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Technical note

Measuring and modelling illuminance in the semi-arid Northeast of Brazil

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ABSTRACT

Illuminance measurement do not make up a part of routine measurements in meteorological stations in Brazil, therefore, they are very rare. This information is important for evaluating the potential contribution of natural illumination in commercial buildings, which would significantly reduce the consumption of electric energy that is used for artificial illumination and refrigeration systems.

To face this lack of information, different models known as luminous efficacy were created, which made possible the estimation of illuminance in regions where there only exists information on solar irradiation. In general, they are statistical models that empirically correlate the relationship between illuminance and solar irradiation with other meteorological variables and/or sky conditions.

In this work, an estimation of hourly luminous efficacy was made by means of several statistical models and by the MLP (multilayer perceptron) artificial neural networks (ANN). The hourly global luminous efficacy was estimated by considering a group of physical variables from the same locality and that were collected in a simultaneous way. The data input of the ANN was the following: dew temperature, precipitable water, sky brilliance index, clearness index of Perez and clearness index.

The results were compared with the statistical models of Perez et al. [Perez R, Seals R, Michalsky J. All-weather model for sky luminance distribuition-preliminary configuration and validation. Solar Energy 1993;50(3):235–45], and Robledo [Robledo L, Soler A. Luminous efficacy of direct solar radiation for all sky types. Energy Conversion & Management 2000;41:1769–79], adjusted with local coefficients. The artificial neural network model shows a statistical performance slightly better than these models with RMSE of 5.8% for the city of Recife and 3.6% for Pesqueira.

1. Introduction

Natural illumination is considered as being an important alternative for obtaining a significant reduction in electrical energy consumption in commercial buildings. Studies show that the greater part of electrical consumption in commercial buildings is directly related to air conditioners and artificial illumination. Natural illumination can be taken advantage of for internal illumination in commercial building, which would reduce the electrical and thermic charge regarding artificial illumination and the electrical charge of the air conditioners. The final energy usage in the business and residential sectors for the US is, respectively, 19% [3] and 6% [4]. In Brazil, those values are 18.8 % [5] and 14% [6]. Air-conditioning is responsible for 7.3% and 9.7% in the business and residential sectors in the US and 40.3% and 20% in Brazil. Those numbers show that a significant power saving can be achieved with the usage of natural illumination, especially in Brazil. It is also worth highlighting that the reduction in electricity usage for both illumination and air-conditioning will result in additional economy by reducing the wiring and circuit-breakers of the building's electrical project.

The electric consumption of air-conditioning systems is related mainly to two factors: the first is the intensity with which luminous solar radiation penetrates inside the building through the windows and that, in turn, contributes to the elevation of the environmental temperature, while the second factor relates to the thermal dissipation of lamps, equipment used in offices, such as computers and faxes, besides human heat originating from the occupiers.

There are studies which show that it is possible to obtain a significant reduction in electric energy consumption through architectural projects that maximize the usage of natural illumination, thus optimizing the artificial illumination system and, in parallel, the cooling system [7–13]. Pyonchan et al. [14] relates 60%

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economy in electricity using an automatically controlled natural illumination system (natural illumination associated with dimming control strategy).

In order to attain this objective, however, it is necessary to know local luminance and, based on such data, search to optimize the building lighting system, through proper positioning and scaling of windows, so as to achieve an optimal point between the refrigeration system and artificial illumination. Fig. 1 shows the behavior of electric demand regarding the window scale variation for a specified illuminance. It is possible to observe, then, a minimal value when the relation between window area and wall area reach an approximate value of 0.13, that is, since natural illumination is considered an efficient illumination, its usage implies in less heat dissipation compared to artificial illumination, thus optimizing the cooling system.

However, for elaborating projects that maximize the use of natural illumination, it is necessary to have knowledge on illuminance and solar irradiation of the region in focus, so that by this it is possible to determine the optimum contribution level of natural illumination in indoor areas. According to recent researches carried out for Brazil [15] solar irradiation measurements for Northeast of Brazil are scarce and illuminance measurements are even rarer. Illuminance measurement do not make up a part of routine measurements in meteorological stations in Brazil, therefore, they are very rare. To face this lack of information, different models were created, known as luminous efficacy, which made possible the estimation of illuminance in regions where there only exists information on solar irradiation. In general, they are statistical models that empirically correlate the relationship between illuminance and solar irradiation with other meteorological variables and/or sky conditions.

There are numerous studies on an international level with empirical models on luminous efficiency [1,2,13,16–19]. All of these models were elaborated and verified with local measurements done in the US, Europe or the Far East. Its usage in other countries or continents like South America requires a careful verification and calibration of local empirical coefficients.

In Brazil, experimental measurements of illuminance are very rare and the first measurements and modelings for it were done for Florianópolis, Santa Catarina [20] and for Recife, Pernambuco [21,22]. Souza and Robledo [20] verified and calibrated several polynomial models and others with multiple regression based on solar altitude for clear sky condition and general sky condition. Tiba et al. [22] started measurements for illuminance in two stations in the state of Pernambuco.

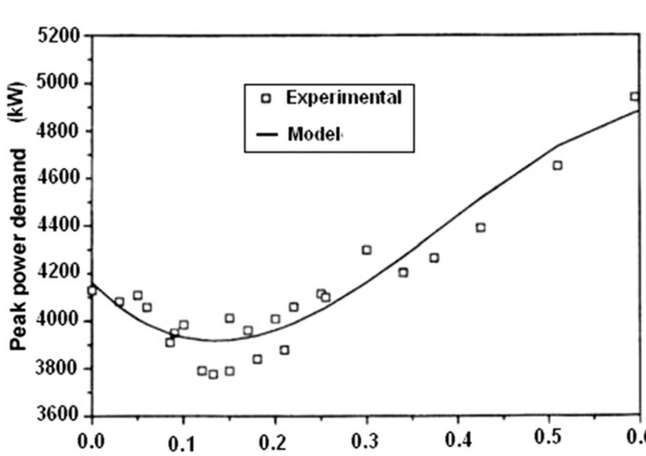

Fig. 1. Correlation between the peak of electric demand and the relation between window area and wall area.

By the aforementioned, the present work carries out an analysis of experimental measurements of illuminance, global solar irradiation and luminous efficiency of the Pesqueira and Recife cities, besides their modeling before three statistical models and one through ANN. Such models will make it possible to estimate the daily illuminance based on global irradiation and other variables, routinely measured in conventional meteorological stations.

2. Material and methods

The illumination of an enclosed area is intimately connected to the level of illuminance. Illuminance, E, is defined as the relationship between the luminous flux and the surface over which the flux is incident.

$$E = 683 \int_{380}^{780} V_\lambda I_\lambda \, d\lambda \tag{1}$$

where V_λ and I_λ are respectively: the spectral sensibility of the human eye at length wave between 380 and 780 nm and the global solar irradiation. The 683 factor is a normalization factor whose value results from a radiant flux of 1 W for the length wave of a 555 nm.

The luminous efficacy is defined as being a relationship between solar illuminance (lm/m^2) and solar irradiation (W/m^2).

$$\eta_L = 683 \int_{380}^{780} V_\lambda I_\lambda \, d\lambda \Big/ \int_{0}^{\infty} I_\lambda = E/I \tag{2}$$

where η_L, V_λ and I_λ are respectively: the global solar luminous efficiency, the spectral sensibility of the human eye at a wavelength interval of 380–780 nm and the global solar irradiation. E and I are, respectively, the illuminance and global solar irradiation measured on an hourly scale. Once we know the luminous efficiency of a determined region, it is possible to calculate the solar illuminance of another region that has similar climatic characteristics, provided that one has the solar irradiation data that refers to this other region.

2.1. Measurements stations and parameters

Two stations were set, in 2008, one in Pesqueira and another in Recife, both in the state of Pernambuco, for simultaneous measurements of the global solar and ultraviolet radiations. Table 1 shows the measurement stations for illuminance and global solar radiation, their geographical coordinates, climatic characterizations and measurement periods.

The measurements were carried out on horizontal plane on a minute scale. The sensors used for the measurements of illuminance and solar irradiation were the LI-210 SA and LI-200SA models, which are both fabricated by LICOR. According to information from LICOR [23] these sensors have a calibration error ±5% and a maximum annual drift of ±2% therefore, we can expect an experimental error in the relationship between the hourly illuminance and the hourly solar irradiation in the order of 10%, after the

Table 1
Stations of measurements.

Stations	Geographics coordinates			Climate	Period
	Lat.	Long.	Alt. (m)		
Recife				Maritime equatorial	April 2003
PE	8° 3′	34° 55′	7	continental	March 2005
Pesqueira	8° 24′	36° 46′	639	Semi-arid equatorial	September 2004
PE					September 2005