Development of the Typical and Design Weather Data for Asian Locations

Qingyuan Zhang¹, Joe Huang² and Hongxing Yang³

¹Associate Professor, Tsukuba College of Technology, Japan
²Staff Scientist, Lawrence Berkeley National Laboratory, USA
³Assistant Professor, The Hong Kong Polytechnic University, P. R. China

Abstract

Two kinds of weather data for 20 Asian locations were developed in this paper. One is the Typical Meteorological Year (TMY) with the 8760-hour data including temperature, humidity, solar radiation, wind speed, wind direction and cloud cover. Another kind of weather data is for air-conditioning equipment design. The source data are the database from weather observation with three-hour intervals. The TMY data files were developed referring to the methods of TMYs of the US and Japan. A model to predict solar radiation developed by the authors was modified with the regional factors. The weather data for air-conditioning design were based on the frequency level of a specific temperature over a time period. The frequencies of 2.5% and 5.0% were selected to decide the design temperatures for the 20 Asian cities.

Keywords: weather data; typical meteorological year; air-conditioning design; building simulations

Introduction

Weather is one of the primary determinants in forming the indoor thermal environments. Therefore building simulations are impossible without proper weather data. Basically, there are two kinds of weather data for building energy calculation. One is for hourly building simulations and another one is for the air-conditioning equipment design. In this study, we pay most attention to the former because the hourly data are used frequently in the thermal behavior simulations. Most dynamic simulation or energy calculation programs, such as HASP (Matsuo et al. 1980) or DOE-2 (Winkelmann et al. 1993), require one-hour weather data including solar radiation, dry-bulb temperature, dew-point temperature or humidity, 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 (Matsuo et al. 1974, NCDC 1981, Clarke 1985, Akasaka et al. 1991 and 1995). Although their development may differ in detail, such 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 on the weather data like the Typical Meteorological Year for Asian locations except for the locations in Japan. The authors have developed the Typical Meteorological Year data for more than forty Chinese locations since 2001 (Zhang and Asano, 2001). With these weather data, the regional characteristics of the air-conditioning loads were analyzed in the previous study (Zhang et al., 2001). However, the typical weather data for most Asian locations except Japan and China remain unavailable.

Akasaka et al. have developed a database of average weather conditions for thermal calculation of buildings at any locations in the world (Akasaka et al. 1991 and 1996). However, because this database does not contain the 8760-hour data for the building simulations, the database mentioned above cannot replace the typical year weather data for the purpose of building thermal simulations.

In this paper, the Typical Meteorological Year data and the weather data for air-conditioning equipment design for 20 Asian cities were developed using the database from the U.S. National Climate Center with three-hour intervals. Because there were no data of solar radiation in the database, solar radiation was predicted with a model developed by the authors in the previous study. The typical meteorological months were selected by how close the variables of a month are to the average. The weather data for the design of air-conditioning equipment are also developed on the basis of frequency level of a specific temperature over the observation period.
Table 1. The Locations and the Years from Which the TMMs were Selected

| Location          | Lat. | Long. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------------------|------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| YEREVAN           | 40.13| 44.46 | 91  | 90  | 87  | 84  | 90  | 90  | 84  | 90  | 87  | 90  | 90  | 85  |
| JERUSALEM         | 31.78| 35.21 | 90  | 90  | 89  | 90  | 90  | 87  | 90  | 92  | 92  | 89  | 89  | 88  |
| NEW DELHI         | 28.58| 77.19 | 83  | 83  | 86  | 95  | 93  | 86  | 83  | 85  | 85  | 86  | 85  | 83  |
| TASHKENT          | 41.27| 69.26 | 84  | 86  | 93  | 93  | 88  | 84  | 93  | 85  | 93  | 92  | 87  | 92  |
| KARAGANDA         | 49.8 | 71.12 | 88  | 90  | 86  | 86  | 88  | 85  | 91  | 86  | 93  | 90  | 90  | 85  |
| DOHA              | 25.25| 51.56 | 88  | 86  | 86  | 83  | 85  | 87  | 87  | 92  | 87  | 89  | 85  | 84  |
| SEOUL             | 37.55| 126.79| 90  | 91  | 89  | 92  | 84  | 89  | 88  | 84  | 90  | 89  | 83  | 84  |
| PYONGYANG         | 39.03| 125.77| 90  | 91  | 91  | 92  | 94  | 85  | 91  | 83  | 89  | 89  | 89  | 84  |
| KUWAIT            | 29.22| 47.97 | 88  | 88  | 89  | 88  | 86  | 93  | 93  | 89  | 89  | 96  | 93  | 85  |
| TBILISI           | 41.68| 44.94 | 86  | 82  | 87  | 90  | 84  | 87  | 88  | 82  | 87  | 89  | 87  | 87  |
| RIYADH            | 24.72| 46.72 | 86  | 83  | 89  | 88  | 86  | 92  | 90  | 86  | 83  | 85  | 86  | 89  |
| SINGAPORE         | 1.37 | 103.97| 93  | 91  | 93  | 93  | 93  | 93  | 95  | 91  | 90  | 96  | 95  | 96  |
| BANGKOK           | 13.92| 100.59| 96  | 92  | 90  | 95  | 90  | 95  | 89  | 93  | 89  | 89  | 89  | 89  |
| DUSHANBE          | 38.55| 68.77 | 91  | 91  | 85  | 86  | 89  | 89  | 93  | 91  | 85  | 85  | 87  | 86  |
| ASHABAD           | 37.97| 58.32 | 93  | 91  | 92  | 86  | 88  | 91  | 88  | 88  | 85  | 94  | 91  | 94  |
| ANKARA            | 40.12| 22.97 | 82  | 82  | 93  | 85  | 88  | 86  | 90  | 92  | 91  | 91  | 92  | 85  |
| BAHRAIN           | 26.27| 50.64 | 90  | 90  | 85  | 85  | 92  | 90  | 93  | 88  | 97  | 89  | 90  | 88  |
| HONG KONG         | 22.33| 114.17| 85  | 82  | 93  | 87  | 86  | 86  | 88  | 89  | 93  | 90  | 89  | 89  |
| KUALA LUMPUR      | 3.12 | 101.54| 89  | 82  | 86  | 91  | 82  | 83  | 83  | 84  | 82  | 83  | 84  | 82  |
| ULAAN BAATOR      | 47.93| 106.97| 85  | 86  | 94  | 86  | 85  | 88  | 84  | 94  | 89  | 89  | 84  | 87  |

Source Data for the Weather Files

The TMY weather files for 20 Asian cities shown in Table 1 were developed from a database of International Surface Weather Observations (ISWO). The weather variables recorded in the ISWO database include dry-bulb and dew-point temperatures, atmospheric pressure, wind speed and direction, and the amounts of cloud cover at various heights. With the exception of a few cities, the ISWO data for Asian locations were all reported at three-hour intervals.

Because the ISWO data do not contain solar radiation data, we developed methods adapted from previous work by Japanese researchers (Ma et al. 1993, Cui et al. 1996) to estimate total solar radiation from reported dry-bulb temperature, temperature change from previous hours, relative humidity, cloud cover and wind speed. To verify the accuracy of these models and adapt them to Asian climate conditions, the authors compared the daily accumulated solar radiation by observation (NASA) with the solar radiation predicted by the solar models developed for the Chinese TMY data in the previous study.

The weather data for most Asian locations in the source data are at three-hour intervals. For use in thermal simulations or annual energy calculations, the data were interpolated to one-hour intervals.

Model for Predicting Solar Radiation

As mentioned above, there is no observed data on solar radiation in the source data. Therefore, it was necessary in this study to predict the amount of solar radiation based on other available climate parameters.

Of the recorded climate parameters, cloud cover is the most influential for estimating the amount of solar radiation. Moreover, low-level cloud cover can affect the solar radiation a great deal. Nevertheless, we did not include low-level cloud cover in our solar model because this climate parameter was often not reported in the weather data. On the other hand, since the rate of increase in dry-bulb temperature is correlated to the amount of solar radiation, it can be used as a secondary parameter for estimating solar radiation. Conversely, a recent study has also shown that relative humidity has a negative correlation to solar radiation (Cui et al. 1996). Ma et al. (1993) developed a model to estimate solar radiation based on cloud cover, dry-bulb temperature difference between sequential observations, relative humidity and wind speed that was then applied to climate data recorded at 6-hour intervals. There were two problems with this approach: 1) the impact of the long six-hour interval on the accuracy of the solar model could not be determined, and 2) the model overestimated at low values and underestimated at high levels of solar radiation.
In a previous study (Zhang and Asano, 2001), we developed a solar model similar in form to the Ma model, with total cloud cover, dry-bulb temperature, relative humidity, and wind speed as the independent variables (see Equation 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 (Sakamoto and Nagata, 1999).

\[
I = \left[ I_0 \cdot \sin(h) \cdot (c_0 + c_1 \cdot CC + c_2 \cdot (CC)^2 + c_3(T_n - T_{n-3}) \right] + c_4 \phi + c_5 V_w \cdot d \cdot k \tag{1}
\]

where

- \( I \) = estimated hourly solar radiation for Beijing and Guangzhou in W/m²
- \( I_0 \) = solar constant, 1355 W/m²
- \( \sin(h) \) = solar altitude angle, i.e., the angle between the horizontal and the line to the sun
- \( CC \) = cloud cover in tenths
- \( \phi \) = relative humidity in %
- \( T_n, T_{n-3} \) = dry-bulb temperature at hours \( n \) and \( n-3 \), 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:

- \( c_0 = 0.5598 \)
- \( c_1 = 0.4982 \)
- \( c_2 = -0.6762 \)
- \( c_3 = 0.02842 \)
- \( c_4 = -0.00317 \)
- \( c_5 = 0.014 \)
- \( d = -17.853 \)
- \( k = 0.843 \)

The prediction of solar radiation by Equation (1) agrees with the observed values with a RSME (root square mean error) of 91 W/m². In order to clarify whether Equation (1) can be used to predict solar radiation in other Asian locations, we calculated the daily accumulative solar radiation of the typical months with Equation (1) and then computed the monthly average value of daily radiation. Figure 1 shows examples of the comparison between the predicted solar radiation by Equation (1) and the monthly average solar radiation from observation (NASA, 2002). The predicted daily solar radiation for the typical months differs from the average solar...
radiation over the observed period in Ankara and Kuala Lumpur. The solar radiation of the typical month should be in the same order as the average solar radiation over a period but not necessarily exact the same for each month because usually the solar radiation of the typical months is close to but not equal to the average over a long period of observation. Nevertheless, the ratio of predicted radiation by observation varies a little throughout a year, which means that such a ratio reflects the regional characteristics of solar radiation. We calculated the yearly average of this ratio and define it as the regional factor by comparing the results from Equation (1) and the observed value by NASA (NASA 2002). The solar radiation of the TMY data can be predicted by the following equation:

\[
I' = I / \eta
\]  

where \(I'\) is the predicted solar radiation (W/m²) for the 20 Asian locations and \(\eta\) is the regional factor.

The comparison between the solar radiation predicted by Equation (2) and the monthly averages over the observed period is shown in Figure 2. Both agree with each other very well in Ankara and Kuala Lumpur as well as other locations shown in Table 1.

It is reasonable to conclude that Equation (2) can be used to predict solar radiation for the Asian locations with the regional factors shown in Table 2.

For Building simulations, it is necessary to separate the global solar radiation into direct and diffuse components. In this study, we used the model developed by Watanabe et al. (1983) for Japanese locations.

**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. (1974) and NREL (NCDC 1981).

In this paper, we combined the methods of Matsuo and NCDC and four steps were conducted in selecting the TMMs. The procedure is as follows:

1. Select the months whose monthly average dry-bulb temperature, dew-point temperature, solar radiation and wind speed are within the range of 0.6 times the standard deviation. If there is only one candidate left after Step 1, the only candidate is selected as the TMM. If there is no candidate left, go to Step 2. If there is more than one candidate after step 1, go to Step 4.
2. Select the months whose monthly average dry-bulb temperature, dew-point temperature, solar radiation and wind speed are within the range of 0.8 times the standard deviation. If there is only one candidate left after Step 2, the only candidate is selected as the TMM. If there is no candidate left, go to Step 2. If there is more than one candidate after step 2, go to Step 4.
3. Select the months whose monthly average dry-bulb temperature, dew-point temperature, solar radiation and wind speed are within the range of one standard deviation. If there is only one candidate left after Step 3, the only candidate is selected as the TMM. If there is more than one candidate left after Step 3, go to Step 4.
4. Compare the WS values of the remaining months, and select the month whose WS is the smallest as the TMM.

The value of WS is calculated as follows:

\[
WS = \sum (w_i \cdot FS_i)
\]  

where \(FS_i\) means the Finkelstein-Shafer (FS) statistic (Finkelstein and Shafer 1971). The smaller the \(FS_i\), the closer the structure of a variable will be to the average year. The weights \(w_i\) applied to the different climate parameters are the same as those used by NCDC in the development of the original TMYs (NCDC 1981).

Table 1 is a list of years from which the TMMs have been selected for the 20 Asian locations. Very few TMMs have been taken from the years 1993 to 1997.

| Locations         | Regional Factor |
|-------------------|-----------------|
| YEREVAN           | 0.96            |
| JERUSALEM         | 0.77            |
| NEW DELHI         | 0.87            |
| TASHKENT          | 0.83            |
| KARAGANDA         | 0.83            |
| DOHA              | 0.77            |
| SEOUL             | 0.76            |
| PYONGYANG         | 0.76            |
| KUWAIT            | 0.77            |
| TBILISI           | 0.96            |
| RIYADH            | 0.77            |
| SINGAPORE         | 0.66            |
| BANGKOK           | 0.91            |
| DUSHANBE          | 0.83            |
| ASHABAD           | 0.83            |
| ANKARA            | 1.15            |
| BAHRAIN           | 0.77            |
| HONG KONG         | 1.00            |
| KUALA LUMPUR      | 0.75            |
| ULAAN BAATOR      | 0.78            |
due not to their climate characteristics, but because there were too much missing data that could not be reliably filled.

Interpolation for Missing Data
The weather data in the source data are at three-hour intervals. For use in thermal simulations or annual energy calculations, the data must be interpolated to one-hour intervals.

We used the same methods of interpolation of climate variables developed in the previous study (Zhang and Asano, 2001); dry-bulb temperature, dew-point temperature, wind speed, and total cloud cover. We did not attempt to interpolate atmospheric pressure because it is only measured at a few stations and its impact of building energy use is secondary.

Weather Data for Air-conditioning Design
The main purpose of TMY data is to simulate the thermal behavior of buildings for an average year, and it is not for the design of air-conditioning equipment. One of the main methods to decide the design temperature is based on the frequency level of a specific temperature over a time period. The frequencies of 2.5% and 5.0% were selected to decide the design temperatures for the 20 Asian cities. The ASHRAE (ASHRAE, 1997) has recommended the weather data for some Asian locations, but there are two problems: (1) only one dry-bulb and one wet-bulb temperatures were given for each city, while 24 hour weather data are necessary for some calculation methods and (2) the number of Asian cities whose weather data for air-conditioning design is too small therefore more studies are needed about other cities.

In this study, we computed the frequencies of dry-bulb temperature and humidity ratio for the 20 Asian locations over the period of 1982-1997 and cumulative frequency curves were drawn for each month and each location. For cooling design temperature, frequencies were calculated over the period of June through September; while for the heating design, frequency calculation was carried out over the period of December through March. Twenty-four hours data were given for the heating design for each location as shown Table 3. The coldest city among the 20 Asian cities is Ulaan- Baator, whose lowest temperature is below -30°C. Usually the there is a gap of about one degree between 2.5% and 5% frequencies.

Table 4 shows the weather data for the cooling design for the 20 locations. The warmest city among the 20 cities is Kuwait whose 2.5% frequency temperature rises to 48.5°C. One of the climatic characteristics of Riyadh is hot and dry, which imply the large potential of evaporative cooling as a passive method in summer. The highest temperature with the 2.5% frequency in Ulaan Baator is 28.9°C, which means that no cooling equipment is needed in Ulaan Baator in summer.

Conclusions
The main conclusions from this study are:
1. A set of Typical Meteorological Year (TMY) data have been developed for 20 Asian locations.
2. A model to estimate global solar radiation on a horizontal surface developed for the Chinese locations has been modified with regional factors, and found to be fairly reliable for locations with measured daily solar radiation.
3. Weather data for equipment design have been developed based on the frequency level of a specific temperature over the period of 1982-1997.

References
1) Akasaka, H., Kuroki, S. and Arii, Y. 1991, “Weather Data Compilation for Design and Average Heat Load Calculation at any Location in the world”, Transactions of Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, No.45, 1991.
2) Ariai, Y., Gondo, T., Akasaka, H. and Saito, M., 1995, “Weather Data Compilation for Design and Average Heat Load Calculation at any Location in the world, Part 3 System for Calculating Dynamic Heat Load at any of 3700 Locations Worldwide for Use in HVAC Design”, Transactions of Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, No.62, 1996.
3) ASHRAE 1997. Handbook of Fundamentals, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, B
4) Clarke, J. 1985. Energy Simulation in Building Design. Adam Hilger, Bristol, UK.
5) Cui, L., Matsuo, Y., Sakamoto, Y. and Nimiya, H., 1996. “The Prediction of Solar Radiation and Its Application” (in Japanese), Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan.
6) Finkelstein, J.M. and Shafer, R.E. 1971, “Improved Goodness of Fit Tests”, Biometrika, Vol. 58, No. 3, pp. 641-655.
7) Matsuo, Y., et al. 1980. “Computation of Dynamic Air-conditioning Loads”, Society for Building Equipment Engineers
8) Ma, Z., Matsuo, Y. Nagata, A and Nimiya. H.1993. “Development of Typical Weather Data of Shanghai with the World Weather” (in Japanese), Annual Meeting, Architectural Institute of Japan.
9) Matsuo, Y., et al. 1974. “Study on Typical Weather Data” (in Japanese), Journal of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, Vol.48, No.7.
10) National Climatic Data Center (NCDC) 1981. Typical Meteorological Year User’s Guide, NCDC, National Oceanic and Atmospheric Administration, US Dept. of Commerce, Asheville NC.
11) See the web page of Atmospheric Sciences Data Center: http://eosweb.larc.nasa.gov
12) National Climatic Data Center (NCDC) 1998. 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.
13) Watanabe, T., et al. 1983. “Procedures for Separating Direct and Diffuse Insolation on a Horizontal Surface and Prediction of Insolation on Tilted Surfaces” (in Japanese), No. 330, Architectural Institute of Japan.
14) Winkelmann, F.C., Birdsal, B.E., Buhi, W.F., Ellington, K.L., Erdem, A.E., Hirsch, J.J., and Gates, S. 1993, “DOE-2 Supplement, Version 2.1E”, LBL-234949, Lawrence Berkeley Laboratory, Berkeley CA, USA.
15) World Radiation Data Center (WRDC) 2001. See http://wwrd-mgo.nrel.gov/ for more details.
16) Sakamoto, Y. and Nagata, A. Measured hourly solar data for Beijing, Guangzhou, and Harbin 1993 (in data file).
17) Zhang, Q and Asano, K. 2001. “Development of the Typical Weather Year Data for the Main Chinese Cities” (in Japanese), Journal of Architecture, Planning and Environmental Engineering, Vol.543
18) Zhang, Q., et al: 2001. "Regional Characteristics of Air-Conditioning Loads for Residences in China", Proceedings of Seventh International IBPSA Conference (Rio de Janeiro, Brazil)
| Locations     | Dry-bulb(℃) | Abs. Hum.(g/kg) |
|--------------|-------------|----------------|
| Ankara       | 30.2        | 31.3           |
| Sabah        | 30.5        | 30.5           |
| Bahrain      | 30.2        | 30.2           |
| Beirut       | 30.1        | 30.1           |
| Hong Kong    | 30.0        | 30.0           |
| Seoul        | 29.9        | 29.9           |
| Tokyo        | 29.8        | 29.8           |
| Jakarta      | 29.7        | 29.7           |
| New Delhi    | 29.6        | 29.6           |
| Peking       | 29.5        | 29.5           |
| Riyadh       | 29.3        | 29.3           |
| Egypt        | 29.2        | 29.2           |
| Singapore    | 28.9        | 28.9           |
| Taibei       | 28.4        | 28.4           |
| Bangkok      | 28.3        | 28.3           |
| Kuala Lumpur | 28.2        | 28.2           |
| Kuwait       | 28.1        | 28.1           |
| Seoul        | 27.9        | 27.9           |
| Tokyo        | 27.7        | 27.7           |
| Hong Kong    | 27.6        | 27.6           |
| Jakarta      | 27.5        | 27.5           |
| New Delhi    | 27.4        | 27.4           |
| Peking       | 27.3        | 27.3           |
| Riyadh       | 27.2        | 27.2           |
| Cairo        | 27.0        | 27.0           |
| Bombay       | 26.9        | 26.9           |
| Seoul        | 26.8        | 26.8           |
| Tokyo        | 26.6        | 26.6           |
| Hong Kong    | 26.5        | 26.5           |
| Jakarta      | 26.4        | 26.4           |
| New Delhi    | 26.3        | 26.3           |
| Peking       | 26.2        | 26.2           |
| Riyadh       | 26.1        | 26.1           |
| Cairo        | 26.0        | 26.0           |
| Bombay       | 25.9        | 25.9           |
| Seoul        | 25.8        | 25.8           |
| Tokyo        | 25.6        | 25.6           |
| Hong Kong    | 25.5        | 25.5           |
| Jakarta      | 25.4        | 25.4           |
| New Delhi    | 25.3        | 25.3           |
| Peking       | 25.2        | 25.2           |
| Riyadh       | 25.1        | 25.1           |
| Cairo        | 25.0        | 25.0           |
| Bombay       | 24.9        | 24.9           |
| Seoul        | 24.8        | 24.8           |
| Tokyo        | 24.6        | 24.6           |
| Hong Kong    | 24.5        | 24.5           |
| Jakarta      | 24.4        | 24.4           |
| New Delhi    | 24.3        | 24.3           |
| Peking       | 24.2        | 24.2           |
| Riyadh       | 24.1        | 24.1           |
| Cairo        | 24.0        | 24.0           |
| Bombay       | 23.9        | 23.9           |
| Seoul        | 23.8        | 23.8           |
| Tokyo        | 23.6        | 23.6           |
| Hong Kong    | 23.5        | 23.5           |
| Jakarta      | 23.4        | 23.4           |
| New Delhi    | 23.3        | 23.3           |
| Peking       | 23.2        | 23.2           |
| Riyadh       | 23.1        | 23.1           |
| Cairo        | 23.0        | 23.0           |
| Bombay       | 22.9        | 22.9           |
| Seoul        | 22.8        | 22.8           |
| Tokyo        | 22.6        | 22.6           |
| Hong Kong    | 22.5        | 22.5           |
| Jakarta      | 22.4        | 22.4           |
| New Delhi    | 22.3        | 22.3           |
| Peking       | 22.2        | 22.2           |
| Riyadh       | 22.1        | 22.1           |
| Cairo        | 22.0        | 22.0           |
| Bombay       | 21.9        | 21.9           |
| Seoul        | 21.8        | 21.8           |
| Tokyo        | 21.6        | 21.6           |
| Hong Kong    | 21.5        | 21.5           |
| Jakarta      | 21.4        | 21.4           |
| New Delhi    | 21.3        | 21.3           |
| Peking       | 21.2        | 21.2           |
| Riyadh       | 21.1        | 21.1           |
| Cairo        | 21.0        | 21.0           |
| Bombay       | 20.9        | 20.9           |
| Seoul        | 20.8        | 20.8           |
| Tokyo        | 20.6        | 20.6           |
| Hong Kong    | 20.5        | 20.5           |
| Jakarta      | 20.4        | 20.4           |
| New Delhi    | 20.3        | 20.3           |
| Peking       | 20.2        | 20.2           |
| Riyadh       | 20.1        | 20.1           |
| Cairo        | 20.0        | 20.0           |
| Bombay       | 19.9        | 19.9           |
| Seoul        | 19.8        | 19.8           |
| Tokyo        | 19.6        | 19.6           |
| Hong Kong    | 19.5        | 19.5           |
| Jakarta      | 19.4        | 19.4           |
| New Delhi    | 19.3        | 19.3           |
| Peking       | 19.2        | 19.2           |
| Riyadh       | 19.1        | 19.1           |
| Cairo        | 19.0        | 19.0           |
| Bombay       | 18.9        | 18.9           |
| Seoul        | 18.8        | 18.8           |
| Tokyo        | 18.6        | 18.6           |
| Hong Kong    | 18.5        | 18.5           |
| Jakarta      | 18.4        | 18.4           |
| New Delhi    | 18.3        | 18.3           |
| Peking       | 18.2        | 18.2           |
| Riyadh       | 18.1        | 18.1           |
| Cairo        | 18.0        | 18.0           |
| Bombay       | 17.9        | 17.9           |
| Seoul        | 17.8        | 17.8           |
| Tokyo        | 17.6        | 17.6           |
| Hong Kong    | 17.5        | 17.5           |
| Jakarta      | 17.4        | 17.4           |
| New Delhi    | 17.3        | 17.3           |

Table 3. Dry-bulb Temperature and Absolute Humidity for Cooling Design
Table 4. Dry-bulb Temperature and Absolute Humidity for Heating Design

| Locations | Frequency | Dry-bulb (℃) | Absolute Hum. (g/kg) |
|-----------|-----------|--------------|----------------------|
| Ankara    | 2.5%      | 16.6          | 5.5                |
|             | 5.0%      | 15.7          | 5.0                |
|             | 10.5%     | 14.5          | 5.0                |
|             | 15.0%     | 13.0          | 5.0                |
|             | 20.0%     | 12.0          | 5.0                |
|             | 25.0%     | 11.0          | 5.0                |
|             | 30.0%     | 10.0          | 5.0                |
|             | 35.0%     | 9.0           | 5.0                |
|             | 40.0%     | 8.0           | 5.0                |
|             | 45.0%     | 7.0           | 5.0                |
|             | 50.0%     | 6.0           | 5.0                |
|             | 55.0%     | 5.0           | 5.0                |
|             | 60.0%     | 4.0           | 5.0                |
|             | 65.0%     | 3.0           | 5.0                |
|             | 70.0%     | 2.0           | 5.0                |
|             | 75.0%     | 1.0           | 5.0                |

Note: Table 4. Dry-bulb Temperature and Absolute Humidity for Heating Design.