Checking Radiation Model Data with the Method of Building Thermal Environment Simulation

Ying Yu, Liu Yang, Liqiang Hou and Qimeng Cao

Abstract Solar radiation data used for the design of building thermal environment in China are seriously deficient; the radiation estimation model is an important way to supplement radiation data. In order to analyze the influence difference in building thermal environment between measured radiation data and radiation model data quantificationally, building indoor temperature, humidity, cooling and heating load are taken as evaluation indexes, and as the same time, meteorological parameters input files with measured data and model data are constructed separately; with the aid of EnergyPlus, building thermal environment simulation was carried out for two types of building—residential building and office building respectively. Simulation results show that the maximum error percentage of building indoor temperature and relative humidity is 6.22% and 11.00%, respectively, on the typical days; the maximum error percentage of annual cooling and heating load is less than 10%. By comparing the simulation results, the influence difference between measured data and model data referring to building indoor temperature, humidity, load and energy consumption can be reflected. It provides reference for designers to use radiation model data in building energy efficiency design.

Keywords Solar radiation · Building thermal environment · Hourly radiation model · EnergyPlus

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1 Introduction

Meteorological data are essential for the building thermal environment design and analysis, but the measured data supply is insufficient in China. Comparing with other meteorological factors, situation of measured solar radiation data is even worse. First, in the spatial scale, the amount of radiation observatory is limited, which is less than one-twentieth of the amount of meteorological station. The spatial coverage area of radiation data is limited; meanwhile, only global radiation data are relatively complete. Data of direct and diffuse radiation are more limited. Second, in the temporal scale, the daily radiation data published by National Meteorological Information Center cannot meet the requirements of building thermal environment design, which should be hourly. Therefore, it can be seen that the scarcity of radiation data is one of the important factors which restricts optimization design and analysis of building thermal environment. Estimation by scientific, reasonable solar radiation model building is a universal method for perfecting radiation data internationally. Therefore, characterizing the difference between radiation model data's and measured data's influence on designing and analyzing building thermal environment quantitatively becomes the decisive factor of judging whether the solar radiation model data can be used in engineering.

Climate is one of the most important factors which influences building thermal environment. Its influence on building thermal environment is manifested in multiple meteorological factors, such as solar radiation and temperature. Therefore, the influence of solar radiation on building thermal environment can be characterized by indoor temperature, humidity and load. Building energy simulation is a very important supporting tool in building energy-saving design and reconstruction. Three methods of evaluating building energy performance are defined in American Green Building Standard LEED [1]; one of the three is building energy simulation. Building environment, systems and devices can be modeled by computer in building energy simulation, in which hourly building energy consumption can be calculated. Building energy simulation can be used in building new structures. Design can be compared and optimized according to results of energy simulation and analysis in the design stage. It can also be used in existing structures to simulate and analyze the energy consumption after energy-saving reconstruction. In view of this, temperature, humidity and load are set up as measure standard in this paper. By means of energy consumption simulating software EnergyPlus, measured radiation data and model data are used separately to form input meteorological parameter file with other measured meteorological data, and then, the energy consumption simulating experiment aiming at residential building and office building is completed separately. By comparing simulation results of different input files, the difference between radiation model data's and measured data's influence on building indoor temperature, humidity and load will be presented quantitatively, which can provide the evidence for using radiation model data in engineering.

2 Building Energy Simulation

2.1 Hourly Radiation Model

In building energy simulation, hourly global radiation, normal surface and diffuse radiation data are required. Based on previous studies, multiple meteorological factors modified CPR model and grouping model are chosen to calculate hourly global radiation and diffuse radiation separately. The normal radiation can be calculated by the above two models.

Multiple Meteorological Factors Modified CPR Model

Multiple meteorological factors modified CPR model is a calculation model for hourly global radiation using variations which are closely related to radiation such as sunshine hours, relative humidity and temperature as correcting factors of CPR decomposition model, as well as adopting the linear functional relationship. The model is shown in Eq. (1).

$$I_g = a_0 + a_1 * (a + b\ \cos\omega)\frac{(\pi/24)(\cos\omega - \cos\omega_s)}{\sin\omega_s - (2\pi\omega_s/360)\cos\omega_s}G + a_2 * S_h + a_3 * T_h + a_4 * RH_h \tag{1}$$

In this equation, $a = 0.409 + 0.5016\ \sin(\omega_s - 60)$, $b = 0.6609 - 0.4767\ \sin(\omega_s - 60)$; I_g is hourly global radiation $\left(\mathrm{MJ/m^2}\right)$;$S_h$ is hourly sunshine hours (h); T_h is hourly temperature (°C); RH_h is hourly relative humidity (%).

Grouping Model

Sun elevation angle α is chosen as constraint index and divided into three groups: 7°–30°, 30°–60° and bigger than 60°. Aiming at every group, the function connection between hourly clearness index k_t and scattering ratio k is established separately, as shown in Eq. (2).

$$k = \begin{cases} 4.0462k_t^3 - 5.5126k_t^2 + 1.1214k_t + 0.8718\ 7^\circ < \alpha \le 30^\circ \\ 5.7246k_t^3 - 7.8243k_t^2 + 1.8369k_t + 0.8396\ 30^\circ < \alpha \le 60^\circ \\ 3.6464k_t^3 - 6.1363k_t^2 + 1.4427k_t + 0.8902\ \alpha > 60^\circ \end{cases} \tag{2}$$

In this equation, $k_t = I_g/I_{\mathrm{oh}}$, $k = I_d/I_g$, in which I_{oh} is hourly extraterrestrial global radiation $\left(\mathrm{MJ/m^2}\right)$ and I_d is hourly diffuse radiation $\left(\mathrm{MJ/m^2}\right)$.

2.2 Building Model

Office Building

The office building in simulation experiment is located at Xi'an; the total floor area is 26,989.2 m^2. Number of floors is 20. Height of the building is 76 m. The size of standard layer is 37.8 m × 35.7 m. Building model is shown in Fig. 1. Floor area is divided into two parts: staircase and office, as shown in Fig. 2.

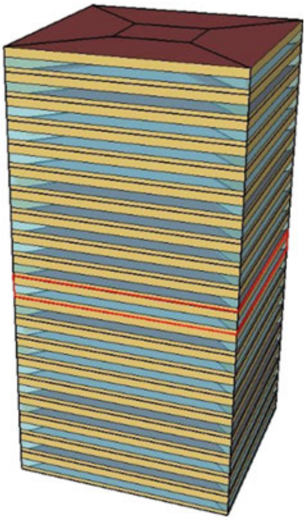

Fig. 1 Model of the office building

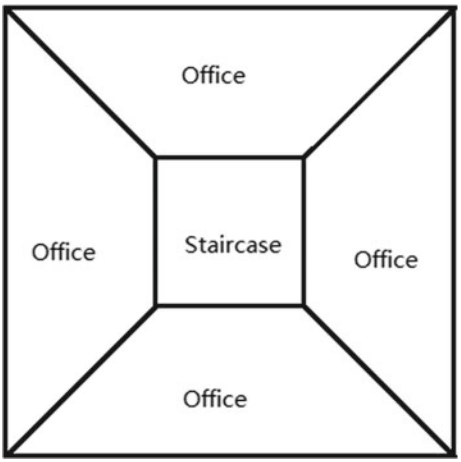

Fig. 2 Areas

Building envelope mainly consisted of exterior wall, interior wall, ground, floor, roof and external window, etc. Material data of building envelope are chosen according to Design standard for energy efficiency of public buildings [2].

Internal interference consisted of indoor personnel, lighting and equipment, so the settings of internal interference are mainly about these factors. According to Design standard for energy efficiency of public buildings, occupant density, lighting power density and equipment power density are set up. In the simulation software, except for occupant density, lighting power density and equipment power density, annual timetable about personnel, lighting and equipment is also needed. Office area is closed on weekends. Personnel work time mainly focuses on 7:00–20:00 on weekdays, which is 15 h in total. Interior design parameters are chosen according to Design standard for energy efficiency of public buildings. The ideal air conditioning system is adopted in office building.

Multi-storied Residential Building

The multi-storied residential building in simulation experiment is located at Xi'an. It has six floors above ground, total floor area is 3255.84 m^2, length is 45.6 m, depth is 11.9 m, story height is 2.9 m, and shape coefficient is 26.94%. Model of the building is shown in Fig. 3.

Building envelope mainly consisted of exterior wall, interior wall, ground, floor, roof and external window, etc. Material data of building envelope are chosen according to Design standard for energy efficiency of residential buildings in severe cold and cold zones [3]. Inner heat source of the multi-storied residential building is set as 3.8 W/m^2. The ideal air conditioning system is adopted in multi-storied residential building.

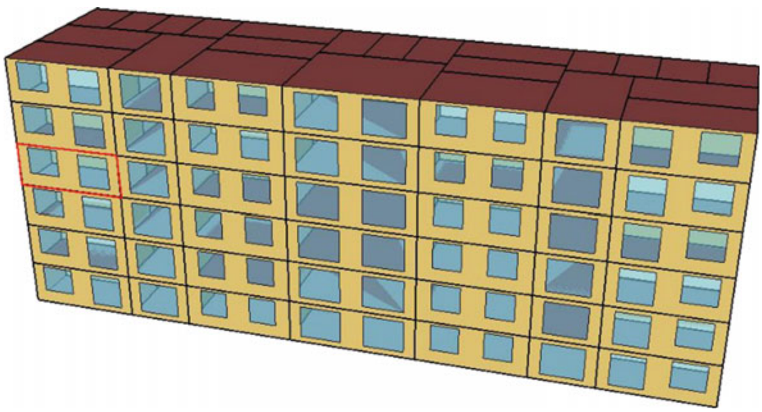

Fig. 3 Model of the multi-storied residential building

2.3 Meteorological Parameter Input File

The meteorological parameter file required by EnergyPlus is an hourly meteorological and radiation data EPW file involving annual 8760 h; the EPW file consisted of dry bulb temperature, dew point temperature, relative humidity, atmospheric pressure, cloud amount, wind speed, wind direction, rainfall amount, horizontal global radiation, horizontal diffuse radiation and normal direct radiation. In the experiment, Xi'an is taken as an example to generate three separate meteorological parameter files according to actual situation of measured radiation data in China and verification target. All data in file EPW1 are actual measured data in 2016. In file EPW2, only horizontal diffuse radiation and normal direct radiation are replaced by model calculation data; rest of the data are the same as file EPW1. This data file represents measured radiation data situation of some areas in China, which means hourly global radiation is already measured. Only hourly diffuse radiation needs to be calculated by the model, and further hourly normal direct radiation data can be calculated by hourly global and diffuse radiation. In file EPW3, all radiation data are replaced by model calculation data. Meteorological data of file EPW3 are the same as file EPW1.

In order to compare the differences of radiation model data with measured data's influence on indoor temperature, humidity and load, files EPW1, EPW2 and EPW3 are set up as input files, respectively, in order to complete experiments aiming at the two kinds of building. Combining the input meteorological parameter files with types of building, six groups of simulation experiment are planned.

3 Analysis of Simulation Results

Meteorological parameter files EPW1, EPW2 and EPW3 are set as input file of EnergyPlus, respectively, for building energy simulation, recording the simulation results involving temperature and humidity in specific building hot area, as well as cooling and heating load of the whole building. As file EPW1 consisted of measured meteorological data, its simulation result is set up as conventional true value. Comparing the simulation results of EPW2 and EPW3 with conventional true value, respectively, the influence of model data on building thermal environment and energy consumption can be analyzed quantitatively. The analysis results can be used to provide a reference to architects in using model data for building thermal environment design and analysis.

3.1 Simulation Analysis of Temperature and Humidity in Hot Areas

There are differences in indoor temperature and humidity in different hot areas within buildings, so the comparison of simulation results must be aimed at the same hot area. The selected hot areas are mostly located in the standard floor, which is representative. As the purpose of simulation is to verify the influence of model data on building thermal environment, priority is given to the areas that are relatively more affected by solar radiation. In summary, office area in the tenth floor of the office building and the westernmost room in the fourth floor of the residential building are chosen as representative hot areas of two types of building. The hot areas above are shown with the red wireframe marking areas in Figs. 1 and 3, respectively.

Temperature and humidity of the selected hot areas can be simulated with EnergyPlus for 365 days and 8760 h a year. In this paper, hourly temperature and humidity and their changing regularity are compared in days. In order to select representative days, three days of January in winter and July in summer are separately chosen, in which the weather types are sunny, cloudy and overcast. Comparing the simulation results of EPW2 and EPW3 in the six representative days with the simulation result of EPW1 in the corresponding days, it is found that the simulation results of hourly temperature and relative humidity are in full accord, and simulation results of EPW2 are generally better than those of EPW3. In order to quantify the difference between the simulation results of EPW2 and EPW3 and the conventional true value, the average absolute error percentage MAE% of the two groups of simulation results in six representative days was calculated, respectively, as shown in Fig. 4. The MAE% of temperature simulation result varies between 0.12 and 6.58%, and the MAE% of relative humidity simulation result varies between 0.08 and 12.08%. The accuracy of temperature simulation results is higher than that of relative humidity, and as a whole, the simulation accuracy of EPW2 is higher than that of EPW3.

3.2 Simulation Analysis of Building Load

Solar radiation affects indoor thermal environment of buildings and then affects the cooling and heating load of buildings. Simulation results of monthly cooling and heating consumption of building with three meteorological parameters files as input are calculated; the statistical results of cooling and heating consumption aiming at two kinds of building are shown in Figs. 5 and 6, respectively. In the figures, the simulation results based on EPW2 and EPW3 are in full accord with the trend of the conventional true value. Errors show that the simulation results based on EPW2 are better than those based on EPW3. According to monthly statistics, the relative error of simulation result based on EPW2 is between 0.71 and 18.25%, with an average error of 5.85%, and that based on EPW3 is between 2.86 and 18.76%, with an average

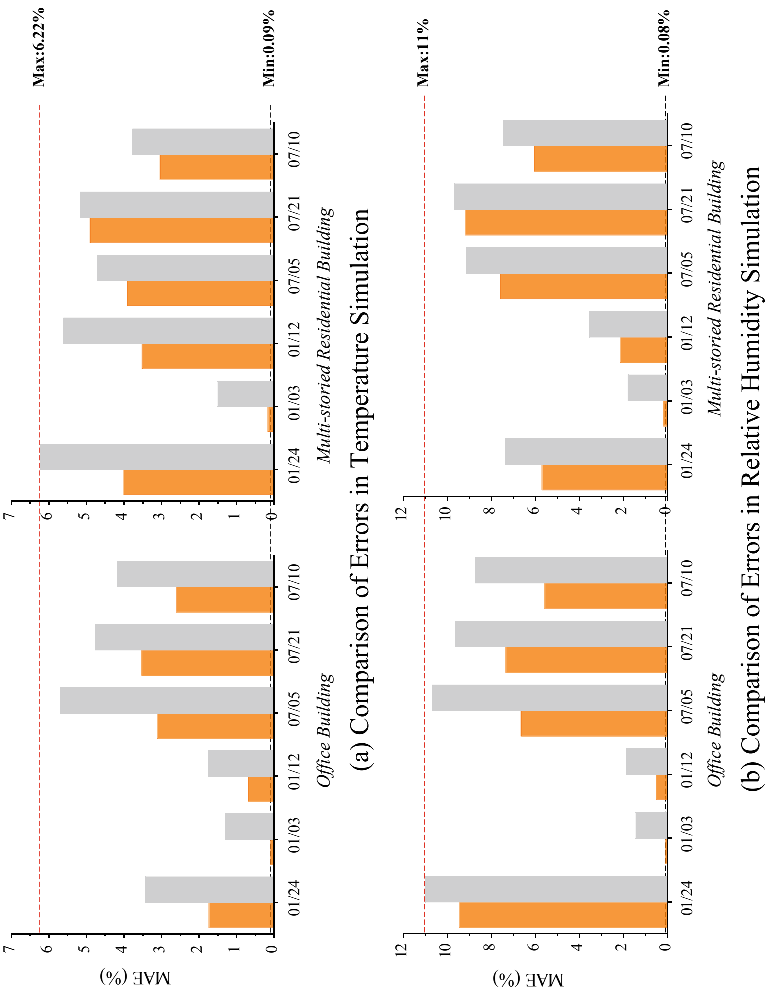

Fig. 4 Comparisons of errors in different meteorological parameters

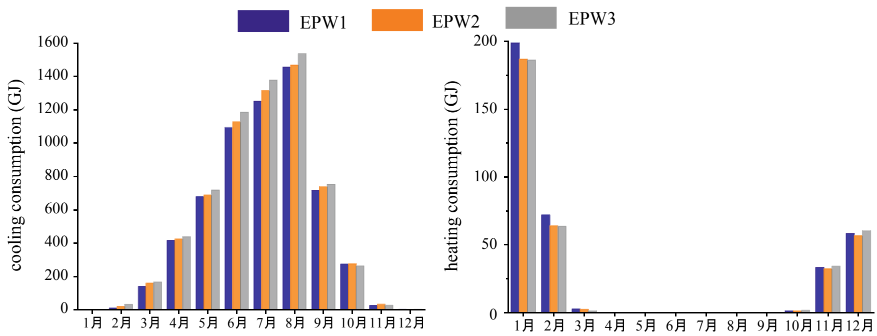

Fig. 5 Comparison of simulated cooling/heating consumption in the office building

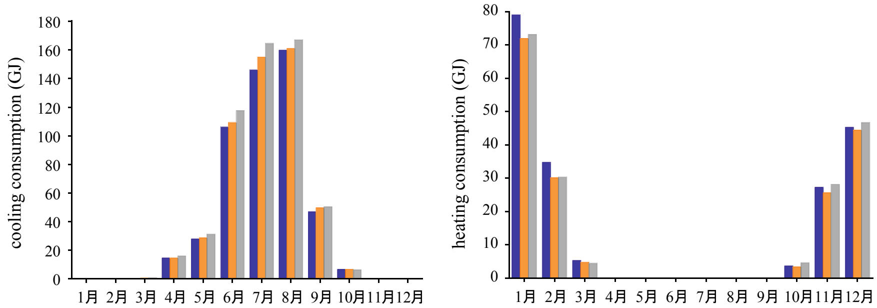

Fig. 6 Comparison of simulated cooling/heating consumption in the multi-storied residential building

error of 8.29%. According to annual statistics, the relative error based on EPW2 is between 3.13 and 11.19%, and the corresponding value based on EPW 3 is between 5.56 and 15.79%.

4 Conclusions

The influence on building thermal environment design and analysis when using solar radiation model data is the most concerned problem for designers. Aiming at this problem, building energy consumption is taken as an entry point; using the simulation tool EnergyPlus, the comparison between the influence of measured data and model data on indoor temperature and humidity, as well as cooling and heating load of the building are completed. Relative error is introduced to quantify this influence, which provides a reference for using model data in building thermal environment design.

The simulation results show that for the same meteorological parameters' EPW input files, the errors of energy consumption simulation are relatively stable and will not change greatly with the change in building type. When the input file is EPW3, the simulation error of indoor temperature, humidity and load is slightly higher than that of EPW2. When EPW2 and EPW3 are set up as input files, respectively, the average simulation errors of daily temperature and humidity can be controlled within 5%; the corresponding simulation errors of annual cooling and heating load are less than 10%. The error results can satisfy the engineering demand.

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