SENSITIVITY STUDIES ON ELEMENTS OF METEOROLOGICAL DATA FOR BUILDING ENERGY SIMULATION IN CHINA

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ABSTRACT

As well known, Hourly weather data should be available before running building energy consumption simulation.A large number of Chinese locations have only six-hourly or daily measured weather data, because observed data are not easily obtained or not digitalized. Measured hourly, six-hourly and daily weather data for four cities in China, namely Xi’an, Kunming, Hangzhou and Shantou were gathered and analyzed. Three climatic variables, namely dry-bulb temperature, relative humidity and atmospheric pressure, were investigated. Some methods of interpolation or meteorological models are applicable, such as linear interpolation, cubic spline interpolation and Fourier’s progression interpolation. The sensitivity of climatic variables on building energy consumption were discussed.

KEYWORDS

Sensitivity， Elements of Meteorological，Building Energy Consumption，DOE2.1E

INTRODUCTION

Building acts as a climatic modifier, separating the indoor built environment from the external climate described by the prevailing long-term weather conditions. So hourly weather data should be available before running building energy consumption simulation. Statistical techniques and graphical methods were used to study the sensitivity of climatic variables on building energy consumption of these four cities. Measured hourly ,six-hourly and daily weather data for four cities in China, namely Xi’an, Kunming, Hangzhou and Shantou were gathered and analyzed. Three climatic variables, namely dry-bulb temperature (DBT), relative humidity (RHM) and atmospheric pressure (RHM), were investigated.

During the process of creating the hourly data for the four cities, different methods of interpolation are used, such as linear interpolation, cubic spline interpolation and Fourier’s progression interpolation. Which interpolation method or meteorological model is better for each element? In this study, Hourly meteorological data for the above three meteorological data are created with different methods of interpolation. Some measured and calculated hourly weather data files were gathered. Replacing one of the measured elements with calculated weather data mentioned above produce a series of weather data files. Which can be used to make simulation by the program named DOE2.1E. To simulate the energy consumption of air-conditioning systems, , one model house for simulation is supposed. The heating and cooling energy consumption of the model house are simulated with the weather data files mentioned above.

By comparing the results produced by different methods, the relatively better method to getting hourly weather data was found. At the same time, the sensitivity of building energy consumption on meteorological data for each elements is given, and the feasibility of the selected interpolation methods or or meteorological models has been proved.

To get some idea about the likely errors from such data generation technique, the yearly measured hourly climate data were used to compare with those generated from the corresponding six-hourly records. Mean bias errors (MBE) and root mean-square errors (RMSE) were used to assess the accuracy as follows:

$$MBE_j = \frac{\sum_{i=1}^{8760}(x_{ij} - y_{ij})}{8760} \quad (1)$$

$$RMSE_j = \sqrt{\frac{\sum_{i=1}^{8760}(x_{ij} - y_{ij})^2}{8760}} \quad (2)$$

where x_{ij} is the calculated hourly elements climate data in year j(j=2000)，including DBT, RHM and ATP, and y_{ij} is the measured hourly elements climate data in year j(j=2000).A positive MBE indicates over-estimation and vice versa. The RMSE is a

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measure of how close the predicted hourly temperature profile is to the corresponding measured data.

DRY BULB TEMPERATURE (DBT)

The dry bulb temperature data obtained were six-hourly recorded at 2:00, 8:00, 14:00 and 20:00. By using four interpolation methods, the six-hourly weather data were converted into hourly weather data, which were shown in *Table 1*. The cubic spline interpolation technique fitted a "smooth curve" through the six-hourly records (Gerald, Wheatley 1999). Hourly DBT can be calculated from six-hourly records easily using Fourier's progression interpolation technique (Yanwei 2002). To get some idea about the likely errors from such data generation technique, the yearly measured hourly climate data were used to compare with those generated from the corresponding six-hourly records. Mean bias errors (MBE) and root mean-square errors (RMSE) are shown in *Table 2*. It can be seen that the MBE ranges from -0.01 to –0.49℃, RMSE ranges from 0.67 to 2.42℃. the method of DBT-SP &DBT-F2 have the minimum MBE & RMSE values which ranges from –0.01 to –0.21℃ or from0.67 to 1.29℃. And the method of DBT-M has the maximum MBE & RMSE values, which ranges from –0.05 to –0.49℃ or from 1.41 to 2.42℃. In other words, the hourly DBT converted with DBT-SP & DBT-F2 are better close to measured DBT.

To get an idea about the correlation among different hourly DBT and the energy consumption, one model house is proposed to simulate the energy consumption of air-conditioning system with the program DOE2.1E. *Table 3,Table 4, Fig.1* and *Fig.2* shows the summary of relative heating energy consumption and its percentage using generated hourly DBT. Relative energy consumption means the difference between energy consumption using measured weather data and generated hourly weather data. It can be seen that the relative heating energy consumption using hourly DBT converted with DBT-SP & DBT-F2 have little difference to measured DBT for Xi'an. And relative cooling energy consumption using hourly DBT converted with DBT-SP & DBT-F2 have smaller difference than the measured DBT for Hangzhou & Shantou.

RELATIVE HUMIDITY (RHM)

The relative humidity data obtained were six-hourly recorded at 2:00, 8:00, 14:00 and 20:00. To convert them into hourly data, we used twelve interpolation methods, which were shown in *Table 5*. To decide the likely errors amonome idea about the likely errors from such data generation technique, the yearly measured hourly climate data were used to compare with those generated from the corresponding six-hourly records. Mean bias errors (MBE) and root mean-square errors (RMSE) are shown in *Table 6*. It can be seen that the MBE ranges from 0.02 to –1.08, RMSE ranges from 2.96 to 9.10. The methods of RHM-LHUM &RHM-LDPT have the minimum MBE & RMSE values. In other words, the hourly RHM converted with RHM-LHUM &RHM-LDPT are better close to measured RHM.

To get an idea about the correlation between different hourly RHM and the cooling energy consumption, one model house for simulation is proposed to simulate the air-conditioning consumption with the program of DOE2.1E. *Table 6 and Fig.3* show the summary of relative cooling energy consumption and its percentage using generated hourly RHM. It can be seen that relative cooling energy consumption using hourly RHM converted with RHM-FHUM, RHM-LHUM, RHM-SPHUM, RHM-FDPT, RHM-LDPT and RHM-SPDPT have smaller difference to the measured RHM for the four cities. Especially, RHM-LHUM &RHM-LDPT have the smallest difference. Taking one with another, RHM-LHUM &RHM-LDPT are the best two interpolation methods for calculating hourly RHM with six-hourly records.

ATMOSPHERIC PRESSURE (ATP)

The atmospheric pressure data obtained were six-hourly recorded at 2:00, 8:00, 14:00 and 20:00 too. To convert the measured data into hourly data, three interpolation methods were used, which were shown in *Table 8*. To get some idea about the likely errors from such data generation technique, the yearly measured hourly climate data were used to compare with those generated from the corresponding six-hourly records. Mean bias errors (MBE) and root mean-square errors (RMSE) are shown in *Table 9*. It can be seen that the MBE ranges from -1 to –10Pa, RMSE ranges from 75 to 369Pa. The methods of ATP-F2 &ATP-SP have the minimum MBE & RMSE values. In a word, the hourly ATP converted with ATP-F2 &ATP-SP are better closer to the measured hourly ATP.

To get an idea about the correlation between different hourly ATP and the energy consumption, one model house is proposed to simulate the energy consumption with the program of DOE2.1E. *Table 10* and *Table 11* show the summary of relative energy consumption and its percentage using generated hourly ATP. It can be seen that energy consumption using hourly ATP converted with interpolation have smaller difference to measured ATP for the four cities than other methods.

CONCLUSION

Measured hourly,six-hourly and daily weather data for four cities in China, namely Xi'an, Kunming, Hangzhou and Shantou were gathered and analyzed. Three climatic variables, namely dry-bulb temperature, relative humidity and atmospheric pressure, were investigated. Statistical techniques and graphical methods were used to study the sensitivity of climatic variables on building energy consumption. The interpolation methods of DBT-SP & DBT-F2 are the better methods for calculating hourly DBT from six-hourly DBT. The interpolation methods of RHM-LHUM & RHM-LDPT are the better methods to calculate hourly RHM from six-hourly RHM records. The methods of ATP-F2 &ATP-SP are closer to measured hourly ATP than the else, but none of this interpolation methods about converting hourly ATP have a serious influence on building energy consumption.

ACKNOWLEDGMENT

This research was suported by young scholar natural science fund(Project No. 50408014) and international cooperation project of national natural science foundation of China(Project No. 50410083). Weather dada were obtained from the China National Meteorological Centre.

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Table 1-interpolation methods used to get hourly DBT in this study

Interpolation method	Description
DBT-F1	Using Fourier's progression interpolation once and the maximum is at 15:00
DBT-F2	Using Fourier's progression interpolation twice and the maximum is at 15:00
DBT-SP	Using cubic spline interpolation
DBT-M	Using the maximum and minimum value reference with daily range multiplier*(US Department of Energy 2006)

Table 2 summary of mean-bias errors and root-mean-square errors from the generated hourly DBT

Interpolation method	Xi'an		Kunming		Hangzhou		Shantou	
	MBE	RMSE	MBE	RMSE	MBE	RMSE	MBE	RMSE
DBT-F1	-0.29	1.52	-0.22	1.17	-0.02	0.93	-0.05	1.04
DBT-F2	-0.10	1.20	-0.21	1.21	-0.01	0.94	-0.03	1.29
DBT-SP	-0.09	0.80	-0.21	0.76	-0.01	0.67	-0.03	1.15
DBT-M	-0.49	2.42	0.11	1.70	-0.05	1.41	-0.06	1.50

Table 3 summary of relative heating energy consumption and percent using generated hourly DBT

Interpolation method	Xi'an	Kunming	Hangzhou	Shantou
DBT-F1	2.84/-4.29%	0.67/-6.12%	0.36/-0.73%	0.00/0.02%
DBT-F2	0.51/-0.77%	0.63/-5.79%	0.23/-0.46%	0.01/-0.53%
DBT-SP	0.34/-0.52%	0.66/-6.05%	0.32/-0.66%	0.02/-1.19%
DBT-M	4.98/-7.53%	-0.15/1.33%	0.42/-0.86%	0.06/-3.46%

Table 4 summary of relative cooling energy consumption and percent using generated DBT

Interpolation method	Xi'an	Kunming	Hangzhou	Shantou
DBT-F1	-0.41/-1.01%	-0.63/-6.49%	-0.22/-0.37%	0.02/0.02%

DBT-F2	-0.20/-0.49%	-0.58/-5.95%	-0.16/-0.26%	0.00/0.00%
DBT-SP	-0.83/-2.02%	-0.63/-6.46%	-0.42/-0.68%	0.04/0.04%
DBT-M	-1.83/-4.46%	1.00/10.25%	-1.4/-2.31%	2.24/2.33%

Table 5 interpolation methods used to get hourly RHM in this study

Interpolation method	Description
RHM-FHUM*	Using Fourier's progression interpolation twice to humidity and the maximum is at 23:00¥
RHM-LHUM*	Using line interpolation to humidity
RHM-SPHUM*	Using cubic spline interpolation to humidity
RHM-LDPT♀	Using line interpolation to dew point temperature (DBT)
RHM-FDPT♀	Using Fourier's progression interpolation twice to DBT and the maximum is at 23:00¥
RHM-SPDPT♀	Using cubic spline interpolation to DBT
RHM-LRHM	Using line interpolation to relative humidity (RHM)
RHM-FRHM	Using Fourier's progression interpolation twice to RHM and the maximum is at 8:00¥
RHM-SPRHM	Using cubic spline interpolation to RHM
RHM-LWBT#	Using line interpolation to wet bulb temperature (WBT)
RHM-FWBT#	Using Fourier's progression interpolation twice to WBT and the maximum is at 16:00¥
RHM-SPWBT#	Using cubic spline interpolation to WBT

Note: * RHM can be calculated from HUM, DBT and ATP (ASHRAE handbook—2005 fundamentals 2005)

♀ RHM can be calculated from DPT, DBT and ATP (ASHRAE handbook—2005 fundamentals 2005)

RHM can be calculated from WBT, DBT and ATP (ASHRAE handbook—2005 fundamentals 2005)

¥ According to the characteristic of hourly weather data analyzing all-year data.

Table 6 summary of mean-bias errors and root-mean-square errors from the generaed hourly RHM

Interpolation method	Xi'an		Kunming		Hangzhou		Shantou	
	MBE	RMSE	MBE	RMSE	MBE	RMSE	MBE	RMSE
RHM-FHUM	0.04	4.42	-0.19	3.89	0.08	3.95	-0.02	6.02
RHM-LHUM	0.09	3.24	-0.17	2.96	0.13	2.52	-0.01	6.24
RHM-SPHUM	0.07	3.38	-0.18	3.07	0.10	2.61	-0.04	6.38
RHM-FDPT	0.11	4.39	-0.09	3.83	0.15	3.88	0.08	5.94
RHM-LDPT	0.06	3.24	-0.12	2.97	0.14	2.52	-0.01	6.21
RHM-SPDPT	0.10	3.39	-0.10	3.10	0.15	2.61	0.02	6.35
RHM-FRHM	0.12	9.10	0.50	7.40	0.05	5.66	-0.13	8.45
RHM-LRHM	0.53	5.21	0.76	4.43	0.17	3.98	0.20	6.33
RHM-SPRHM	0.53	4.88	0.76	4.10	0.17	3.72	0.21	6.17
RHM-FWBT	-0.62	5.39	-1.08	4.90	-0.48	4.15	-0.64	7.50
RHM-LWBT	-0.38	4.84	-0.82	4.17	-0.38	3.32	-0.70	8.76
RHM-SPWBT	-0.59	4.66	-1.03	4.29	-0.43	3.29	-0.77	8.76

Table 7 summary of cooling relative energy consumption and percentage using generation RHM

Interpolation method	Xi'an	Kunming	Hangzhou	Shantou
RHM-FHUM	0.09/0.22%	-0.01/-0.15%	-0.31/-0.51%	-0.34/-0.35%
RHM-LHUM	0.03/0.08%	0.00/-0.04%	-0.45/-0.75%	-0.95/-0.99%
RHM-SPHUM	0.09/0.22%	-0.01/-0.08%	-0.42/-0.69%	-0.36/-0.37%
RHM-FDPT	0.11/0.28%	-0.01/-0.13%	-0.28/-0.46%	-0.33/-0.34%
RHM-LDPT	0.03/0.07%	0.00/-0.03%	-0.46/-0.77%	-1.00/-1.04%
RHM-SPDPT	0.10/0.24%	-0.01/-0.07%	-0.60/-0.99%	-0.39/-0.4%

RHM-FRHM	0.56/1.36%	0.00/-0.05%	1.57/2.6%	-2.03/-2.11%
RHM-LRHM	0.84/2.05%	0.02/0.19%	0.96/1.59%	-0.36/-0.38%
RHM-SPRHM	0.64/1.55%	0.01/0.12%	0.49/0.81%	0.01/0.01%
RHM-FWBT	-0.19/-0.45%	-0.03/-0.36%	-0.17/-0.28%	-0.67/-0.7%
RHM-LWBT	-0.26/-0.63%	-0.04/-0.38%	-0.49/-0.82%	-0.74/-0.77%
RHM-SPWBT	-0.20/-0.48%	-0.03/-0.35%	-0.42/-0.69%	-0.46/-0.48%

Table 8 interpolation methods used to get hourly ATP in this study

Interpolation method	Description
ATP-F1	Using Fourier's progression interpolation once and the maximum at 15:00
ATP-F2	Using Fourier's progression interpolation twice and the maximum at 15:00
ATP-L	Using line interpolation
ATP- SP	Using cubic spline interpolation

Table 9 summary of mean-bias errors and root-mean-square errors from the generated hourly ATP

Interpolation method	Xi'an		Kunming		Hangzhou		Shantou	
	MBE	RMSE	MBE	RMSE	MBE	RMSE	MBE	RMSE
ATP-F2	-5	82	-4	79	-2	75	-2	158
ATP-F1	-10	125	-6	105	-4	106	-5	163
ATP-L	-6	276	-4	116	-2	168	-2	309
ATP-SP	-6	79	-4	77	-2	77	-1	160

Table 10 summary of relative heating energy consumption and percentage using generaed ATP

Interpolation method	Xi'an	Kunming	Hangzhou	Shantou
ATP-F2	0.00/0.00%	0.00/0.01%	-0.01/0.01%	0.00/0.00%
ATP-F1	0.00/0.00%	0.00/0.01%	0.00/0.01%	0.00/0.00%
ATP-L	0.00/0.00%	0.00/0.01%	0.00/0.01%	0.00/0.00%
ATP-SP	0.00/0.00%	0.00/0.01%	0.00/0.01%	0.00/0.00%

Table 11 summary of relative cooling energy consumption and percentage using generated ATP

Interpolation method	Xi'an	Kunming	Hangzhou	Shantou
ATP-F2	0.00/-0.01%	0.00/0.01%	0.00/-0.01%	-0.01/-0.01%
ATP-F1	0.00/0.00%	0.00/0.02%	0.00/0.00%	-0.01/-0.01%
ATP-L	0.00/0.00%	0.00/0.01%	0.00/-0.01%	0.00/0.00%
ATP-SP	0.00/0.00%	0.00/0.01%	0.00/-0.01%	0.00/0.00%

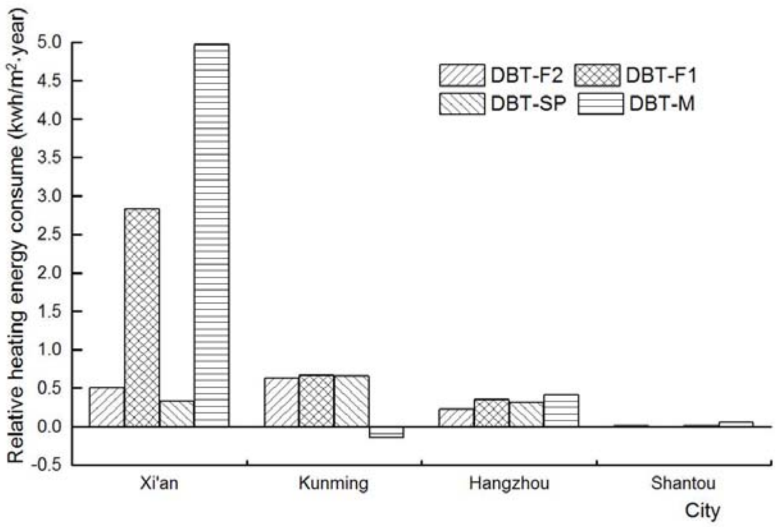

Figure 1. Relative heating energy consumption in the four cities with different hourly DBT data

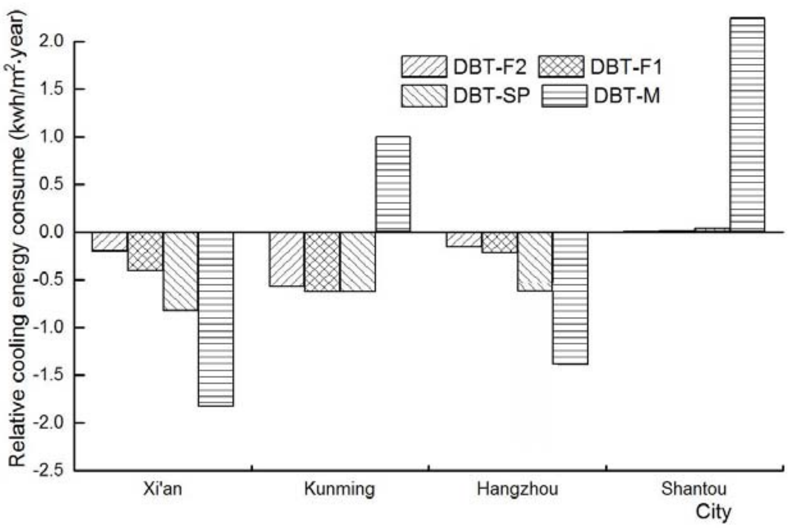

Figure 2 Relative cooling energy consumption in the four cities with different hourly DBT data

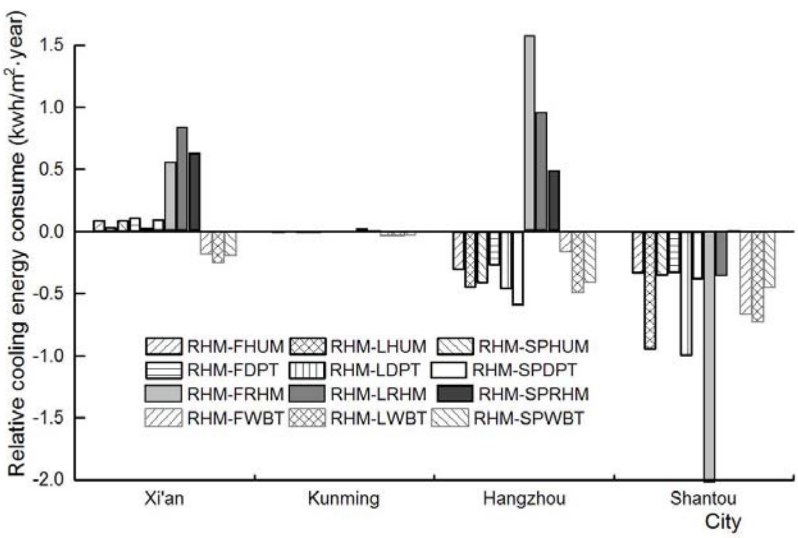

Figure 3 Relative heating energy consumption in the four cities with different hourly RHM data