Examination on Expanded AMeDAS Design Weather Data for HVAC Systems

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Abstract

Expanded AMeDAS (Automated Meteorological Data Acquisition System) design weather data were developed for various locations in Japan. They were produced by selecting the extreme-weather days from Expanded AMeDAS Weather Data using two weather indices. The present paper examined the extremity of the proposed design weather data and the availability for HVAC system design. The cumulative frequencies of occurrence for several daily values of the design weather data and the probability of the thermal load exceeding the design peak load calculated using the design weather data were used for the examination and evaluation. The validity of the proposed design weather data was confirmed through the examination.

Keywords: design weather data; Expanded AMeDAS weather data; extreme weather; thermal peak load; HVAC system

Introduction

In the United States, ASHRAE (2001) provided the heating design single value of dry-bulb temperature, which was selected from the hourly weather records over a period of 10 to 40 years based on the cumulative frequency of occurrence. For summer design conditions, the single value of one weather element was presented with the mean coincident value of other weather elements, such as the design dry-bulb temperature with the mean coincident wet-bulb temperature for cooling. Colliver et al. (1989) proposed design weather sequences that include the real weather values for 1-, 3-, 5- and 7-day periods selected from the weather records using one weather index.

In Japan, the most popular design weather conditions are 24-hour values of dry-bulb temperature and humidity ratio (SHASE, 1989 and SHASE, 2001). These conditions were produced by selecting the extreme values based on the cumulative frequency of occurrence from the weather records for each hour and for each weather element. Takeda (1989) presented 24-hour design weather data including temperature, humidity ratio and solar radiation for Tokyo. Takizawa (1989) proposed 24-hour design weather data including temperature, humidity ratio, solar radiation, nocturnal radiation, wind speed and wind direction for 25 cities. These design weather values were independently selected for each hour and for each weather element from the weather records, and so may be unrealistic, extreme conditions. Chiba (1966) proposed a production method of design weather data in which extreme-weather days are selected using one weather index and the values of each weather element are averaged over the selected days for each hour.

The present authors developed a new production method of design weather data in which the extreme-weather days are selected using two weather indices and three types of cooling design data, and two types of heating design data are produced. Each type has noticeably distinct weather characteristics. The present paper attempts (1) to present and examine the extremity of each weather element in the design weather data, (2) to examine and clarify the availability of the design weather data for the design of several types of equipment, and (3) to confirm the adequacy of the design peak load determined using two or three types of design weather data.

Production method of design weather data

The production method of design weather data is summarized in Table 1. Data sources are Expanded AMeDAS Weather Data, which provide hourly weather values of various weather elements from 1981 to 2000 for 842 locations in Japan. For the selection of extreme-weather days, the 1st weather index and the 2nd weather index are used. Three types of cooling design weather data and two types of heating design weather data are produced using different combinations of the weather indices.

For the cooling design weather data on the h-t basis, the daily mean enthalpy $h_m$ is used as the 1st index and the daily mean dry-bulb temperature $t_m$ is used as the 2nd index, in order to produce the extreme temperature and enthalpy conditions, which are required for the design of equipment such as air-handling units (AHUs) that introduce fresh air. The cooling design weather data on the Jc-t basis and on the Js-t basis include the
conditions of intense solar radiation that are required for the design of equipment expected to remove solar heat gains through windows and condition perimeter zones. The 1st index is the daily total solar radiation incident on the vertical surface of a cylinder Tj for the data on the Jc-t basis and the daily total solar radiation incident on the south quarter of the vertical surface of a cylinder TJs for the data on the Js-t basis. The 2nd index is the tm for both types of design weather data.

For the heating design weather data, tm is used as the 1st index. The heating design weather data on the t-x basis are produced for the design of equipment such as AHUs that introduce fresh air, using the daily mean humidity ratio xm as the 2nd index. Extreme conditions of temperature and enthalpy are necessary for such equipment. The heating design weather data on the t-Jh basis are produced for the design of equipment such as FCUs, using the daily total of horizontal solar radiation Tjh as the 2nd index. The peak load of such equipment occurs on days with weak solar radiation and extremely low temperature.

In the procedure of selecting the extreme-weather days, first, 145 or 73 days that have the F-value for the 1st weather index close to the target value are selected. The F-value is the percentage of the cumulative frequency of occurrence. Next, 24 extreme-weather days with severe values of the 2nd index are chosen from the days selected by the 1st index. The weather values are averaged over these 24 extreme-weather days for each weather element and for each hour.

**Hourly changes in weather values**

Hourly changes in three types of cooling design weather data for 10 cities are shown in Fig.1. There are fewer differences in temperature between cities in the data on the h-t basis than in the other types of data. The temperature values for six southern cities in the data on the Jc-t basis are as high as those in the data on the h-t basis. The temperature and humidity ratios are so low for Asahikawa and Sapporo in the data on the Js-t basis that free cooling may be available. The peak value of solar radiation incident on the west and east surfaces, respectively, in the data on the Jc-t basis is relatively higher than that of the data on the h-t basis. The peak value of solar radiation incident on the south surface in the data on the Js-t basis is also relatively higher than that of the other types of data.

Hourly changes in two types of heating design weather data for nine cities are presented in Fig.2. The weather values for Naha are not shown in Fig.2 because heating is not required there. The data on the t-x basis include lower daily minimum temperature, lower humidity ratio, increased solar radiation and increased nocturnal radiation compared to the data on the t-Jh basis. The daily temperature range is narrow

Table 1. Production Method of Design Weather Data

| Weather type          | Cooling design weather data | Heating design weather data |
|-----------------------|-----------------------------|----------------------------|
|                       | h-t basis | Jc-t basis | Js-t basis | t-x basis | t-Jh basis |
| Date sources          | Expanded AMeDAS Weather Data for 20 years from 1981 to 2000 |
| The 1st index *1      | hm        | Tj        | TJs       | tm        | tm        |
| The 2nd index *1      | tm        | tm        | tm        | xm        | Tjh       |
| Ranking period for the 1st index | From June through Sept. (From June through Oct. for the southern area*2) | From Dec. through Mar. |
| Months designated for selection of extreme-weather days | July and Aug. | Sept. (Oct. for southern area) | Jan. and Feb. |
| The number of days selected | By the 1st index | 73 days | 145 days |
| By the 2nd index      | 24 days   |            |
| F-value for the 1st index *3 | 0.5% | minimum*4 | minimum*4 | 1% | 1% |

Selection procedures of extreme-weather days
(1) Rank the value for the 1st index over the designated period in the extremity.
(2) Select 73 or 145 days on which the F-values for the 1st index are close to the target value from the designated months. In case of the data on the Jc-t basis and on the Js-t basis, the days selected by the 1st index have the most extreme F-values for the 1st index among the days during the designated months.
(3) Select 24 days on which the 2nd index are severe from the days already selected by the 1st index. In this procedure, consideration is given to ensure the production of design weather data which have the F-value for the 1st index close to the target value.

Averaging procedures for every hour
(1) Produce the design values of weather elements including dry-bulb temperature, humidity ratio, horizontal solar radiation, horizontal nocturnal radiation and wind velocity through averaging the values over the selected 24 days. The design wind direction is determined by averaging the wind vector.
(2) Split the hourly mean value of horizontal radiation into the direct and diffuse components using Bourger's equation and Watanabe's equation (Watanabe et al., 1983).

*1 tm, hm and xm are the daily mean values of dry-bulb temperature, enthalpy and humidity ratio, respectively.
* Tjh, Tj and TJs are the daily total values of solar radiation incident on a horizontal surface, the vertical surface of a cylinder and the south quarter of the vertical surface of a cylinder, respectively
* The southern area is defined as the region where the north latitude is lower than 29°
*3 The F-value is the percentage of cumulative frequency of occurrence.
* The F-value for the 1st index that ranks 37th among those for the days in the designated months. This means the minimum F-value for the 1st index among those for the design weather data that can be produced from the designated months.
and solar radiation is weak in the data on the t-Jh basis. There are cities, such as Niigata and Asahikawa, in which the differences in temperature and humidity between the two weather types are not evident. However, the intensity of solar radiation for both weather types differs significantly for all cities.

Daily weather values and their extremity

Although the extremity of the 1st index of the design weather data is specified with the given F-value, the extremity of other weather elements is not obvious. The extremity of the daily values of the primary weather element was evaluated using their F-values for approximately 20 cities. The location of each city is shown in Table 2.

Fig.3. presents the daily weather values tm, hm, xm and TJsouth, TJwest, TJnorth and TJeast, and tm, hm and xm. In the data on the h-t basis with the given F-value of 0.5% for hm, the F-value for tm, tmax and xm are within 1%, approximately 2%, and approximately 1%, respectively, and the F-values...
for TJnorth are within 5% for many cities. The data on the h-t basis include the extreme conditions of high enthalpy, temperature and humidity ratio and intense solar radiation for north surfaces. In the data

Table 2. Location of 21 cities in Japan

| No. | City       | Latitude (°) | Longitude (°) |
|-----|------------|--------------|---------------|
| 1   | Asahikawa  | 43.77        | 142.37        |
| 2   | Sapporo    | 43.07        | 141.33        |
| 3   | Hakodate   | 41.82        | 140.75        |
| 4   | Aomori     | 40.82        | 140.77        |
| 5   | Sendai     | 38.27        | 140.90        |
| 6   | Utsunomiya | 36.55        | 138.87        |
| 7   | Maebashi   | 36.40        | 139.07        |
| 8   | Hachioji   | 35.67        | 139.32        |
| 9   | Tokyo      | 35.68        | 139.77        |
| 10  | Matsumoto  | 36.25        | 137.97        |
| 11  | Nagoya     | 35.17        | 136.97        |
| 12  | Niigata    | 37.92        | 139.05        |
| 13  | Kyoto      | 35.02        | 135.73        |
| 14  | Osaka      | 34.68        | 135.52        |
| 15  | Hiroshima  | 34.40        | 132.47        |
| 16  | Matsue     | 35.45        | 133.07        |
| 17  | Kochi      | 33.57        | 133.55        |
| 18  | Fukuoka    | 33.58        | 130.38        |
| 19  | Kumamoto   | 32.82        | 130.72        |
| 20  | Kagoshima  | 31.55        | 130.55        |
| 21  | Naha       | 26.20        | 127.68        |

tm, hm and xm: Daily mean values of dry-bulb temperature, enthalpy and humidity ratio, respectively

TJh: Daily total values of horizontal solar radiation

F-value: Frequency of occurrence

Fig.3. Daily Weather Values of Cooling Design Weather Data

For TJnorth, TJwest, TJnorth and TJeast: Daily total values of solar radiation incident on the south, west, north and east surfaces, respectively.
The daily weather values and their F-values for two types of heating weather data are shown in Figs. 5 and 6. The daily temperature range in the data on the t-x basis is wider than in the data on the t-Jh basis by 1 to 8 K according to cities. The values of TJh in the data on the t-Jh basis are lower than half of those in the data on the t-x basis. The F-values were obtained for the daily minimum and maximum temperature tm and tmax as well as hm, xm and TJh. In the data on the t-x basis, the F-values for both tm and tmax are 1 to 2% and the F-values for both hm and xm are approximately 0.5%, although the F-values for both TJsouth and TJnorth are approximately 10% for many cities. The data on the t-x basis include the extreme conditions of high temperature, as well as intense solar radiation, for west and east surfaces. In the data on the t-Jh basis, the F-values for TJsouth are 0.5%, although the F-values for tm, hm and xm are approximately 20%. The data on the t-Jh basis include extremely intense solar radiation for south surfaces and moderate temperature and humidity.

The daily weather values and their F-values for two types of heating weather data are shown in Figs. 5 and 6. The daily temperature range in the data on the t-x basis is wider than in the data on the t-Jh basis by 1 to 8 K according to cities. The values of TJh in the data on the t-Jh basis are lower than half of those in the data on the t-x basis. The F-values were obtained for the daily minimum and maximum temperature tm and tmax as well as hm, xm and TJh. In the data on the t-x basis, the F-values for both tm and tmax are 1 to 2% and the F-values for both hm and xm are approximately 0.5%, although the F-values for TJh range from 20 to 30%. The data on the t-x basis include the extreme conditions of temperature, enthalpy and humidity ratio with a considerable amount of solar radiation. In the data on the t-Jh basis, the F-values for tmax are approximately 0.5% and the F-values for hm

Design peak loads and their adequacy

Equipment design peak loads were calculated using the design weather data. Hourly equipment loads were also calculated over a period of 20 years using Expanded AMeDAS weather data. The method and assumptions for the thermal load calculation are as follows.

1. Heat conduction through walls and floors is calculated by the response factor method.
2. Air temperatures for 4 points and surface temperatures for 11 points are obtained by solving the convective and radiative heat balance equations.
3. It is assumed that equipment load is constant from 8:00 to 9:00 and space air temperature reaches the set point precisely at 9:00.
4. The equipment capacity is assumed to be sufficient in order to maintain the set point temperature and humidity in the conditioned space.
The adequacy of the equipment design peak load was evaluated using the P-value. The P-value is the percentage of the probability of occurrence of the thermal load exceeding the design peak load and is obtained with the ranking of hourly equipment load over 20 years. An office section and the HVAC systems for calculation are shown in Fig.7. Table 3. gives the calculation conditions. Design peak loads and corresponding P-values were calculated for three types of equipment, an air-handling unit (AHU) for the interior zone in system A and B, Fan coil units (FCUs) in system A and an AHU for the perimeter zone in system B. The AHU load for the interior zone is imposed by ventilation, internal heat generation and thermal storage due to intermittent operation. The FCU load depends on the sensible heat gain or loss through exterior walls and windows. The AHU load for the perimeter zone consists of all load components due to ventilation, heating and cooling for the perimeter zone. Calculations were performed for four cases of window orientation.

Fig.8. shows the ranking for hourly equipment load over 20 years. FCU cooling loads are affected by solar radiation transmitted through windows, and the ranking curves differ for the four different window orientations. For the evaluation of the adequacy of the calculated design peak load, the three grades according to the P-value were assumed. The P-values greater than 1%, within the range from 0.1 to 1% and within 0.1% are regarded as inadequate, adequate and sufficient, respectively.

It is recommended in the cooling design procedures to calculate cooling design peak loads using three types of design weather data for south facing spaces and two types of design weather data for other spaces, and to determine equipment capacity based on the maximum value of the design peak loads. The maximum of the design peak load corresponds to the minimum of the P-value. Fig.9. shows the P-values obtained with two or three types of design weather data for each type of cooling equipment for 12 cities. The minimum P-values obtained using different types of design weather data were within 1% for all equipment and all cities. The data on the h-t basis are suitable for the design of AHUs for interior zones and the P-value obtained using these data were within 0.2%. The data on the Js-t basis for the south facing space, the Jc-t basis for the west and east facing spaces and on the h-t basis for the north facing space lead to the minimum P-values for FCU, which were within 0.5% for almost all cases. The minimum P-values for AHU for the perimeter zone were obtained using the data on the h-t basis for south and north facing spaces, and were obtained using the data on the Jc-t basis for the west and east facing spaces. These P-values were within 0.2% for almost all cases.

Calculation of design peak loads using two types of design weather data for every case is recommended in the heating design procedures. The P-values for heating equipment are shown in Fig.10. The results for the east
**P-value**: Probability of occurrence of the thermal load exceeding the design peak load

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**Fig.9.** Probability of Occurrence of Cooling Load Exceeding the Design Peak Load Calculated with Three Types of Cooling Design Weather Data

- The minimum P-values were also within 1% for all heating equipment.
- For all three types of equipment, the data on the t-Jh basis tend to lead the minimum P-values for south facing spaces and the data on the t-x basis tend to lead the minimum P-values for north facing spaces.
- The minimum P-values were within 0.2% for AHUs for the interior zone and for the perimeter zone.
- Except for a few cases the minimum P-values for FCUs were within 0.5%.

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**Fig.10.** Probability of Occurrence of Heating Load Exceeding the Design Peak Load Calculated with Two Types of Heating Design Weather Data

- and west facing spaces are not shown in Fig.10., because they are similar to those for the south and north facing spaces, respectively.
- The minimum P-values were also within 1% for all heating equipment.
- For all three types of equipment, the data on the t-Jh basis tend to lead the minimum P-values for south facing spaces and the data on the t-x basis tend to lead the minimum P-values for north facing spaces.
- The minimum P-values were within 0.2% for AHUs for the interior zone and for the perimeter zone. Except for a few cases the minimum P-values for FCUs were within 0.5%.

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Conclusion

The extremity and the availability of the design weather data were examined and the adequacy of the design peak load calculated using the design weather data was confirmed.

1) The cooling design weather data on the h-t basis include the extreme conditions of high enthalpy, high temperature and intense solar radiation incident on a north surface. The F-values for hm are given as 0.5%. The F-values for tm and TJnorth are within 1% and 5%, respectively. These data are suitable for the design of AHUs for interior zones, FCUs for north facing spaces and AHUs for perimeter zones with north or south facing windows.

2) The cooling design weather data on the Jc-t basis include the extreme conditions of intense solar radiation incident on west and east surfaces and high temperature. The F-values for both TJwest and TJeast are 2 to 3% and the F-values of tmax are approximately 2%. These data are suitable for the design of FCUs and AHUs for perimeter zones in west and east facing spaces.

3) The cooling design weather data on the Js-t basis include the extreme conditions of intense solar radiation incident on the south surface and mild conditions of temperature and humidity ratio. The F-values for TJsouth are approximately 0.5% and the F-values for tm and hm are approximately 20%. These data are suitable for the design of FCUs for south facing spaces.

4) The heating design weather data on the t-x basis include the extreme conditions of low temperature and low enthalpy. The F-values for tm are given as 1%. The F-values for hm are approximately 0.5%. The data include a significant amount of solar radiation and the F-values for TJh range from 20 to 30%. These data are suitable for the design of equipment for north or west facing spaces.

5) The heating design weather data on the t-Jh basis include the extreme conditions of low temperature with a narrow daily temperature range and weak solar radiation. The F-values for tm are given as 1% and the F-values for TJh are approximately 5%. These data are suitable for the design of equipment for south or east facing spaces.

6) If design peak load calculations are performed with two or three types of design weather data and the maximum value of the design peak loads is adopted for the determination of equipment capacity, the P-values corresponding to the adopted design peak load are expected to be within 0.5% for most cases. This means that an adequate value of the design peak load can be obtained.

References

1) Akasaka, H. et al. (2000) Expanded AMeDAS Weather Data, AIJ
2) ASHRAE. 2001 (2001) ASHRAE Handbook-Fundamentals, 27.1-27.71
3) Chiba, T. (1966) Design outdoor conditions for air conditioning load estimation, Journal of SHASE, 40 (6), 25-36
4) Colliver, D. G., R. S. Gates et al. (1998) Sequences of extreme temperature and humidity for design calculations (RP-828). ASHRAE Transactions, 104 (1), 133-144
5) Kohri, K. and Ishino H. (1986) A study on total evaluation method of thermal environment and energy consumption, Journal of AIJ, 365, 40-48
6) Kohri, K. and Ishino H. (2004) A study on production method of design weather data for heating and air-conditioning using two weather indices, Journal of AIJ, 575, 27-32
7) Kohri, K. and Ishino H. (2005a) A study on the production method of design weather data for heating and air-conditioning using two weather indices part 2, Examination on a production method of heating design weather on a sunny day and a cloudy day and cooling design weather on a sultry day, Journal of AIJ, 588, 51-56
8) Kohri, K., Ishiono, H. et al. (2005b) A proposal of HVAC design weather data produced by using two weather indices Part 1, Technical Papers of Annual Meeting of IBPSA-Japan, 269-278
9) Kohri, K., Ishiono, H. et al. (2005c) A proposal of HVAC design weather data produced by using two weather indices Part 2, Technical Papers of Annual Meeting of IBPSA-Japan, 279-286
10) SHASE (1989) Calculation method of design thermal peak load, 4-9, 131-160
11) SHASE (2001) Handbook of Heating, Air-Conditioning and Sanitation, 13 (3), SHASE Tokyo
12) Takeda H. (1989) Tokyo weather data for air conditioning, Part 1 Outdoor design conditions for heating and cooling loads by T.A.C. method, Transactions of SHASE, 41, 105-115
13) Takizawa H. (1989) Micro-peak program, SHASE Symposium ‘Thermal load and software’, 13-24
14) Watanabe T., Urano Y. and Hayashi T. (1983) Procedures for Separating Direct and Diffuse Insolation on a Horizontal Surface and Prediction of Insolation on Tilted Surfaces, Journal of AIJ, 330, 96-108