher than Spain but lower than Thailand for correspondent solar altitudes due to locating of Thailand in tropical region. Mean hourly iluminances at working hours in Iran are considerably higher than other countries so that the average of these hourly values in Iran is 1.3, 1.5, 1.7 and 1.7 times more than Thailand, Turkey, Malaysia and India, respectively. These findings confirm the idea that Iran has a high potentiality for daylighting and energy saving for buildings and industries. In spite of tendency of mean calculated illuminances to higher values rather than mean measured values, there is a good linear regression between measured and calculated values of horizontal illuminance (r = 0.703). For more accurate data it is necessary to measure illuminance values at corresponding solar times at three stations in a long time also to identify accurately predominant sky type and daylight availability, long-term measurement of irradiance, sky luminance and illuminance must be made.

REFERENCES

Ahmed, A.Z., K. Sopian, Z.Z. Abidin and M.Y.H. Othman, 2002. The availability of daylight from tropical skies a case study of Malaysia. Renewable Energy, 25: 21-30.

Alshaibani, K., 2001. Potentiality of daylighting in a maritime desert climate: The Eastern coast of Saudi Arabia. Renewable Energy, 23: 325-331.

Chirarattananon, S., P. Chaiwiwatworakul and S. Pattanasethanon, 2002. Daylight availability and models for and diffuse horizontal illuminance and irradiance for Bangkok. Renewable Energy, 26: 68-89.

Hasdemir, B., 1984. Daylight availability in Turkey. Energy Build., 6: 267-272.

Joshi, M., R.L. Sawhney and D. Buddhi, 2007. Estimation of Luminous efficacy of daylight and exterior illuminance for composite climate of Indoor city in Mid Western India. Renewable Energy, 32: 1363-1378.

Kambedezidis, D., T. Oikonomou and D. Zevgolis, 2002. Daylight climatology in the Athens urban environment: Guidance for building designers. Lighting Res. Technol., 34: 297-312.

Li, D.H.W. and J.C. Lam, 2003. An investigation of daylighting performance and energy saving in a daylight corridor. Energy Build., 35: 365-373.

Li, D.H.W. and G.H.W. Cheung, 2006. Average daylight factor for the 15 CIE's standard skies. Lighting Res. Technol., 38: 137-152.

Nabil, A. and J. Mardaljevic, 2006. Useful daylight illuminance: A replacement for daylight factors. Energy Build., 38: 905-913.

Rea Mrks, 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.

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

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

Wittkopf, S.K., E. Yuniarti and L.K. Soon, 2006. Prediction of energy savings with anabolic integrated ceiling across different daylight climates. Energy Build., 38: 1120-1129.