METEOROLOGICAL DATA SET FOR BUILDING THERMAL ENVIRONMENT ANALYSIS OF CHINA

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ABSTRACT

Meteorological data set for China building thermal environment analysis has been developed by Climatic Data Center of China Meteorological Administration and Tsinghua University. The data set is based on observation meteorological data and provides hourly climate data for dynamic simulation. This paper introduces (1) source data of the data set; (2) the methodology used to get the hourly data based on the observation time-lapse data and daily data; (3) the select method of typical meteorological year and different typical years for design.

KEYWORDS

Hourly climate data, Different typical years, Building simulation

INTRODUCTION

Hourly climate data is the necessary condition for building thermal environment dynamic simulation. Because of the source data from weather station is not all in 1-hour interval, it is necessary to develop a method to get hourly climate data for those stations with only limited source data(such as 6-hour intervals data). Some scholars (Lang S. 2002; Zhang Q. and Joe H. 2004) have gotten hourly climate data by interpolation and some new model based on limited source data. For the study about climatic data, source data is very important and sensitive. The source data is different, the method that can be used to generate hourly data is different. And also, the acceptance of result is different. The work in these reference are all based on unofficial source data. The source data lack of some important weather parameters such as daily maximum and minimum temperatures and the observation solar radiation. So the work in these reference can't guarantee the extremum temperatures and the total amount of solar radiation. In fact, all these parameters are very important for building energy simulation.

Because of the stochastic variations in the weather, the simulation results of building thermal environment based on climate data of different years are quite different. It is necessary to select typical climate data of one year from long-term data. In fact, what the building simulation emphasizes particularly on is changed with simulation purpose, so the requirement for climate data may also change. For example, the climate data used for checking capacity of HVAC system is different from that used for predicting the energy consumption of HVAC system. Also, the climate data used for testing the dependability of solar energy HVAC system and of regular HVAC system are obviously different. Thus it is necessary to select different typical climate data of one year to meet different purposes of building simulation.

To solve the problems above, Climatic Data Center of China Meteorological Administration and Tsinghua University work together to develop the meteorological data set for 270 China cities. As for the stations which have no hourly measured data, the author gives a method to generate the hourly climate data based on the time-lapse and daily data. This paper is to give a brief introduction in the source data of data set; the methodology used to get the hourly data based on the observation time-lapse data and daily data; the select method of typical meteorological year and different typical years for design.

SOURCE DATA

Introduction

The source data of the meteorological data set is based on two official meteorological data sets completed by the Climatic Data Center that belong to the National Meteorological Information Center of China Meteorological Administration. One of the two official meteorological data sets is the ground climatic data set of China, the other is the weather radiation data set of China. The ground climatic data set of China includes all kinds of ground weather data from national datum stations and national basic stations those are all included in the national groud climatic observation network. The national datum stations provide 1-hour interval observation data while the national basic stations provide 6-hour intervals observation data. To cover different region of China, 270 stations have been selected from the national groud climatic observation network. The countrywide distribution of all 270 stations is shown in Figure 1. In the 270 stations, there are 136 national basic stations and 134 national datum stations that were rebuilt in succession based on national basic stations since 1987. The time span of the selected ground climatic data is from 1971 to 2003. The selected elements of ground climatic data include ambient dry-bulb temperature, wet-bulb temperature, relative humidity, surface temperature, wind speed and wind direction, local atmospheric pressure and sunlight hour. The quality of all observation ground climatic data are strictly controlled by verifying the weather confine, the weather extremum and the inner coherence etc.

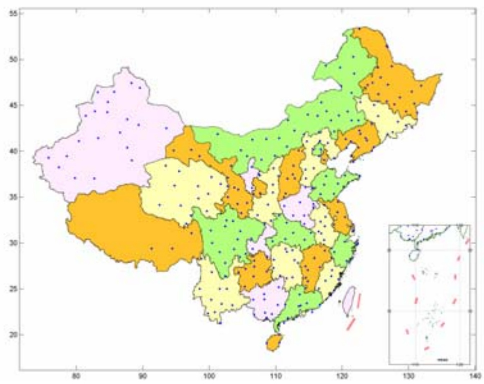

Figure 1 Countrywide distribution of climate stations

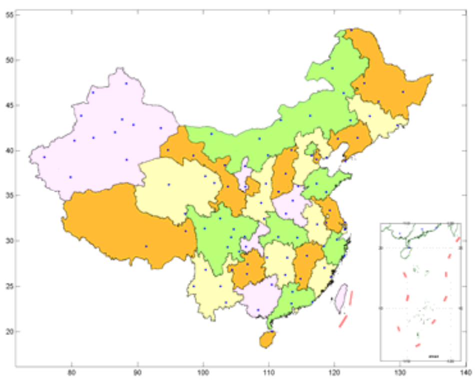

Figure 2 Countrywide distribution of radiant stations

The weather radiation data set of China includes all kinds of radiation data from the national weather radiation observation network. The scale of the national weather radiation observation network is less than that of the national ground climatic observation network. Since the new criterion for radiation observation was carried out in the beginning of 90's of last century, all the radiation observation stations have been classified into three levels. The first level stations can provide the most detail observed radiation data and the third level stations can only provide the observed daily total horizontal solar radiation. The countrywide distribution of the selected 93 radiation stations is shown in Figure 2. The time span of the selected weather radiation data is also from 1971 to 2003. The selected elements of radiation data include total horizontal solar radiation and scatter horizontal solar radiation. The quality of all observation radiation data are controlled by verifying the weather confine, the weather extremum and the inner coherence etc.

Select weather elements

Based on the situation of source data and the requirement of building thermal environment simulation, dry-bulb air temperature, relative humidity, total horizontal solar radiation, horizontal scattered solar radiation, surface temperature, sky temperature, wind speed and wind direction are available and suitable weather elements for building thermal environment simulation. But for the wind speed and wind direction, it is very difficult to generate appropriate hourly data only based on four time-lapse observed data which are the only available source data for most stations. So this work only takes the other six weather elements into account.

Make source data integrated

As described before, the situation of the source data is very complex. To sum up there are three characteristics: (1) the observation items of different weather elements are different; (2) the observation data situation such as the starting time of different stations are different; (3) the radiation observation is self-existent and the number of radiation stations is much less than 270. To get all the weather elements hourly data of all 270 stations, it's necessary to complement the radiation source data for all those stations which have no radiation observation data.

For the stations without radiation observation data, the following method is used to get the daily total horizontal solar radiation:

(1) Find out the most adjacent station B that has observation radiation data for the supposed station A without observation radiation data in accordance with the latitude and longitude;

(2) Analyse the relation among the monthly mean value of daily total horizontal solar radiation of station B ($\overline{Q_B}$), the monthly mean value of astronomical daily total horizontal solar radiation of station B ($\overline{Q_{0,B}}$), and the monthly mean value of daily ratio of sunshine hour of station B ($\overline{S_B}$): $\overline{Q_B} = \overline{Q_{0,B}}(x + y \cdot \overline{S_B})$. Where x , y indicate the fitted parameters for each month. The ratio of sunshine hour is the ratio of observed sunshine hours to possible sunshine hours.

(3) Presume the relation among the three monthly mean values for station A is the same with that of station B: $\overline{Q_A} = \overline{Q_{0,A}}(x + y \cdot \overline{S_A})$. Where $\overline{Q_A}$ is the monthly mean value of daily total horizontal solar radiation of station A; $\overline{Q_{0,A}}$ is the monthly mean value of astronomical daily total horizontal solar radiation of station A; $\overline{S_A}$ is the monthly mean value of daily ratio of sunshine hour of station A.

(4) Then the daily total horizontal solar radiation of station A (Q_A) can be calculated approximatively based on the astronomical daily total horizontal solar radiation of station A ($Q_{0,A}$) and the daily ratio of sunshine hour of station A (S_A): $Q_A = Q_{0,A}(x + y \cdot S_A)$.

METHODOLOGY

As described before, in the selected 270 stations there are still 136 national basic stations. These stations only provide 6-hour intervals observation data, daily extremum data and daily cumulate data. To get hourly climate data for these stations it is necessary to develop a method to generate the hourly climate data based on the time-lapse and daily observation data.

Air temperature

All the observation data used for generating hourly temperature include all four time-lapse (Beijing time 02:00, 08:00, 14:00, 20:00) temperatures and daily maximum temperature, daily minimum temperature. For the daily extremum temperatures, the day is a meteorologic day that is from previous 20:00 to intraday 20:00. To keep the daily extremum temperatures in the hourly temperature data, the daily maximum temperature and the daily minimum temperature have been presumed to just appear at one of the 24 hours of a meteorologic day when interpolating the missing hourly dry-bulb temperatures. To confirm the right time of the daily extremum temperatures, a meteorologic day has been divided into four zones: previous 20:00 to intraday 2:00; intraday 2:00 to 8:00; intraday 8:00 to 14:00; intraday 14:00 to 20:00. Firstly, it is necessary to confirm which zones the daily extremum temperatures belong to respectively.

For the daily maximum temperature:

$$
\begin{aligned}
& if\ t_{i,\max} \le t_{i-1,20}, \quad t_{i,\max} \in zone1 \\
& if\ t_{i,\max} > t_{i-1,20}, \\
& \quad t_{i,t} = \max(t_{i,2}, t_{i,8}, t_{i,14}, t_{i,20}) \\
& \quad if\ t_{i,t} = t_{i,20}, \quad t_{i,\max} \in zone4 \\
& \quad if\ t_{i,t} \ne t_{i,20}\ \&\ t_{i,t} = t_{i,14} \\
& \quad\quad t_{sub\max} = \max(t_{i,8}, t_{i,20}) \\
& \quad\quad t_{i,\max} \in zone(t_{i,t}, t_{sub\max}) \\
& \quad if\ t_{i,t} \ne t_{i,20}\ \&\ t_{i,t} \ne t_{i,14}\ \&\ t_{i,t} = t_{i,8} \\
& \quad\quad t_{sub\max} = \max(t_{i,2}, t_{i,14}) \\
& \quad\quad t_{i,\max} \in zone(t_{i,t}, t_{sub\max}) \\
& \quad if\ t_{i,t} \ne t_{i,20}\ \&\ t_{i,t} \ne t_{i,14}\ \&\ t_{i,t} \ne t_{i,8}\ \&\ t_{i,t} = t_{i,2} \\
& \quad\quad t_{sub\max} = \max(t_{i-1,20}, t_{i,8}) \\
& \quad\quad t_{i,\max} \in zone(t_{i,t}, t_{sub\max})
\end{aligned}
\tag{1}
$$

Where $t_{i,\max}$ respects the daily maximum temperature of day i ; $t_{i-1,20}$, $t_{i,2}$, $t_{i,8}$, $t_{i,14}$, $t_{i,20}$ respect the previous day 20:00 temperature, intraday 2:00, 8:00, 14:00 and 20:00 temperature respectively.

For the daily minimum temperature:

$$
\begin{aligned}
& t_{t,\min} = \min(t_{i-1,20}, t_{i,2}, t_{i,8}, t_{i,14}, t_{i,20}) \\
& if\ t_{i,2} = t_{t,\min}, t_{i,\min} \in zone2 \\
& if\ t_{i,2} \ne t_{t,\min} \\
& \quad if\ t_{i-1,20} = t_{t,\min}, \quad t_{i,\min} \in zone1 \\
& \quad if\ t_{i-1,20} \ne t_{t,\min} \\
& \quad\quad if\ t_{i,8} = t_{t,\min} \\
& \quad\quad\quad t_{t,sub\min} = \min(t_{i,2}, t_{i,14}) \\
& \quad\quad\quad t_{i,\min} \in zone(t_{t,\min}, t_{t,sub\min}) \\
& \quad\quad if\ t_{i,8} \ne t_{t,\min}\ \&\ t_{i,14} = t_{t,\min} \\
& \quad\quad\quad t_{t,sub\min} = \min(t_{i,8}, t_{i,20}) \\
& \quad\quad\quad t_{i,\min} \in zone(t_{t,\min}, t_{t,sub\min}) \\
& \quad\quad if\ t_{i,8} \ne t_{t,\min}\ \&\ t_{i,14} \ne t_{t,\min}\ \&\ t_{i,20} = t_{t,\min} \\
& \quad\quad\quad t_{i,\min} \in zone4
\end{aligned}
\tag{2}
$$

Where $t_{i,\min}$ respects the daily minimum temperature of day i.

After confirming the zones of the daily extremum temperatures based on above methodology, the right time when the maximum temperature and the minimum temperature appear will be decided by linear interpolating based on their values. Distinguishingly, if the minimum temperature appears in zone2, in general, the right time will be presumed to be the hour closely before sunrise. For else conditions, all the hours belong to the four zones except previous 20:00 are taken into account.

After confirming the right hours of the extremum temperatures, we can get a temperature time series composed by all the six temperatures (the daily minimum temperature, the daily maximum temperature, 2:00, 8:00, 14:00 and 20:00 temperature). For each section from the previous extremum to the current extremum among the time series, the hourly temperature is generated by cubic spline interpolation with end conditions. The interpolation uses all the six temperatures as the base points.

By using the above method, the hourly temperatures of 270 stations have been generated. In Figure 3, the interpolated hourly temperature and the observed hourly temperature during January 4 to January 8 in 1998 of Miyun station at Beijing have been shown. The interpolated results show a good consistency with observed data except the hours when weather mutates because of unknown reason.

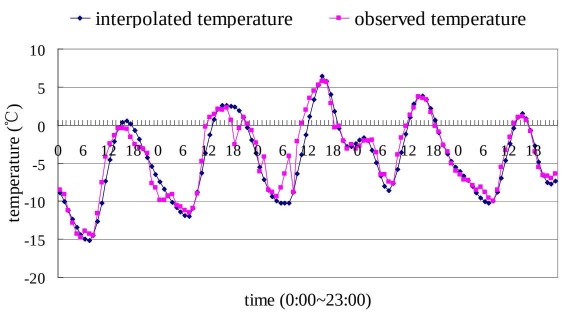

Figure 3 Comparison between interpolated temperature and observed temperature

Relative humidity

All the observation data used for generating hourly relative humidity include all four time-lapse (Beijing time 02:00, 08:00, 14:00, 20:00) relative humidities. Because of the differences of observation facility and precision, the observed daily minimum relative humidity has not been used to do the hourly relative humidity interpolation.

Based on four time-lapse observed relative humidities, the hourly relative humidity is generated by cubic spline interpolation with natural boundary conditions. For the over saturation interpolated results, it is necessary to make some adjustment.

In Figure 4, the interpolated hourly relative humidity and the observed hourly relative humidity during January 4 to January 8 in 1998 of Miyun station at Beijing have been shown. The interpolated results show an acceptable consistency with observed data.

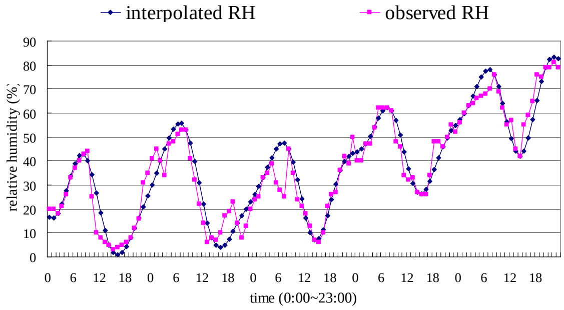

Figure 4 Comparison between interpolated relative humidity and observed relative humidity

Solar radiation

All the observation data used for generating hourly total horizontal solar radiation and hourly horizontal scattered solar radiation include daily total horizontal solar radiation and daily horizontal scattered solar radiation. As described before, the observation items of different station are different. There are stations with total horizontal solar radiation and horizontal scattered solar radiation and also stations with only total horizontal solar radiation.

The calculation process has been divided into two steps. In the first step, the hourly total horizontal solar radiation is calculated and adjusted based on observed daily total horizontal solar radiation. The hourly horizontal scattered solar radiation is separated based on the judgement of weather state in the second step. The detail about two steps calculation is as follows:

(1) The model (called C.P.R model for short) used to calculate the hourly total horizontal solar radiation was developped by Collores-Perein and Rabl (Jiang Y. 1980):

$R_{CPR}(\tau) = Q \cdot r_\tau \cdot (a + b\cos\omega_\tau)$. Where τ indicates hour; R_{CPR} is the original result of hourly total horizontal solar radiation; Q is the daily total horizontal solar radiation; r_τ is the ratio of astronomical hourly total horizontal solar radiation (I_0) to astronomical daily total horizontal solar radiation (Q_0) at τ hour: $r_\tau = I_0(\tau)/Q_0$; $a = 0.409 + 0.5016\sin(\omega_s - 60^o)$ and $b = 0.6609 + 0.4767\sin(\omega_s - 60^o)$ and ω_s is the hour angle for sunset; ω_τ is the hour angle for τ hour.

(2) Adjust the original result R_{CPR} in accordance with the proportion defined by the ratio of

observed daily total horizontal solar radiation to calculated daily total horizontal solar radiation.

(3) Make judgement of the weather state based on the ratio (Kt) of observed daily total horizontal solar radiation to astronomical daily total horizontal solar radiation and Markov chain. In the present work, three weather states: sunny, cloudy and overcast have been taken into account. Based on the reference (Jiang Y. 1980), the weather state is supposed to be sunny when the value of Kt is greater than 0.74 and to be overcast when the value is less than 0.28. When the value is between 0.28 and 0.5, the weather state is supposed to be overcast or cloudy. When the value is between 0.5 and 0.74, the weather state is supposed to be overcast or cloudy or sunny. The decision is based on a Markov chain that makes decision based on the previous hour weather state and the random numbers distributed uniformly between 0 and 1. The decision process is shown in Figure 5.

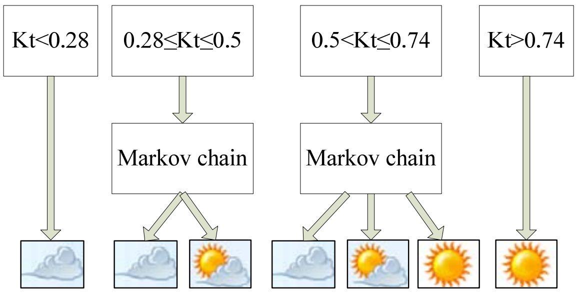

Figure 5 Make judgement of the weather state

(4) For different weather state, the hourly horizontal scattered solar radiation is separated by different separation model. The three separation models for different weather states are as follows:

Sunny (Liu and Jordan. 1960):

$$\tau_d = 1.416\tau_t - 0.384 \; ; \; \tau_s = 0.271 - 0.2939\tau_d \; .$$

Where τ_d is the ratio of hourly horizontal direct solar radiation to astronomical hourly total horizontal solar radiation; τ_t is the ratio of hourly total horizontal solar radiation to astronomical hourly total horizontal solar radiation; τ_s is the ratio of hourly horizontal scattered solar radiation to astronomical hourly total horizontal solar radiation.

Cloudy (Hayakawa K. and Shimizu K.1976):

$$\tau_d = \begin{cases} 1.492\tau_t - 0.492 & \tau_t > 0.6 \\ \exp(0.935\tau_t^2) - 1 , & \tau_t \le 0.6 \end{cases} ; \tau_s = \tau_t - \tau_d \; .$$

Overcast:

$$\tau_d = \tau_t \; ; \; \tau_s = 0 \; .$$

(5) Adjust the result of hourly horizontal scattered solar radiation in accordance with the proportion defined by the ratio of observed daily horizontal scattered solar radiation to calculated daily horizontal scattered solar radiation if the station has the observed daily data.

In Figure 6, the calculated hourly total horizontal solar radiation and hourly horizontal scattered solar radiation during January 2 to January 6 in 2003 have been shown with the observed values for Zhengzhou station.

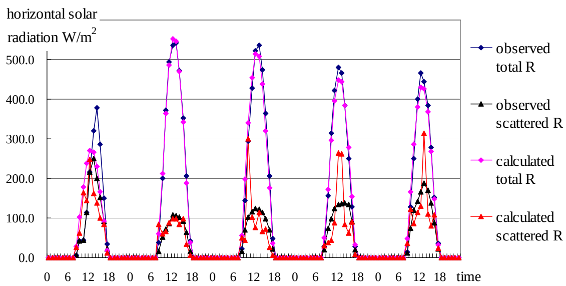

Figure 6 Comparison between calculated and observed horizontal solar radiation

The calculated results of hourly total horizontal solar radiation show an acceptable consistency with observed data. Because of the uncertainty of hourly weather state and the deficiency of separation models, the calculated results of hourly horizontal scattered solar radiation show a rather large difference with the observed data.

Surface temperature

For all the 270 stations, the available observed data include only four time-lapse (Beijing time 02:00, 08:00, 14:00, 20:00) surface temperatures. Based on four time-lapse observed surface temperatures, the hourly surface temperature is generated by cubic spline interpolation with natural boundary conditions.

In Figure 7, the interpolated hourly surface temperature and the observed hourly surface temperature (the observed data was provided by Shanghai Institute of Architecture and Science) during June 1 to June 5 in 2001 of Shanghai have been shown. The interpolated results show an acceptable consistency with observed data.

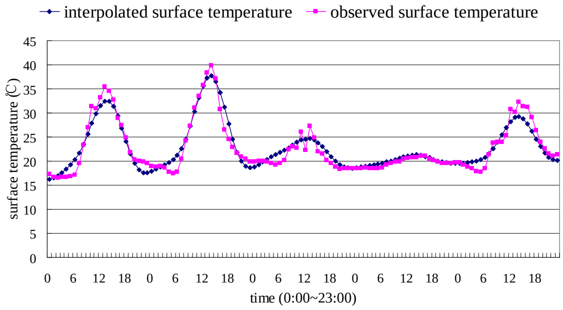

Figure 7 Comparison between interpolated surface temperature and observed surface temperature

Sky temperature

From the reference (Liu S. and Huang Y. 1983), the sky temperature can be calculated based on dry-bulb temperature, surface temperature, vapor pressure and the ratio of observed sunshine hours to possible sunshine hours. The equation is shown as follows:

$$T_{sky} = \left[0.9T_s^4 - (0.32 - 0.026\sqrt{e_d})(0.30 + 0.70\sigma_h)T_a^4\right]^{1/4} \quad (3)$$

Where T_a, T_s, e_d, σ_h respect the absolute dry-bulb temperature, the absolute surface temperature, vapor pressure and the ratio of sunshine hour. Because only daily value is available, the hourly sky temperature is calculated based on daily ratio of sunshine hour. In fact, the ratio of sunshine hour in equation (3) indicates the state of cloud cover. If the observed cloud cover is available, it is more applicable to use the observed cloud cover to calculate the sky temperature.

SELECT METHOD OF TYPICAL YEAR

As described before, it is necessary to select different typical climate data of one year to meet different purposes of building simulation. In the following, the select methods for different simulation purposes are presented.

Typical year for building energy consumption simulation

For building energy consumption simulation, the emphasis is the meteorological representation of the climate data. In general, to select representative data some factors are selected firstly as referent. For multifactor selection, the weight of each factor should be decided based on the analysis of each factor effectiveness on the result. However, the analysis for building energy consumption simulation is too much complex. Many researchers (M Petrakis，S Lykoudis，P Kassomenos, 1996; Soteris A Kalogirou, 2003) only gave the weight based on qualitative analysis. Based on the situation of source data, to avoid the influence of the calculated methodology on selected result, seven observation factors have been chosed as factors for meteorological typical year selection. Table 1 presents all the seven factors and their weights.

Table 1 Factors and their weights for selection

	FACTOR	WEIGHT
1	Daily average temperature	2/16
2	Daily minimum temperature	1/16
3	Daily maximum temperature	1/16
4	Daily average vapor pressure	2/16
5	Daily total horizontal solar radiation	8/16
6	Daily average surface temperature	1/16
7	Daily average wind speed	1/16

After fixing the factors and their weights, the selecting process is carried out as follows:

(1) Calculate all the monthly mean values for each factor from 1971 to 2003: $X_{i,m,y}$. Where i indicates the factor number; m indicates month and y indicates year.

(2) Calculate the mean and the standard deviation of monthly mean values for each factor: $\bar{X}_{i,m}$ and $S_{i,m}$.

(3) Normalize the monthly mean values: $\eta_{i,m,y} = \left(X_{i,m,y} - \bar{X}_{i,m}\right) / S_{i,m}$.

(4) Calculate the criterion: $D_{m,y} = \sum_i K_i \cdot \left|\eta_{i,m,y}\right|$.

(5) Select the minimum $D_{m,y}$: $D_{\min} = \min(D_{m,y})_{y=1994\sim2003}$.

Then, the data of corresponding month and year with $D_{\min}$ become to the same month data of meteorological typical year. So, the twelve monthes of meteorological typical year are possibly selected from different years. For example, Table 2 presents the selected results of twelve monthes for meteorological typical year.

Table 2 Selected results of Miyun station at Beijing

MONTH	YEAR	MONTH	YEAR
1	1998	7	2002
2	1997	8	2001
3	1995	9	1996
4	2001	10	2003
5	1999	11	1998
6	2003	12	1999

Typical years for HVAC system design

For air conditioning system design, it is very important to make sure the capacity of the system and equipments. The climate data for checking capacity should embody the bad conditions for the system. Against five different emphases for HVAC system design, five different typical years have been selected based on different criterions as follows:

Table 3 Five typical years for design

NAME	CRITERION
Max-enthalpy year	The year with maximum monthly mean enthalpy
Max-temperature year	The year with maximum monthly mean of daily maximum temperature
Min-temperature year	The year with minimum monthly mean of daily minimum temperature
Max-radiation year	The year with maximum monthly total horizontal solar radiation
Min-radiation year	The year with minimum monthly total horizontal solar radiation

Table 4 presents the selected results of five typical years for design of Miyun station at Beijing.

Table 4 Five typical years of Miyun station at Beijing

NAME	YEAR
Max-enthalpy year	2000
Max-temperature year	2000
Min-temperature year	2001
Max-radiation year	2003
Min-radiation year	1994

CONCLUSION

Hourly climate data is necessary for building thermal environment dynamic simulation. Because of the source data from weather station is not all in 1-hour interval, it is necessary to develop a method to get hourly climate data for those stations with only limited source data. The methodology introduced in this paper is based on the time-lapse and daily data. All the calculated results show an acceptable consistency with the observed data except the result of hourly horizontal scattered solar radiation. In the future work, the methodology generating horizontal scattered solar radiation will be improved.

Because of the stochastic variations in the weather, it is necessary to select typical climate data of one year from long-term data based on the simulation purpose. In this paper, the selection methods for different typical years have been presented. The selection of typical years for design is an attempt to specify the function of climatic data for simulation.

In a word, the meteorological data set of 270 China cities developped by Climatic Data Center of China Meteorological Administration and Tsinghua University has provided basal hourly climatic data for building thermal environment analysis. And also, the data set presents a new viewpoint about typical year. It provdes six different typical years for different simulation purposes.

NOMENCLATURE

Make source data integrated

$\overline{Q_B}$ = the monthly mean value of daily total horizontal solar radiation of station B;

$\overline{Q_{0,B}}$ = the monthly mean value of astronomical daily total horizontal solar radiation of station B;

$\overline{S_B}$ = the monthly mean value of daily ratio of sunshine hour of station B;

$\overline{Q_A}$ = the monthly mean value of daily total horizontal solar radiation of station A;

$\overline{Q_{0,A}}$ = the monthly mean value of astronomical daily total horizontal solar radiation of station A;

$\overline{S_A}$ = the monthly mean value of daily ratio of sunshine hour of station A;

Q_A = the daily total horizontal solar radiation of station A;

$Q_{0,A}$ = the astronomical daily total horizontal solar radiation of station A;

S_A = the daily ratio of sunshine hour of station A;

Air temperature

$t_{i,\max}$ = the daily maximum temperature of day i;

$t_{i-1,20}$, $t_{i,2}$, $t_{i,8}$, $t_{i,14}$, $t_{i,20}$ = the previous day 20:00 temperature, intraday 2:00, 8:00, 14:00 and 20:00 temperature respectively;

$t_{i,\min}$ = the daily minimum temperature of day i;

Solar radiation

R_{CPR} = the original result of hourly total horizontal solar radiation based on C.P.R model;

Q = the daily total horizontal solar radiation;

I_0 = the astronomical hourly total horizontal solar radiation;

Q_0 = the astronomical daily total horizontal solar radiation;

ω_s = the hour angle for sunset;

ω_τ = the hour angle for τ hour;

Sky temperature

T_a = the absolute dry-bulb temperature, K;

T_s = the absolute surface temperature, K;

e_d = the vapor pressure, Pa;

σ_h = the ratio of observed daily sunshine hours to possible daily sunshine hours.

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