Research Journal of

Environmental Sciences

ISSN 1819-3412

Academic Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 4 (1): 42-49, 2010
ISSN 1819-3412

Ergonomic and Economic Daylight for Workplaces in Iran

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

Abstract: Even today lighting design of buildings is too often solely based on task illuminance levels with little consideration of the importance of the light distribution for the appearance and visual appeal of the lit spaces. In respect to no available information or calculation models on illuminance in Iran, equations proposed by Illuminating Engineering Society of North America in 2000 were adopted to calculate illuminance on the south facing vertical surfaces. Generally 315 times measurements were taken at three measuring stations over 15 days at one hour intervals between 12 July and 1 August 2007 from 9:00 a.m. to 3:00 p.m. to confirm calculated data. Mean respective values of measured and calculated illuminance exceed 33.59 and 33.27 KLx. Measured illuminance in each standard time at three stations exhibited a better agreement with calculated illuminance by IESNA equations in correspondent daylight times (related in 1 h later) rather than those calculated for the same standard times. A regression model with a good linear correlation (R^2 = 0.806) was developed between measured and calculated values of south facing vertical illuminance. Economic and ergonomic daylight found to be 46.5 and 17.8 KLx, respectively. The maximum Daylight Autonomy for maintaining average internal illuminance of 500Lx, also maximum useful daylight illuminance to achieve internal illuminance in range of 100-2000 Lx found to be more than 55% of working year in Iran.

Key words: Vertical illuminance, daylight autonomy, useful daylight illuminance

INTRODUCTION

Sunlight is the universal and free source of renewable energy available everywhere and the survival of life and health (Kittler and Darula, 2002). 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). Bright lighting 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).

Daylight is much more effective than electric lighting at ‘entraining’ the circadian system; this is because the circadian system responds only to high levels of blue light, such as those found in daylight. Studies have revealed that daylight is three to four times more effective on circadian rhythm than fluorescent lamps and twenty times more effective than incandescent lamps (Hashmi, 2008). Moreover, natural lighting provides both a more pleasant and attractive indoor environment that can foster higher productivity and performance (Ihm *et al*., 2009).

Even today lighting design of buildings is too often solely based on task illuminance levels with little consideration of the importance of the light distribution for the appearance and visual appeal of the lit spaces (Johnsen, 1998).

Corresponding Author: Shamsi Shekari Soleimanlou, Department of Occupational Health, Public Health School, Hamadan University of Medical Sciences, P.O. Box 4171, Hamadan, Iran
Tel/Fax: +982614457944

The lack of simplified evaluation tools, capable of providing information on the suitability and the cost-effectiveness of day lighting, is considered as one of the major reasons for the reluctance of building professionals in incorporating day lighting features in their design (Ihm *et al*., 2009).

Energy surveys conducted on different locations indicate that electrical lighting in office interiors can make up for 22-40% of the total building energy consumption (Wittkopf *et al*., 2006; Leslie, 2003; Ibrahim and Zain-Ahmed, 2007).

To meet the energy efficiency challenge, the common view is to utilize daylight as much as possible to minimize electricity consumption due to lighting power and generated cooling load due to artificial lighting system (Ibrahim and Zain-Ahmed, 2007). Electric energy savings also result in fewer power plant emissions that contribute to acid rain, air pollution and global warming (Leslie, 2003). For instance in a typical 6-storey office building, annual energy savings for lighting of 56-62% and a reduction in CO_2 emissions of nearly 3 tones were predicted by changing the lighting and day lighting specifications (Jenkins and Newborough, 2007).

Economic daylight refers to those outdoor illuminance values which can provide interior required task illuminance levels (i.g., 500 Lx) solely hence cause to decrease in electrical energy consumption. Ergonomic daylight refers to those outdoor illuminance values which can maintain indoor illuminance in range of 100-2000 Lx, which are responsible of non visual effects of light on workers. The information of percentage of working year in which a given outdoor illuminance (economic or ergonomic values) is exceeded is valuable in designing the building for specific interior illuminance (Joshi *et al*., 2007). Economic daylight and Ergonomic daylight address with Daylight Autonomy and Useful Daylight Illuminance, respectively. Daylight Autonomy (DA) is a measure of how often (e.g., percentage of the working year) a minimum work plane illuminance threshold of 500 Lx can be maintained by daylight alone, whereas the Useful Daylight Illuminance (UDI) is founded on a measure of how often in the year, interior daylight illuminance within a range of 100-2000 Lx are achieved. This range is considered effective either as the sole source of illuminance or in conjunction with artificial lighting and desirable or at least tolerable (Nabil and Mardaljevic, 2006).

This study was undertaken to estimate economic and ergonomic outdoor illuminance on the south facing vertical surfaces, as well as daylight autonomy and useful daylight illuminance in Iran.

MATERIALS AND METHODS

The conditions of environmental comfort and prosperity are dependent on effective utilization of daylight and parametric definition of the daylight climate (Kittler and Darula, 2002). Since, no parameter of daylight climate has not yet been defined in the country, there are no reliable data on luminance and illuminance in Iran so equations proposed by Illuminating Engineering Society of North America(IESNA) were taken in to account to predict outdoor global illminances (Rea Mrks, 2000). This study was based on following stages: 1) Calculation and field measurement of outdoor south facing vertical illuminance synchronically for Developing an adequate model to predict vertical illuminance throughout a working year. 2) Prediction of economic and ergonomic illuminance for a given workplace. 3) Determination of Daylight Autonomy and Useful Daylight Illuminance for Iran.

Developing Outdoor Illuminance Model

Studies have proven that vertical external illuminance can be provide more accurate information than the horizontal one to determine the average indoor illuminance (Li and Lam, 2000). calculation of south facing vertical illuminance were carried out utilizing equations proposed by IESNA (Rea Mrks, 2000) in Excel calculation sheets. for the purpose of validating calculated data, 315 sets of illuminance measurements on vertical surface were taken at three different stations (Eshtehard, Hamadan and Kerman) over 15 days between 12 July and 1 August 2007 at 1 h intervals from 9:00 a.m. to 3:00 p.m. sky type was determined as clear, partly cloudy and overcast skies Synchronically. Since, clear skies occurred for 87% of measuring period, data related to clear skies were taken in to account solely. All of the collected data were entered in statistical sheet of SPSS software. Multiple regression models were applied to develop adequate model between corresponding calculated and measured values of south oriented vertical illuminance. Contrary to expectation measured vertical illuminance exhibited better correlation with those calculated for 1 h later ($R^2 = 0.806$). More details on applied equations, measuring periods and monitoring stations are accessible in authors, earlier study (Shekari *et al*., 2008).

Prediction of Economic and Ergonomic Illuminance

The outdoor required vertical illuminance (E_{xv}) on the south facing windows to provide desired internal horizontal illuminance (500 Lx or 100-2000 Lx), was calculated using the following equations derived from Lumen method (Rea Mrks, 2000).

$$E_{itotal} = \frac{A_w.E_{des}}{A_S} \quad (1)$$

where, E_{itotal} is total interior horizontal illuminance on a reference point from window in Lx, E_{des} is desired indoor illuminance (500 Lx or range of 100-2000 Lx), A_w and A_s are, the area of the window wall in m^2 and the area of the window in m^2, respectively.

$$E_{ig} = E_{xg}.CU_g.\tau \quad (2)$$

where, E_{ig} is interior horizontal illuminance on a reference point from the ground in Lx, E_{xg} is exterior vertical illuminance from the ground on the window in Lx, CU_g and τ are, respectively coefficient of utilization from the ground and net transmittance of the window wall.

$$E_{itotal} = E_i + E_{ig} \quad (3)$$

where, E_i is interior horizontal illuminance on a reference point from window in Lx.

$$E_i = E_{xv}.\tau.cu_{sky} \quad (4)$$

where, cu_{sky} and E_{xv} are, respectively coefficient of utilization from the sky and exterior required vertical illuminance on the window to maintain interior desired illuminance in Lx. Based on Eq.1-4 ergonomic and economic daylight were determined for Iran.

Determination of Daylight Autonomy and Useful Daylight Illuminance

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 illuminance on the south facing vertical surfaces using correspondent linear model were obtained. In respect to average clear days of 55% throughout a year in the country, frequencies of clear days in a working year (162 days) were calculated in which economic and ergonomic outdoor vertical illuminance is exceeded. Virtually based on cumulative percentages of working days with occurrence of above mentioned outdoor vertical illuminance, Daylight Autonomy and Useful Daylight Illuminance were obtained for Iran.

RESULTS

Measured illuminance in each standard time at three stations exhibited a better agreement with calculated illuminance by IESNA equations in correspondent daylight times (1 h later). Comparative curves of mean measured and mean calculated vertical illuminance for the same standard times also

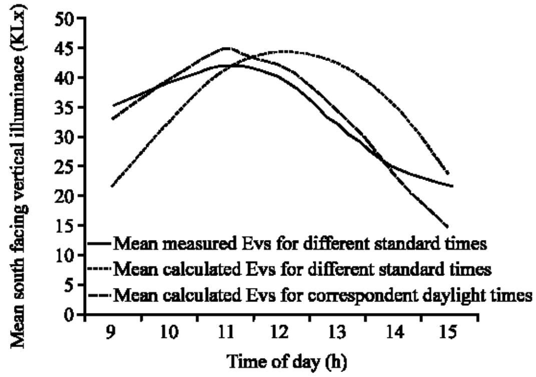

Fig. 1: Comparison of mean measured and calculated vertical illuminance at different standard times and correspondent daylight times

Table 1: Comparison of measured and calculated values of south facing vertical surfaces

Measuring station	No.	Minimum (KLx)	Maximum (KLx)	Mean (KLx)	SD (KLx)
Hamadan	96	12.34	47.40	32.63	10.43
	96	7.340	50.17	34.57	11.96
Eshtehard	95	15.50	79.60	41.76	18.68
	95	10.44	54.96	38.06	13.06
Kerman	85	10.50	42.70	25.53	9.240
	85	11.53	37.19	26.42	7.210
Total	276	10.50	79.60	33.59	15.05
	276	7.340	54.96	33.27	12.10

Upper and lower numbers in each station are related in measured and calculated illuminance, respectively

mean corrected values to one hour later (correspondent daylight times) are exhibited in Fig. 1. Descriptive analysis of measured and calculated illuminance in three stations are shown in Table 1. In accordance with Table 1, values of field measured and calculated illuminance at all stations range from 10.5 to 79.6 KLx and from 7.24 to 54.96 KLx, respectively. Also, mean respective values of measured and calculated illuminance exceed 33.59 and 33.27 KLx.

Measured values of vertical illuminance (E_{vs}) plotted related calculated values, exhibited a good regression as they are shown in Fig. 2. A simple regression model fitted between measured and calculated values using following equation ($R^2 = 0.806$).

$$E_{vsm} = 0.919Evs_c + 1.661 \quad (5)$$

where, E_{vsm} and E_{vsc} are, respectively predicted south facing vertical illuminance and calculated south facing vertical illuminance (for 1 h later) in KLx.

Based on fitted values of south facing vertical illuminance at different standard times were calculated for a working year. Table 2 illustrates mean hourly and monthly vertical illuminance for different months of the year. The maximum mean monthly value is related in January (73.37 KLx) whereas the minimum corresponding value occurs in June (28.63 KLx). Also the maximum and minimum hourly illuminance occur in hours of 12 and 15, respectively. Based on frequencies of working days having vertical illuminance exceeded a given value, the Cumulative percentages of working year with occurrence of vertical illuminance were calculated which are exhibited in Fig. 3.

In respect to Eq. 1-4, the south facing vertical illuminance required to achieve the desired internal illuminance (500 Lx or range of 100-2000 Lx) were determined. Then in respect to Fig. 3 values of daylight autonomy and useful daylight illuminance were achieved. For an illustration, a workplace with

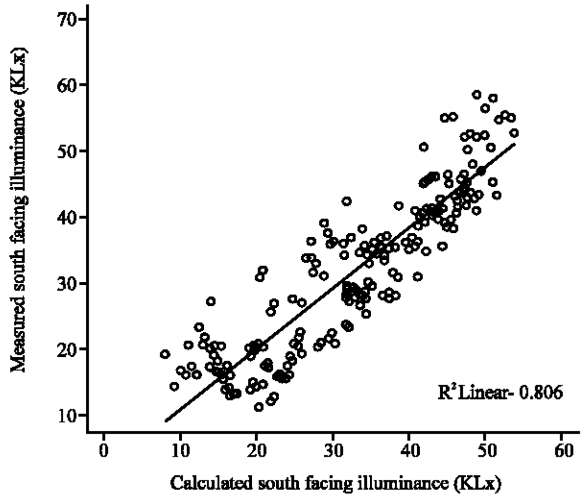

Fig. 2: Relation between measured and calculated values of south facing vertical illuminance

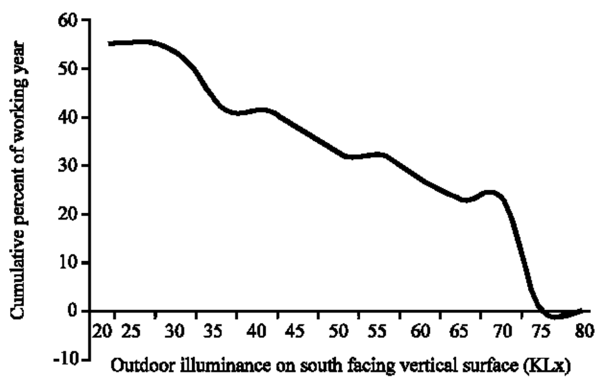

Fig. 3: Cumulative frequency distribution for outdoor illuminance on the south facing vertical surface

Table 2: Prediction of mean hourly and monthly vertical illuminance for a working year in Iran

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

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

width of 30 m, depth of 12 m from window wall to the rear wall, height of 4 m, window width of 6 m, window height of 3 m, net transmittance of the window of 0.9, exterior vertical illuminance from the ground on the window of 1KLx, coefficient of utilization from the sky also from the ground of 0.078, the required outdoor vertical illuminance for maintaining average internal illuminance of 500 Lx at reference point of 0.5 depth of room , found to be 46.5 KLx which refers to daylight autonomy of 36.5%. In the other word, economic outdoor vertical illuminance of 46.5 KLx would occur for 36.5% of working year which means 36.5% of energy saving for this workplace. Also required outdoor vertical illuminance for maintaining internal illuminance of 200 Lx within the range of 100-2000 Lx found to be 17.8 KLx which suggests to useful daylight illuminance of 55%. This means that by occurrence of ergonomic vertical illuminance of 17.8 KLx, workers would have comfortable visual conditions for more than 55% of working year in this workplace.

DISCUSSION

This study was undertaken to estimate required exterior vertical illuminance to maintain interior illuminance levels to preserve of electrical lighting or creating an ergonomic environment. Fitted model for predicting of vertical illuminance was different from authors? prior model due to Calculation of vertical illuminance based on new equations proposed by IESNA as well as good agreement of measured vertical illuminance with calculated illuminance in corresponding daylight times (1 h later). The reason of this unexpected correlation was not revealed for Authors.

Results of this study exhibited a great variation of illuminance during a working year so that maximum hourly values of monthly data were 2.4 times more than the minimum values also the maximum value of mean monthly illuminance exceeded 73 KLx which is accessible more than 25% of working year. These findings indicated high daylight availability on vertical surfaces.

Although, measured and calculated values of total data were pretty close in mean values, but calculated data had smaller standard deviations and more tendency tended to higher values therefore calculated values lied in smaller ranges also resulted in higher mean hourly illuminance than those measured. The reason of these differences could be restricted ability of IESNA method in identification of real sky conditions. There are 15 sky illuminance models of international commission on illumination (CIE) as General Standard Skies (Li and Cheung, 2006), whereas in IESNA method only three sky conditions of clear, partly cloudy and cloudy are defined which this limitation results in calculating concentrated vertical values in higher levels by comparison with measured illuminance. In contrast with horizontal illuminance which are higher in summer, mean monthly values of vertical illuminance were higher in late fall and winter which is in good agreement with distribution of vertical illuminance in San Francisco (Navvab *et al*., 1984).

While authors agree on the positive impact of day lighting, there is a disagreement in corresponding quantifying energy saving potential. So that in this study, an annual electrical energy conservation of 55% was estimated for an assumed workplace in Iran whereas day lighting case studies exhibit energy savings of 33 to 60% (Leslie, 2003; Chirarattananon *et al*., 2002, 2007; Pattanasethanon *et al*., 2008; Roisin *et al*., 2008; Ihm *et al*., 2009). The reason of this difference could be explained as such savings are functions of several variables. These are associated with the characteristics of the internal and external spaces of the buildings and the amount of external daylight available. Therefore, savings from daylight will vary from location to another, based on the prevailing climate and sky conditions (Alshaibani, 2001).

CONCLUSION

Daylight Autonomy and Useful Daylight Illuminaces found to be accessible for more than 55% of working year suggesting that there is good potentiality for energy saving and non visual implication of daylight in workplaces in Iran. For more accurate data long term measurement of illuminance and luminance must be made for all sky types.

ACKNOWLEDGMENTS

This study is based on the first author M.Sc thesis which was conducted in Hamadan University of Medical Sciences, IRAN in 2008.

REFERENCES

Alshaibani, K., 2001. Potentiality of day lighting 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. Renew. Energ., 26: 68-89.

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.

Hashmi, K., 2008. Daylight vs Artificial Light. Swedish Energy Agency.

Ibrahim, N. and A. Zain-Ahmed, 2007. Daylight availability in an office interior due to various fenestration options. Proceedings of the 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, 2007, Greece, Crete Island, pp: 436-440.

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

Jenkins, D. and M. Newborough, 2007. An approach for estimating the carbon emissions associated with office lighting with a daylight contribution. Appl. Energ., 84: 608-622.

Johnsen, K., 1998. Daylight in buildings collaborative research in the International Energy Agency (IEA Task 21). Renew. Energ., 15: 142-150.

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. Renew. Energ., 32: 1363-1378.

Kittler, R. and S. Darula, 2002. Parametric definition of the daylight climate. Renew. Energ., 26: 177-187.

Leslie, R.P., 2003. Capturing the daylight dividend in buildings: Why and how. Build. Environ., 38: 381-385.

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.

Li, D.H.W. and J.C. Lam, 2000. Measurement of solar radiation and illuminance on vertical surfaces and day lighting implications. Renew. Energ., 20: 389-404.

Nabil, A. and J. Mardaljevic, 2006. Useful daylight illuminance a replacement for daylight factors. Energ. Buildings., 38: 905-913.

Navvab, M., M. Karayel, E. Neeman and S. Selkowitz, 1984. Daylight availability data for San Francisco. Energ. Buildings., 6: 273-81.

Pattanasethanon, S., C. Lertsatitthanakorn, S. Atthajariyakul and S. Soponronnarit, 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. Energ. Convers. Manage., 49: 1999-2005.

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.

Roisin, B., M. Bodart, A. Deneyer and P.D. Herdt, 2008. Lighting energy savings in offices using different control systems and their real consumption. Energ. Buildings., 40: 514-523.

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.

Webb, A.R., 2006. Considerations for lighting in the built environment Non visual effects of light. Energ. Buildings., 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. Energ. Buildings., 38: 1120-1129.