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Generation of typical meteorological years using genetic algorithm for different energy systems

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ABSTRACT

Computer simulation plays an important role in investigating the thermal/energy performance of buildings and energy systems. In order to reduce the computational time and provide a consistent form of weather data, simulation run with multi-year weather files is generally avoided. In contrast, representative weather data is widely adopted. For developing typical meteorological year (TMY) weather files, Sandia method is one of the commonly adopted approaches. During the generation of TMY, different weighting factors are assigned to some key climatic indices. Currently, the values of weighting factors mainly depend on the researchers' judgement. As these weighting factors can express the relative importance of impact of a particular climatic index on the thermal/energy performance of an energy system, computer simulation using different TMYs may lead to different conclusions. Therefore, it is inappropriate to apply one single TMY for all energy systems. In this study, a novel TMY weather file generator has been developed to link up an optimization algorithm and an energy simulation program. Through four application examples (one air-conditioned building and three renewable energy systems), this weather file generator demonstrated its capability to search optimal/near optimal combinations of weighting factors for generating appropriate TMY for computer simulations of different energy systems.

1. Introduction

The concern on green and sustainable living environment leads to a growing demand for minimization of energy use. As building is one of the largest energy consuming sectors in a modern city, it is important to study the thermal and energy performance of buildings and building energy systems (such as air-conditioned building, photovoltaic system, etc.) for energy-efficient design and operation. In this regard, energy simulation software is an essential and useful tool. Since climatic condition has a significant influence on the thermal and energy performance of buildings and energy systems, it is required to input hourly meteorological data during energy simulations. As the climatic condition can vary significantly from year to year, there is a need to derive typical weather data to represent the long-term typical weather condition at a specific location over a reasonably long period of time, such as 30 years [1].

In the selection process of typical weather data, different weighting factors are assigned to some key climatic variables such as dry bulb air temperature, solar radiation, etc. These weighting factors can express the relative importance of impact of a particular climatic variable on the thermal and energy performance of a building or energy system. For instance, in a conventional selection process [2], a typical weather data file developed with high weighting on dry bulb temperature and solar radiation is appropriate for studying the long-term average performance of buildings or solar energy systems. However, even though the wind speed is included in the selection process, its relatively lower weighting with respect to the other climatic variables prevents the weather data file from being sufficiently typical for simulating the energy performance of wind turbine systems [1]. Computer simulation using different typical weather data may lead to different conclusions on the thermal and energy performance of different energy systems. Therefore, it is not appropriate to rely on one single typical weather file and adopt it in computer simulations for all applications. Different energy systems may require different weather data files. Since there are enormous combinations of weighting factors which can be used in the selection process of typical weather data, it is infeasible to search an optimal solution by examining all the combinations. A new approach should be developed for this application.

In the present study, a TMY weather file generator was

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developed in which an optimization algorithm (Genetic Algorithm) was linked up with a building/solar energy simulation program. This weather file generator can be employed to search optimal combinations of weighting factors to generate appropriate TMY weather files for computer simulation of different energy systems. This paper reports the methodology and findings of the current study.

2. Literature review

2.1. Review on the development of typical weather data

Currently, there are two common types of typical weather data adopted for building energy simulations, namely Test Reference Year (TRY) and Typical Meteorological Year (TMY). In a TRY, climatic information of 8760 h for a particular year is selected by a simple procedure established by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in 1970s [3]. In the whole selection process, only one single climatic index – dry bulb temperature is adopted. All the months of the candidate years in the period of study are ranked by alternating between the warm half (May–October) and the cold half (November–April) of the year. The extreme months are arranged in the order of monthly average dry bulb temperature, reflecting the importance for energy comparisons. A TRY is selected by eliminating those candidate years in the period of study containing months with extremely high or low dry bulb temperatures. The elimination process is then continued until only one year remains which is the selected TRY.

During the selection of TRY, the candidate months with extremely high or low monthly average dry bulb temperatures are progressively eliminated, resulting in a particularly mild year that may not be able to represent the long-term typical weather condition. Building energy simulation runs using TRY weather data are obviously less reliable in reproducing the average historical conditions [4]. TRY weather tapes were originally developed by the US National Climatic Data Center for research purposes. ASHRAE stated that TRY weather tapes are not recommended for use in the study of long-term mean performance of buildings or energy systems [5].

TMY is another common type of weather data which is widely adopted by various researchers. A TMY data set provides weather data of one year that typify climatic conditions at a specific city over a reasonably long period of time, such as 30 years. In the selection of a TMY, data of nine critical climatic indices including the daily maximum, minimum and mean dry bulb and dew point temperatures; the daily maximum and mean wind speed; and the daily total horizontal solar radiation are used. Principle of *Finkelstein–Schafer* (*FS*) statistics [6] is applied to calculate the values of cumulative distribution function (*CDF*) of these nine climatic indices for each calendar month of each candidate year and the long-term composite of all the years in the period of study. With the application of various weighting factors in the nine climatic indices, weighted sums are then calculated for selecting 12 typical meteorological months (TMMs) that will be used to form a TMY. Details of the selection procedure are described in Section 3 of this paper.

By employing this TMY selection procedure, Hall et al. had developed TMY weather data sets for 26 SOLMET Rehabilitation Stations in USA (known as the Sandia method) [2]. In 1994, the National Solar Radiation Data Base (NSRDB) followed the Sandia method with modified weighting factors (as shown in Table 1) to generate 239 TMY data sets for a number of meteorological stations in USA [7]. This new set of TMY weather data was labelled as TMY2.

Similarly, a set of TMY weather files was produced by ASHRAE in 1997 by using another set of new weighting factors (see Table 1) for the climatic indices used in the Sandia method [8]. This data set, named as the International Weather for Energy Calculation (IWEC) weather files, contains hourly TMY weather files for 227 cities located over 70 different countries. In 2007, a new set of TMY weather data (entitled as TMY3), was generated by the National Renewable Energy Laboratory (NREL) [1]. These TMY3 weather files provide updated weather data with greater coverage over more than 1000 locations in USA.

TMY weather data are adopted in some solar energy simulation software. In a solar system, there are two major categories namely non-concentrating photovoltaic (PV) system and concentrating solar power (CSP) system. The former can utilize the direct normal irradiance and a substantial amount of diffuse irradiance. However, in a CSP system with a technology to concentrate sunlight, optical concentration cannot be achieved based on diffuse irradiance coming from various directions. Only the direct normal irradiance (DNI) component of solar radiation is relevant for a CSP system [9].

In a CSP system, DNI with high variability in space and time is a key resource for successful prediction of power generation. Banks and lenders generally expect a more conservative approach for financial decision on a solar project in which weather data for a CSP system should facilitate a lower probability of under-prediction on system performance. The uncertainly of DNI (solar resource) should be handled with care. Usually, data with a lower uncertainty for robust estimation of energy generation exceedance probability are required to satisfy the requirement of the banks/lenders.

During the development process of a TMY, TMMs are selected to represent the long-term properties of the weather data. Extreme weather conditions caused by outlier events are filtered out to ensure that the TMY weather file can represent the long-term climatic condition [10]. For financial analysis of a solar project, these outlier events may represent the worst-case years that significantly affect the financial decision of the project. Since TMY files do not include weather data from the potential worst-cases years, they are more appropriate for studying the long-term performance of a solar system rather than for financial decision-making.

For financial decision on a solar project, P50 and P90 TMY weather data were derived and considered as more appropriate for this purpose [10]. P50 and P90 represent the data for a typical year in which values are exceeded in 70% or 90%, respectively, of all years under study, while TMY weather data are more suitable for studying the long-term average performance of a thermal system.

For generating TMY weather files, a number of methods had been developed by different researchers such as Sandia method [2], Danish method [11], Festa-Ratto method [12], Crow method [13], Miquel-Bilbao method [14], Gazela–Mathioulakis method [15] and Stochastic Approach (First Order Multivariate Markov Chain Model) [16,17]. Some researchers including Skeiker [18], Janjai & Deeyai [19] and Ebrahimpour & Maerefat [20] had conducted detailed comparisons among various methods for TMY generation and concluded that the Sandia method could give the closest evaluation to the long-term average performance of a building thermal system. This Sandia method has been adopted by researchers worldwide to generate hourly weather data of typical meteorological year [21–26].

2.2. Review on the generation of TMYs with different weighting factors

The values of weighting factors of the climatic indices used in Sandia method play an important role in the process of TMY generation. These weighting factors express the relative importance of the impact of a particular climatic index on the thermal and energy performance of a building or an energy system. There are various sets of weighting factors adopted by different researchers worldwide as listed in Table 1. The values of these weighting factors were