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Annual variation of air temperature and thermal environment in a three-year data set obtained in urbanized areas of Japan

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阪神・播磨地域における３年間の気温観測結果に見る気温および熱環境の年較差

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The air temperature was measured at 27 sites located in an urbanized area for 3 years to evaluate the annual/seasonal variation of the air temperature. The air temperature showed a larger variation in the winter season than in the summer season. However, the annual variation was observed even in the summer season when it was evaluated using some indexes to represent the living environment. The air temperature should be evaluated from the viewpoint of the living environment in addition to the air temperature itself, especially when the heat island phenomenon is considered.

Keywords: Air temperature, Thermal environment, Urban heat island, Intensely hot night, Hot day, Extremely hot day

I　INTRODUCTION

The thermal environment in urbanized areas has become severe for humans due to the urban heat island phenomenon. The urban heat island phenomenon has been studied worldwide with the objective of limiting thermal pollution in urban areas [1-6] (e.g., Oke, 1973; Oke and Maxwell, 1975; Gotoh, 1993; Saitoh et al., 1996; Yamashita, 1996; Oke et al., 1999). The Hyogo Prefectural Government of Japan settled on an action plan for the heat island phenomenon and constructed a monitoring network to measure the air temperature for the verification of the effects of the action plan. The action plan aims to mitigate the heat island phenomenon by measures such as decreasing the artificial waste heat, improving the urban earth's surface, reshaping the urban form, and changing people's lifestyle. Aikawa et al.[7] thoroughly analyzed the data sets obtained in

the new monitoring network and clearly defined the growing heat island phenomenon in the area. Furthermore, Aikawa et al.[8-10] showed the air temperature distribution and clarified the severer thermal condition in inland areas than in coastal areas. The monitoring network was constructed in 2005. The annual variation of the air temperature as well as the seasonal variation was analyzed in the present study. The findings are reported below.

II METHODS

1. Air temperature measurement

The air temperature was measured at elementary and junior high schools located within the 10 x 15-km (eastern area) and 20 x 15-km (western area) regions in Hyogo Prefecture. The air temperature was measured at 27 sites. The location of the site is shown in Fig. 1. The eastern area is between Osaka City (population density: 2,634,000/ 222 km^2) and Kobe City (population density: 1,520,000/ 551 km^2), and the western area is in the west of Kobe City. The southern areas are characterized by intensive industrial development and dense populations, which categorize them as urban areas. In contrast, the urbanization has been progressing rapidly in the northern areas, which mainly include satellite cities of Osaka and Kobe[11].

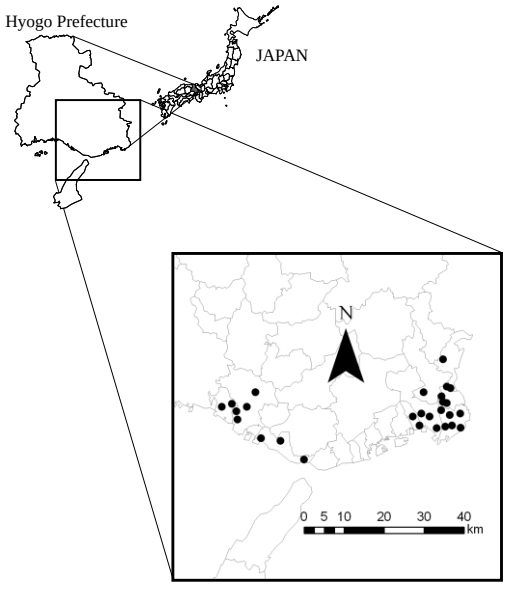

Fig. 1 Location map of the survey sites.

The air temperature was measured using a thermometer (Thermo Recorder TR-52, TandD Corporation, Nagano, Japan) calibrated with a thermostat bath at two temperatures of 5 and 35°C. The measurement resolution was 0.1°C. The measurement accuracy was ± 0.3°C. The thermometer was installed in a naturally ventilated thermometer shelter (about 1.5 m above the ground). The air temperature was measured at the survey site every 15 minutes, and hourly data measured on the hour were used for the evaluation. The air temperature measured from July 2005 to April 2008 was analyzed in the study.

2. Survey site characteristics

The survey area can be classified into three categories: (1) the highly urbanized area along the coast, (2) the suburban area, primarily in the southern part of the study areas, and (3) the residential area being developed as satellite cities, primarily in the northern part of the study areas. This categorization is reported in detail elsewhere[10-11] .

III RESULTS AND DISCUSSION

1. Trend of monthly air temperature

Fig. 2 shows the trend of the averaged monthly mean air temperature of all sites and the highest and the lowest monthly means among all sites. Here, the averaged monthly mean air temperature is the average of the monthly mean air temperature of the 27 sites, and the highest and the lowest monthly means are the highest and the lowest values among the monthly mean air temperature of the 27 sites, respectively. In Fig. 2, the highest air temperature was always observed in August for 3 years. In contrast, the large variation was observed at the lowest air temperature: the lowest air temperature was observed in December, January, and February in the 2005, 2006, and 2007 winter season, respectively. Fig. 3 shows the trend of the difference between the highest and the lowest monthly means. The large difference was observed in the winter season, while the difference was small in the summer season. Taking Fig. 1 and Fig. 2 into account, the annual variation of the air temperature was large in the winter season and small in the

summer season. (Aikawa and Hiraki[12]; Horie and Hiraki[13]) analyzed the annual variation in August and December between 2005 and 2006 in detail. The conclusions of their detailed analysis were coincident with the finding in the present study.

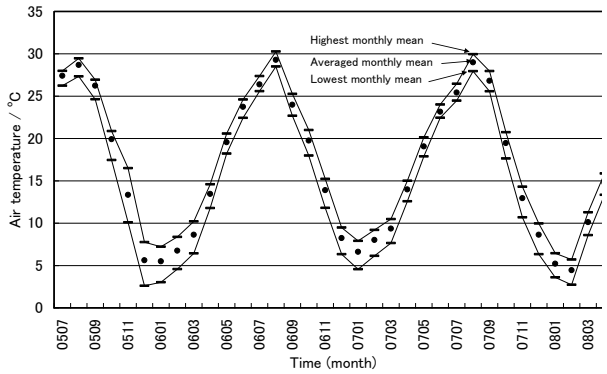

Fig. 2 Trend of the averaged monthly mean air temperature of all sites, and the highest and the lowest monthly means among all sites.

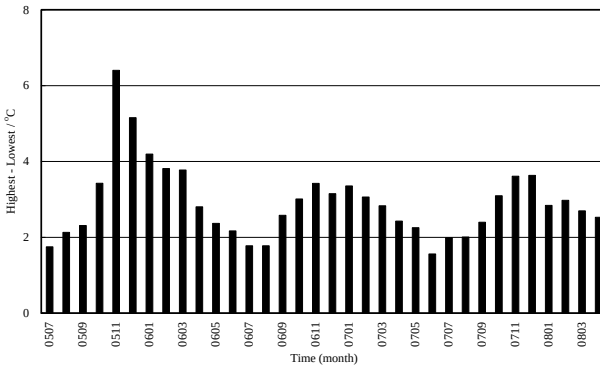

Fig. 3 Trend of the difference between the highest and the lowest monthly means.

2. Annual variation of thermally severe condition

Miyazaki et al.[14] introduced an index for an urban heat island that shows the total number of hours during which the air temperature was higher than a threshold value. Miyazaki et al.[14] adopted the threshold values of 25°C and 30°C. Fig. 4(a) and (b) shows the trend of the index for an urban heat island introduced by Miyazaki et al. for 25°C and 30°C, respectively, where air temperature data, which are not corrected by the altitude of the sites, are used. Fig. 4(a) and (b) shows that the number of hours during which the air temperature was higher than 25°C and 30°C was the largest in August at all sites. The number of hours in August of 2006 was large for all sites, with a smaller variation, while the number of hours in August of 2005 and 2007 was smaller than that in August of 2006. Furthermore, the number of hours at some sites in August of 2005 and 2007 was notably small.

The annual variation of the monthly air temperature in the summer was smaller than that in the winter, as shown in Section III -1. However, the thermally severe condition showed the annual variation when it was evaluated by the number of hours during which the air temperature was higher than a threshold value.

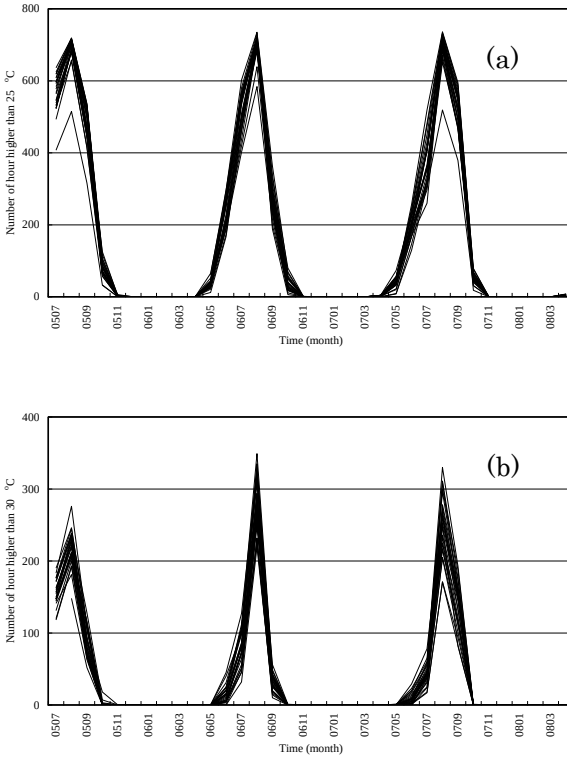

Fig. 4 Trend of the index for an urban heat island introduced by Miyazaki et al. for 25°C (a) and 30°C (b).

3. Characteristic differences between two indexes that indicate a living environment

Some indexes to indicate a living environment are frequently used in Japan: i) an intensely hot night (Nettaiya in Japanese); ii) a summer day (Natsubi in Japanese); iii) a hot day (Manatsubi in Japanese), and iv) an extremely hot day (Mousyobi in Japanese). Each index is defined as follows:

i) An intensely hot night is one in which the lowest air

temperature is 25°C or higher during the nighttime.

ii) A summer day is one in which the highest air temperature is 25°C or higher.

iii) A hot day is one in which the highest air temperature is 30°C or higher.

iv) An extremely hot day is one in which the highest air temperature is 35°C or higher.

The above four indexes can be classified into two categories. An intensely hot night is typified by sleeplessness; on the other hand, a summer day, a hot day, and an extremely hot day are characterized by severe heat during the daytime.

Fig. 5(a) shows the number of days with intensely hot nights at each site. Variation was observed among the sites regarding the number of days with intensely hot nights. Fig. 5(b), (c), and (d) shows the number of summer days, hot days, and extremely hot days, respectively. All days in August were categorized as summer days (Fig. 5(b)). Either no variation or a small one was observed in the number of summer (Fig. 5(b)) and hot days (Fig. 5(c)). In contrast, some variation was observed in the number of extremely hot days (Fig. 5(d)). Furthermore, the number of summer and hot days in 2006 exceeded those in 2005 and 2007; this was particularly notable in the case of hot days (Fig. 5(c)). There was no specific correlation between the number of summer, hot, and extremely hot days and that of intensely hot nights among the sites, which suggests that the nighttime living environment should be evaluated separately from the living environment in the daytime.

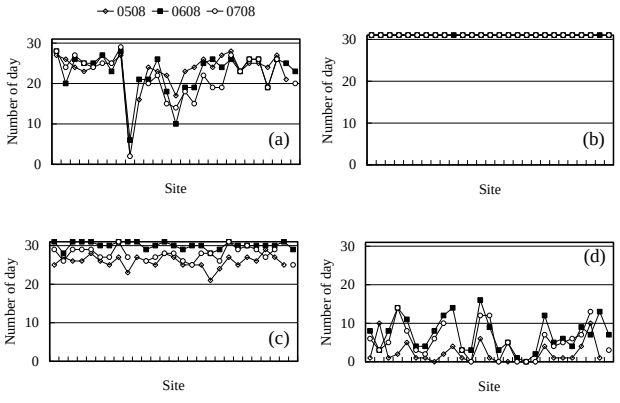

Fig. 5 Number of day of intensely hot night (a), summer day (b), hot day (c), and extremely hot day (d) at each site.

IV CONCLUSIONS

The air temperature was measured at 27 sites in urbanized areas of Japan from July 2005 to April 2008 to understand the annual/seasonal variation of the air temperature. The annual/seasonal variation was evaluated not only by the air temperature itself but also by the thermal conditions. The number of days and/or number of hours during which the air temperature was higher than a threshold value was used to evaluate the thermal condition. The findings are summarized as follows:

1) The highest monthly mean air temperature was observed in August in all summer seasons, while the lowest mean air temperature was observed in December 2005, January 2007, and February 2008 in the 2005, 2006, and 2007 winter seasons, respectively.
2) The annual variation in the summer was small, while that in the winter was large.
3) Although the annual variation was small when it was evaluated by the air temperature itself, a clear annual variation was revealed when it was evaluated by the thermal conditions.

In conclusion, the thermal conditions should be evaluated in detail using the above-described indexes to represent the living environment as well as the air temperature itself.

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要　約

平成１７年８月に策定した「兵庫県ヒートアイランド対策推進計画」の効果検証のため，阪神・播磨地域の小中学校２７校の百葉箱に温度計を設置し気温の測定を行っている．本研究では，平成２０年４月までの３年間の観測結果を解析し，気温等を評価する際に重要となる年較差について考察した．その結果，冬季において夏季よりも大きい年較差が観測された．その一方，生活環境を表すいくつかの指標で評価すると，夏季においても年較差が観測された．ヒートアイランド現象を評価する上では，単純に気温だけではなく生活環境を表す指標もあわせて用いて，気温や熱環境を評価することが必要である．