NIGHT LENGTH DURATION AND PUBLIC ILUMINATION

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ABSTRACT

The present work shows the development of an operational methodology to calculate the effective duration of the night by means of estimations of natural sky illumination during twilight. The time interval required for the journey of the Sun between solar elevations associated to given thresholds of illuminance at dawn and at dusk, can be determined using established astronomical relations and an empirical function relating the clear sky illuminance and the solar elevation angle. Deviations around 1% was observed when estimated illuminance was compared with ground measurements provided by a calibrated radiometer in clear sky days. The "night length" in clear sky days along one year period was calculated by assuming 80lux and 20lux as dusk-down thresholds, respectively. It was observed deviations up to 2.5% due to cloud cover influence. From this work it was possible to reduce community expenses by optimizing the public illumination system.

1. INTRODUCTION

The incident solar radiation on the atmosphere controls its radiative balance and, for consequence, the climate. Besides that, the study of its space and time variability has economic and social impacts in agriculture, architecture, and energy planning. However, these studies are still insufficient for solar elevation angles lower than zero degrees, when the direct component of solar radiation is null.

Illumination levels around 10lux are required by the human eyes to perceive contours and 1 klux to distinguish colors. This illumination levels occurs normally during twilight and presents great importance in planning and optimization of illumination of public areas. Many studies have approached the issue of the influence of luminosity in public comfort and security. Erwine and Heschong (2000) have noted that scholar performance is improved when adequate sources of light are incorporate to the building architecture. Some studies addressed the influence of illuminance conditions in the number of accidents during twilight hours or other situations with low luminosity. Statistical data for Cape Town/South Africa (City of Cape Town, 2002) shows that 25% of traffic accidents in 2001 took place at low levels of illumination. Data provided by Department of Transport of USA demonstrate that 2/3 of the fatal accidents have occurred in low public illumination conditions (USDOT NHTSA, 1997). Thirty five percent of accidents with airplanes and air traffic control are related with low illumination conditions at twilight (Pape and Wiegmann, 2001).

In face of that, it is necessary the implementation of policies for public illumination and based on sound scientifically based information in order to provide adequate visual comfort and security levels. Furthermore, from the economic standpoint, the optimization of public illumination system would have a great impact on municipalities' budget by the optimization in consumption of electric energy.

The present work shows the development of a simple and operational methodology to estimate the effective duration of the night based on these low levels of natural sky illumination hereafter denominated by the "night length". The "night length" is defined as the time interval required by the Sun to complete its path between solar elevation angles associated with given illuminance thresholds at dusk and dawn. An empirical function relating the clear sky illuminance and solar elevation angle (Seildelmann, 1992) was used to calculate the night length. The exact time that the Sun reaches a specific solar elevation angle related to a given illuminance value was determined using established mathematical equations for the astronomical relations.

2. METHODOLOGY

The term "night length" is adopted in this paper to represent the time interval of the day where the natural illuminance, whose main source is the Sun, is under predefined values resulting in the requirement of the use of artificial lights to illuminate streets, avenues, squares and other public spaces.

In the Brazilian case, the technical standard for the public illumination system are established by Brazilian Association of Technical Standards (ABNT). Table 1 presents the illuminance thresholds for starting up and turning off the public illumination system in the morning and afternoon as recommended by the ABNT.

TABLE 1: THRESHOLDS ILLUMINANCE VALUES TO START AND TO STOP THE PUBLIC ILLUMINATION SYSTEM.

Brazilian Standard	Starting up threshold	Stopping threshold
NBR-5123	80lux	20lux

2.1 Solar zenith angle and natural illuminance relationship

The first step to get the night length is to associate the illuminance thresholds presented in Table 1 with the Sun position in the sky (solar zenith angle or solar altitude). Fig. 1 shows the empirical function described by Seidelmann (1992) relating the clear sky illuminance and solar zenith angle. From this function, it is possible to obtain the solar zenith angle associate to the illuminance thresholds for any day of interest under clear sky condition.

Field measurements were used to investigate the accuracy of the estimates provided by this empirical function. The ground measurements were made on 25-day period between March and April, 2004 by using a calibrated photometric sensor with maximum resolution of 0.01lux and accuracy on the order of 5%. There were no natural obstacles or buildings around the measurement site. Two data sets were obtained per day: one during sunrise hours and another during sunset hours, except when it was raining.. Only five from 30 datasets acquired were obtained in clear sky condition and the maximum observed deviation between estimations and ground data was 1%. Estimated values of illuminance as a function of solar zenith angle agreed well with measured data in all five cases. Fig.2 shows a comparison among surface illuminance estimates and ground measurements for one clear sky sunrise at Cachoeira Paulista/Brazil (22.6°S, 45°W).

All remained datasets were obtained in overcast or partial cloud cover. The cloud cover brings in two effects on surface illuminance and both cases will change the night length:

a) A decrease in illuminance levels due to absorption and scattering of solar radiation by cloud droplets;
b) An increase of illuminance level caused by caused by reflection of solar radiation when Sun is close to the horizon (solar zenith angle near 90degrees).

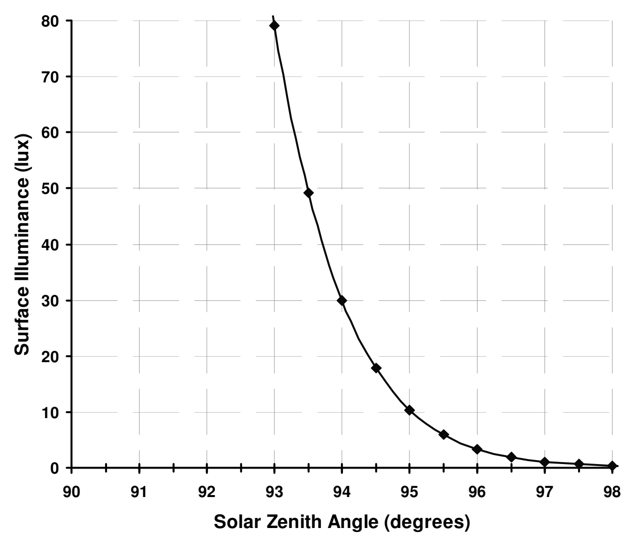
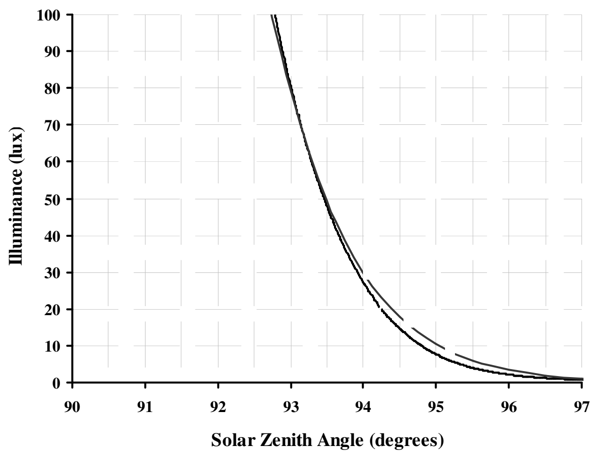
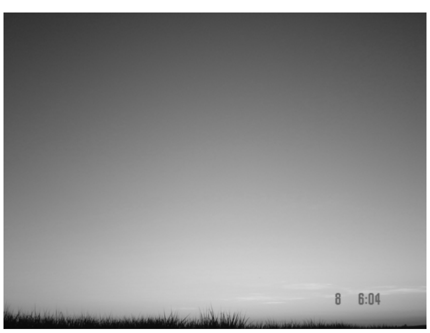


Fig. 1: Plot of empirical relation of surface illuminance in function of solar zenith angle for clear sky days.

Table 2 presents the mean deviation of the threshold solar zenith angle from the expected value for clear sky condition due to the presence of clouds in the sky. The variance around these mean deviations was high due to the great variability of cloud types and their radiative processes absorbing or scattering solar radiation. A larger amount of datasets are required to evaluate and describe the cloud cover influence over natural illuminance in function of cloud type and cloud amount. Fig. 3 shows a comparison among ground data of surface illuminance and estimates provided by the empirical function for an overcast sky sunset. It can be noted that an angular deviation on the order of 1.25 degrees at 80 lux was observed as a consequence of the natural illuminance decrease. In this case, the night length has increased since the illuminance threshold was achieved later in the morning than it would have been in clear sky condition.





(B)

Fig.2: (A) Comparison among estimated illuminance and ground data measured (solid line) at sunrise of 04/08/2004 in Cachoeira Paulista/Brazil; (B) Image of sky condition at the moment of data acquisition.

Other atmospheric conditions like atmospheric aerosols emitted by anthropogenic activities – induced fires or consumption of fossil fuels – can affect the natural illuminance. Besides that, topography, other obstacles like buildings or vegetation, and ground cover can change the natural illuminance. These factors were not evaluated in this work and it will subject of future research.

TABLE 2: STATISTICAL ANALYSIS OF SOLAR ZENITH ANGLE DEVIATIONS DUE TO CLOUD COVER. THE DEVIATIONS ARE RELATIVE TO THE SOLAR ZENITH ANGLE PROVIDED BY THE EMPIRICAL FUNCTION SUITABLE FOR CLEAR SKY CONDITION.

Illuminance threshold	Mean deviation (degrees)	Standard error (degrees)
80 lux	0.04	0.75
20 lux	0.18	0.65

2.2 Night length calculation

Once the solar zenith angles related with illuminance thresholds were determined for clear sky condition, the next step to calculate the night length is to obtain what times of the day the Sun will reach these positions. The following equations were used:

$$\begin{aligned} AFTER\_TIME &= UT + LHA \\ MORN\_TIME &= UT - LHA \end{aligned} \quad (1)$$

$$LHA = \frac{1}{15{,}04107} \arccos\left(\frac{\cos(\theta_0) - sen(LAT)sen(DEC)}{\cos(LAT)\cos(DEC)} \right) \quad (2)$$

$$UT = \frac{(RA - GMTS_0 - LONG)}{15} \quad (3)$$

where **MORN_TIME** and **AFTER_TIME** are the time, respectively in the morning and in the afternoon, when the Sun reaches one specific solar zenith angle designated by $\boldsymbol{\theta_0}$ in Eq. (2). The variables **LAT** and **LONG** stand for latitude and longitude (in degrees) of the site, **DEC** is the solar declination, **$GMTS_0$** is the sideral time at 0:00UTC and **RA** is the solar right ascension.

The last three variables can be calculated using well-known astronomical equations described in (4) where **hora, dia**, **mes** and **ano** represents time, day, month and year of interest, respectively. It should be use an iterative procedure to get more accuracy. The time 12:00pm should be used as input in first iteration and the result of each iteration (**MORN_TIME or AFTER_TIME**) should be used in the next iteration until the required precision is achieved.

$$
\begin{aligned}
d &= \frac{367ano - 7(ano + (mes+9)/12)}{4 + 275mes/9 + dia - 730530} + hora/24 \\
M &= 356{,}047 + 0{,}9856002585d \\
w &= 282{,}9404 + 4{,}70935.10^{-5}d \\
e &= 0{,}016709 - 1{,}151.10^{-9}d \\
ecl &= 23{,}4393 - 3{,}563.10^{-7}d \\
L &= M + w \\
GMST_0 &= L + 180 \\
E &= M + e\frac{180}{\pi}\sin(M)(1 + e\cos(M)) \\
xv &= \cos(E) - e \\
yv &= \sin(E)\sqrt{(1-e^2)} \\
v &= \arctan\left(\frac{yv}{xv}\right) \\
r &= \sqrt{xv^2 + yv^2} \\
xe &= r\cos(v+w) \\
ye &= r\sin(v+w)\cos(ecl) \\
ze &= r\sin(v+w)\sin(ecl) \\
RA &= \arctan\left(\frac{ye}{xe}\right) \\
DEC &= \arctan\left(\frac{ze}{\sqrt{xe^2 + ye^2}}\right)
\end{aligned} \tag{4}
$$

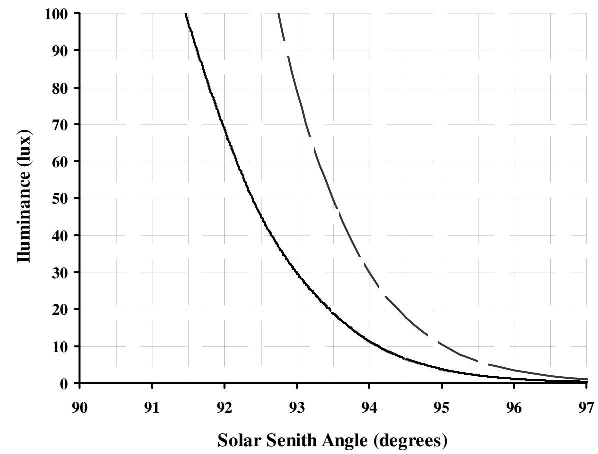
Finally, the night length can be obtained by:

$$ARTF\_LIGHT = 24 - (AFTER\_TIME - MORN\_TIME) \tag{5}$$

where **ARTF_LIGHT** is the night length and represents the time interval when artificial lights are required to keep illuminance at required levels established in regulation standards.

3. RESULTS

The night length obtained for Cachoeira Paulista is presented in Fig. 4 for one-year period. The values presented are valid only for clear sky condition and they were calculated using the illuminance thresholds described in Table 1. It is expected that the night length value will present a small variability around the curve plotted in Fig. 4 due to the variability of atmospheric conditions (cloud cover, visibility, pollution dispersion, and others). In spite of a small number of ground datasets, it was observed that cloud cover can either increase or decrease the night length. It was observed a mean deviation equals to 16 minutes in night length in ground datasets measured in partial or total cloudy sky conditions. This mean deviation is equivalent to 2.5% of the annual mean night length presented in Fig. 4.



(B)

Fig.3: (A) Comparison among estimated illuminance and ground data measured (solid line) at sunrise of 04/08/2004 in Cachoeira Paulista/Brazil; (B) Image of sky condition at the moment of data acquisition.

The night length has a large dependence on the latitude of the site: the higher latitude the higher will be the difference among maximum and minimum night length observed along the year. Special attention is required for latitudes higher than Polar circle where night length larger than 24 hours can occur in the winter and no dark periods will happen in the summer.

The topography and other obstacles can produce slight spatial variability in neighborhood of the measurement site. New field experiments will be developed to study the influence of ground cover, topography and other atmospheric conditions like low visibility caused by smoke and induced forest fires.

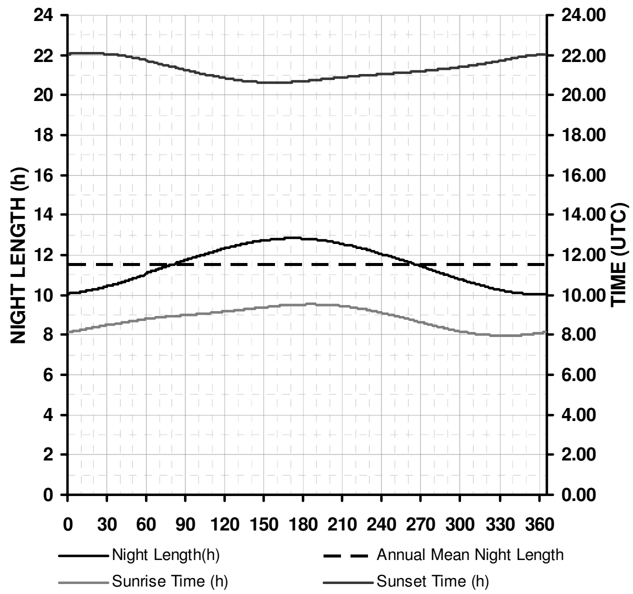


Fig. 4: Night length along one-year period for Cachoeira Paulista is plotted in black continuous line. Its annual mean value is presented in dotted line. The sunrise and sunset time are also presented in upper and bottom lines.

4. CONCLUSIONS

This paper describes a simple method to estimate the "night length" i.e. the time interval when natural illuminance is below thresholds established by technical standards to assure the comfort and security of people in public areas like streets, squares, etc. It was observed a good agreement between estimated surface illuminance and ground data obtained in clear sky conditions. The cloud cover accounted for mean deviation on the order of 2.5% (16 minutes) in the night length. Other atmospheric conditions like low visibility caused by pollution, smoke or induced fires were not considered by now. New fields experiments are being planned to get a better understanding of their role on the variability of natural illuminance. The ground data acquired in these experiments aims to parameterize all physical processes, including radiative processes in the atmosphere and obstructions by topography and buildings, to develop a numerical code to estimate the total time when the public illumination system has to be in service.

The topography, ground cover, buildings and other obstacles were not considered now, but it is expected that their influence is not significant during twilight once the direct component of solar radiation is null. The next field experiments will evaluate their contribution in the illuminance decline.

From economic standpoint, the optimization of public illumination system will have a great impact on public finances since it will be possible to achieve a fair agreement between the municipalities and the electricity distribution companies to charge correct fares for electricity consumption in public illumination, based on the effective duration of the night. Currently in Brazil electricity companies charge for a fixed 12h-period per day of public illumination regardless the time of the year or the location of the city.

5. ACKNOWLEDGMENTS

The following institutional acknowledgment is due to Centre for Weather Forecast and Climate Studies (CPTEC/INPE) and FINEP (project no. 22.01.0569.00). Thanks are due to the following colleagues: Karla Longo and Fernando Sampaio Recuero from CPTEC/INPE for their assistance in field experiments and technical discussions.

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