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PROPOSAL OF SEVEN-DAY DESIGN WEATHER DATA FOR HVAC PEAK LOAD CALCULATION

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ABSTRACT

This paper proposes a method for creating an extreme seven-day weather data set for HVAC design purposes and examines its suitability. The method involves reviewing data from 20 years of weather observations and selecting a seven-day period during which the weather conditions were extreme. The dry-bulb temperature, the humidity ratio, the solar radiation and other weather elements were obtained for one-hour intervals during the selected period as the design weather conditions. In order to select a meteorologically extreme period with distinct weather characteristics, two weather indices were used. The extremity of the design weather data was evaluated by determining both the frequency of occurrence of characteristic weather values and the likelihood of the thermal load exceeding the design peak load, which was calculated using the design weather data. The results confirmed the validity of using the data to determine sufficient capacities for HVAC equipment.

INTRODUCTION

In the past, weather data used for HVAC design in Japan has been determined by taking the weather values over the previous ten years or so, and then carrying out statistical processing to extract extreme values for each weather element and time category (SHASE, 2001). These values are then linked and used as one-day design weather data. However, this design weather data represents unrealistically severe weather, and can lead to overestimation in the required equipment capacity. In the United States, to give the design weather conditions, an extreme value of a certain weather element was selected from among the weather observation values recorded over all time, and the other weather element values corresponding to that time were taken as a set (ASHRAE, 2001). Colliver et al proposed a method for determining design weather sequences that uses the mean value for a certain weather element over a given period of time as an index in order to select several days of extreme weather (Colliver et al, 1998). The real values for several weather elements during that period were then proposed for the design weather conditions. Although various types of design weather sequences that differ in the indices and length of the sequence used have been obtained, an individual must decide the sequence to be used.

Based on the fact that the characteristics of the weather when the peak load occurs vary depending on the HVAC equipment, the author proposed a method in which several types of extreme-weather period are selected based on two weather indices. This allows for the selection of realistic weather with distinct characteristics and allows for a reduction in the number of types of design weather data. The proposed method is for creation of seven-day design weather data including weather elements required for design peak load calculation such as dry-bulb temperature, humidity ratio, normal direct solar radiation, horizontal diffuse solar radiation and horizontal nocturnal radiation. Weather can be affected by urban heat generation and exhausted gas and weather characteristics on holidays may be different from those on weekdays. Therefore, the design weather data are provided for 7-day period matching the human weekly working cycle.

METHOD OF CREATING DESIGN WEATHER DATA

Data sources

The data source is the expanded AMeDAS weather database (Akasaka et al, 2003). This database comprised of 20 years (1981-2000) of data of primary weather elements for approximately 840 domestic locations in Japan. This paper employed the data for seven cities: Tokyo, Sapporo, Sendai, Nagoya, Osaka, Fukuoka and Naha.

Weather type and weather indices

A method for creating two types of weather data for heating design and three types of weather data for cooling design is proposed.

The two types of weather data for heating design are called the t-x basis data and the t-Jh basis data.

1) In the t-x basis data, the dry-bulb temperature (t)

and the humidity ratio (x) are extreme. This design data is suitable for equipment such as air-handling units in which fresh air is introduced. For the weather indices, the mean dry-bulb temperature (tm) over a seven-day period is used as the first index, and the mean humidity ratio over a seven-day period (xm) is used as the second index. A seven-day period is selected over which both of these are extreme.

2) The t-Jh basis data is taken from cloudy weather data with extreme dry-bulb temperatures and weak horizontal solar radiation (Jh). This is suitable for equipment such as air-handling units for perimeter zones with good sunlight. The mean dry-bulb temperature over seven days is used as the first index, and the mean value over seven days for the daily cumulative horizontal solar radiation (Jh, m) is used as the second index.

The three types of weather data used for cooling design are the h-t basis, Jc-t basis, and Jcs-t basis data.

1) The h-t basis data is taken from humid weather data with extreme enthalpy (h) and dry-bulb temperature. This is suitable for devices such as air-handling units into which fresh air is introduced. The mean enthalpy (hm) over a seven-day period is used as the first index and the mean dry-bulb temperature over a seven-day period is used as the second index.

2) The design intention for the Jc-t basis data was to represent a period with a high level of ambient solar radiation and an extreme dry-bulb temperature around the outside perimeter of the building. This is suitable for devices such as an air-handling units used at a perimeter. The first index uses the mean value over a seven-day period for the daily cumulative solar radiation incident on the vertical side of a cylindrical surface (Jc, m), and the second index uses the mean value over a seven-day period for the dry-bulb temperature.

3) The Jcs-t basis data gives design weather data for HVAC equipment in south-facing zones. The first index used the mean value over a seven-day period for the daily cumulative solar radiation incident on 1/4 of the south-facing side of a cylindrical surface (Jcs, m), and the second index used the mean value over a seven-day period for the dry-bulb temperature. Although there is a higher load on the air-handling unit for south-facing zones during autumn, the month in which the peak load occurs depends upon the building characteristics. For this reason, extreme weather from September and October was selected and used to create the two types of Jcs-t basis data. However, since the peak summer period is short in Sapporo, August and September were selected as the extreme weather periods, and because the peak summer period is long in Naha, October and November were selected as the extreme weather periods.

Data Creation Procedure

1) Ranking of the values of the first index

For the heating design, the mean weather values were calculated over seven-day periods during the four-month period from December through March. For the cooling design, the mean weather values were calculated over seven-day periods during the five-month period from June through October (for Naha, this was the six-month period from June through November). These mean values were ranked in order of extremity. The seven-day mean values were calculated for seven-day periods by shifting the value one day at a time.

2) Target value for the frequency of occurrence

The target values for the frequency of occurrence were obtained for the first and second indices. The target value means the probability of occurrence of weather periods that have more extreme value of the first/second index than that for the selected period as the extreme-weather period. The frequency of occurrence of the weather values such as the first and second index is presented as the percentage value based on the number of all periods over 20 years that is 7305 periods. This paper indicates the results based on a target frequency of occurrence of 1%.

3) Selecting the extreme-weather period

For the t-x basis data, 30 periods (corresponding to 0.4% of the total number of periods over 20 years) were initially selected such that the frequency of occurrence of the first index was close to the target value. Next, out of these 30 periods, one period from both January and February was selected as the extreme-weather period such that the frequency of occurrence for the second index was close to the target value. For the t-Jh basis data, 73 periods (corresponding to 1% of the total number of periods over 20 years) were selected using the first index, because there are fewer seven-day periods of cloudy weather.

For the h-t and Jc-t basis data, 30 periods were selected for which the frequency of occurrence of the first index was close to the target value. Then, out of these 30 periods, one period from both July and August was selected as the extreme-weather period such that the frequency of occurrence of the second index was close to the target value. For the Jcs-t basis data, 30 periods were selected for which the frequency of occurrence of the first index was close to the target value from the specified month. Then, one period was selected for which the frequency of occurrence of the second index was close to the target value. As mentioned above, two months were specified for each city depending on the peak

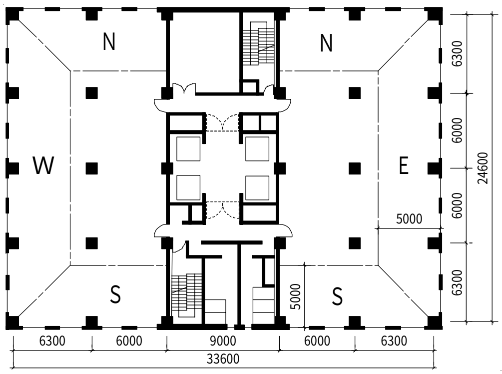


Figure 1 Typical floor plan of an office building

Table 1 Simulation conditions

Set points of space air temperature and relative humidity 26C and 50% in summer season from June through September 24C and 50% in spring season from April through May 22C and 50% in winter season from December through March 24C and 50% in autumn season from October through November
Cooling and Heating hours from 7:00 to 18:00 in winter season (warming-up hours from 7:00 to 9:00) from 8:00 to 18:00 in the other season (pulling-down hours from 8:00 to 9:00)
Ventilation Fresh airflow rate 4 CMH/m2 Ventilating hours from 9:00 to 18:00
Internal heat generation Lighting 20W/m2 Occupant 0.2 persons/m2 OA equipment 25W/m2

Ftm, Fxm and FJh,m: frequencies of occurrence of tm, xm and Jh,m
tm: mean dry-bulb temperature over a 7-day period, xm: mean humidity ratio over a 7-day period
Jh,m: mean value over a 7-day period for the daily cumulative horizontal solar radiation

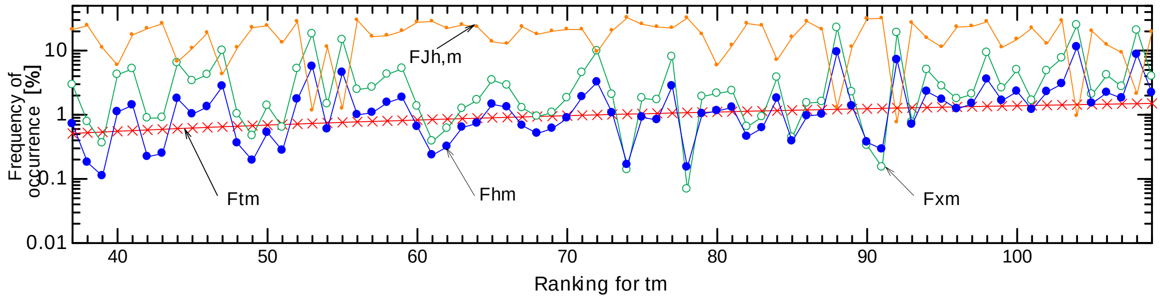


Figure 2 Frequencies of occurrence of weather characteristic values compared with ranking for the seven-day mean of dry-bulb temperature (tm)

summer period. One extreme-weather period from each of these months was then selected.

Sapporo: August and September;
Sendai, Tokyo, Nagoya, Osaka and Fukuoka:
September and October;
Naha: October and November

In the case of the h-t basis data that have the frequency of occurrence for each of the first and second index equal to the target value, the same design weather data can be created even if enthalpy and temperature are changed with humidity ratio and temperature as the two weather indices. However, the frequency of occurrence for the first or second index is not always equal to the target value. Therefore, the important weather elements for the equipment were used as the index.

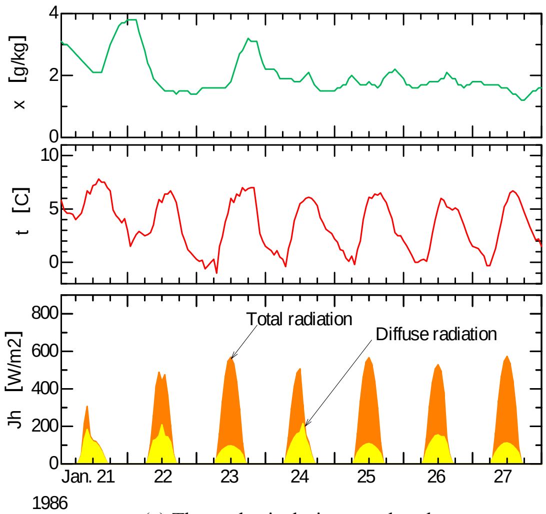
4) Weather elements for the design weather data

The dry-bulb temperature, humidity radio, total horizontal solar radiation, nocturnal radiation, and wind direction and velocity values at hourly intervals for the selected extreme-weather periods were presented as the design weather data.

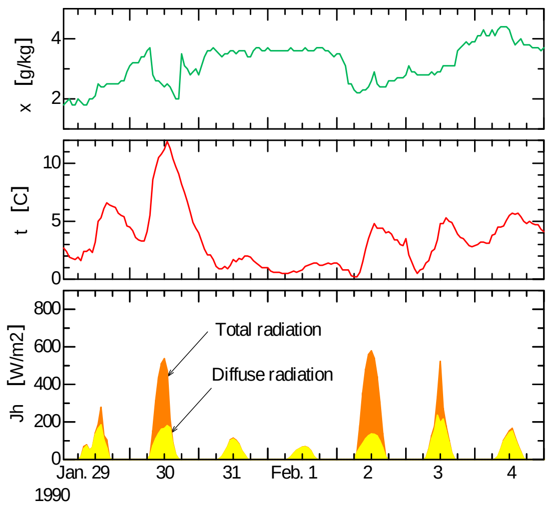
EXAMINATION METHOD

The severity of the proposed design weather was first examined from the standpoint of the frequency of occurrence for the weather characteristic values. Next, the dynamic thermal loads were calculated for the weekly periods used for the design weather data, and the design peak load obtained from calculation and likelihood of the thermal load exceeding the design peak load were evaluated. Calculation of the dynamic thermal load was performed using the New HASP/ACLD-β (Nagai et al., 2004). In Japan, HVAC systems generally operate intermittently, and the peak heating load occurs during the warming-up time. This program performs calculations without the need to input the heating capacity based on the assumptions that the heating rate during the warming-up time is constant and that the room air temperature reaches the set point at precisely the time that warming-up finishes. Based on these assumptions, the design peak load can be determined for the heating equipment. These calculations were carried out for four directional zones on a typical floor in an office building, as shown in Fig. 1. Each zone is conditioned by each air-handling unit that introduces outside air for the zone. The calculation conditions are provided in Table 1. The likelihood of the thermal load exceeding the design peak load was determined using the rankings of the hourly thermal load calculated over 20 years with the expanded AMeDAS weather data.

RESULTS



(a) The t-x basis design weather data

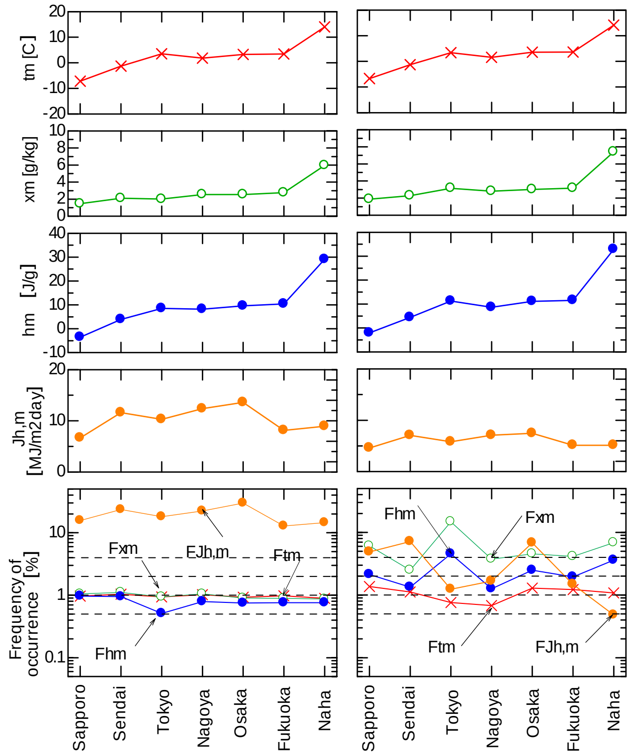


(b) The t-Jh basis design weather data

Figure 3 Fluctuation of dry-bulb temperature (t), humidity ratio (x) and horizontal solar radiation (Jh) in two types of heating design weather data

Heating design weather data

First, examinations were conducted using the design data for Tokyo. Fig. 2 shows the frequencies of occurrence Ftm, Fxm, Fhm and FJh,m for tm, xm, hm and Jh, respectively, as a function of the ranking sequence based on the first index tm. The 73 periods from 37 to 109, which correspond to frequencies of occurrence between 0.5 to 1.5%, are indicated. There were many periods during which both Ftm and Fxm were around 1%, making it possible to select the t-x basis data with a frequency of occurrence of around 1% from the 30 periods from 58 to 87. On the other hand, there were few cases in which FJh,m was around 1%, and selecting the t-Jh basis with a frequency of occurrence of 1% required 73 periods from 37 to 109. The time fluctuations for the t-x and t-Jh basis data for Tokyo are shown in Fig. 3. The t-x basis data is characterized by clear days and a large



(a) The t-x basis design weather data (b) The t-Jh basis design weather data

Figure 4 Weather characteristic values and their frequencies of occurrence in two types of heating design weather data

daily variation in dry-bulb temperatures. In the t-Jh basis data, on the other hand, the level of solar radiation is low and the daily variation in dry-bulb temperatures is small, while on many days the humidity was somewhat high. Two types of design weather data could be created with vastly different weather characteristics.

Fig. 4 shows the principal weather characteristic values for the t-x and t-Jh basis data of the seven cities in Japan, along with their frequencies of occurrence. The t-x basis data for all cities is severe, with Ftm, Fxm and Fhm being around 1%, while FJh,m ranges between 20 and 30%. Therefore, it was possible to create design weather data with a similar degree of extremity. Although there were some cities in which the frequencies of occurrence of the first and second indices, Ftm and FJh,m, were both close to the target of around 1% for the t-Jh basis data, there were also cities such as Sendai and Osaka where FJh,m was around 7% and the level of solar radiation was somewhat high.

Cooling design weather data

Figs. 5 and 6 show the frequencies of occurrence for the weather characteristics for Tokyo with rankings between 58 to 87 for hm and Jc,m, respectively. From Fig. 5, it can be seen that periods

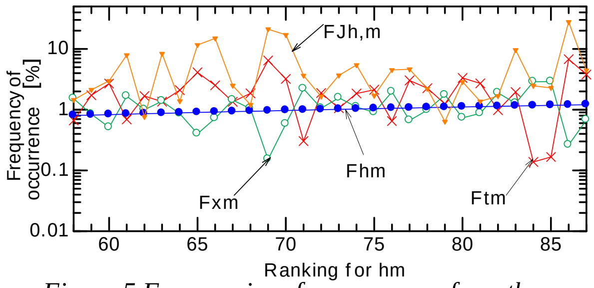


Figure 5 Frequencies of occurrence of weather characteristic values compared with ranking for the seven-day mean of enthalpy (hm)

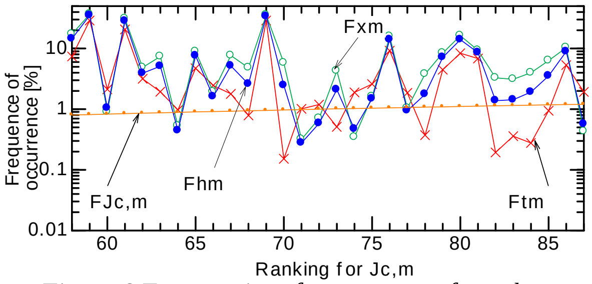
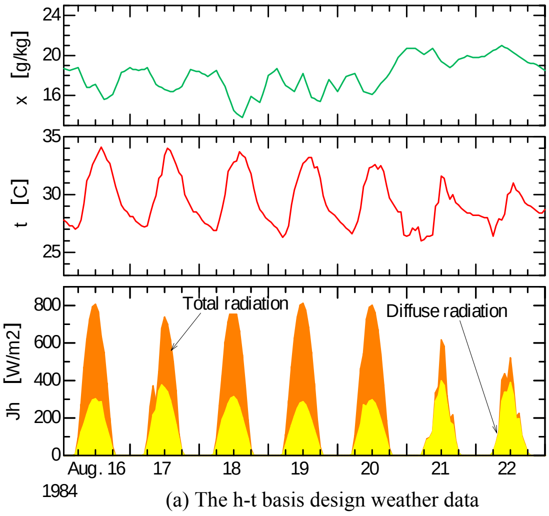


Figure 6 Frequencies of occurrence of weather characteristic values compared with ranking for the seven-day mean of daily cumulative solar radiation incident on a cylindrical surface (Jc,m)

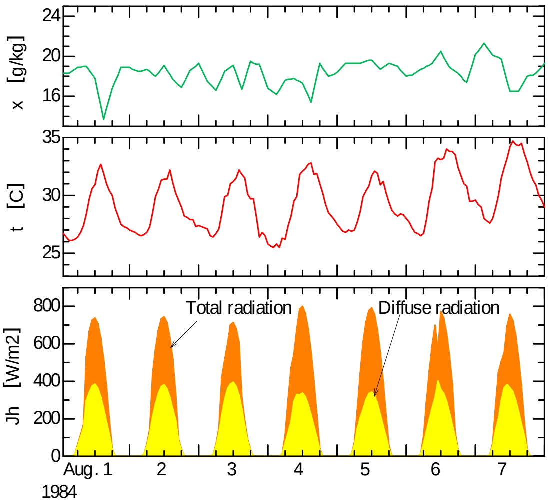
in which both Fhm and Ftm are around 1% were selected from the 30 periods from 58 to 87. Similarly, Fig. 6 shows that periods can be selected in which both FJc,m and Ftm are around 1%. The time fluctuations in the h-t basis data and the Jc-t basis for Tokyo are shown in Fig. 7. The Jc-t basis data reflects more consecutive days during which there was strong solar radiation. The differences observed in the dry-bulb temperature and humidity characteristics were not that significant between the two types of data.

Fig. 8 shows the frequencies of occurrence for the weather characteristic values for Tokyo with rankings between 58 to 87 for Jcs,m during the months of June through October. Most of the periods in this range were in October. The frequency of occurrence for the second index Ftm is 30 to 40%, and it was not possible to select a period within October that would produce the target value of 1% . Fig. 9 shows the time fluctuations in the Jcs-t basis data for September and October for Tokyo. The solar radiation is the value for the south-facing surface. The dry-bulb temperature for the September design weather data is fairly extreme, exceeding 30 ^{o}C on consecutive days. Both the dry-bulb temperature and the humidity are low in the October design weather data, and the data includes cloudy days. The October data could possibly be used to study natural ventilation.

Fig. 10 shows the weather characteristic values



(a) The h-t basis design weather data



(b) The Jc-t basis design weather data

Figure 7 Fluctuation of dry-bulb temperature (t), humidity ratio (x) and horizontal solar radiation (Jh) in two types of cooling design weather data

and their frequencies of occurrence for the four types of cooling design weather data. In the results, FJh,m, Ftm, Fxm, and Fhm of the Jc-t basis data are all around 1%. The data Jc-t basis was found to be more extreme than the h-t basis data from the viewpoints of horizontal solar radiation, dry-bulb temperature, and humidity. Fig. 11 shows the frequencies of occurrence of the mean values over seven days for the daily cumulative solar radiation incident on the south-, west-, north- and east-facing surfaces for the four types of cooling design weather data in Tokyo. In the Jcs-t basis data, the frequency of occurrence for the solar radiation incident on the south-facing surface is the target value of 1% for October, but was 4% for September. In the Jc-t basis data, the frequencies of occurrence for solar radiation incident on the west-, north- and east-facing surfaces are around the target value of 1%, so the Jc-t basis data may be suitable for HVAC equipment in zones

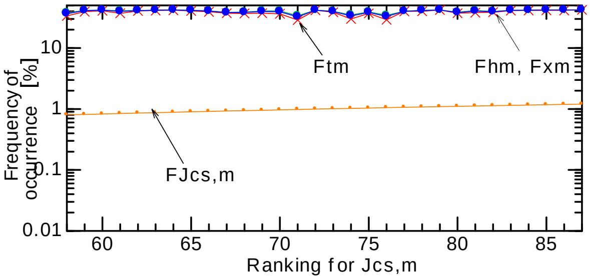
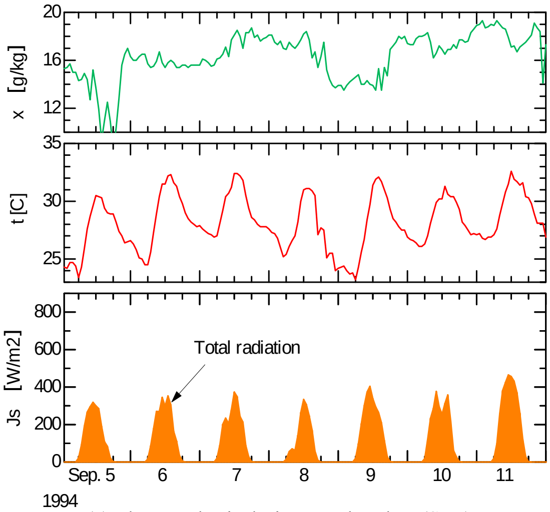
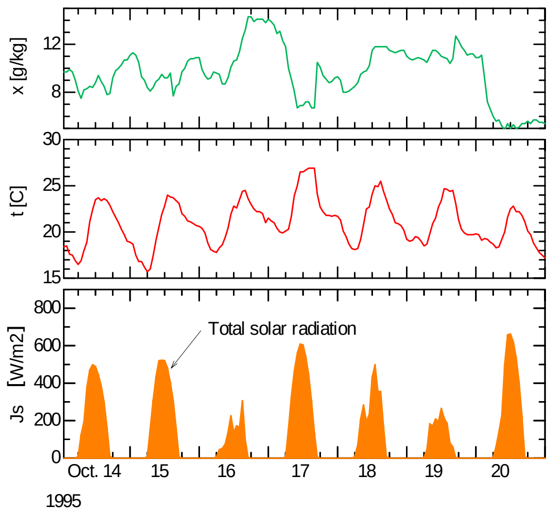


Figure 8 Frequencies of occurrence of weather characteristic values compared with ranking for the seven-day mean of daily cumulative solar radiation incident on the south-facing side of a cylindrical surface (Jcs,m)



(a) The Jcs-t basis design weather data (Sep.)



(b) The Jcs-t basis design weather data (Oct.)

Figure 9 Fluctuation of dry-bulb temperature (t), humidity ratio (x) and solar radiation incident on a south-facing surface (Js) in two types of the Jcs-t basis cooling design weather data

facing these three directions.

Fig. 12 shows the weather characteristic values and their frequencies of occurrence for the four types of

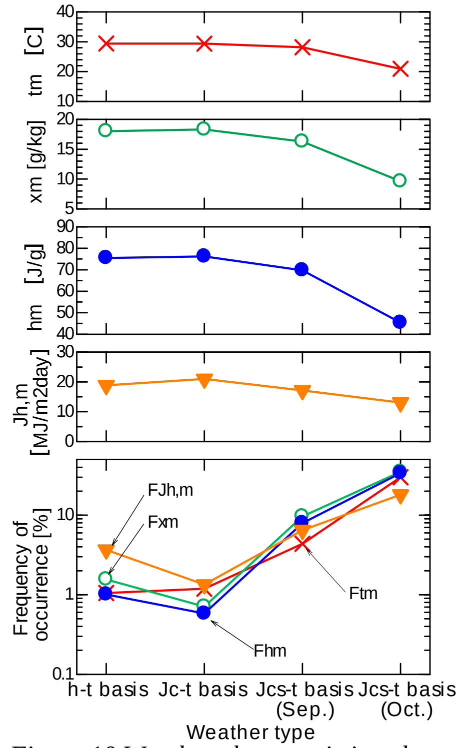


Figure 10 Weather characteristic values and their frequencies of occurrence in four types of cooling design weather data

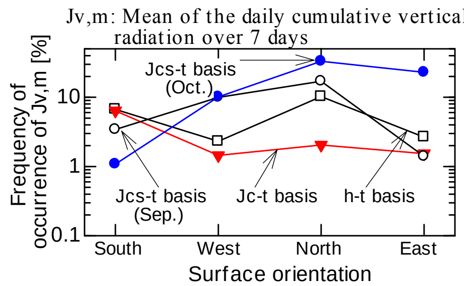
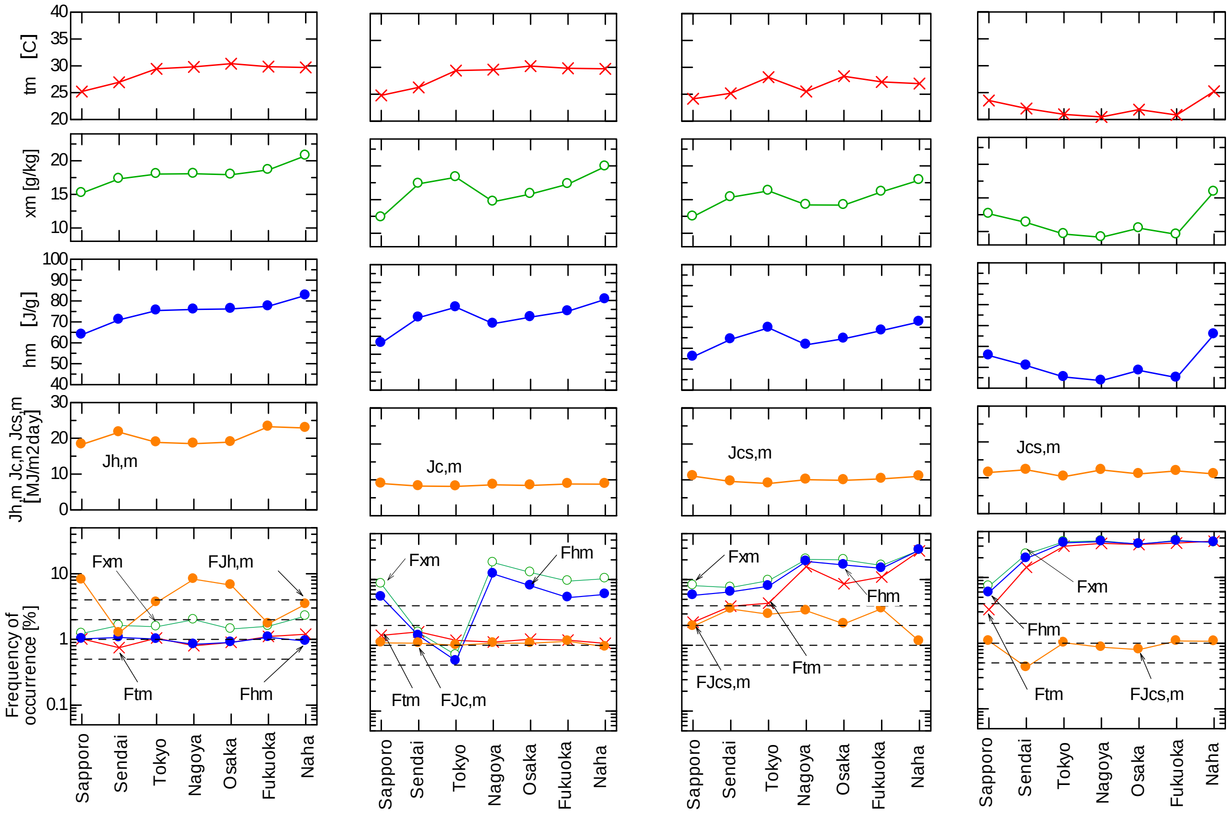


Figure 11 Frequencies of occurrence of the seven-day mean of daily cumulative vertical solar radiation (Jv,m)

cooling design weather data for the seven cities. The results show that in the h-t basis data for Sendai and Fukuoka and in the Jc-t basis data for Tokyo, the frequencies of occurrence of all of the weather characteristic values are around 1%. The h-t basis data may be sufficient for Sendai and Fukuoka without using the Jc-t basis data. Conversely, for Tokyo, the design weather Jc-t basis data may be sufficient without using the h-t basis data. The Fxm and Fhm values for the Jc-t basis data are around 10% for all cities, with the exception of Sendai and Tokyo, due to slightly high humidity.

Design thermal peak load

Fig. 13 shows the design peak load for the four directional zones in office buildings in Tokyo determined using the design weather data, as well as values for the likelihood of the thermal load



(a) The h-t basis design weather data

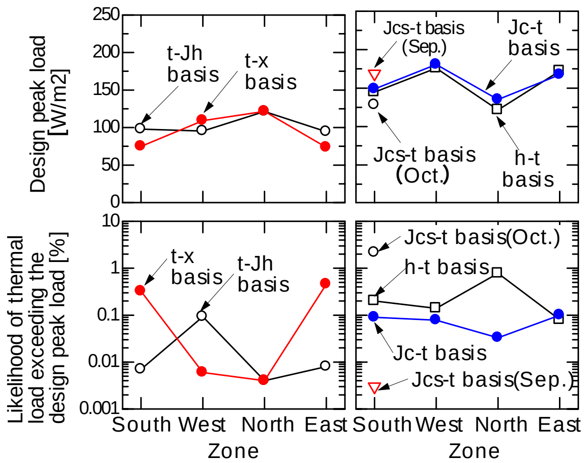
(b) The Jc-t basis design weather data

(c) The Jcs-t basis design weather data (Aug. for Sapporo, Oct. for Naha and Sep. for the other cities)

(d) The Jcs-t basis design weather data (Sep. for Sapporo, Nov. for Naha and Oct. for the other cities)

Figure 12 Weather characteristic values and their frequencies of occurrence in four types of cooling design weather data for seven cities

exceeding the design peak load. The likelihood of the thermal load exceeding the design peak load was determined using the rankings of the hourly thermal load. In this paper, the design peak load is regarded as sufficiently safe if the likelihood of the thermal load exceeding the design peak load is 0.1% or less. The heating design peak load was higher in the south- and east-facing zones when the t-Jh basis data was used, while in the west-facing zone the t-x basis data produced a larger load. The t-Jh basis data tends to be suitable in zones that receive good sunlight and the t-x basis data tends to be suitable in zones that do not receive good sunlight. Also, the likelihood of the thermal load exceeding the design peak load for heating of was low in all zones, at around 0.01%. The cooling design peak load was higher in the south-facing zone when the Jcs-t basis data from September was used. For the west- and east-facing zones, the difference in using the h-t basis and Jc-t basis data was not significant, while in the north-facing zone, the cooling design peak load was larger when the Jc-t basis data was used. From the perspective of the likelihood of the thermal load exceeding the design peak load, sufficiently valid results will generally be produced for all zones if the Jc-t basis design data is used.



(a)Heating dsign peak load

(b)Cooling design peak load

Figure 13 Design peak loads and likelihood of thermal load exceeding the design peak load

CONCLUSION

Two types of weather data for heating design and three types of weather data for cooling design were proposed and evaluated.

1) Using two weather indices, different types of real weather with clear differences in weather characteristics, such as t-x basis data and t-Jh basis data, could be selected.

2) In some cities, the h-t basis data and Jc-t basis data had similar characteristics. Both these design weather data sets included extreme values for the enthalpy, dry-bulb temperature and solar radiation.

3) If the equipment capacity is determined from the maximum value of the design peak load in all of the design weather types, it will be possible to design HVAC equipment with a sufficient capacity.

In the future, case studies will need to be conducted on a wider scale to clarify which type of design weather data is appropriate for which type of HVAC equipment.

NOMENCLATURE

t = Dry-bulb temperature [°C]
x = Humidity ratio [g/kg]
h = Enthalpy [J/g]
Jy = Solar radiation incident on a surface y[W]
y is as follows
h = A horizontal surface
c = A cylindrical surface
cs = 1/4 of the south-facing side of a cylindrical surface
s = A south-facing surface
tm, xm, hm = Mean of *t, x, h* over 7 days
Jy,m = Mean of the daily total of *Jy* over 7 days [MJ/m2day]
Fz = Annual cumulative frequency of occurrence of weather parameter z [%]

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