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Estimation of Illuminance on the South Facing Surfaces for Clear Skies in Iran

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Abstract

Background: Daylight availability data are essential for designing effectively day lighted buildings. In respect to no available daylight availability data in Iran, illuminance data on the south facing vertical surfaces were estimated using a proper method.
Methods: An illuminance measuring set was designed for measuring vertical illuminances for standard times over 15 days at one hour intervals from 9 a.m. to 3 p.m. at three measuring stations (Hamadan, Eshtehard and Kerman). Measuring data were used to confirm predicted by the IESNA method.
Results: Measurement of respective illuminances on the south vertical surfaces resulted in minimum values of 10.5 KLx, mean values of 33.59 KLx and maximum values of 79.6 KLx.
Conclusion: In this study was developed a regression model between measured and calculated data of south facing vertical illuminance. This model, have a good linear correlation between measured and calculated values (r= 0.892).

Keywords: *Light, South, Vertical illuminance, Iran*

Introduction

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 (1). Daylight consists of direct (or beam), diffuse and ground reflected components. To accurately estimate daylight in the interiors it is required to estimate daylight availability outdoors a room. Daylight availability can be defined as the average amount of skylight and sunlight available during typical period (day, month, season or year) taking in to account average turbidity (water vapor and particle content of the atmosphere and cloud type and cover) (2). 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 (3).

In respect to no available data regarding irradiance, sky luminance and illuminance in Iran, external illumination was estimated by equations proposed by "Illuminating Engineering Society of North America" (IESNA). Based on IESNA equations basic data and beam normal illuminance and solar altitude and azimuth were calculated for each station using following equations (4).

$$ET = 0.17 \sin\left[\frac{4\pi(J-80)}{373}\right] - 0.129 \sin\left[\frac{2\pi(J-8)}{355}\right] \quad [1]$$

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$$ts = td - 1$$
[2]
$$t = t_S + ET + \frac{12(SM - L)}{\pi}$$
[3]
$$\delta = 0.4093 \sin\left[\frac{2\pi(J - 81)}{368}\right]$$
[4]
$$a_t = \arcsin\left[\sin l . \sin \delta - \cos l . \cos \delta . \cos\left(\pi t / 12\right)\right]$$
[5]
$$E_{xt} = E_{SC}\left[1 + 0.034 \cos \frac{2\pi(J - 2)}{365}\right]$$
[6]
$$as = \arctan\left(\frac{-\left[\cos \delta . \sin\left(\pi t / 12\right)\right]}{-\left[\cos l . \sin \delta + \sin l . \cos \delta . \cos\left(\pi t / 12\right)\right]}\right)$$
[7]
$$m = \frac{1}{\sin a_t}$$
[8]
$$E_{dn} = E_{xt} \cdot e^{-cm}$$
[9]
$$E_{dh} = E_{dn} . \sin at$$
[10]
$$E_{kh} = A + B \sin^C a_t$$
[11]

Where:
ET: Equation of time (the difference between solar time and clock time) expressed in decimal hours (for example, 1:30 p.m.= 13.5).
J: Julian date, a number between 1 and 365.
ts: standard time in decimal hours.
td: 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).
as:solar azimuth in rad.
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).

Estimation of illuminance on south facing vertical surfaces was simply achieved by following equations (4):
$$a_z = a_s - a_e$$
[12]
$$a_i = \arccos(\cos a_t . \cos a_z)$$
[13]
$$E_{dv} = E_{dn} . \cos ai$$
[14]
$$E_{kv} = A + B \cos a_i^C$$
[15]
$$E_g = \rho . (E_{dh} + E_{kh})$$
[16]
$$Ev_{south} = E_{dv} + E_{kv} + E_g$$
[17]

Where:
a_z: Solar- elevation azimuth in rad
a_e: Elevation azimuth in rad
a_i: Incident angle in rad
E_{dv}: Direct vertical solar illuminance in KLx

E_{kv}: Diffuse vertical illuminance 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 (0.33 for clear, 1 for partly cloudy and 1 for cloudy sky).
E_g: Ground reflected illuminance in KLx
Ev_{south}: Global illuminance on south facing vertical surface in KLx

Electrical lighting directly shares 20% of electricity use in a building and contributes 20% of cooling load to the air conditioning system. Air conditioning shares 60% of electricity use, so electric lighting also contributes indirectly another 12% of electricity use through the air conditioning system. Nevertheless, a number of studies have shown the daylight integrated electric lighting in commercial buildings can help reduce more than 50% of energy and power use from those due to lighting (5).
For the purpose of showing the potentiality of having a certain external average illuminance during a full working year, mean hourly and then mean monthly illuminances on south facing vertical window using correspondent linear model were obtained. Subsequently frequencies of days in a working year (294 d) which a given outdoor vertical illuminace is exceeded were determined.

Materials and Methods

Daylight measurements were carried out in three measuring stations having different geographical coordinate and climatic conditions. Table 1 shows the characteristics of measuring stations. Illuminance values on south facing vertical surfaces were taken using a simple illuminance measuring equipment Lutron Lx-101. A measuring set which consists of two adjustable plans to support and keep the photo sensor of measuring equipment in a vertical position on any desired orientation. Vertical illuminance values were taken over 15 d at one hour intervals between 12 July and 1 August 2007 from 9 a.m. to 3 p.m. generally 105 sets of measurements were taken at each station which are referred to standard time. All of the collected data were entered in statistical sheet of SPSS software. Multiple regression models were applied to develop a model between calculated and measured variables of illumination.

Results

Measurement of illuminance on the south oriented surface was carried out for the purpose of confirming calculated data. In order to study the frequency of occurrence of cloud cover, the sky conditions were determined experimentally and clear skies were selected as those without any cloud. Generally from 315 times measurement of vertical illuminance on the south orientation, respective frequency of occurrence of clear, partly cloudy and cloudy skies found to be 277, 6 and 32. The frequency of occurrence of clear skies is shown in Table 2. Table 3 shows the frequency of clear days in a working year which a given outdoor vertical illuminance is exceeded. Fig. 1 shows the percent of clear days in different locations. In respect to more common clear skies at reporting period, data related to partly cloudy and cloudy sky conditions were eliminated and solely clear skies were considered.
In accordance with Table 4, descriptive analysis of data exhibits that values of field measured and calculated illuminance at total station range from 10.5 to 79.6 KLx and from 7.05 to 54.9 KLx, respectively. Also mean respective values of measured and calculated illuminances exceed 33.5 KLx and 33.9 KLx. Table 5 exhibits that the

maximum value of measured illuminances in Iran (79.6 KLx) compare to Saudi Arabia (3), Thailand (5), India (6) Hong Kong (7), San Francisco (8) and France (9) at corresponding measuring time.

Frequency analysis of total data of measured and calculated south facing vertical illuminances were performed by dividing them in to 9 categories. In accordance with Table 6, maximum frequencies of measured and calculated illuminances on the south facing surface found to be 56(20.3%) and 46(16.7%), respectively. related values of these maximum frequencies range from 33.41 KLx to 41.1 KLx and from 28.43 KLx to 33.72 KLx.

Mean measured and calculated hourly values on south vertical surface were determined at all stations for entire period. In respect to Table 5, minimum values of mean hourly measured illuminances on the south oriented surface at total station touch 21.54 KLx. Table 5 exhibits that the maximum mean hourly values in Iran (41.75 KLx) is considerably higher than Thailand, France, San Francisco, India and Saudi Arabia (3). Table 7 shows the mean hourly values of measured and calculated on south facing vertical illuminance at standard time. Table 8 exhibits comparison of mean hourly and mean monthly values of the south facing vertical surfaces in Iran and other locations at corresponding measuring period.

Patterns of comparative curves of mean measured and mean calculated hourly illuminances on the south facing surfaces illustrate that IESNA equations are not able to estimate vertical illuminances exactly as the measured values at corresponding standard times. Figure 2 illustrates comparative curves of measured and calculated mean hourly values on the south fact surfaces. In respect to coefficients of determination of total data, the correlation appears to be reasonable for measured and calculated values on the south facing vertical surface (r = 0.529).

Measured values of the south facing illuminances plotted related calculated values; exhibit a good regression as shown in Figure 3. A simple regression model fitted between measured and calculated values on the south surfaces (r^2= 0.796). This model suggested for predicting vertical illuminance by calculated values using following equations:

$$Evs_m = 0.773 Evs_c + 6.912$$

[20]

Where:

Evs_m: *measured south facing vertical illuminance in KLx*

Evs_c: *calculated south facing vertical illuminance in KLx*

Table 9 shows the prediction of mean hourly and monthly illuminance on the south facing vertical surface for working year based on developed calculation model for Iran (Eshtehard location).

Table 1: Characteristics of daylight measuring stations

Station name	Location	Climatic condition	Longitude	latitude	Measuring time (Julian date)
Hamadan	West of Iran	predominantly cold weather	E48°29.340′	N34°47.406′	195-200,202-206, 210-213
Eshtehard	Central near the west	Moderate	E50° 19.538′	N35°41.944′	194-208
Kerman	East of Iran	Hot and dry	E56°43.782′	N29°56.973′	194-208

Table 2: Sky condition frequency at stations

Station name	Sky cover			
	Clear (%)	Partly cloudy (%)	Cloudy (%)	sum
Hamadan	96(91.4)	-	9(6.8)	105
Eshtehard	96(91.4)	3(2.9)	6(5.7)	105
Kerman	85(81)	3(2.9)	17(16.2)	105
total	277(87.9)	6(1.9)	32(10.8)	315

Table 3: frequency of clear days in a working year which a given outdoor vertical illuminance is exceeded

Illuminance on south facing vertical surface(KLx)	Frequency of clear days in working year
20	162
30	126
40	120
50	93
60	79
70	42
80	0

Table 4: Comparisons of measured and calculated values of south facing vertical surfaces

Measuring station	n	Min(KLx)	Max(KLx)	Mean(KLx)	sd(KLx)
Hamadan	96	12.34	47.40	32.63	10.43
	96	18.64	50.17	36.05	9.20
Eshtehard	95	15.50	79.60	41.76	18.68
	95	23.90	54.96	40.14	9.42
Kerman	85	10.50	42.70	25.53	9.24
	85	7.05	37.19	24.68	8.37
Tatal	276	10.5	79.60	33.59	15.05
	276	7.05	54.96	33.96	11.05

Note: Uupper and lower data at each station are related in mean measured and mean calculated illuminances respectively.

Table 5: Compare of mean, maximum mean hourly and maximum of south facing vertical illuminance in different locations

Locations	South facing vertical illuminance (KLx)		
	Mean	Maximum mean hourly	Maximum
Iran*	33.59	41.75	79.60
Thailand (5)	16.57	18.60	60.00
France (9)	31.78	40.00	75.00
San Francisco (8)	34.48	40.00	-
India (6)	25.7	28.50	-
Saudia Arabia (3)	-	34.00	-
Hong Kong (7)	-	-	90.00

Results of this study

Table 6: Category and frequency of measured and calculated values on south facing vertical surface

Category	Measured southern vertical illuminance(KLx)		Calculated southern vertical illuminance(KLx)	
	Range	**Frequency (%)**	**Range**	**Frequency (%)**
1	10.5 -18	52(18.8)	7.05 - 12.5	9(3.3)
2	18.01 - 25.7	42(15.2)	12.51 - 17.80	10(3.6)
3	25.71 - 33.4	46(16.7)	17.81 - 23.11	30(10.9)
4	33.41 -41.1	56(20.3)	23.12 - 28.42	39(14.1)
5	41.11 - 48.8	38(13.8)	28.43 - 33.72	46(16.7)
6	48.81 - 56.5	15(5.4)	33.73 - 39.03	44(15.9)
7	56.51 - 64.2	16(5.8)	39.04 - 44.34	39(14.1)
8	64.21 -71.9	7(2.5)	44.35 - 49.64	39(14.1)
9	79.6 -71.91	4(1.4)	54.96 -49.65	20(7.2)
Total	-	276(100)	-	276(100)

Table 7: Mean hourly values of measured and calculated on south facing vertical illuminances

Measuring station	Mean hourly south facing vertical illuminance at standard time(KLx)						
	9	**10**	**11**	**12**	**13**	**14**	**15**
Hamadan	33.19	42.28	42.67	38.63	30.14	21.8	15.54
	25.637	37.18	44.15	46.13	42.80	34.52	21.78
Eshtehard	59.51	61.84	56.94	45.43	28.70	21.66	18.70
	27.70	40.50	48.48	51.23	48.45	40.25	27.24
Kerman	14.21	15.49	23.14	32.25	36.10	34.90	32.75
	11.58	21.31	30.08	34.31	34.06	28.95	19.29
total	35.14	38.77	41.75	39.48	31.67	24.66	21.54
	21.36	32.45	41.39	44.06	41.88	35.52	22.91

Note: Uupper and lower data at each station are related in mean measured and mean calculated illuminances respectively.

Table 8: mean hourly and monthly measured illuminances on the south facing vertical surfaces in different locations

location	Reporting period	Mean hourly illuminance(KLx)							Mean monthly illuminance (KLx)
		9	**10**	**11**	**12**	**13**	**14**	**15**	
Iran*	July(2007)	35.14	38.77	41.75	39.48	31.67	24.66	21.54	33.29
Thailand	July(1998-2000)	12.6	15.4	17.9	18.4	18.6	17.8	15.3	6.57
France	July(1993- 1994)	12.5	20	30	40	40	40	40	31.78
India	June(2005)	22.5	25	28.5	28.5	28.5	25	22.5	25.7
San Francisco	July(1980-1984)	20	30	40	40	40	40	30	34.48

* - Results of this study

Table 9: Prediction of mean hourly and monthly illuminances on the south facing vertical surface for working year in Iran

month	Mean hourly south facing vertical illuminance(KLx)							Mean monthly Illuminance (KLx)
	9	10	11	12	13	14	15	
January	55.22	68.98	77.24	80.38	78.49	71.49	59.08	70.12
February	53.75	66.38	74.41	77.76	76.35	70.19	59.39	68.32
March	49.06	60.07	67.21	70.04	68.38	62.3	52.18	61.32
April	38.55	48.11	54.15	56.19	54.02	47.77	38.01	48.11
May	27.15	36.2	41.72	43.43	41.16	34.99	25.38	35.72
June	22.76	28.97	34.72	36.65	34.69	28.83	18.97	29.37
July	23.38	31.32	37.38	39.64	38	32.41	23.15	32.18
August	32.9	42.57	48.76	51.04	49.19	43.29	33.88	43.09
September	47.26	57.08	63.09	64.85	62.2	55.31	44.72	56.36
October	58.68	70.83	76.76	77.89	74.16	65.62	52.25	68.03
November	61.67	72.9	79.03	80.16	76.29	67.37	53.03	70.06
December	58.66	71.64	78.9	80.91	77.71	69.18	54.63	70.24

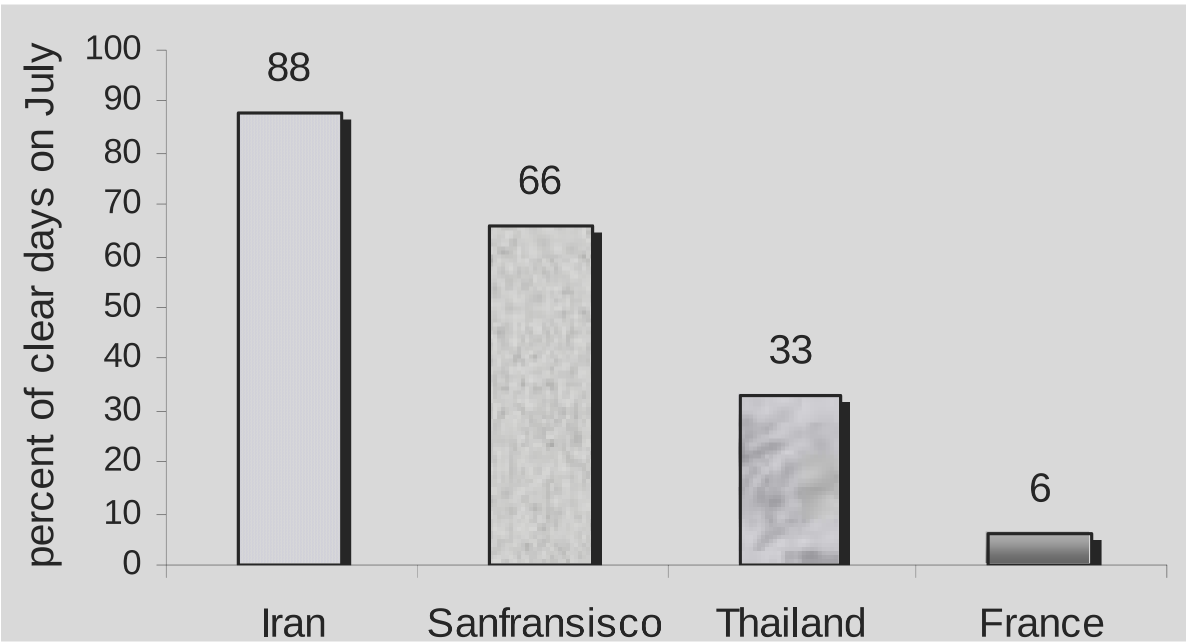

Fig.1: percent of clear days in different locations on July

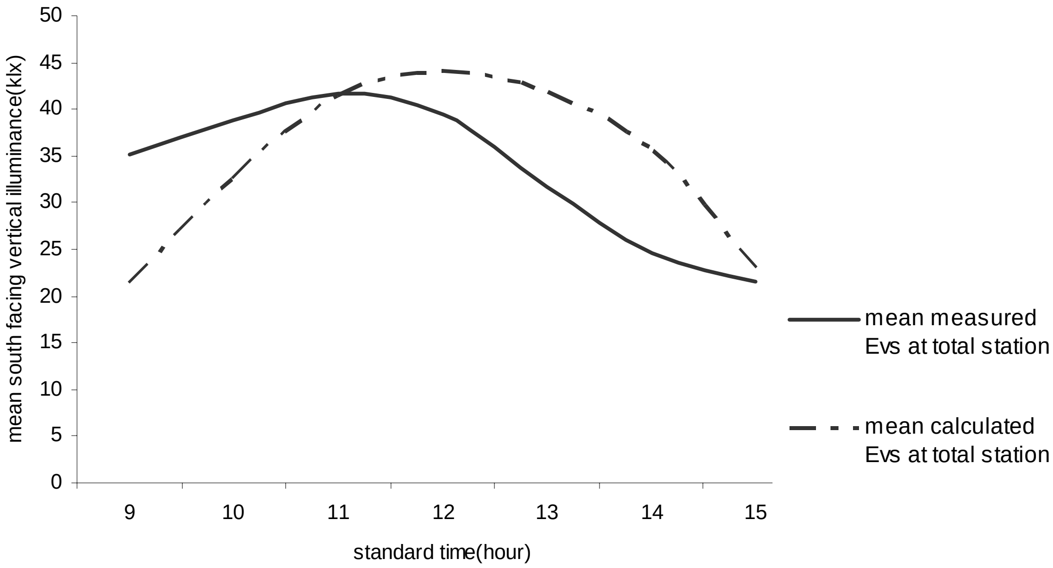

Fig. 2: Comparison of mean measured and means calculated values on the south facing vertical surface (*Evs*) at total stations

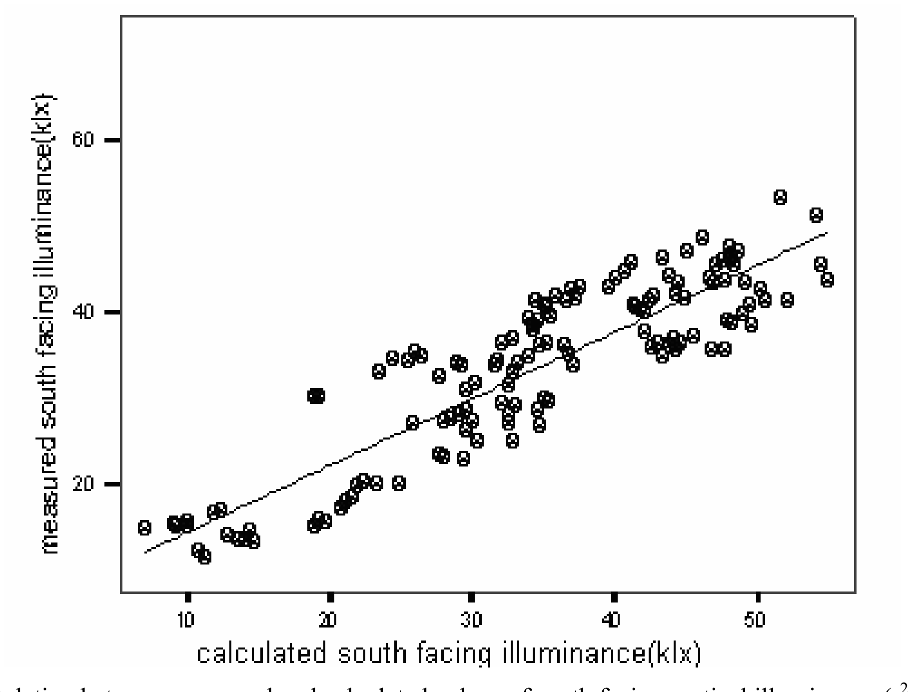

Fig. 3: Relation between measured and calculated values of south facing vertical illuminance (r^2= 0.795).

Discussion

Objective of this paper was to estimate illuminance on the south facing vertical surface based on IESNA method in Iran and compare to other world location to obtain a developed regression model.

In accordance with Table 5, Descriptive analysis of data exhibits that the maximum mean hourly value of measured illuminances in Iran (79.6 KLx) is higher than Saudi Arabia (3), Thailand (5), Thailand (5), India (6) Hong Kong (7), France(9) and San Francisco (8) at corresponding measuring time. Also, mean values of measured illuminances in Iran are markedly higher than Thailand, France, India and San Francisco (5-8).

Frequency of occurrence of clear skies (87.9%) in Iran is 1.33, 2.6 and 14 times more than San Francisco Thailand and France, respectively. This means that Iran, as other subtropical locations has good daylighting potential. Also Results showed that the percent of clear days in Iran was considerably higher than San Francisco, Thailand and France at corresponding measuring period (7-9). The climate of the subtropics and much of the tropical area is dry and clear most of the year with an annual average direct sun component typically about 8 hour per day (10).

Although measured and calculated values of total data are pretty close in mean values, maximum measured values tend to higher levels in the morning than calculated illuminances whereas at the rest of time calculated values are higher than measured values. On the other hand calculated values are more concentrated and have smaller standard deviation rather than measured values. The reason of this difference could be restricted ability of IESNA method in identification of real sky conditions. recently Kittler et al(2) have proposed a new range of 15 standard sky luminance distributions including five clear, five partly cloudy and five overcast sky types. These 15 sky illuminance model have been adopted by CIE (international commission on illumination) as General Standard Skies (11) and completely described by Kambedezidis (12). 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 vertical illuminances rather than measured illuminances.

Maximum value of measured south facing vertical illuminances at total station in Iran (79.6 KLx) found to be 1.06, 0.8 and 1.3 times more than France, Hong Kong and Thailand, respectively. The respective ratios of maximum mean hourly values on south facing surface of Iran (41.7KLx) to Thailand, France and San Francisco and India found to be 2.2, 1, 1 and 1.4. Mean monthly south facing vertical illuminance in Iran was measured 2 and 1.2 times more than Thailand and India, respectively and nearly equal to correspondent values in France and San Francisco.

A regression model was developed between measured and calculated data of south facing vertical illuminance. This model, have a good linear correlation between measured and calculated values ($r^2 = 0.796$).

Conclusively, the suggested model could nicely predict of south facing illuminance in Iranian locations.

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