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Evaluation of global solar radiation models for Shanghai, China

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ABSTRACT

In this paper, 89 existing monthly average daily global solar radiation models and 19 existing daily global solar radiation models are compared and analyzed by 42 years meteorological data. The results show that for existing monthly average daily global solar radiation models, linear models and polynomial models have been able to estimate global solar radiation accurately, and complex equation types cannot obviously improve the precision. Considering direct parameters such as latitude, altitude, solar altitude and sunshine duration can help improve the accuracy of the models, but indirect parameters cannot. For existing daily global solar radiation models, multi-parameter models are more accurate than single-parameter models, polynomial models are more accurate than linear models. Then measured data fitting monthly average daily global solar radiation models (MADGSR models) and daily global solar radiation models (DGSR models) are established according to 42 years meteorological data. Finally, existing models and fitting models based on measured data are comparative analysis by recent 10 years meteorological data, and the results show that polynomial models (MADGSR model 2, DGSR model 2 and Maduekwe model 2) are the most accurate models.

1. Introduction

Prediction the efficiency of solar photovoltaic and solar thermal systems needs global solar radiation data and its estimation model [1–3]. Building heat gain also needs global solar radiation data as the research foundation. Furthermore, daily global solar radiation models are required for engineering design and planning projects [4,5]. The study on global solar radiation models is relatively late in our country, the recorded data is large time scale (many meteorological station can only provide daily values, but cannot provide hourly value), while other meteorological parameters (e.g. sunshine duration, temperature, humidity and rainfall) were recorded more comprehensive and detailed [6,7]. On the other hand, it was reported that the measurements of the sunshine recorders were accurate, while the measurements of the actinographs had some errors because of the thermal sensitivity of their mechanical components [8,9]. In addition, due to the lack of global solar radiation data recorded in many region, along with data loss caused by equipment repair or replacement and meteorological station relocation, so it is need to study the empirical models estimate of global solar radiation by other meteorological parameters. The study of models which estimate daily global solar radiation from sunshine duration is the earliest, and developing more sufficient. Among these models, monthly average daily global solar radiation models are developed earlier, the first such model can be traced back to Angström model [10]. He used sunshine duration and clear sky radiation data to estimate global solar radiation. Prescott [11] suggested using the extraterrestrial radiation to replace clear sky radiation, and the modification in this way led to the formation of the Angström-Prescott equation. In order to predict the global solar radiation incident on a horizontal surface, many models have been developed which relate the radiation to measure meteorological parameters, such as sunshine duration, solar altitude, humidity, ambient temperature etc. [12–58]. As the solar radiation data accumulation, and measuring instruments updated, daily global solar radiation models have been developed [24,35,38,46,59]. These formulae are semi-empirical in nature, and values of the constants depend on the location of the station where the measurements are made in [60].

We propose to study diffuse radiation influence on building heat gain and sunshade in the wet urban environment. But due to lack of adequate diffuse radiation data, it is necessary to use the global solar radiation model to estimate global solar radiation by sunshine hours, and then global solar radiation is decomposed into beam solar radiation and diffuse radiation by global solar radiation separation model. This paper will solve the first problem, namely the establishment of global solar radiation estimation model. First of all, 10 groups of 89 existing monthly average daily global solar radiation models and 4 groups of 19 daily global solar

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Nomenclature

G	daily global radiation on horizontal surface (MJ/m^2)
G_0	daily extraterrestrial radiation on horizontal surface (MJ/m^2)
H	monthly average daily global radiation on horizontal surface (MJ/m^2)
H_0	monthly average daily extraterrestrial radiation on horizontal surface (MJ/m^2)
H'_0	daily extraterrestrial radiation on horizontal surface on cloudless days (MJ/m^2)
h	altitude of location above sea level (km)
h_n	the noon altitude of the sun on the 15th of the month (degree)
R	monthly mean daily relative humidity (expressed as a decimal)
S	sunshine duration (h)
S_0	maximum possible sunshine duration (h)
T	monthly mean daily maximum temperature (°C)
ϕ	latitude of site (degree)
ψ	longitude of site (degree)

radiation models are compared and analyzed by 42 years meteorological data and choose more accurate existing monthly average daily models and daily global solar radiation models. Secondly, measured data fitting monthly average daily global solar radiation models and daily global solar radiation models are established according to 42 years meteorological data. Finally, existing models and fitting models based on measured data are comparative analysis, and models which are suitable for the calculation of global solar radiation in Shanghai are obtained.

2. Existing global solar radiation models

2.1. Background information of existing global solar radiation models

Due to the large number of monthly average daily global solar radiation models, in order to the comparative study of classification, background information about different models is summarized as showed in Table 1.

As Table 1 shows, according to the different research purpose and time scale, the global solar radiation models can be divided into monthly average daily global solar radiation models and daily global solar radiation models.

2.2. Existing monthly average daily global solar radiation models

This type of models developed earlier, and they are suitable for long-term prediction of solar radiation. They are also suitable for the calculation of daily solar radiation, but in the daily value calculation using these models are generally relatively low accuracy. In order to compare the accuracy of different models, according to the structural form of the equation, such models are divided into 10 groups.

2.2.1. Group I (One parameter linear models)

(1) *Page model* [12]

$$\frac{H}{H_0} = 0.23 + 0.48\left(\frac{S}{S_0}\right) \tag{1}$$

(2) *Ahmad et al. model* [13]

$$\frac{H}{H_0} = 0.458 + 0.175\left(\frac{S}{S_0}\right) \tag{2}$$

(3) *Jain model* [14]

$$\frac{H}{H_0} = 0.177 + 0.692\left(\frac{S}{S_0}\right) \tag{3}$$

(4) *Bahel et al. model 1* [15]

$$\frac{H}{H_0} = 0.175 + 0.552\left(\frac{S}{S_0}\right) \tag{4}$$

(5) *Jain and Jain model* [16]

$$\frac{H}{H_0} = 0.24 + 0.513\left(\frac{S}{S_0}\right) \tag{5}$$

(6) *Newland model 1* [17]

$$\frac{H}{H_0} = 0.18 + 0.615\left(\frac{S}{S_0}\right) \tag{6}$$

(7) *Raja and Twidell model 1* [18]

$$\frac{H}{H_0} = 0.335 + 0.367\left(\frac{S}{S_0}\right) \tag{7}$$

(8) *Raja and Twidell model 2* [18]

$$\frac{H}{H_0} = 0.319 + 0.407\left(\frac{S}{S_0}\right) \tag{8}$$

Remark: The original equation is as follow:

$$\frac{H}{H_0} = 3.319 + 0.407\left(\frac{S}{S_0}\right) \tag{9}$$

Eq. (9) must have some mistake, because the value H/H_0 could not larger than 1.2. it might be the wrong number, so we change Eq. (9) as Eq. (8).

(9) *Alsaad model* [19]

$$\frac{H}{H_0} = 0.174 + 0.615\left(\frac{S}{S_0}\right) \tag{10}$$

(10) *Luhanga and Andringa model* [20]

$$\frac{H}{H_0} = 0.241 + 0.488\left(\frac{S}{S_0}\right) \tag{11}$$

(11) *Srivastava et al. model* [21]

$$\frac{H}{H_0} = 0.2006 + 0.5313\left(\frac{S}{S_0}\right) \tag{12}$$

(12) *Veeran and Kumar model 1* [22]

$$\frac{H}{H_0} = 0.34 + 0.32\left(\frac{S}{S_0}\right) \tag{13}$$

(13) *Veeran and Kumar model 2* [22]

$$\frac{H}{H_0} = 0.27 + 0.65\left(\frac{S}{S_0}\right) \tag{14}$$

(14) *Karsten model 1* [23]

$$\frac{H}{H_0} = 0.23 + 0.38\left(\frac{S}{S_0}\right) \tag{15}$$

(15) *Karsten model 2* [23]

$$\frac{H}{H_0} = 0.22 + 0.42\left(\frac{S}{S_0}\right) \tag{16}$$