RAINFALL PREDICTIVE MODELS FOR BUILDING SIMULATION I – RAINY TIME IDENTIFICATION

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ABSTRACT

Rainfall simulation is a key problem for the evaluation of the energy saving potential of passive cooling by natural rainfall evaporation in humid and hot areas. Using a set of data in Guangzhou Area from weather bureau as the training sample, and the data generated by Medpha (Meteorological Data Producer for HVAC Analysis) as the testing sample, distance discriminant analysis was applied to identify the rainy time. Dry bulb temperature, relative humidity, total solar radiation and direct solar radiation were chosen as the key factors determining rainy days identification and the simulated results were found to be in good agreement with the measured ones in the months before May, however adjustment was needed after May. Rainy hours identification was performed in daytime and nighttime separately using distance discriminant analysis and the predictive model was effective in the month that rainfall plays dominant influence.

KEYWORDS

Rainfall predictive model, rainy days identification, rainy hours identification, distance discriminant analysis

INTRODUCTION

The annual rainfall is abundant in the subtropical area of China due to the monsoon. The variation of rainfall has an obvious seasonal feature that the period of high temperature coincides with that of rich rainfall. Based on this key feature, passive evaporation cooling effect can be achieved by storing natural rainfall with porous materials or other specially designed structure, which can greatly decrease outer surface temperature of building envelope, cut down the heat flow from outdoor into indoor and improve indoor thermal environment.

To simulate the passive evaporation cooling effect and evaluate the potential energy savings, hourly rainfall data are needed. However, in currently used building energy simulation software, such as DOE (1982), EnergyPlus (2001) and DeST (2006), no rainfall information is provided in the climatic database.

In hydraulics research fields, stochastic simulation of daily rainfall has attracted wide attentions. Model describing daily rainfall is composed of two parts (Stern 1980). One is focused on rainfall distribution, the other is used to calculate rainfall amount. Generally speaking, the model for rainfall distribution can be classified into three categories: one-order Markov Chain with two statuses (Haan et al. 1976), high-order Markov Chain (Jimoh and Webster 1996) and Spell Length. Currently, most widely used approach to describe rainfall distribution is the combination of one-order Markov Chain and Gamma distribution function (Geng et al. 1986). In this approach, one-order Markov Chain is used to describe rainfall distribution and Gamma distribution function is used to simulate daily rainfall amount.

Although daily rainfall forecast in hydraulics research field has made great progress, no hourly rainfall predictive model can be obtained for energy saving evaluation of natural rainfall passive cooling. The study makes efforts on the rainfall predictive models.

METHODOLOGY

Weather data resources

One approach to get weather data is from weather bureau. The following data were bought from Guangzhou Weather Bureau:

- Hourly weather data of the year of 2003 (the period of solar radiation data are from May to December)
- Hourly weather data of the year of 2004
- Ten-day rainfall data from the year of 1971 to 2000
- Daily rainfall data from the year of 1993 to 2002

The other approach to get weather data is from the simulation model. Medpha (Meteorological Data Producer for HVAC Analysis) is developed by Tsinghua University and used to generate weather data, which applies a set of stochastic algorithm to generate weather data based on the statistic information of weather data of 193 cities in China.

The weather data provided by Medpha include: dry bulb air temperature, wet bulb air temperature, dew point temperature, relative humidity, absolute humidity, direct solar radiation, diffused solar radiation and total solar radiation on the horizontal plane and normal solar radiation.

Weather data judgment analysis

The method of two-phase simulation is used in Medpha to generate weather data (Jiang 1981). Firstly, the change of daily value of each weather element is considered as a stochastic process and simulated by time series method. Secondly, hourly data is obtained by random distribution of daily value. This method was also used to analyze rainfall determination (Refeim 1984). Rainy days are selected out from whole year data sample, and then rainy hours are selected out and numbered according to rainy days information (Connolly et al. 1998).

The data from weather bureau were used as training sample, while the data generated by Medpha were used as testing sample. According to the difference between training and testing sample, linear discriminant can be obtained, which will be used to judge whether the data from testing sample has rainy features. Many methods can be used to analyze the difference between the samples, such as distance discriminant analysis, Bayes discriminant analysis and step discriminant analysis. In the present study, distance discriminant analysis was applied.

Research Framework

As the framework shown in Figure 1, the study includes two parts of work:

- Rainy time identification: to distinguish rainy days and rainy hours
- Rainfall estimation: to estimate monthly rainfall, daily rainfall and hourly rainfall.

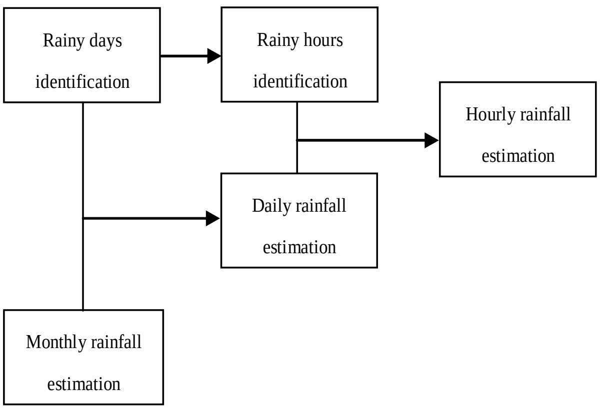

Figure 1 Research Framework of the present study

This paper presents the first part of the work and the second part is presented in another paper.

RAINY DAYS IDENTIFICATION

The difference between rainy days and non-rainy days

The occurrence frequency of rainy days and the corresponding change of weather element are different from month to month. Therefore, rainy days identification should be analyzed within a month. The daily whether data for each month in 2003 and 2004 were divided into two kinds of samples: rainy day sample and non-rainy day sample (including sunny and cloudy days). The differences of the mean value of all whether elements between two samples were calculated for each month and some results are shown in Figure 2-5.

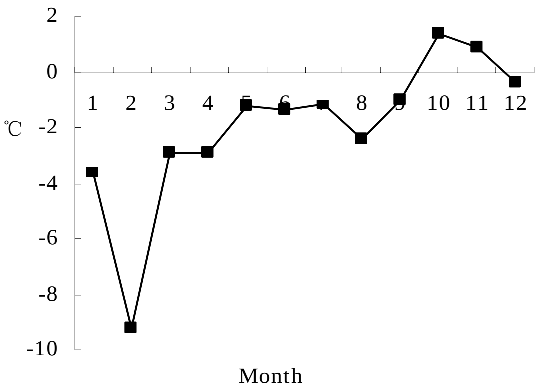

Figure 2 Difference of dry bulb temperature

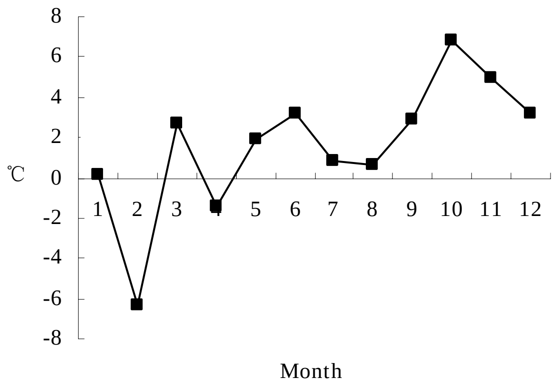

Figure 3 Difference of wet bulb temperature

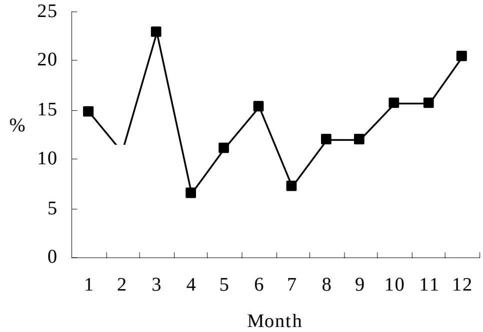

Figure 4 Difference of relative humidity

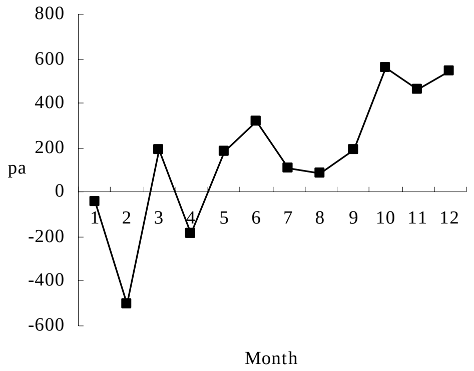

Figure 5 Difference of vapor pressure

The mean values of total solar radiation, direct solar radiation and diffused solar radiation in rainy days were found to be significantly smaller than the ones in non-rainy days. In January, February, March, November and December, the mean value of daily solar radiation for rainy days is only 25 to 30 percent of the one for non-rainy days. However, in the months from April to August, the percentage changes to 50%~80% because the period of rainy days in those months is much shorter.

As shown in Figure2~5, the differences of dry bulb air temperature, wet bulb air temperature, relative humidity, and vapor pressure between rainy days and non-rainy days vary with month, which in some degree represents the difference of rainfall condition between seasons. It can be seen from the figures that except October and November, the mean value of dry bulb air temperature in rainy days is lower than that in non-rainy days, and the difference is greater in January, February and March, which is 2 to 9 ºC. In most of the cases, the mean value of wet bulb air temperature in rainy days is 0 to 7 ºC higher than that in non-rainy day. The difference on relative humidity is even remarkable and the mean value of relative humidity in rainy days is 6.5% to 23% higher than that in non-rainy days. The monthly variation of difference on vapor pressure is similar with the one on wet bulb air temperature.

Distance discriminant analysis

The above analysis indicates that there exists notable difference on solar radiation, air temperature and humidity between rainy days and non-rainy days and the difference changes monthly. Therefore, the guideline for rainy days identification was proposed based on these whether elements. As wet bulb temperature, vapor pressure and diffused solar radiation can be derived from others, dry bulb temperature, relative humidity, total solar radiation and direct solar radiation are chosen as the key factors determining rainy days identification. Distance discriminant analysis was used and the rainy days identification model can be expressed as:

$$W = C + C_1 T + C_2 \varphi + C_3 Q_{total} + C_4 Q_{dir} \qquad (1)$$

where C, C_1 , C_2 , C_3 are coefficients of the function and W is the discriminant index. W_1 means the day is a rainy day and W_2 means the day is a non-rainy day.

The data were analyzed month by month and the results are shown in Table 1.

Table 1 Coefficients of the rainy days identification model for each month

MONTH		C	C1	C2	C3	C4
Jan	W_1	-36.934	-1.055	1.051	0.026	-0.005
	W_2	-44.888	-1.472	1.260	0.018	0.002
Feb	W_1	-83.242	1.669	1.508	0.030	-0.002
	W_2	-63.565	1.053	1.438	0.016	0.003
Mar	W_1	-52.903	1.757	0.783	0.023	0.000
	W_2	-53.258	1.226	0.937	0.018	0.006
Apr	W_1	-171.898	1.521	3.416	0.055	-0.027
	W_2	-171.389	1.066	3.556	0.053	-0.024
May	W_1	-207.205	0.921	4.989	0.025	0.008
	W_2	-246.085	0.243	5.718	0.027	0.009
Jun	W_1	-426.001	19.642	4.069	0.007	0.003
	W_2	-453.574	19.500	4.495	0.007	0.005
Jul	W_1	-2358.000	91.109	27.923	0.023	0.053
	W_2	-2417.000	92.147	28.376	0.020	0.056
Aug	W_1	-2073.000	95.715	19.267	-0.068	0.061
	W_2	-2089.000	95.507	19.580	-0.069	0.061
Sep	W_1	-449.567	15.918	5.965	0.049	-0.030
	W_2	-498.581	15.845	6.606	0.054	-0.034
Oct	W_1	-118.579	2.928	0.042	-0.009	2.240
	W_2	-132.128	2.770	0.049	-0.019	2.560
Nov	W_1	-114.054	-0.277	0.029	0.015	2.828
	W_2	-125.928	-0.261	0.029	0.015	2.992
Dec	W_1	-45.147	0.621	0.012	0.016	0.861
	W_2	-52.956	1.464	0.001	0.018	0.863

Results of rainy days identification

The predicted and measured rainy days for each month are shown in Table 2. It can be seen that the simulated results are in good agreement with the measured ones in the months before May. After May Guangzhou Region enters rainy season and the differences of whether elements between rainy days and cloudy days are less distinct, which results in overestimation of rainy days. On the other hand, weather data generated by simulation software are average values in past years, which greatly weaken the difference of weather elements among sunny days, rainy days and cloudy days. Therefore, further study is needed to revise the predicted results of rainy days identification according to the above considerations.

Table 2 Comparison of simulated and measured rainy days for each month

MONTH	SIMULATED RESULTS （DAYS）	MEASURED RESULTS （DAYS）
Jan	4	4
Feb	8	8
Mar	18	15
Apr	17	14
May	24	17
Jun	23	15
Jul	28	12
Aug	22	12
Sep	13	13
Oct	8	8
Nov	13	6
Dec	1	3

RAINY HOURS IDENTIFICATION

For the monthly change of the whether data, rainy hours identification was analyzed month by month. In addition, the changes of weather elements resulted from rainfall in daytime are different from nighttime, so rainy hours identification was performed in daytime and nighttime separately. The occurrence of rainy hours accompanies with the change of air temperature, relative humidity, vapor pressure and solar radiation. Taking the measured hourly weather data as training sample, the discriminant function was obtained by analysis of the change of whether data and then the rainy hours were estimated.

Preprocess of weather data

The difference of dry bulb temperature Δt , relative humidity $\Delta\varphi$ and vapor pressure ΔP_q in the two continuous hours is calculated based on the whether data respectively.

The maximum values of total solar radiation, direct solar radiation and diffused solar radiation are calculated for each hour in a month. The ratios of hourly value of total solar radiation, direct solar radiation and diffused solar radiation to the corresponding maximum value are calculated and marked as ratio of total solar radiation QL_{total} , ratio of direct solar radiation QL_{dirl} and ratio of diffused solar radiation QL_{sca} .

According to total solar radiation, hourly weather data are classified as daytime sample if the total solar radiation is above zero and nighttime sample if the total solar radiation is below zero.

Difference analysis of rainy hour and non-rainy hour

According to the hourly rainfall information, measured hourly whether data were classified into four kinds of samples: daytime sample with rainfall, daytime sample without rainfall, nighttime sample with rainfall, and nighttime sample without rainfall. The data were analyzed and it was found that dry bulb temperature in rainy hours is 3℃ lower than that in non-rainy hours in average and relative humidity in rainy hours is 11% higher than that in non-rainy days in average. For daytime sample without rainfall, QL_{total} is about 0.5, QL_{dir} is about 0.26 and QL_{sca} is about 0.6 in average. However, for daytime sample with rainfall, QL_{total} is below 0.3, QL_{dir} is close to 0 and QL_{sca} is about 0.3 in average. Therefore, the solar radiation changes greatly with rainfall and rainy hours identification should be performed in daytime and nighttime separately. For daytime, Δt , φ , $\Delta\varphi$, ΔP_q , QL_{total} , QL_{dir} and QL_{sca} should be included into rainy hours identification. For nighttime, Δt , φ $\Delta\varphi$ and ΔP_q should be included into rainy hours identification.

Results of rainy hours identification

Distance discriminant analysis was used for rainy hours identification and the rainy hours identification model was similar with equation (1). Taking January as an example, results of rainy hours identification are shown in Table 3.

Table 3 Coefficient estimation and error of January

	COEFFICIENT OF RAIN DISTINGUISH EQUATION IN DAYTIME		COEFFICIENT OF RAIN DISTINGUISH EQUATION IN NIGHTTIME	
Rain or not	no	yes	no	yes
Constant	-23.98	-33.70	-18.21	-27.71
Δt	-0.66	0.82	-17.39	-17.75
$\Delta\varphi$	0.57	0.99	-3.15	-3.22
φ	0.58	-0.05	0.49	0.59
ΔP_q	-0.02	0.71	0.20	0.20
QL_{total}	5.94	4.50	0.00	0.00
QL_{dri}	14.12	16.22	0.00	0.00
QL_{sca}	16.99	13.12	0.00	0.00
Error	8.19%		10.78%	

For rainy days identification, rainy hours identification model is effective in the month that rainfall places dominant influence on other meteorological elements, such as Jan, Feb, Mar, Oct, Nov and Dec. While in other months, ratio of prediction error is comparably high and modification is needed. Rainy hours identification shows the error in daytime is comparably high than that in nighttime. The mean error ratio in daytime is about 10%, while that in nighttime is about 16%. The reason is that meteorological elements difference resulted from rainfall in daytime is greater than that in nighttime.

CONCLUSIONS

As an important component of weather database, hourly rainfall model is indispensable for evaporation cooling effect evaluation. In the present paper, distance discriminant analysis was applied to distinguish rainy days and rainy hours and the following conclusions were drawn:

1. Dry bulb temperature, relative humidity, total solar radiation and direct solar radiation were the key factors determining rainy days identification and rainy days identification model was established based on the four key factors.
2. The rainy days simulated results were found to be in good agreement with the measured ones in the months before May, however adjustment was needed after May.
3. Rainy hours identification was performed in daytime and nighttime separately using distance discriminant analysis and the rainy hours identification model was effective in the month that rainfall plays dominant influence.

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