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# Numerical methods to calculate solar radiation, validation through a new Graphic User Interface design

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ABSTRACT

The present paper is basically devoted to the estimation of solar radiation in order to provide data on the situation of solar applications in a given site; it also aims at contributing to the performance improvement of solar energy systems. I aim to show and evaluate the performance of the most appropriate models used to recover solar components at ground level, via confronting meteorological techniques to selected semi empirical methods. I have adopted an innovative approach to testing the theory through numerical simulation by providing a friendly user ergonomic Graphic User Interface 'GUI', carefully designed and that principally makes use of a large range of models for the calculation of solar components. In this article I may consider three numerical models namely: Lacis & Hansen, Atwater & Ball and Lui & Jordon, which are used here to elucidate the performance of such methods facing meteorological models such as those of Angstrom, Garg and Coppolino. I debate the advantages of these latest methods, and I argue that they are of big importance because the main variable that is used is sunshine duration. Some of them involve the water content in the atmosphere, a particularly important parameter which strongly absorbs solar radiation in the infrared region. They are also perfectly suited for locations where solar irradiance is not being measured by all hydrometeorological stations, and where only meteorological data are collected. I want to complete this paper by demonstrating the efficiency of the new interface, through comprehensive comparative studies that are made possible. Results of the study are evaluated and assessed in the lights of experimental measurements. These are supplied by the Unit for Applied Research in Renewable Energy-UARRE-(Ghardaïa, Algeria, 3.80°E, 32.4°N). This is a selected station of the National Office of Meteorology which is quite interesting as it is situated a hundred kilometers far from the famous hybrid (solar, gas) station of Hassi R'Mel, moreover it provides reliable data. Finally, I find it necessary to mention that obtained results are with attractive margins of error and in accordance with experimental measurements.



## 1. Introduction

As the world is in a quest for low-carbon sources of energy, solar power stands out as the single most abundant energy resource on Earth [1–3]. However, I claim that insufficient attention has been paid to developers wishing to integrate solar components. In particular, this has concerned the tools used to aid the design as well as the evaluation of long-term performance of solar energy converting systems. In writing this paper I had some goals in mind. I attempt to provide some solutions which will allow comparing the alternatives, debating the projects and realizing the importance of a more rational use of energy. Indeed, many models ranging from the simple empirical relationships to the most complex and sophisticated computer codes have been undertaken by researchers [4–13]. Thus, to achieve this purpose, I am first intended to gather these methods which are in most cases separately presented in literature to bypass this major setback. This is achieved in such a manner that makes obvious rather than difficult, understanding their theoretical foundations, their strengths and their limitations compared to other methods of estimating solar radiations. I then suggest an interface design, and validate the main and most appropriate techniques which are applied in recovering solar radiations. A set of models is offered in this study. They are meteorological models that are more appropriate to many measurement networks [8–13] facing suitable semi empirical methods consisting of the models of Lacis and Hansen [14], Atwater and Ball [15,16] and Lui and Jordon [17]. These latest have the advantage of generating solar radiation for various inclined surfaces which is essential to design photovoltaic conversion systems and sensors. The meteorological models are hereby the models of Angstrom [18–20], Garg [8,10,21] and Coppolino [8,13,22]. Through the new methodological framework that

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I propose, I could show and comment on advantages and limitations of each simulated model. In this study I consider the site of Ghardaïa in Algeria, (3.80°E and 32.4°N). This station is particularly geographically interesting and provides daily records of solar radiation, collected every 5 min. A Kipp Zonen pyranometer measures the global radiation while sunshine duration is provided by a Campbell-Stokes heliograph. After analyzing the data, their pre-processing becomes a necessary stage to make them convenient to the calculation methods to be implemented in order to achieve the expected objectives. Ensuring regular and accurate measurements will allow a reliable analysis and comparison of obtained results.

## 2. Methodology

The structure of the article can be outlined as follows. The first section briefly describes the models that have served the present study to estimate the solar radiation. Section 2 portrays the new interface and spells out in more detail the offered functionalities. In Section 3 I will compare measured values to the performed calculations. Finally I will discuss and comment on the obtained results that verify and confirm efficiency of such proposed software component. Please notice that all variables involved in calculations below are defined in Appendix A.

### 2.1. Description of meteorological models

The main variable of such global solar radiation model is sunshine duration. Such data are readily available in many parts of the world; within their accuracy, they are quite reliable since they are measured basically by simple Campbell-Stokes sunshine recorders [23]. These models are able to achieve high precision. It is mainly because the monthly average daily value eliminates the effects of individual values for results.[1]

#### 2.1.1. Angstrom model

Angstrom [18–20] has developed a linear relationship of type

$$\frac{\overline{G}}{\overline{G_o}} = a \cdot \frac{S}{S_o} + b \tag{1}$$

From geometrical considerations, one can determine the daily extraterrestrial global radiation $G_o(nj)$ for given latitude and surface. $nj$ is the number of day of year starting from the first of January.

- For a horizontal surface

$$G_o(nj) = \frac{24}{\pi} I_{sc}(nj)\left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \frac{\pi}{180}\omega_s \sin(\varphi)\sin(\delta)\right] (\mathrm{W\,h/m^2}) \tag{2}$$

$$\omega_s = \cos^{-1}[-\tan(\varphi)\cdot\tan(\delta)] \qquad (\mathrm{deg}) \tag{3}$$

- For a tilted surface

$$G_o(nj) = \frac{24}{\pi} I_{sc}(nj)\left[\cos(\varphi-\beta')\cos(\delta)\sin(\omega_s) + \frac{\pi}{180}\omega_s \sin(\varphi-\beta')\sin(\delta)\right] (\mathrm{W\,h/m^2}) \tag{4}$$

and

$$\omega_s = \cos^{-1}[-\tan(\varphi-\beta')\cdot\tan(\delta)], \qquad (\mathrm{deg}) \tag{5}$$

[1] It is worth noting that variables involved in calculation of these models are used in terms of their daily monthly means.

It is crucial to highlight that parameters $a$ and $b$ in Eq. (1) are empirical constants which depend on the site. They are obtained from the relationship given by Tiwari and Sangeeta [24] and confirmed by the method of Frere et al. [25]. Several attempts are made in the literature to explore them more precisely [8,11,12,26,27]. At this point, I should mention that in this study I have used results of previous work performed in Algeria by Mefti and Bouroubi [28]; where a regressive method was used, which encompasses the use of the pair ($G/G_o$, $S/S_o$) to adjust coefficients $a$ and $b$. Corresponding values for a horizontal surface are given in Table 1.

#### 2.1.2. Model of Garg

According to Garg et al. [8,10,21], the atmospheric water vapor or specific humidity is used with the sunshine duration to get a relationship to estimate the global radiation at any location. For a given region, the hourly values of the ambient temperature and relative humidity are known so that one can determine the water content of air per volume unit. This method has two positive points: first, it is easier to work with a reduced number of variables. Furthermore, by clear skies, relative humidity increases from morning to night when the ambient temperature decreases. This makes the amount of steam per volume unit changing very little. Garg et al. have suggested a relationship that is:

$$G = G_o\left(0.414 - 0.400\left(\frac{S}{S_o}\right) - 0.0055\ H_a\right) \qquad (\mathrm{W\,h/m^2}) \tag{6}$$

The analytical way to determine water content in the atmosphere uses the equation

$$H_a = HR\left(4.7923 + 0.3647\ T + 0.0055\ T^2 + 0.0003\ T^3\right) \tag{7}$$

#### 2.1.3. Coppolino model

Coppolino [8,10,22] has proposed a relationship involving only the sunshine duration $S$ and the height of the sun at noon $h_n$ on the 15th day of each month as sole input parameters. These data can be accurately determined. The equation is of type

$$G = 0.002167\ S^{0.5}(\sin(h_n))^{1.15} \qquad (\mathrm{W\,h/m^2}) \tag{8}$$

### 2.2. Description of semi empirical models

As far as the models used in this paper are concerned, it is important to emphasize that verification and validation of the new interface, has enabled me to consider the most frequently used methods in the literature, as well as the most suitable one for my case of study [5,29]. They consist of models of Lacis & Hansen, Atwater & Ball and Liu & Jordan which estimate hourly global radiation $G(h)$. A brief description of these methods could be found in Appendices B, C and D of this manuscript.

The daily global radiation $G_j$ is derived from the hourly values $G(h)$ as

$$G_j = \sum_{h=1}^{24} G(h) \tag{9}$$

**Table 1**
Coefficients of type Angstrom [28].

| Site | $a$ | $B$ | Validity |
|---|---|---|---|
| Algiers | 0.49 | 0.45 | Lat > 35.5° |
| Saida | 0.41 | 0.55 | 33° < Lat < 35.5° |
| Bechar | 0.5 | 0.23 | 31° < Lat < 33° |
| Beni abbes | 0.33 | 0.65 | 23° < Lat < 31° |
| Tamanrasset | 0.25 | 0.7 | Lat < 23° |