Energy and Built Environment 1 (2020) 417–422

Contents lists available at ScienceDirect

Energy and Built Environment

journal homepage: www.elsevier.com/locate/enbenv

Deviation of design air-conditioning load based on weather database of reference weather year and actual weather year

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A R T I C L E I N F O

Keywords:
Design air-conditioning load
Annual air-conditioning load time ratio
Reference weather year
Actual weather year
New HASP/ACLD

A B S T R A C T

In Japan, in order to determine the capacity of air-conditioning equipment, designers usually use the weather database of Reference Weather Year (RWY) to obtain the design air-conditioning load by using software such as New HASP/ACLD and Building Energy Simulation Tool (BEST) that are often used in Japan. In recent years, with the global warming due to climate change, the weather database used to calculate air conditioning load also changes. Thus, in order to determine an appropriate capacity of air-conditioning equipment for energy conservation of buildings, the deviation of design air-conditioning load calculated using the weather database of RWY and Actual Weather Year (AWY) should be discussed.

In this paper, New HASP/ACLD was used to calculate the building heat loads of eight major Japanese cities over 30 years (1981–2010) between RWY and AWY. The heat load at an exceedance probability of 2.5% is defined as the design air-conditioning load in this paper. Comparing the design air-conditioning load obtained from RWY and AWY, it is shown that it is not necessarily the most appropriate when using the RWY to calculate the design air-conditioning load, especially for heating load in winter. Additionally, it is also shown that the annual heating load time ratio has decreased and the annual cooling load time ratio has increased over the 30 years.

1. Introduction

In the past, it was difficult to evaluate the heat loads of buildings due to the lack of weather data and computer performance. In order to evaluate heat loads of buildings and prevent the evaluated values from getting too larger or too small that may lead to excessive or small air-conditioning capacity selection, the Reference Weather Year (RWY) has been designed to calculate the design air-conditioning load [1,2]. In EU and US, it is also called "Typical Meteorological Year (TMY)" [3].

Up to now, Expanded Automated Meteorological Data Acquisition System (AMeDAS) weather data from 1981 to 2010 were developed for 842 locations in Japan [4,5], and each location has three types of RWY weather data, that are the period from 1981 to 1995 (RWY_1), the period from 1991 to 2000 (RWY_2), and the period from 2001 to 2010 (RWY_3).

Currently, with the global warming due to climate change, the design air-conditioning load for building energy savings is also changing. Under the call of environmental improvement and energy conservation, the accuracy of the design air-conditioning load calculation from RWY needs to be improved. There are several methods to calculate the design air-conditioning load [6–9], and the method which is choosing the 2.5% exceedance probability heat load as the reference standard is selected in this study [10].

In order to evaluate the effect of climate change on design air-conditioning load of buildings in Japan [11], the deviation of design air-conditioning load based on the weather database of RWY and Actual Weather Year (AWY), and the change in annual cooling and heating load time ratio over 30 years (1981–2010) is analyzed using the program "New HASP/ACLD" [12,13] in this paper.

2. Reference weather year

Japan has been producing and using RWY to calculate heat load of buildings since 1970. So far, there have been two main methods of making RWY, one is the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) method, and the other is the Expanded AMeDAS (EA) method [14,15]. SHASE method is almost same as International Standard (ISO15927-4: 2005) [16], and it chose the candidate month from statistics determined by using three elements; dry bulb temperature, absolute humidity, and horizontal global solar irradiation. The deviation of these three elements times weight coefficient determined by data of building monthly names "DM" is calculated at first, then the

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https://doi.org/10.1016/j.enbenv.2020.04.010
Received 16 March 2020; Received in revised form 24 April 2020; Accepted 24 April 2020
Available online 18 May 2020

Table 1
Location of eight main cities in Japan.

Location	Sapporo	Sendai	Tokyo	Nagoya
Longitude	141.33°E	140.90°E	140.76°E	136.96°E
Latitude	43.06°N	38.26°N	35.69°N	35.17°N
Location	Osaka	Hiroshima	Fukuoka	Naha
Longitude	135.52°E	132.46°E	130.38°E	127.69°E
Latitude	34.68°N	34.40°N	33.58°N	26.21°N

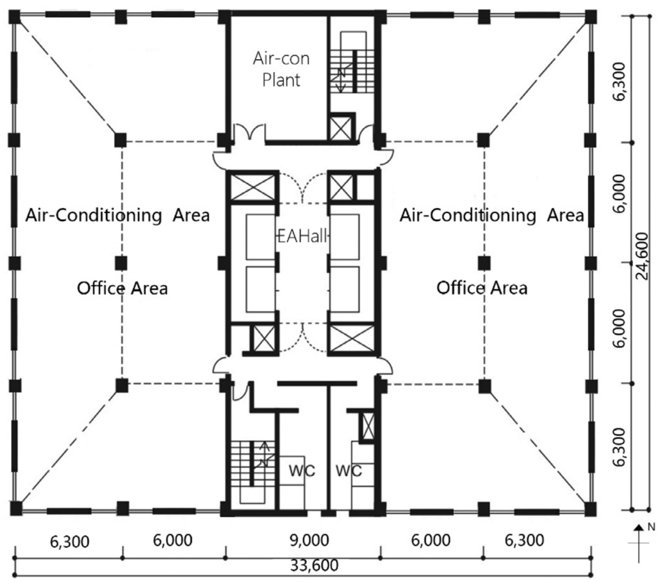

Fig. 1. Typical level of simulation building with 605m^2 air-conditioning area.

typical month with minimum “DM” is selected, and the 12 selected typical months are concatenated to form a complete year finally.

The RWY made by EA method has three types, based on EA weather data from 1981 to 1995 (1995 version), from 1991 to 2000 (2000 version), and from 2001 to 2010 (2010 version), Unlike SHASE method, EA method [17,18] has added two elements for choosing the candidate month, wind speed and precipitation. Because of the change of building insulation performance and others, 2000 and 2010 versions of EA method chose typical month with minimum deviation of monthly average temperature but not “DM” value, and it could eliminate the influence of the building conditions, compared to SHASE method. However, if only the “temperature” factor is considered to select the typical months of RWY instead of three factors (dry bulb temperature, absolute humidity and horizontal global solar irradiation), it may leads to a deviation in calculating air conditioning load based on RWY.

3. Study target and simulation building

3.1. Main cities of Japan

In this paper, in order to know the deviation of design air-conditioning load based on RWY and AWY and the difference between different cities of Japan, eight major cities in Japan from north to south are selected. The geographic locations of eight cities are detailed in Table 1.

3.2. Simulation building

To make the results representative and in accordance with the building use standards [19,20] in different areas, a standard office building model [21] with an air-conditioned area of 605m^2 (shown in Fig. 1) often used in Japan [22–24], is adopted as the building simulation in this study, and it is assumed to be located in eight major cities of Japan. Windows account for one-third of the outer wall area. The details of the building simulation and the operation schedule of air-conditioning are shown in Table 2.

4. Methodology

4.1. New HASP/ACLD

New HASP/ACLD is a typical simulation program often used in Japan [25,26], and the program use triangle pulse wave to calculate the indoor temperature, absolute humidity and air-conditioning load hourly, the result that we get is 1-hr averages of air-conditioning load. The weather data for calculating the air-conditioning load of simulation building by New HASP/ACLD include 7 hourly elements in a specific form; dry-bulb temperature, absolute humidity, wind direction, wind speed, cloud cover or nocturnal radiation, direct solar radiation and diffuse solar radiation.

4.2. Load exceedance probability

Based on the relation between load exceedance probability and temperature exceedance probability, an exceedance probability of 2.5% of heat loads including cooling load and heating load, is selected as design air-conditioning load in this study. The selection method is described as follows:

- 1st step: set the device capacity be infinity for simulation.
- 2nd step: take four months respectively as cooling period (from June to September) and heating period (from December to March).
- 3rd step: calculate the hourly heat load respectively for the cooling period and heating period.
- 4th step: arrange and rank the calculated hourly cooling load and heating load, select the value at the exceedance probability of 2.5% (large value in descending order for design cooling load and small value in ascending order for design heating load).

4.3. Deviation of design air-conditioning load and change in annual load time ratio

In order to know the effect of climate change on the design air-conditioning load, the deviations of design air-conditioning load based on RWY and AWY weather database over 30 years (1981–2010) are calculated for eight main locations of Japan. Moreover, the frequency distributions of design air-conditioning load deviation are analyzed for eight main locations in this study. Because the weather data from 1991 to 1995 are existing in both versions of RWY (1995 ver. and 2000 ver.), in order to integrate meteorological data for a 10-year period of RWY, the RWY of 2000 version has been used to evaluate the deviation in this study.

In addition, the change in annual load time ratio that includes heating load ratio, cooling load ratio and zero load ratio are also analyzed for eight main locations in this study.

5. Results and discussion

The deviation of design air-conditioning load (cooling load and heating load) between RWY and AWY over 30 years and its frequency distribution for eight main locations of Japan are respectively shown in Fig. 2 and Fig. 3.

Fig. 2 shows the changes in deviation of design air-conditioning load over 30 years (1981–2010) between RWY and AWY in eight main cities of Japan. The result showed the deviations of design cooling load in Tokyo and Naha are almost negative over 30 years, and it is found that the mean temperature of RWY used for calculating design cooling load are almost higher than the temperature of AWY, thus it may lead to such

Table 2
Details of the building simulation and the operation schedule of air-conditioning.

Type of building	Office building			
Amount of fresh air	Infiltration 0.2 times/hour		Air conditioning ventilation 6 m^3/m^2h	
Air conditioning service	Weekday 8:00~18:00 (8:00~9:00 without ventilation)			
Temperature and humidity		Heating season (Dec~Mar)	Cooling season (Jun~Sep)	Heating season (Apr~May;Oct~Nov)
	Temperature(°C)	22	26	22~26
	Humidity(%)	40	50	40–50
Internal heat	Expectation rate	100%	50%	75%
Internal heat generation and using schedule	Lighting	Body		OA Equipment
	Efficiency: 0.9	0.2 person/m^2		Sensible heat
	20 W/ m^2	119 W/person		30 W/m^2
	Schedule	9:00~18:00 (100%)		
Thickness of external wall insulation material	Cold area (Sapporo)	Warm area (Six cities)		Hot area (Naha)
	50 mm	25 mm		0 mm

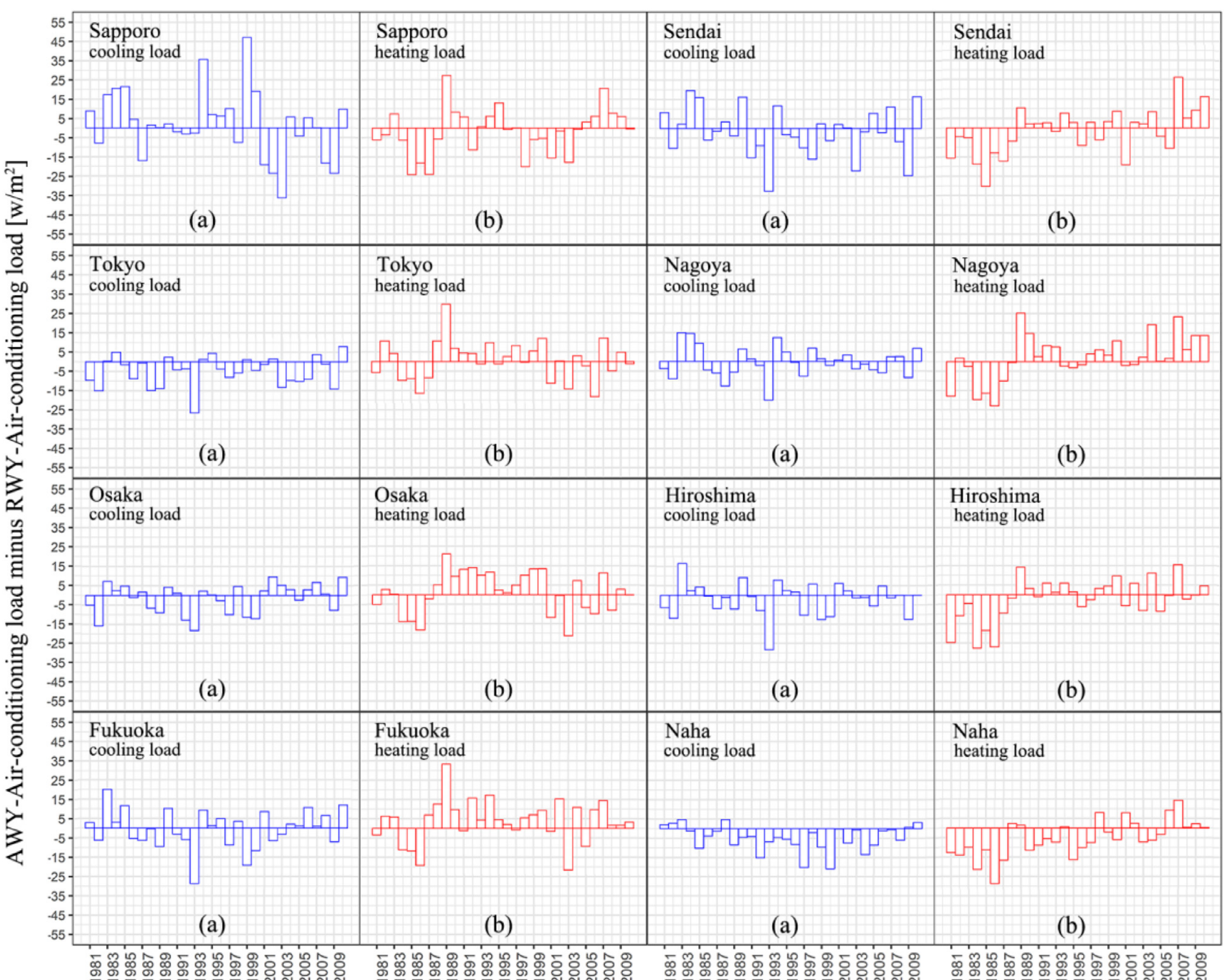

Fig. 2. Deviation of design air-conditioning load over 30 years (1981–2010) ((a): design cooling load; (b): design heating load).

a result the design air-conditioning cooling load based on AWY is less than that based on RWY in the two cities. However, the deviations of design cooling load in the other six cities are almost normalized.

For deviation of design heating load in Naha, it is shown that it is almost negative from 1981 to 2000, and becoming normalized from 2000. In addition, the deviation of design heating load in Nagoya is almost negative until 1988, and it starts showing positive values after 1988. In Tokyo, Osaka, Hiroshima and Fukuoka, the deviations of design heating load are positive from 1988 to 2000, a report [27] described that most locations of Japan had a warm winter from 1988 to 2000, and it was relatively warmer than the other periods. However, the deviations of design heating load in Sapporo and Sendai are showing normalized.

Fig. 3 shows the frequency distribution of design cooling and heating load deviation over 30 years (1981–2010) between RWY and AWY in

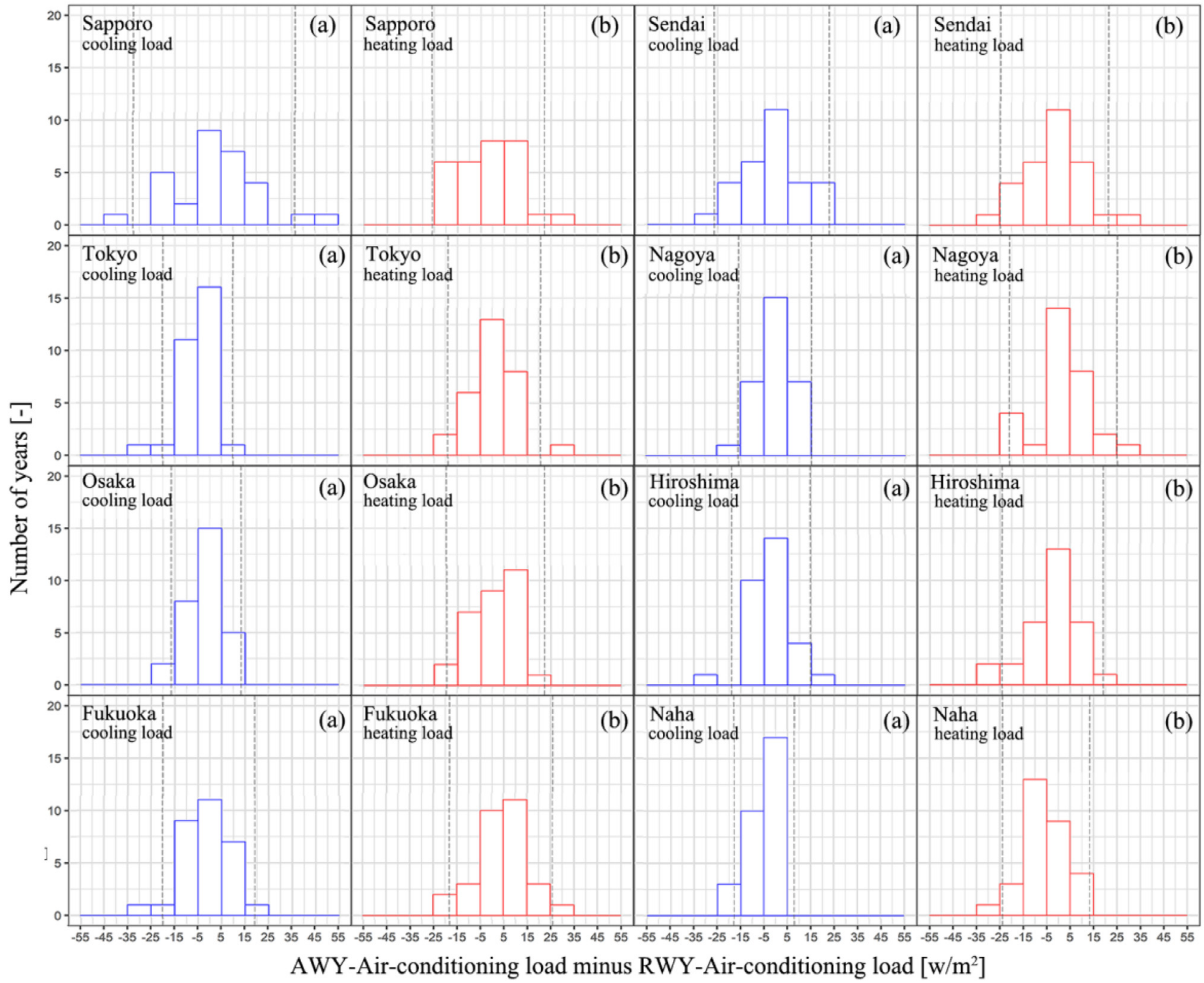

Fig. 3. Frequency distribution of design air-conditioning load deviation over 30 years ((a): design cooling load; (b): design heating load).

eight cities. The dotted borders in Fig. 3 represent 95% confidence interval of design air-conditioning load deviation. The result showed the frequency distributions of design cooling and heating load deviations are very close to a normal distribution for eight main cities. It is shown the mean deviation of design cooling load between RWY and AWY in Tokyo and Naha are approximately −5.0 W/m^2 (the largest), and within approximately −2.2 W/m^2 in the other cities except for Sapporo (with the mean deviation of design cooling load of about +1.9 W/m^2). For the mean deviation of design heating load, Naha has the largest deviation of approximately −5.3 W/m^2, and the mean deviations in the other regions are within ±3.9 W/m^2. The mean deviation of design cooling and heating loads in eight main cities of Japan are calculated and summarized in Table 3.

The design air-conditioning loads calculated by AWY weather data fluctuate around that calculated by RWY, thus the result more or less can explain why we use RWY weather database to do the air-conditioning load design. In addition, the result indicated the latitude has a relative influence on the design air-conditioning heating load over these 30 years from 1981 to 2010.

Fig. 4 shows the change in annual air-conditioning load time ratio over 30 years (1981–2010) in eight main locations of Japan.

Table 3
Details of mean deviation of design air-conditioning load in eight locations.

Location	Mean deviation of design air-conditioning load [W/m^2] (AWY-design air conditioning load minus RWY-design air conditioning load)	
	Design cooling load	Design heating load
Sapporo	+1.85	−1.88
Sendai	−1.95	−1.69
Tokyo	−5.09	+0.80
Nagoya	−0.36	+2.10
Osaka	−1.58	+1.37
Hiroshima	−2.15	−2.49
Fukuoka	−0.50	3.85
Naha	−4.91	−5.25

Results showed that the annual cooling load time ratios are on the rise, and the annual heating load time ratios show a downward trend in eight locations of Japan, especially in Sapporo and Sendai. The result is considered to be the effect of global warming.

With the call of improving environment and saving energy, to create an appropriate RWY weather database used for air-conditioning load design of buildings is becoming more important and necessary in current years.

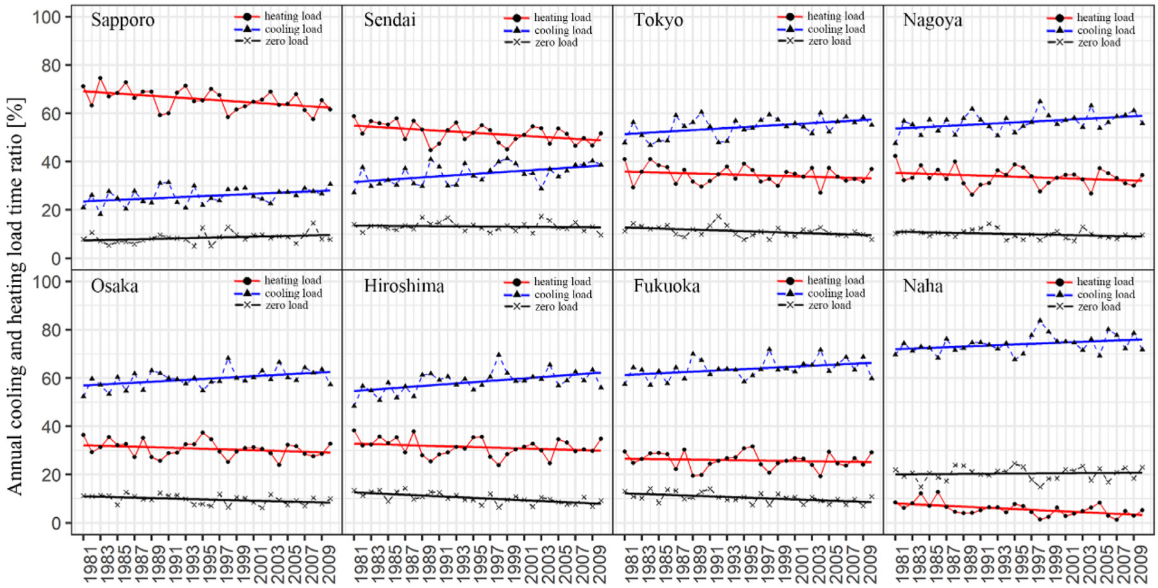

Fig. 4. Change in design air-conditioning load time ratios in eight locations over 30 years.

6. Conclusions and future work

In order to know the effect of climate change on the design air-conditioning load of buildings, the deviation of design air-conditioning load over 30 years between RWY and AWY in eight main locations of Japan are analyzed. Additionally, the change in air-conditioning load time ratios is also discussed to evaluate the effect of global warming in Japan.

The main points obtained in this study are summarized in the following.

- New HASP/ACLD is utilized to evaluate the deviation of design air-conditioning load between RWY and AWY and change in air-conditioning load time ratios over 30 years under specified conditions.
- In most cities, the design air-conditioning loads calculated by AWY weather data fluctuate around that calculated by RWY. Thus, it more or less can explain why we use RWY weather database to do the air-conditioning load design of buildings.
- However, there is a relatively larger deviation between design air-conditioning cooling load based on RWY and AWY in Tokyo and Naha while compared to the other cities, and the deviations of design air-conditioning heating load based on RWY and AWY were also a little larger in Fukuoka and Naha while compared to the other cities. Therefore, it is considered it maybe not the best choice if we just use the RWY database to calculate the design air-conditioning load.
- Due to the effect of global warming, the annual cooling load time ratios are on the rise and the annual heating load time ratios show a downward trend in eight locations of Japan, this is also in agreement with the observations [28,29] by Japanese and American meteorological agencies, it shows that summer gets longer and winter gets shorter in Japan and around the world. Thus, it is considered that the creation and update of an appropriate RWY weather database are becoming more important and necessary as time for the aim of energy conservation and environment improvement.

The future work aims to calculate the deviation of design air-conditioning load based on RWY and AWY in the other more than 800 locations of Japan. Moreover, the effects of urbanization, different latitudes and different terrains are also analyzed to find the cause of the deviation.

Conflict of interest

The authors declared that there is no conflict of interest.

Author Contributions

J. Yuan and K. Kazuo designed this research and proposed the analysis method;

Z. Jiao collected the database, implemented the analysis and wrote the paper;

J. Yuan and C. Farnham checked and revised the content.

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