

Generating hourly temperature values for future change to climate

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ABSTRACT: Building designers often now predict the performance of buildings simulation programmes that require hourly weather data. However, not all weather stations provide hourly data. Climate prediction models such as HadCM3 also provide the daily average dry bulb temperature as well as the maximum and minimum. Hourly temperature values are available for building thermal simulations that accounts for future changes to climate. In order to make full use of these predicted future weather data in building simulation programmes, algorithms for downscaling daily values to hourly values are required. This paper describes a more accurate method for generating hourly temperature values in the South Korea that uses the improvement of the quality of the generated values. All methods were evaluated for accuracy and stability in terms of the absolute mean error and the mean-square error. They were compared with hourly data collected in Seoul and Ulsan, South Korea.

Keywords: hourly temperature, downscaling, CIBSE guide, climate change

1. INTRODUCTION

Temperature is clearly an extremely important weather factor predicting the performance of buildings simulation programmes. However, not all weather stations provide hourly data. In standard weather records and forecasts, daily maximum, minimum and average air temperatures are commonly reported.

Climate prediction models such as HadCM3 also provide the daily average dry bulb temperature as well as the maximum and minimum. Hourly temperature values are available for building thermal simulations that accounts for future changes to the climate. In order to make full use of these predicted future weather data in building simulation programmes, algorithms for

downscaling daily values to hourly values are required.

The shape of the diurnal temperature curves has been modeled in a variety of ways that vary from simple curve-fitting models based upon sine curves (CIBSE method, 1982; Wann et al., 1985) to more sophisticated techniques using daily average values (Reicosky et al., 1989; Chew and levermore, 2007). They were evaluated for accuracy and stability in terms of the absolute mean error, the mean-square error and cumulative error. Thus, the objective of this paper was to determine the accuracy of different methods for generated hourly air temperatures from daily maximum, minimum and average temperatures. The results were compared with hourly data collected in Seoul and Ulsan, South Korea.

2. MATHEMATICAL MODELS

Suppose that the maximum temperature will occur sometime between sunrise t_r and sunset t_s , and that the minimum temperature

will occur in the early morning. Then the time of maximum temperature is given by

$$t_{\max} = 1/2(t_r + t_s) + \alpha \quad (1)$$

Where α is the time difference between $t_{\max}$ and midday. Similarly, the time of minimum temperature is

$$t_{\min} = t_r + \beta \quad (2)$$

Where β is the time difference between $t_{\min}$ and sunrise. Furthermore

$$1/2(t_r - t_s) + \beta < \alpha < 1/2(t_s + t_r) \quad (3)$$

The first inequality guarantees that the minimum temperature will occur before the time of the maximum temperature. The second inequality expresses the assumption that the maximum temperature will occur before sunset.[1] All models rely on the strategically allocating times ($t_{\max}$ and $t_{\min}$) for which $T_{\max}$ and $T_{\min}$ occur in the day (See Table 1) and uses two sinusoidal curves to fit the data.

Table 1: $T_{\max}$ and $T_{\min}$ times suggested by *CIBSE Guide A2 (1982)* and calculation

month	T _{max} time (t _{max})		T _{min} time (t _{min})			
	CIBSE	Seoul	Ulsan	CIBSE	Seoul	Ulsan
January	14	15	15	6	6	6
February	14	15	15	6	6	6
March	14	15	14	5	6	6
April	15	15	14	5	6	5
May	15	15	14	4	6	5
June	16	15	14	4	5	5
July	15	15	14	4	5	5
August	15	15	14	5	6	5
September	15	15	14	5	6	5
October	14	15	14	6	6	6
November	14	15	14	6	6	6
December	14	15	15	7	6	6

2.1 CIBSE method (1982)

The CIBSE method[2] algorithm (similar to the ASHRAE method[3]) for generating hourly dry-bulb temperature uses simply the daily maximum temperature, T_{MAX} , and the daily minimum temperature, T_{MIN} . Hourly temperatures, $T(t)$ are calculated by (4)

$$T(t) = f_1 \cdot T_{MIN} + f_2 \cdot T_{MAX} \quad (4)$$

where f_1 and f_2 are factors given in a table in the guide, and T_{MIN} and T_{MAX} are the daily minimum and maximum temperatures respectively. These are related to sinusoidal interpolations, and can be expressed more mathematically in (5) to (8)

$$f1 = \frac{\cos\left(\frac{\pi(t_{min} - t)}{24 + t_{min} - t_{max}}\right) + 1}{2}$$

For $t < t_{min}$ (5)

$$f1 = \frac{\cos\left(\frac{\pi(t - t_{min})}{t_{max} - t_{min}}\right) + 1}{2}$$

For $t_{min} < t < t_{max}$ (6)

$$f1 = \frac{\cos\left(\frac{\pi(24 + t_{min} - t)}{24 + t_{min} - t_{max}}\right) + 1}{2}$$

For $t_{max} < t$ (7)

$$f1 + f2 = 1 \quad (8)$$

2.2 CIBSE Linking days

The above algorithms produce data for only one day. If the days are simply put together, as would be necessary in constructing a year of data, there will often be steps between the ends of days and the

starts of the next days. However, the T_{MAX} of any day can also be linked, using a sinusoidal curve, with the T_{MIN} of the following day, rather than treating them separately. This would produce a smoother transition between days. The equation for calculating this is given by

$$T(t) = \left(\frac{Temp_{(next)} + Temp_{(prev)}}{2} \right) + \left[\left(\frac{Temp_{(next)} - Temp_{(prev)}}{2} \right) \times \cos\left(\frac{\pi(t - t_{(prev)})}{(t_{(next)} - t_{(prev)})} \right) \right] \quad (9)$$

where: $Temp(next)$ is the next known temperature value (T_{MAX} or T_{MIN}); $Temp(prev)$ is the previous known temperature value (T_{MAX} or T_{MIN}); $t(next)$ is the time for the next known temperature value; $t(prev)$ is the time for the previous known temperature value; t is the time.

2.3 Q-Sine Method

The Quarter-Sine (Q-Sin) method was developed to utilizes values of T_{MAX} , T_{MIN} and T_{AVE} . To ascertain the correct average value, a point is selected between the T_{max} and T_{min} (at a variable time) and quarter sine waves fitted between the three points. This will not affect the final generated value of T_{AVE} , as the correction procedures to fit the given T_{AVE} value occur later on. Originally, there will be a difference between the given value of T_{AVE} and the daily average of generated hourly data, so a way of correcting the values in the generated data is required. This can be done by the application of the quarter-sine wave [4]. The temperature between t_{min} and λ is generated as shown in

$$T(t) = \left(\frac{T_{MAX} - T_{MIN}}{2} \right) \times \left[\cos\left(\frac{(t - 2\lambda + t_{min})\pi}{2(\lambda - t_{min})} \right) + 1 \right] \quad (10)$$

The temperature between λ and t_{max} is generated as shown in

$$T(t) = \left(\frac{T_{MAX} - T_{MIN}}{2} \right) \times \left[\cos \left(\frac{(t - t_{max})\pi}{2(t_{min} - \lambda)} \right) + 1 \right] + T_{MIN} \quad (11)$$

$$\therefore \lambda = \frac{t_{max} + t_{min}}{2} - \left(\frac{12D_2\pi}{T_{max} - T_{min}} \right) \quad (12)$$

Having calculated, where λ is to be situated to correct for the differences, hourly temperatures can be generated keeping the T_{MAX} , T_{MIN} and also agreeing with the value of T_{AVE} from the model. There are occasions when λ actually lies outside the times between t_{min} and t_{max} . This can cause problems, and T_{MAX} , T_{MIN} or T_{AVE} would not be kept. However, these are very rare and considered not to affect results greatly.

2.4 Linking Q-Sine

In the interval between the times of maximum and minimum of the next day, the temperatures are the same as that of the CIBSE Linking days. To ascertain the correct average value, a point is selected between the T_{max} and T_{min} (at a variable time) and quarter sine waves fitted between the three points. The algorithms between the times of minimum and maximum are the same as that of the Q-Sine method.

3. EVALUATION OF MODELS

Air temperature data from two locations in South Korea were used for parameter estimation. They consist of (a) twenty one years (1986-2006) of KMA records (KMA, 2007) at Seoul station, (b) twenty years (1986-2005) of KMA records (KMA, 2006) at Ulsan station. To test the accuracy of the various models, temperatures measured at

hourly intervals were compared to the calculated values over a 24-h interval. The absolute mean error, the mean-square error and cumulative error were used as an indicator of goodness of fit of the model.

3.1 Methods of error analysis

The "goodness of fit" of each of the models was assembled in several ways. First, the absolute mean error (AME), defined as the sum of the absolute value of the difference between the estimated and observed temperature for a 24-h period, is given by

$$AME = \sum_{i=1}^n |Te_i - To_i| / 2 \quad (13)$$

Where n is the number of observation, Te is the estimated temperature and To is the observed temperature at any time. The root mean squarer error (RMSE) calculated to reflect the overall accuracy of the shape of the predicted curve is defined by

$$RMSE = \left[\sum_{i=1}^n (To_i - Te_i)^2 / n \right]^{1/2} \quad (14)$$

The closer the estimated temperatures are to the observed temperature, the smaller the RMSE. The RMSE tends to penalize large individual error heavily and as such may be the better criterion of performance.[5]

3.2 Performance on selected days

The data for the random days were grouped and analyzed using the 20~21 year means of the various error parameters to draw conclusions about the accuracy of each method with selected examples of the daily results to show the magnitude of error possible within a single day.

In case of Ulsan, best fit date of the day (DY 183, 2000) was selected because the diurnal trend was smooth throughout the 24-

h period, the range between maximum and minimum was medium (8.2°C), and the most of the assumptions of the models were met (See Figs 1). The calculated results for all methods are reasonably close to the observed values. The error analysis for DY 183, 2000 is summarized in Table 2. The RMSE varied from a low of 0.38 for Linking Q-Sine to 0.51 for Q-Sine. The AME varied from a low of 0.30 to 0.41 for the same methods. In this case the R^2 (coefficient of determination) varied from a low of 0.97 for Q-Sine to a high of 0.98 for Linking Q-Sine, suggesting reasonable fit based on the overall diurnal trend.

Worst fit date of the day (DY 204, 2000) were selected to illustrate a relatively poor fit of all of the methods for calculating hourly temperatures (See Figs 1). There was not a smooth trend in the observed temperatures and only a small difference between the $T_{\text{MAX}}(27.9^{\circ}\text{C})$ and the $T_{\text{MIN}}(21.0^{\circ}\text{C})$. The trends throughout the 24-h period were not well fitted because the diurnal trends of the observed temperature were not smooth and did not closely match the assumptions in the various methods. The error parameters for DY 204, 2000, are summarized in Table 2. According to the change of maximum and minimum temperature times, RMSE varied from a low of 3.80 for Linking Q-Sine to

4.12 for CIBSE individual days. A similar trend is shown in the AME.

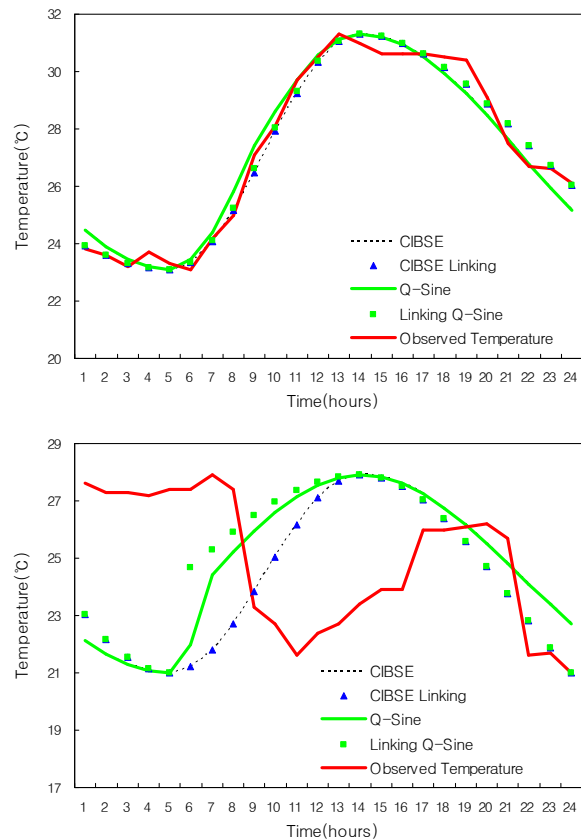


Figure 1: Summary of the trend of the differences between the estimated and observed temperatures for each of the methods on Day 183 and 204, 2000 for Ulsan

Table 2: Summary of the statistics for July, 2000 for Ulsan

	STAT.	CIBSE Individual days	CIBSE Linking days	Q-sine	Linking Q-sine
Best fit date	R^2	0.98	0.98	0.97	0.98
(Day 183)	AME	0.38	0.31	0.41	0.30
	RMSE	0.46	0.39	0.51	0.38
Median fit date	R^2	0.94	0.88	0.92	0.77
(Day 208)	AME	0.71	1.01	0.76	1.35
	RMSE	0.91	1.26	1.03	1.78
Worst fit date	R^2	0.25	0.14	0.23	0.08
(Day 204)	AME	3.63	3.44	3.53	3.21
	RMSE	4.12	3.93	4.05	3.80

In the case of Seoul, best fit date of the day (DY 199, 2000) was selected because the diurnal trend was smooth throughout the 24-

h period and most of the assumptions of the models were met. The calculated results for all methods are reasonably close to the

observed values in Figs 2. The error analysis for DY 199, 2000 is summarized in Table 3. The RMSE varied from a low of 0.22 for Q-Sine to 0.29 for CIBSE individual days. The AME varied from a low of 0.17 to 0.24 for the same methods. In this case the R^2 varied from a low of 0.93 for CIBSE individual days to a high of 0.96 for CIBSE Linking days, suggesting reasonable fit based on the overall diurnal trend.

Worst fit date of the day (DY 196, 2000) were selected to illustrate a relatively poor fit of all of the methods for calculating hourly temperatures in Figs 2. The trends throughout the 24-h period were not well fitted because the diurnal trends of the observed temperature were not smooth and did not closely match the assumptions in the various methods. The error parameters for DY 196, 2000, are summarized in Table 3. RMSE varied from a low of 2.48 for Linking Q-Sine to 3.19 for CIBSE individual days. A similar trend is shown in the AME.

The performance of the Q-Sin methods are slightly better than the CIBSE methods. It should also be noted that the methods where the days are linked together rather than treated separately also performed better, having smaller errors.

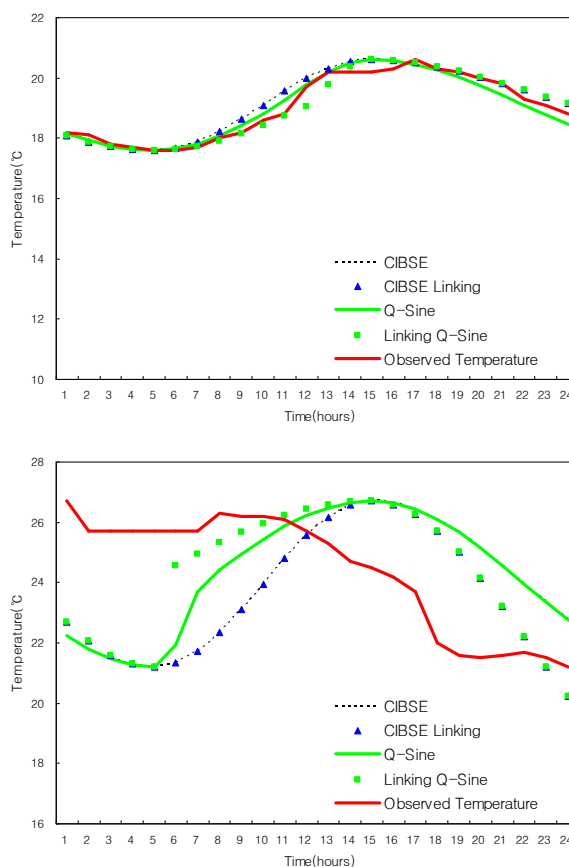


Figure 2: Summary of the trend of the differences between the estimated and observed temperatures for each of the methods on Day 199 and 206, 2000 for Seoul

Table 3: Summary of the statistics for July, 2000 for Seoul

	STAT.	CIBSE Individual days	CIBSE Linking days	Q-sine	Linking Q-sine
Best fit date	R^2	0.93	0.96	0.96	0.96
(Day 199)	AME	0.24	0.19	0.18	0.17
	RMSE	0.29	0.23	0.22	0.23
Median fit date	R^2	0.93	0.94	0.92	0.89
(Day 192)	AME	0.61	0.58	0.64	0.73
	RMSE	0.70	0.66	0.73	0.86
Worst fit date	R^2	0.14	0.01	0.04	0.06
(Day 196)	AME	2.99	2.58	2.62	2.03
	RMSE	3.19	2.85	2.93	2.48

4. CONCLUSION

The specified times of the daily maximum and minimum temperatures are vital to the accuracy of the remodelled hourly values. It was evident from this study that the best times for the daily minimum temperatures is the hour before sunrise of the day, and the times for the daily maximum temperatures appear to be those described in Table 1. Seoul and Ulsan show that the times for the daily maximum and minimum temperatures are considerably different. This suggests that these times may need to be separately calibrated for each region.

From the two analyses, it can be concluded that all methods gave reasonable estimates of hourly temperatures. Despite the variability in the results from day to day for the more sophisticated methods, the performances of the Q-Sin methods are slightly better than the CIBSE methods. It should also be noted that the methods where the days are linked together rather than treated separately also performed better, having smaller errors. The use of these methods is useful particularly for generating TRYs for future time-slices and available for building thermal simulations that accounts for future changes to the climate.

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