DEVELOPMENT OF CHINESE WEATHER DATA FOR BUILDING ENERGY CALCULATIONS

Zhang Qingyuan
Tsukuba College of Technology
Tsukuba Japan

Joe Huang
Lawrence Berkeley National Laboratory
Berkeley CA USA

Lang Siwei
China Academy of Building Research
Beijing China

ABSTRACT

To support the development of building energy standards in China, the authors have recently developed a set of Typical Meteorological Year (TMY) weather data for 26 locations. These TMY weather data have been produced from 16 years of historical weather (1982-1997) reported by Chinese airports and recorded by the U.S. Climatic Data Service. Since the weather data records only cloud conditions at various heights, a substantial effort was made towards estimating the total and direct solar radiation from the cloud information, combined with information on temperature, humidity, and wind speed. Comparisons of the estimated solar to actual measured hourly solar for three locations and daily totals for all 26 locations showed good agreement to with 20% for hourly and 10% for daily values. The 26 weather files are available as either ASCII files in SI units, or as packed DOE-2.1E weather files.

INTRODUCTION

Weather is one of the primary determinants of indoor thermal conditions and space conditioning energy use. In particular, dynamic simulations using modern computer programs are impossible without hourly data of weather conditions like solar radiation, dry-bulb temperature, dew point temperature or humidity, atmospheric pressure, wind direction, and wind speed. Since weather conditions can vary significantly from year to year, researchers in many countries have devised Typical Meteorological Year (TMY) data to represent long-term typical weather conditions over a year [1][2][3]. Although their development may differ in detail, TMY weather data share the same principle whereby twelve months judged to have weather conditions most representative of that month are combined into a single synthetic "typical year" weather file.

So far, there have been very few reports of TMY weather data developed for Chinese locations. There are three major barriers in the development of such weather data: (1) although the Chinese weather service has recorded weather data for all major cities for several decades, the data are not in a digital format, making their transcription and purchase prohibitively expensive, (2) with the exception of very few stations such as Beijing, the data are not recorded hourly, but rather at a three or six hour interval, plus daily max/min values, and (3) solar data, if available, are daily totals for direct and diffuse radiation. In 1992, Lang obtained TMY weather files for Beijing and Shanghai developed by colleagues at the China Academy of Building Research [4].

In 1999, Lang and Huang became involved in a national effort to draft a residential building energy standard for the Hot Summer Cold Winter climate region of China. That work is described in another paper presented in this conference [5]. Since the Code Compilation Committee agreed to use the DOE-2 computer simulation program to calculate building energy performance, there became an acute need to have hourly TMY weather files for Chinese locations. Although the raw weather data obtained permitted the development of TMY weather files for 70 Chinese locations, we decided to create first a set of 26 files covering most of the provincial capitals in China, and then create a second set of the remaining 44 files as time and resources permit.

SOURCE DATA FOR TMY WEATHER FILES

The TMY weather files for 26 major Chinese cities were developed from a large database of International Surface Weather Observations (ISWO) released as a set of 5 CD's by the U.S. National Climatic Data Center (NCDC) [6]. The ISWO database was compiled originally by NCDC for the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) to update the design climate tables in the ASHRAE's *Handbook of Fundamentals* [7]. The database contains 16 years of climate data (1982-1997) for 922 U.S. and 880 non-U.S. locations, among which 70 are Chinese locations. The original source for the ISWO data are weather reports broadcast by local airport stations that have been recorded by U.S. military satellites. Therefore, although the database was obtained from a US government organization, the weather data themselves should be consistent with local records. When the ISWO data are compared to those obtained previously by Lang from the Chinese weather service for the same city and time period, the recorded dry-bulb temperatures were found to be identical.

The weather variables recorded in the ISWO weather database include dry-bulb and dewpoint temperatures, atmospheric pressure, wind speed and direction, and the amounts of cloud cover at various heights. With the exception of Beijing, Shanghai, and Guangzhou starting in 1988, all the ISWO data for Chinese locations were reported at three-hour intervals. In order to produce hourly records from the three-hour data, interpolation methods were developed and tested.

Because the ISWO data contain no solar radiation data, we developed methods adapted from previous work by Japanese researchers to predict total solar radiation from reported dry-bulb temperature, temperature change from previous hours, relative humidity, cloud cover and wind speed, and the split between direct and diffuse solar from the solar angle and ratio of total to extraterrestrial solar radiation. These estimates were tested against measured hourly solar obtained for three Chinese locations.

The selection of Typical Meteorological Months was based on how closely the climate variables of a month matched the long-term average values over the 16 years of record (1982-1997), following the criteria developed by the US National Renewable Energy Laboratory (NREL) in the early 1980's to create the TMY weather files for US locations [3]. Table 1 lists the 26 cities for which TMY weather files have already been developed. These files will provide architects and engineers with typical weather conditions of temperature, humidity, pressure, wind speed and direction, cloud cover, and solar radiation for all major Chinese cities that can be conveniently used in building energy simulation programs.

MODEL FOR ESTIMATING SOLAR RADIATION

As mentioned above, there are no observed data on solar radiation in the ISWO data base. Consequently, the most challenging task in this study was to develop a methodology to estimate the amount of solar radiation, which is one of the most important factors affecting the indoor environment, especially in passive solar buildings, houses with large windows, or during the cooling season for all buildings.

Of the recorded climate parameters, cloud cover is the most influential for predicting the amount of solar radiation. Although low-level cloud cover can have a significant effect on solar radiation, we chose not to include this climate parameter in our solar model because it was not consistently reported in the ISWO data. On the other hand, we did include the rate of increase in dry-bulb temperature, as well as the relative humidity which has a negative correlation to solar radiation. Matsuo et al. [8] developed a model to predict solar radiation based on cloud cover, dry-bulb temperature difference, relative humidity and wind speed that he applied to climate data recorded at 6-hour intervals. There were two problems with this approach, the first being that the impact of the long six-hour interval on the precision of the solar model could not be determined, and the second being that the model overpredicted solar radiation when it is weak, and underpredicted solar radiation when it is strong.

For this study, we developed a solar model similar in form to the Matsuo model, with total cloud cover, dry-bulb temperature, relative humidity, and wind speed as the independent variables (see Eq. 1), and calculated the constants with multi-parameter analyses against measured hourly total horizontal solar radiation for Beijing and Guangzhou in 1993 obtained from another colleague [9].

$$
\begin{aligned}
I &= [I_0 \cdot 3600 \cdot \sin h \cdot \{C_0 + C_1(CC) + C_2(CC)^2 + C_3(T_n - T_{n-3}) + C_4\Phi + C_5V_w\} - d] / k && \text{when } I > 0 \\
&= 0 && \text{when } I < 0 \qquad (1)
\end{aligned}
$$

where I = predicted solar radiation in $J/(m^2h)$

I_0 = solar constant in W/m^2

h = solar angle, i.e, the angle between sunlight and the horizon

CC = cloud cover in fractions

Φ = relative humidity in %

T_n, T_{n-3} = dry-bulb temperature at hours n and n-1, respectively

V_w = wind speed in m/s.

C_0, C_1, C_2, C_3, C_4, C_5, d, k = regression coefficients

The constants determined from multi-parameter analyses against the 1993 measured data for Beijing and Guangzhou are as follows:

$$C_0=0.560,\ C_1=0.498,\ C_2=-0.676,\ C_3=0.0284,\ C_4=-0.0032,$$
$$C_5=0.014,\ d=-17.85,\ k=0.843.$$

The relationship between the observed solar radiation and the values from Eq. 1 is shown in Figure 1. The correlation coefficient is 0.93, which implies that Eq. 1 can be used to predict the hourly total horizontal solar radiation with good accuracy in both Beijing and Guangzhou. To verify the accuracy of Eq. 1 when applied to other locations and times, available measured total daily solar are compared to the estimated values using Eq. 1 for a number of different cities and time periods. Figure 2 shows typical results for Chongqing 1988. Based on these comparisons, it is reasonable to conclude that Eq. 1 can be used to predict total global horizontal solar radiation for other Chinese locations as well.

For building energy simulations, it is necessary to separate the total global solar radiation into direct and diffuse components. In this study, we used the following model developed by Watanabe for Japanese locations [10]:

$$K_T = I/(I_0 \sin h),\ K_{TC} = 0.4268 + 0.1934 \bullet \sin h$$
$$K_{DS} = K_T - (1.107 + 0.03569 \bullet \sin h + 1.681 \bullet \sin^2 h)(1 - K_T)^2 \qquad \text{when } K_T \geq K_{TC}$$
$$K_{DS} = (3.996 - 3.862 \bullet \sin h + 1.540 \bullet \sin^2 h)\, K_T^3 \qquad \text{when } K_T < K_{TC}$$
$$DH = I_0 \bullet \sin h \bullet K_{DS}(1 - K_T)/(1 - K_{DS})$$
$$SH = I_0 \bullet \sin h\, (K_T - K_{DS})/(1 - K_{DS}) \qquad (2)$$

where I = global solar radiation on the horizontal surface in W/m^2
DH = direct solar radiation on the horizontal surface in W/m^2
SH = diffuse radiation in W/m^2.

Because we were unable to obtain any hourly measured diffuse solar radiation for Chinese locations, we compared measured to predicted daily total diffuse solar radiation for several cities (see Figures 3 and 4). The predicted values agree with the measured ones fairly well throughout the year except for less than 10% of the days.

Figure 5 compares predicted to measured annual total and diffuse solar radiation for nine Chinese cities. The predicted total annual solar radiation on the horizontal surface agrees with the measured in all nine cities, while the errors in the predicted diffuse solar are somewhat larger. The reason for this is that diffuse solar radiation is predicted as a fraction of the predicted total global radiation. Therefore, any error in the prediction of global solar radiation will permeate into the prediction of the diffuse solar radiation.

SELECTION OF TYPICAL METEOROLOGICAL MONTHS

The TMY weather file contains measured data for 12 historical months, between which some of the variables have been smoothed to avoid abrupt changes. Different methods have been developed to select the Typical Meteorological Months (TMMs) by Matsuo et al. and NREL[1,3]. In this study, we used a method that combined elements from both methods.

The characteristics of this method are as follows: first, it considers both the average values and the data structure of all the variables to ensure the selected months not only are close to the average of the period of the weather observation, but also have a similar structure with the average month; second, it avoids the procedure of air-conditioning load calculation used as the final selection procedure in the method by Matsuo et al. The procedure eliminates those months whose monthly average dry-bulb temperature, dew point temperature, solar radiation and wind speed are outside a specified range of standard deviation, compares the WS values of the remaining months, and selects the month with the smallest WS as the TMM. The value of WS is calculated as follows:

$$WS = \sum W_i \bullet FS_i \tag{3}$$

where W_i are the weights and FS_i the Finkelstein-Schafer (FS) statistics for the following 9 climate variables : maximum, minimum, and mean dry bulb and dew point, maximum and mean wind velocity, and average solar radiation. The smaller the FS is, the closer the structure of a variable will be to the average year [3]. In a few cases, it might possible that no candidate exist after Step 3. If that happens, the criterion for wind speed or dew point temperature should be relaxed so that at least one candidate TMM remains. As a practical consideration, very few TMMs were taken between the years 1993 to 1997, not because of their climate characteristics, but because there were too much missing data.

INTERPOLATION PROCEDURES FOR MISSING DATA

Since most of the data consists of three-hour recordings, we developed interpolation procedures for the following climate variables: dry-bulb temperature, dew point temperature, solar radiation, wind speed, and total cloud cover.

To interpolate for dry-bulb temperatures, we used two separate equations depending on the time of day. Since the change in dry-bulb temperature is periodical, we tried to approximate it with a Fourier Series as follows:

$$\Theta(t) = b_0 + \sum\{ b_n \cos n\frac{\pi}{12} t) + a_0 \sin n\frac{\pi}{12} t) \} \tag{4}$$

where $b_0 = 1/8 \sum_{k=1}^{8} \Theta(k)$

$b_n = 1/4 \sum_{k=1}^{8} \Theta(k) \cos\frac{n\pi k}{4}$

$a_n = 1/4 \sum_{k=1}^{8} \Theta(k) \sin\frac{n\pi k}{4}$

In a previous study using Japanese weather data [11], we found that Eq. 4 approximated measured dry-bulb temperatures most closely with n=3 or n=4. However, we found that dry-bulb temperatures from Hour 20 to Hour 5 the next day could not be approximated by Eq. 4, because a Fourier Series assumes that the temperature function is periodic, i.e., the temperature at the beginning of a day must be equal to that at the end of the day, which is not necessarily true. Therefore, between Hours 20 and 5, we use the following equation based on regression analyses with measured Japanese weather data for Sapporo, Tokyo, and Kagoshima:

$$\Theta_j = \Theta_{j-1} - 0.3419 + 0.2449\,(\Theta_{j+2} - \Theta_{j-1}) + 0.2282 \bullet CC + 0.3243 \bullet CC^2 \qquad (j=21,24,3)$$

$$\Theta_j = \Theta_{j-2} - 0.5617 + 0.6900\,(\Theta_{j+1} - \Theta_{j-2}) + 0.07229 \bullet CC + 0.02331 \bullet CC^2 \quad (j=22,1,4) \qquad (5)$$

To illustrate this interpolation procedure, two examples using Eqs. 4 and 5 are shown. Figure 6 compares measured to interpolated dry-bulb temperatures for a summer day, while Figure 7 shows a similar comparison for a winter day in Tokyo.

To interpolate for dew point temperatures, we also used a Fourier Series like Eq. 4 for the daytime hours, but a simple linear interpolation for the nighttime hours instead of Eq. 5. The interpolations for wind speed and cloud cover were both done with linear approximations. Solar radiation is calculated using Eqs. 1 and 2 with the interpolated values of temperature, humidity, and cloud cover.

REFERENCES

1. Y. Matsuo et al., “Study on Typical Weather Data”, *Journal of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan*, Vol.48, No.7, Tokyo, Japan, 1974.
2. H. Akasaka, “Typical Weather Data and the Expanded AMEDAS Data”, *Solar Energy,* Vol. 25, No.5, 1999.
3. National Climatic Data Center (NCDC), *Typical Meteorological Year User’s Guide,* NCDC, National Oceanic and Atmospheric Administration, US Dept. of Commerce, Asheville NC, 1981.
4. S.W. Lang and Y.J. Huang, "Energy conservation standard for space heating in Chinese urban residential buildings," *Energy, the International Journal*, 1993.
5. J. Hogan, R. Watson, Y.J. Huang, S.W. Lang, X.Z. Fu, and H.Y. Lin, “Development of China’s Transition Zone energy code for residential buildings”, Proceedings of the 4th International Conference on Indoor Air Quality, ventilation, and Energy Conservation in Buildings, Changsha, China, 2001.
6. ASHRAE,*Handbook of Fundamentals,* American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Atlanta, GA, USA, 1997.
7. National Climatic Data Center (NCDC), *International Surface Weather Observations 1982-1997*, Volumes 1 through 5, jointly produced by NCDC, National Oceanic and Atmospheric Administration, US Dept. of Commerce, Asheville NC, and the Air Force Combat Climatology Center (AFCCC), US Dept. of Air Force, Asheville NC, 1998.
8. Y. Matsuo et al., “Development of Typical Weather Data of Shanghai with the World Weather”, Annual Meeting, Architectural Institute of Japan, Tokyo, Japan, 1993.
9. H.X. Yang, Measured hourly solar data for Beijing, Guangzhou, and Harbin 1993, Hong Kong Polytechnic University, 1993.
10. T. Watanabe et al., “Procedures for Separating Direct and Diffuse Insolation on a Horizontal Surface and Prediction of Insolation on Tilted Surfaces”, *Transactions,* No. 330, Architectural Institute of Japan, Tokyo, Japan, 1983.
11. Q.Y. Zhang et al., “About Typical Weather Data for China”, *Summaries of Technical Papers of Annual Meeting*, Architectural Institute of Japan, Tokyo, Japan, 2000.

Table 1. Climate statistics for 26 completed Chinese TMY weather files

			Degree- Days				Temperatures				Avg Daily Solar	
Location	Lat (N)	Lon (E)	HDD 18C	CDD 18C	CDD 26C	CDH 26C	Max (C)	Avg Daily Max	Avg Daily Min	Min (C)	Total Horiz (W/m^2)	Direct Normal (W/m^2)
Beijing	39.9	116.3	2685	875	73	3633	39.3	32.1	-8.4	-12.8	3821	3930
Changchun	43.9	125.2	4820	376	1	520	30.8	26.6	-21.5	-25.4	3414	3408
Changsha	28.2	112.9	1556	1353	281	7340	39.2	34.2	0.3	-2.2	2631	1464
Chengdu	30.7	104.0	1426	888	32	2056	33.2	28.3	3.1	-1.3	2324	1049
Chongqing	29.5	106.5	1069	1388	251	6831	38.4	33.1	4.0	2.5	1950	621
Fuzhou	26.1	119.3	800	1605	319	6693	38.8	32.7	5.1	2.4	2892	1543
Guangzhou	23.1	113.3	390	2075	365	8639	35.9	32.4	7.1	4.8	2806	1310
Guiyang	26.6	106.7	1536	735	3	818	31.3	27.3	1.0	-1.7	2503	1132
Hangzhou	30.2	120.2	1649	1236	208	5430	36.9	32.0	-1.2	-3.6	2914	1764
Harbin	45.8	126.8	5360	318	0	352	30.3	25.8	-24.8	-32.4	3320	3410
Hefei	31.9	117.2	1863	973	113	3389	36.4	32.0	-2.9	-5.3	2925	1901
Hohhot	40.8	111.7	4302	301	0	783	33.8	26.3	-19.2	-23.1	4156	4435
Ji'nan	36.7	117.0	2280	1198	156	5334	37.4	32.4	-6.8	-9.5	3674	3187
Kunming	25.0	102.7	1256	341	0	31	29.9	23.0	-9.6	-35.3	3781	2927
Lanzhou	36.1	103.9	3171	368	0	1195	35.4	26.3	-14.9	-18.3	3576	2900
Nanchang	28.6	115.9	1471	1413	265	6566	37.5	33.0	-1.9	-3.6	2798	1463
Nanjing	32.0	118.8	1995	1123	179	4934	36.6	32.5	-1.9	-5.7	3070	2107
Nanning	22.8	108.4	432	2088	406	9253	38.1	31.8	8.2	4.5	2698	1194
Shanghai	31.2	121.4	1707	1075	166	4304	37.3	32.8	-0.4	-3.5	2885	1761
Shenyang	41.8	123.4	3956	585	16	1491	32.3	28.3	-17.2	-22.2	3484	3310
Urumqi	43.8	87.6	4443	468	12	1635	36.3	32.8	-21.6	-24.6	3605	3438
Wuhan	30.6	114.1	1695	1250	222	5833	37.3	32.9	-0.5	-2.9	2887	1669
Xi'an	34.3	108.9	2337	839	82	3529	38.1	30.3	-5.4	-9.6	3190	2264
Xining	36.6	101.8	3984	40	0	85	30.0	21.1	-12.2	-19.2	3883	3587
Yinchuan	38.5	106.2	3640	416	3	1132	33.4	27.0	-14.9	-19.9	3976	3831
Zhengzhou	34.7	113.7	2263	1016	107	4468	37.6	30.4	-5.8	-10.8	3560	2973

Additional Chinese locations in the ISWO weather data set for which TMY weather files will be produced are: Andirlan, Anyang, Baoding, Bayan Mod, Bengbu, Dalian, Dandong, Datong, Deqen, Dinghai, Erenhot, Golmud, Guilin, Hami, Jingdezhen, Jinzhou, Jixi, Kashi, Korla, Lhasa, Liuzhou, Longzhou, Mudanjiang, Nenjiang, Qingdao, Qiqihar, Shantou, Shaoguan, Shijiazhuang, Tangshan, Tianjin, Weifang, Wenzhou, Xiamen, Xuzhou, Yaxian, Yichang, Yichun, Yingkou, Yining, Yueyang, Zhangjiakou, and Zhanjiang.

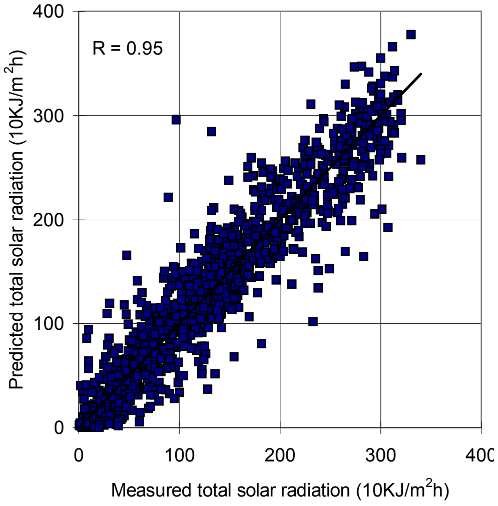

Figure 1. Comparison of predicted to measured hourly total solar radiation for Beijing and Guangzhou 1993

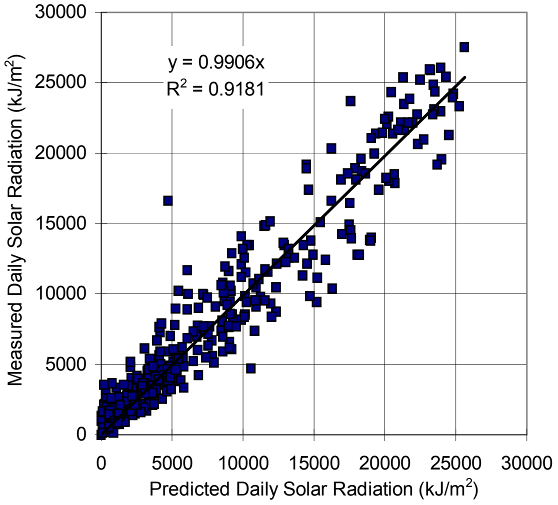

Figure 2. Comparison of predicted to measured daily total solar radiation for Chongqing 1988

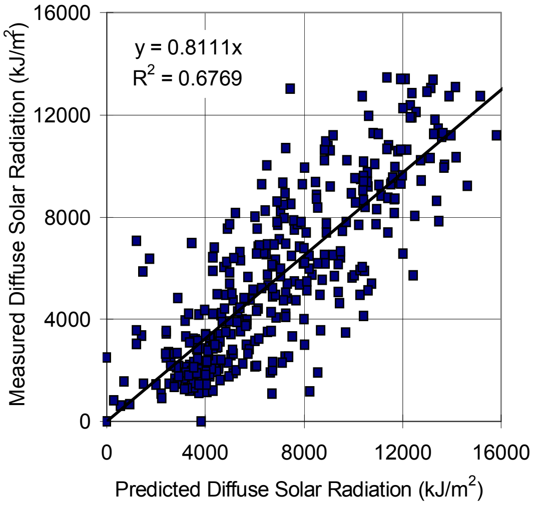

Figure 3. Comparison of predicted to measured daily diffuse solar radiation for Beijing 1984

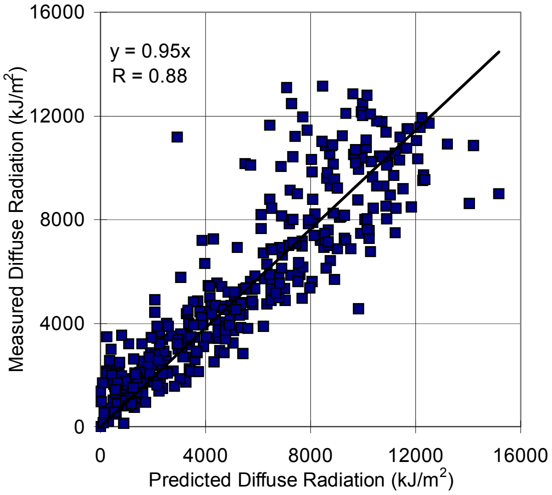

Figure 4. Comparison of predicted to measured daily diffuse solar radiation for Chongqing 1988

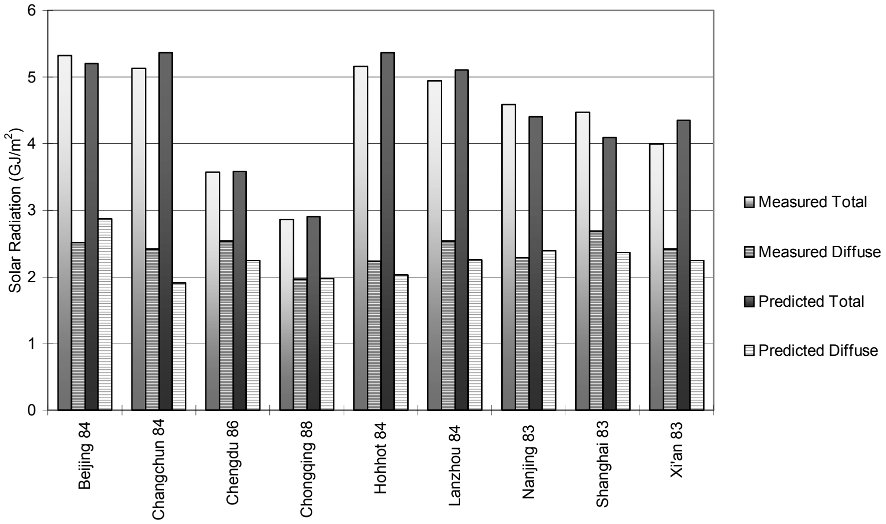

Figure 5. Comparison of measured and predicted annual solar radiation

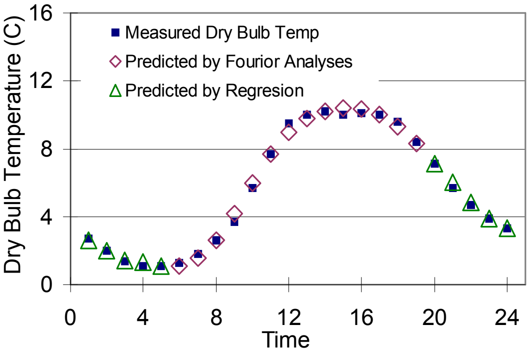

Figure 6. Example of dry-bulb temperature interpolation for Tokyo, June 21

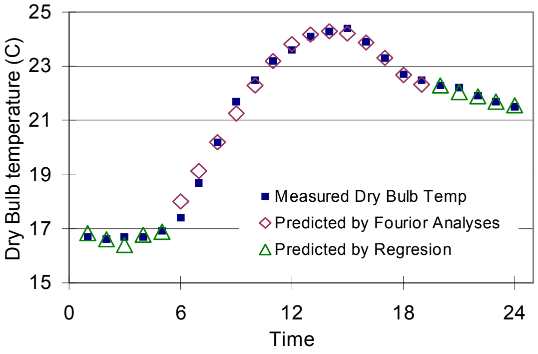

Figure 7. Example of dry-bulb temperature interpolation for Tokyo, December 21