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Solar radiation modelling using ANNs for different climates in China

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Abstract

Artificial neural networks (ANNs) were used to develop prediction models for daily global solar radiation using measured sunshine duration for 40 cities covering nine major thermal climatic zones and sub-zones in China. Coefficients of determination (R^2) for all the 40 cities and nine climatic zones/sub-zones are 0.82 or higher, indicating reasonably strong correlation between daily solar radiation and the corresponding sunshine hours. Mean bias error (MBE) varies from −3.3 MJ/m^2 in Ruoqiang (cold climates) to 2.19 MJ/m^2 in Anyang (cold climates). Root mean square error (RMSE) ranges from 1.4 MJ/m^2 in Altay (severe cold climates) to 4.01 MJ/m^2 in Ruoqiang. The three principal statistics (i.e., R^2, MBE and RMSE) of the climatic zone/sub-zone ANN models are very close to the corresponding zone/sub-zone averages of the individual city ANN models, suggesting that climatic zone ANN models could be used to estimate global solar radiation for locations within the respective zones/sub-zones where only measured sunshine duration data are available.

Keywords: Solar radiation modelling; Sunshine hours; Artificial neural networks; Climatic zones; China

1. Introduction

In China, total energy use rose from 603 million tons of standard coal equivalent in 1980 to 1320 in 2001, representing an average annual increase of 3.8% during that 22 year period [1]. With growing concerns about energy use and its impacts on the environment, energy conservation is a key economic as well as environmental policy [2–4]. It was estimated that buildings stocks accounted for about 27% of total national energy use in mainland China during the 1999–2001 period and is projected to increase to 35% by the year 2020 [5,6]. Building stocks will continue to be a key energy end user. One way to alleviate the ever growing demand for energy is to have more energy efficient building designs and proper building energy conservation programmes. To this end, there have been a number of initiatives to improve energy efficiency, one of which is the introduction of new building regulations with tighter requirements in the thermal and energy performance of the building envelope and better operation efficiency of the building services installation [7–10].

Solar radiation plays an important role in the design and analysis of energy efficient buildings in different climates. In cold and severe cold regions, passive solar designs and active solar systems help lower the reliance on conventional heating means using fossil fuels [11]. In tropical and subtropical climates, solar heat gain is a major cooling load component, especially in cooling dominated buildings [12]. The effects of prevailing climate and local topography would determine the actual amount of solar radiation reaching a particular location. China has an extensive territory with complex topography and, hence many different climates with distinct features are found [13,14]. Solar availability in China is excellent with more than two thirds of the areas having 2200 h of sunshine and annual solar radiation in excess of 5860 MJ/m^2 [15,16]. Information on solar availability is useful for the assessment and modelling of solar energy systems as well as the design and

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analysis of energy efficient buildings. A comprehensive solar radiation database is an integral part of an energy efficiency policy/programme. In China, there are cities/regions that do not have measured solar radiation data. There were several studies on the correlation between recorded sunshine hours and measured global solar radiation in subtropical Hong Kong and the Yunnan province during the 1990s [17–20] and more recently for other parts of China [21–24], largely based on linear/non-linear regression techniques. There is, however, very little work on solar radiation modelling using artificial neural networks (ANNs) for the different climates in China except a recent study on the wavelet analysis of solar irradiance in Shanghai and some preliminary work on sunshine duration and cloud cover [25,26]. In recent years, ANNs have been used in solar radiation modelling work for locations with different latitudes and climates (e.g., Saudi Arabia [27,28], Spain [29–31] and Turkey [32–35]). Comparative studies of ANNs and the traditional regression approaches in modelling global solar radiation have also been conducted, and it has been shown that ANN methodology offers a promising alternative to the traditional approach [36,37]. The primary aim of this study is to model global solar radiation in the different climatic zones in China using ANNs.

2. Thermal climatic zones and data gathering

China has an area of about 9.6 million km^2. About 98% of the land area stretches between a latitude of 20 °N and 50 °N, from subtropical zones in the south to the temperate zones (including warm temperate and cool temperate) in the north. The maximum solar altitudes vary a great deal, and there is a large diversity in climates, especially the temperature distributions during winters [13,14]. In terms of the thermal design of buildings, there are five major types, namely severe cold (SC), cold (C), hot summer and cold winter (HSCW), mild (M) and hot summer and warm winter (HSWW) [38]. This simple climate classification is concerned mainly with conduction heat gain/loss and the corresponding thermal insulation issues. The zoning criteria are mainly based on the average temperatures in the coldest and hottest months of the year. The numbers of days that the daily average temperature is below 5 or above 25 °C are counted as the complementary indices for determining the zones. Because of the varying topology and, hence, elevations, both the severe cold and cold climates have three sub-zones. Fig. 1 shows an overall layout of the nine major thermal climatic zones and sub-zones and their locations relative to Beijing. For the present study, daily global solar radiation and sunshine duration measured at 40 stations in different climatic zones across China were gathered and analysed. The period of records ranges from 8 to 30 years covering the period between 1971 and 2000. Table 1 shows a summary of the general information on the 40 stations investigated, the periods of records and the corresponding thermal climates. There are 20 cities in the severe cold climates (six SC-I, five SC-II and nine SC-III), 10 in the cold climatic zone (four C-I, two C-II and four C-III), four HWCW, three mild and three HSWW. The latitude ranges from 22°18′N (Hong Kong in the

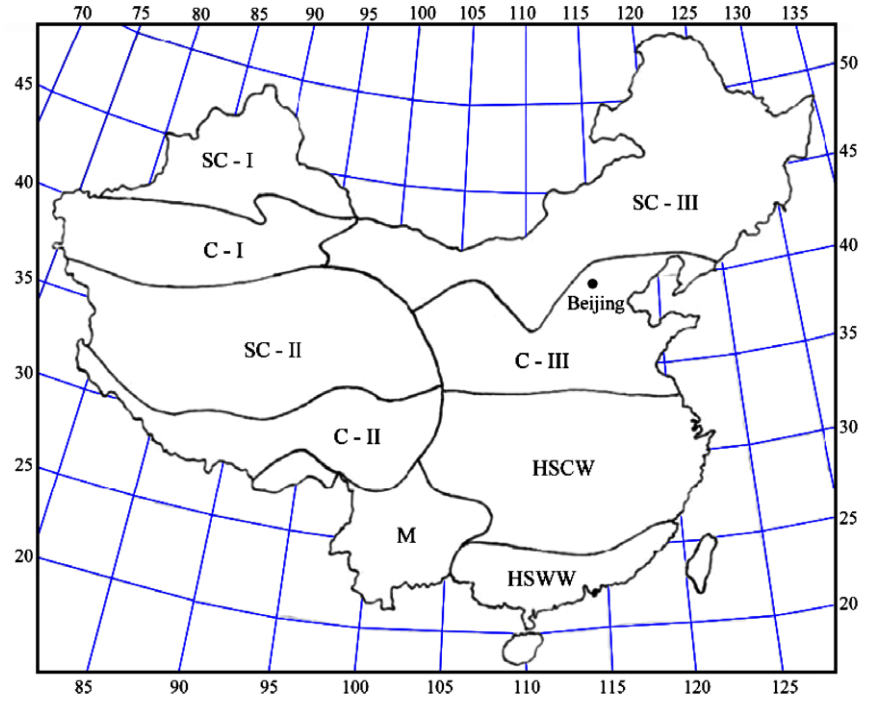

Fig. 1. The nine major climatic zones and sub-zones.