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Comparison of methods for generating typical meteorological year using meteorological data from a tropical environment

S. Janjai *, P. Deeyai

Laboratory of Tropical Atmospheric Physics, Department of Physics, Faculty of Science, Silpakorn University, Nakhon Pathom 73000, Thailand

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ABSTRACT

This paper presents the comparison of methods for generating typical meteorological year (TMY) data set using a 10-year period of meteorological data from four stations in a tropical environment of Thailand. These methods are the Sadia National Laboratory method, the Danish method and the Festa and Ratto method. In investigating their performance, these methods were employed to generate TMYs for each station. For all parameters of the TMYs and the stations, statistical test indicates that there is no significant difference between the 10-year average values of these parameters and the corresponding average values from TMY generated from each method. The TMY obtained from each method was also used as input data to simulate two solar water heating systems and two photovoltaic systems with different sizes at the four stations by using the TRNSYS simulation program. Solar fractions and electrical output calculated using TMYs are in good agreement with those computed employing the 10-year period hourly meteorological data. It is concluded that the performance of the three methods has no significant difference for all stations under this investigation. Due to its simplicity, the method of Sandia National Laboratories is recommended for the generation of TMY for this tropical environment. The TMYs developed in this work can be used for solar energy and energy conservation applications at the four locations in Thailand.

1. Introduction

A prediction of the annual performance of a solar energy system for a particular location by using computer simulation usually requires hourly meteorological data covering the period of a whole year. As meteorological data have inter-annual variation, several years of hourly meteorological data should be used to obtain the average performance. However, the use of such data is inconvenient and time consuming. To overcome this problem, a typical meteorological year (TMY) data set or test reference year (TRY) data set of that location was proposed to replace the several year data set. This TMY is composed of hourly meteorological data of 12 months. Each month, called a typical meteorological month (TMM), is sorted from various years with the condition that it has to represent statistical characteristic of the meteorological condition of that month. A number of methods have been developed to generate TMY. Among the pioneering works, Benseman and Cook [1] proposed to select the typical meteorological month for solar radiation by comparing the monthly radiation to its long-term monthly average. The month whose total radiation was closest to the long-term average was selected to be a member of the typical meteorological year or standard solar year. Klein et al. [2] used a similar method to construct an average year data set of solar radiation and ambient temperature for Madison, USA. Hall et al. [3] developed a method for the generation of TMY by using Finkelstien–Schafer statistics. Skeiker [4], Chan et al. [5], Jin et al. [6], Bulut [7], Kalogirou [8] and Pissimanis et al. [9] applied this method to generate TMY for different locations. In order to eliminate seasonal variation effect, Andersen et al. [10] and Lund and Eidorff [11] proposed to convert meteorological parameters into their residuals, then analysed the residuals to create statistical indicators to select typical meteorological months which are components of TMY. Ratto and Festa [12] introduced more complicated statistical indicator, called distance as an indicator to select the typical meteorological months. Petrie and McClintock [13], Feuermann et al. [14], Shaltout and Tadros [15], Al-Hinai and Al-Alawi [16] created a TMY only for solar radiation by using different procedures to select the representative months. Ecevit et al. [17] used daily sunshine duration instead of daily global solar radiation to generate a TMY.

As there are several TMY generation methods with different levels of complexity and accuracy, Argiriou et al. [18] have compared the performance of some TMY generation methods using 20-year period of data from Athens, Greece. They concluded that the best-performing TMY generation method was the one proposed by Festa and Ratto [12] with a slight modification. In addition, Bilbao et al. [19] also carried out a similar comparative study based on the meteorological data measured at two sites in Spain: Madrid

* Corresponding author. Tel.: +66 34 270761; fax: +66 34 271189.
E-mail address: serm@su.ac.th (S. Janjai).

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and Valladolid. Their study showed that the most appropriate method depended on the characteristics of the sites and varied from month to month. To date, no definitive conclusions on this matter have been made. In addition, the existing comparisons were undertaken based on the European sites. Therefore, more intensive investigations are still needed, especially for the sites in the tropics, which are characterized by high temperature, relative humidity and global radiation and a slight variation of day length throughout the year.

The objective of this work is to compare the performance of three methods which are commonly used for generating TMY based on meteorological data obtained from four stations in the tropical environment of Thailand.

2. Measurements and data

In this study, solar radiation data, which are the main data of TMY, were obtained from our four solar radiation monitoring stations. The stations were established by our Laboratory of Tropical Atmospheric Physics, Silpakorn University. As Thailand is geographically divided into four main regions, one station was established in each region. These are Chiang Mai (18.78°N, 98.98°E) situated in the North of Thailand, Ubon Ratchathani (15.25°N, 104.87°E) in the Northeast, Nakhon Pathom (13.82°N, 100.04°E) in the Central region and Songkhla (7.20°N, 100.60°E) in the South. The locations of the four stations are shown in Fig. 1. For Chiang Mai, Ubon Ratchathani and Songkhla, global radiation was measured by using pyranometers of Kipp and Zonen (model CM 21) whereas diffuse radiation was measured by Kipp and Zonen pyranometers (model CM 11) with Kipp and Zonen shade rings (model CM 121). Both global and diffuse radiations at Nakhon Pathom were measured by Kipp and Zonen pyranometers (model CM 11). For each station, the voltage signals were recorded by a datalogger (Campbell, model 21× and Yokogawa, model DC 100). The signal was captured every second and averaged over a time period of 10 min. The average data were recorded in the memory of the data logger and loaded at the end of every month. The pyranometers were calibrated against a new pyranometer recently calibrated from Kipp and Zonen once a year. The shade rings for diffuse radiation measurement were adjusted every day. The glass domes of the pyranometers were regularly cleaned. As the stations of Chiang Mai, Ubon Ratchathani and Songkhla are situated at regional meteorological centers of Thai Meteorological Department, other meteorological data required for generating TMY such as air temperature, relative humidity, wind speed, sunshine duration, and atmospheric pressure were obtained from the measurement at the same stations. For Nakhon Pathom, the station is situated in our university where only solar radiation was measured. The other meteorological data were obtained from a meteorological station located at the distance of 25 km from Nakhon Pathom station.

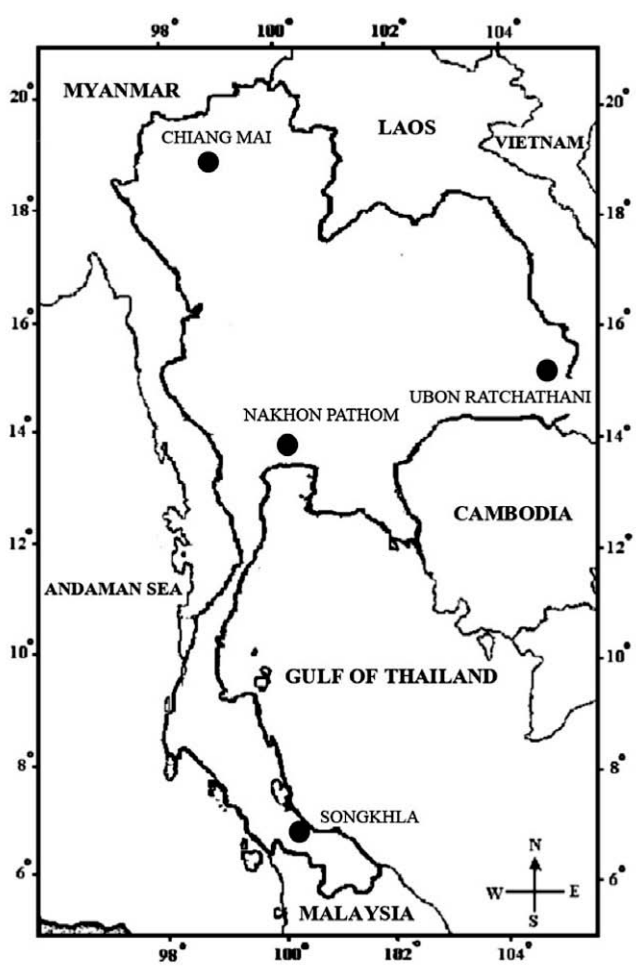

Fig. 1. Locations of the stations where meteorological parameters were measured and used to generate TMYs.

For quality control, global radiation data which violate physical laws, such as diffuse radiation being greater than global radiation or global radiation greater than extraterrestrial radiation, were discarded from the data set. Similar controls were also carried out for the other meteorological data. As air temperature and wind speed are 3-h period data, these were mathematically interpolated to obtain the hourly data. The 10-min average solar radiation was again averaged to give hourly mean of solar irradiance. For each station, a 10-year period (1995–2004) of these data was used to generate the TMYs.

3. TMY generation

Since the method of Sandia National Laboratories [3], the Danish method [10–11] and the method of Festa–Ratto [12] are usually used to generate TMY, these methods were subjected to this comparative study. Each method was used to generate TMYs for Chiang Mai, Ubon Ratchathani, Nakhon Pathom and Songkhla. The description of these methods and the TMYs obtained from each method are presented as follows.

3.1. Sandia National Laboratories method

This method, called the Sandia method in this paper, was proposed by Hall et al. [3] and was slightly modified by several investigators [9,18]. In this work, the method of Hall et al with the slight modification of Pissimanis et al [9] was used to generate TMY for the four stations. For each station, nine daily meteorological parameters: maximum air temperature (T_{max}), minimum air temperature (T_{min}), mean air temperature (T_{mean}), maximum air relative humidity (RH_{max}), minimum air relative humidity (RH_{min}), mean air relative humidity (RH_{mean}), maximum wind speed (W_{max}), mean wind speed (W_{mean}) and global solar radiation (G) were employed to create an indicator for selecting typical months (TMM). Later on, these typical meteorological months were used to form a typical meteorological year (TMY). These nine parameters are denoted in a general form as x_i (i = 1,2,. . .,9).

In the first step, for a given parameter x_i, a long-term cumulative distribution function (CDF_m) of x_i for each month covering the period of 10-year (1995–2004) was created. A short-term cumulative distribution function ($CDF_{y,m}$) of x_i for year y and month m was also generated. From CDF_m and $CDF_{y,m}$, the Finkelst-