

Models for simulating hourly ambient temperature based on daily mean and range of temperature*

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Abstract: Hourly temperature is essential for building energy consumption analysis by dynamic load method. In most cases of China, hourly temperature data is not available, so simulating model is required. Based on hourly data of Kunming and Fuzhou, spectrum of hourly standard temperature are determined and Fourier models including 2 harmonics are built by Fourier transform. The models can simulate hourly temperature with only daily mean and range of temperature. The form of Fourier model may be universal for regions of which only data of 6 records/day is available. Least-squares technique should be employed to estimate the coefficients in such cases.

Keywords: building energy consumption analysis; hourly temperature; Fourier model

1. Introduction

Hourly climatic variables are essential for energy consumption analysis by dynamic load method [1]. One of the most important variables is hourly temperature. In most cases of China, only data of temperature at 2,8,14,20 clock plus the highest and lowest temperature is available, while hourly temperature data is not available. So simulating model for hourly temperature is wanted. Considering the data limitation of China, it is suitable to model the daily temperature at first, and then to model hourly temperature based on daily values [2,3]. Daily mean and range of temperature may be modeled by time series analysis [2-5]. Only hourly temperature models will be built in this paper.

2. Data and pre-treatment

Data of temperature at 2,8,14,20 clock plus the highest and lowest temperature during 1991-2000 are available for Beijing, Xi'an, Chengdu and Chongqing. Hourly temperature data during 1999-2000 for Kunming and Fuzhou are also analyzed. Hourly data are employed to find the general structure of hourly temperature model.

Considering that hourly model must be based on daily model [2], hourly temperature data are standardized as follow:

$$t_{h,std} = \frac{t_h - T}{\Delta T} \quad (1)$$

where, $t_{h,std}$ is standard temperature, which falls in $(-1,1)$, and t_h is hourly temperature, and T is daily mean of temperature, and ΔT is day range of temperature. Seasonal trend of temperature may be removed by this operation.

3. Analysis of hourly data

3.1 Daily variation of hourly standard temperature

The daily variation of hourly standard temperature of Kunming and Fuzhou is shown in Fig.1.

It could be seen that periodic trend is very significant, which is caused by the rotation of the earth around its axis. Randomness exists of course. However, periodic trend has the advantage over randomness. Thus deterministic model for hourly temperature may be sufficient for energy analysis.

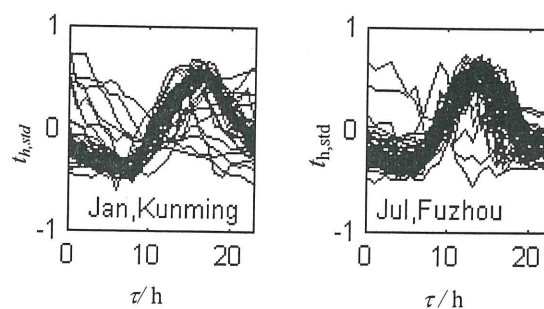


Fig.1 Daily variation of hourly standard temperature

3.2 Seasonal variation of hourly standard temperature

Not only daily variation but also seasonal variation exists in original hourly data. To investigate the

seasonal trend of standard hourly temperature, monthly means of standard hourly temperature are plotted in Fig.2. It shows that curves get very close to each other. That means seasonal trend of standard hourly temperature is not significant. So a general model for a location may be applicable to every month. for simplification.

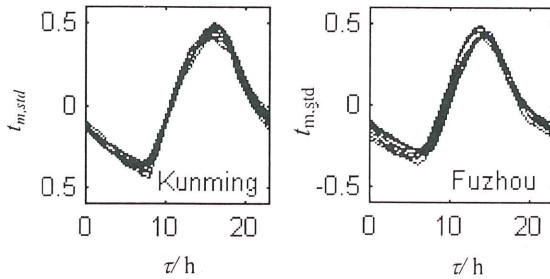


Fig.2 Monthly mean of hourly standard temperature

3.3 Hour of extreme temperature

Usually, the highest temperature occurs after 12, and the lowest temperature occurs before sunrise. But the exact hour of extreme temperature of Kunming and Fuzhou is different when standard time(Beijing clock for China) is employed. The highest and lowest temperature of Kunming occurs at about 16 PM and 7 AM. The highest and lowest temperature of Fuzhou occurs at about 15 PM and 6 AM. The main reason is the difference of longitude. So it isn't appropriate to fit the extreme temperature of different locations at the same hour. Although data of Beijing, Xi'an, Chengdu and Chongqing include the extreme temperatures, the corresponding hours were not recorded. In such cases, proper hour for extreme temperature must be determined according to longitude.

3.4 Spectrum analysis for standard hourly temperature and Fourier model

The model for standard hourly temperature may be experientially supposed as a simple sine wave [2]. In this paper, Fourier analysis was performed on data of standard hourly temperature, and the spectrum structure was determined. For details of Fourier analysis, refer to Refs. [3-5]. Only significant frequencies should be included in the model, and others should be neglected. Standard hourly temperature should be reconstructed as following:

$$t_{h, \text{std}} = \sum_{j=0} \left[a_j \cos \frac{2\pi\omega_j h}{24} + b_j \sin \frac{2\pi\omega_j h}{24} \right] \quad h=0,1,\dots,23 \quad (2)$$

where, $a_j(j>0)$ is twice the real part of Fourier

transforms, and $b_j(j>0)$ is the negative of twice the imaginary part of Fourier transform, and a_0 is the mean of data, and b_0 is zero, and h is hour of day, and ω is significant frequencies[cycles/day].

The spectrum structure of Kunming and Fuzhou data are shown in Fig.3. The amplitude, i.e. $\sqrt{a_j^2 + b_j^2}$, of every frequency shows its significance. It could be determined that the most important frequencies are 1,2 cycles/day. a_j and b_j for 0,1,2,3,4 cycles/day determined by Fourier transforms are shown in table 1. Fig.4 shows that models including 1,2,3,4 cycles/day are not significantly different from that including 1,2 cycles/day only.

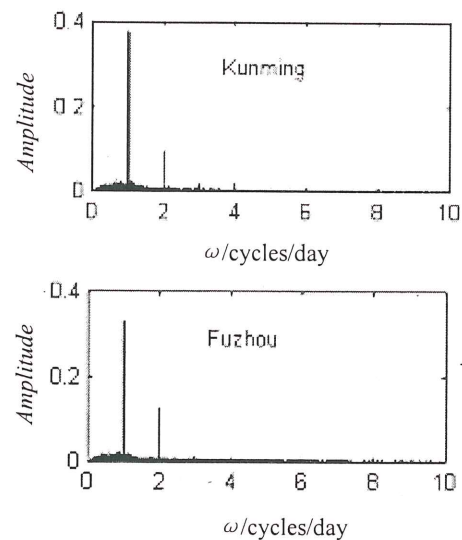


Fig.3 Spectrum of hourly standard temperature

Table.1 Coefficients of models for hourly standard temperature determined by Fourier transforms

Cycles /d	Kunming		Fuzhou	
	a	b	a	b
0	0.0000	0.0000	0.0000	0.0000
1	-0.1402	-0.2493	-0.2129	0.018
2	0.0088	0.0957	0.0809	-0.0393
3	-0.0063	-0.0034	-0.0106	0.0084
4	0.0144	-0.0045	-0.0055	-0.0094

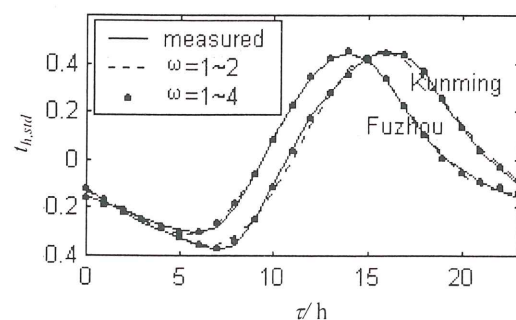


Fig.4 Simulated and measured hourly standard temperature

3.5 Simulating hourly temperature

Fig.5 shows the measured and simulated hourly temperature of Kunming and Fuzhou. In Fig.5, the smooth solid lines represent simulated values, and the smooth dash lines represent one standard deviation, and black dots represent measured values. It could be drawn that the models capture the basic trend of measured values. Furthermore, the models can guarantee the daily mean of temperature theoretically. In fact, hourly temperature is calculated as following:

$$t_h = T + \Delta T \cdot t_{h, \text{std}} \quad (3)$$

Integration of sine or cosine function during one period is zero, so integration of equation (3) from 0 to 24 is $24T$. $24T$ divided by 24 is T , which is daily mean of temperature.

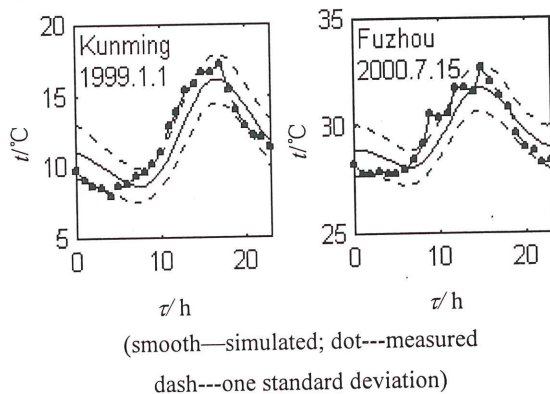


Fig.5 Simulated and measured hourly temperature

The ability of the model to capture the basic trend and to guarantee the daily mean of temperature makes it accurate enough for energy analysis.

4. Analysis of data of 6 records/day

In this section, Eq. (2) is applied to data of 6 records/day. Data of 6 records/day refers to those data of temperature at 2, 8, 14, 20 plus the highest and lowest temperature.

4.1 Reliability of data of 6 records/day

Data of 6 records/day can't describe the details of daily variation of temperature of course. Daily mean of temperature may be more important than detail variation for annual energy analysis. So the question is if the daily means of temperature calculated from hourly data and data of 6 records/day are significantly different. Fig.6 shows that the daily means of temperature calculated from hourly data and data of 6

records/day are not significantly different. Thus data of 6 records/day could be employed to build hourly temperature model for energy analysis.

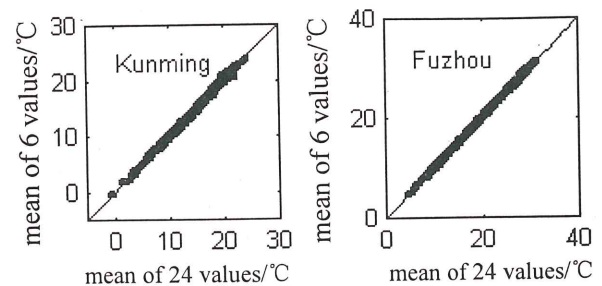


Fig.6 Daily mean of temperature calculated from hourly data and data of 6 records/day

4.2 Hours of extreme temperature

Although data of Beijing, Xi'an, Chengdu and Chongqing include the extreme temperatures, the corresponding hours were not recorded. The time at which extreme temperature occurs is different from place to place, and the most important reason is the longitude difference.

The longitude of Beijing is almost equal to that of Fuzhou (Beijing: $116^{\circ} 17'E$; Fuzhou: $119^{\circ} 17'E$), so the time of the highest temperature and lowest of Beijing is taken as 15 PM and 6 AM. The time of the highest temperature and lowest temperature of Xi'an, Chengdu and Chongqing is taken as 16 PM and 7 AM, for their longitudes are close to that of Kunming (Xi'an: $108^{\circ} 56'E$; Chengdu: $104^{\circ} 01'E$; Chongqing: $106^{\circ} 28'E$; Kunming: $102^{\circ} 41'E$).

4.3 Estimation of coefficients of model based on data of 6 records/day

The data of 6 records/day were not sampled at equal interval, so coefficients of Fourier model could not be determined directly by Fourier transforms. However, since the form of the model (i.e. Eq. 2) is universal at different locations, the coefficient may be estimated by nonlinear least square method [6.7].

Coefficients of hourly temperature for Beijing, Xi'an, Chengdu and Chongqing are shown in Tables 2 and 3. Curves obtained with these coefficients are plotted in Fig.7. They represent the most probable trend. The curves of Xi'an, Chengdu and Chongqing coincide almost. This means that general model may be employed at locations of which longitudes are close.

Table.2 Coefficients of models for hourly standard temperature determined by least square method

Cycles /d	Beijing		Xi'an	
	a	b	a	b
0	0.0000	0.0000	0.0000	0.0000
1	-0.2186	-0.3312	-0.1282	0.0143
2	0.0927	0.0679	-0.3653	0.1219

Table.3 Coefficients of models for hourly standard temperature determined by least square method

Cycles/ d	Chengdu		Chongqing	
	a	b	a	b
0	0.0000	0.0000	0.0000	0.0000
1	-0.1228	-0.3678	-0.0965	-0.3662
2	0.0053	0.1269	0.0035	0.1216

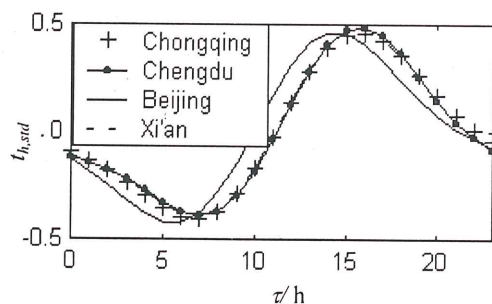


Fig.7 Simulated hourly standard temperature of Beijing, Xi'an, Chengdu and Chongqing

5. Conclusions

Based on the analysis on hourly temperature data and data of 6 records/day, the following conclusions may be drawn.

- 1) The main trend of hourly standard temperature is daily trend, and seasonal trend is not significant. A general model may be applicable during the whole year.
- 2) Hourly standard temperature may be simulated by Fourier model including frequencies of 1,2 cycles/day. The coefficients of model may be determined by Fourier transforms or nonlinear least square method.

- 3) The daily mean of temperature may be guaranteed by Fourier model for hourly standard temperature.
- 4) In regard to daily mean of temperature, data of 6 records/day is as accurate as hourly data.
- 5) When only data of 6 records/day is available, proper hour of extreme temperature must be selected according to longitude.

Acknowledgements

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Notations

- a_0the mean of data
 $a_j(j>0)$ twice the real part of Fourier transforms
 $b_j(j>0)$the negative of twice the imaginary part of Fourier transform
 b_0 zero
 hhour of day
 $t_{h, std}$standard temperature
 t_hhourly temperature
 Tdaily mean of temperature
 ΔTdaily range of temperature
 ωsignificant frequencies[cycles/d]

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