A Basic Study on Utilization of the Cooling Effect of Sea Breeze in Waterfront Areas along Tokyo Bay

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Abstract

“Priority Urban Redevelopment Areas” in Tokyo, Japan, are currently undergoing large-scale urban renewal. However, the heat island phenomenon has become a serious problem in large cities in Japan.

We surveyed the temperature and wind conditions in two adjacent areas: a new skyscraper district on the coast (A district) and a typical inland urban district (B district). Our observations indicated local temperature increases and unstable wind with weak velocity in B district.

It is possible that differences in the wind environment influence the local temperature. We analyzed the relationship between undulations in ground level and the wind environment by wind tunnel experiments. The results confirmed that there was a weak wind area in B district located behind A district from the direction of the coastline.

Our findings indicate that it is important to consider the heat island phenomenon in urban planning in order to make best use of the cooling effect of the breeze from the sea at waterfront areas.

Keywords: cooling effect of the sea breeze; heat island phenomenon; urban structure

1. Introduction

In Tokyo, Japan, areas designated “Priority Urban Redevelopment Areas” are currently undergoing large-scale urban renewal. However, the heat island phenomenon has become a serious problem in large Japanese cities. We examined urban structures with regard to utilization of the cooling effect of the sea breeze in waterfront areas.

In the present study, we surveyed the temperature and wind conditions and performed wind tunnel experiments in two adjacent areas: a new skyscraper district on the coast (A district) and a typical inland urban district (B district). B district is located behind A district from the direction of the coastline of Tokyo Bay.

There have been a number of related studies on the effects of rivers on the thermal environment in seaside cities and on the cooling effects of going-up sea breeze on the urban climate. KATAYAMA and Kyushu University researchers carried out three types of field observation of urban thermal environments to examine the cooling effects of a river. MURAKAWA and researchers at Hiroshima Universities conducted observations in and around the Ota River flowing through Hiroshima City in each season at two sites with different river widths and structures. HASHIMOTO and HORIKOSHI's studies clarified the cooling effects of going-up sea breeze along a canal in Nagoya. KIYOTA analyzed the relationship between sea-land breezes and air temperature in Hiroshima in the summer. NARITA examined the heat budget of river water and reported moving observations to clarify the horizontal extent of its thermal effects. KANDA and researchers at the Tokyo Institute of Technology reported on a study regarding the verification of wind channel effect around an urban river by the map of sea breeze front line.

This thesis focuses on the influence of differences in urban structures on urban climate.

2. Research areas

The A district consists of a park of about 25 hectares facing Tokyo Bay and an adjacent large-scale development district of about 31 ha. Development started in 2002, and the area will eventually be lined with 14 skyscrapers from 100 to 200 m in height in 2007. The ratio of building volume to the lot is from 900 to 1200%, and the total floor space is about $1.5 \times 10^6$ m$^2$. The area is designated chiefly for business
use.

B district is a typical urban district also chiefly for business use. The specified ratio of building volume to lot is from 600 to 700%, and the specified building coverage is 80%.

3. Outline of the observation survey

The observation survey was performed over a period of 24 h from 15:00 on 2 September 2004 to 15:00 the following day. The points of this survey are shown in Fig.1.

We examined the temperature at 5 points in A district and 18 points in B district. In addition, we examined the direction and velocity of the wind at 1 point in A district and 1 point in B district. Table 1. outlines the observation equipment used. A compulsion funnel was installed with a thermometer, and was ventilated throughout the entire survey period.

4. Weather conditions

The heat island phenomenon during the summer of 2004 was more marked than the annual average. On both September 2 and 3, it was generally clear with only temporary periods of cloud cover. The highest and lowest temperatures on these days were 31.4°C and 24.2°C and 30.8°C and 23.1°C, respectively. Both were midsummer days, although the nights were not excessively warm (over 25.0°C).

5. Findings of the observation survey

First, we report both day and night findings regarding the wind environment, then discuss the timing of sea breezes, and present an analysis of the wind environment and temperature distribution.

5.1. Wind environment

Fig.2. shows the wind distribution from 18:00 on September 2 to 06:00 on September 3.

Table 2. shows both day and night wind velocities. The results indicated that the wind was steady day and night in A district and came from the direction of the sea. On the other hand, in B district, the wind velocity was weak during the day and its direction changed at night.

As show in Fig.2., the wind came mostly from the south-southeast during the day in A district. We examined the wind environment from 12:00 to 13:00 when the wind direction was stable from the south-southeast.

Fig.3. shows the wind distribution from 18:00 on September 2 to 06:00 on September 3.

Table 2. shows both day and night wind velocities. The results indicated that the wind was steady day and night in A district and came from the direction of the sea. On the other hand, in B district, the wind velocity was weak during the day and its direction changed at night.

As show in Fig.2., the wind came mostly from the south-southeast during the day in A district. We examined the wind environment from 12:00 to 13:00 when the wind direction was stable from the south-southeast.

Fig.3. Nighttime Wind Distribution

Table 2. Wind Velocities in A and B Districts

|          | Day   | Night  |
|----------|-------|--------|
| A district | 1.48 m/s | 1.18 m/s |
| B district | 1.06 m/s | 1.34 m/s |

Fig.4. shows the wind distribution from 12:00 to 13:00 on September 3. Both survey points are almost on the same line from the direction of the coastline of
Tokyo Bay. Table 3. shows the average wind velocity and maximum instantaneous wind speed from 12:00 to 13:00 on September 3. These results indicated that the wind was steady in A district. On the other hand, in B district, the wind was unsteady and had lower velocity than that in A district.

5.2. Temperature distribution

A temperature distribution chart was plotted using GMT (Generic Mapping Tools) based on the temperature data obtained in this survey.

Fig.5. shows the temperature distribution chart from 12:00 to 13:00 on September 3. The average temperature of A district was 28.8°C, while that of B district was 30.2°C. Thus, the average temperature of B district was 1.4°C higher than that of A district.

Table 3. Wind Velocities in A and B Districts from 12:00 to 13:00

|            | Average wind velocity | Maximum instantaneous wind speed |
|------------|-----------------------|----------------------------------|
| A district | 2.37m/s               | 4.5 m/s                          |
| B district | 1.21m/s               | 2.5 m/s                          |

6. Analysis of the observation survey

The findings of the observation survey described above confirmed that the temperature showed local increases and that the wind was both unstable and of weak velocity in B district. These observations suggested that differences in the wind environment have an influence on temperature.

Fig.7. shows a section of the ground level (Altitude and Building height) and temperature (Refer to Fig.6.). The distance between A and B districts was 500 m and there was a temperature difference of 2.4°C. These observations suggested that the undulations in ground level in A district influence the high temperature in B district.

7. Outline of the wind tunnel experiment

An experiment was performed using the temperature stratification wind tunnel at the Building Research Institute. This wind tunnel, with a cross-section of 1 m×1 m and a measurement area 10 m in length was sealed with circulating air.

As shown in Fig.8., the target area in this experiment had sides of about 1 km in length and a 1/1000 reduced scale model was used.

The results of the survey suggested that the undulations in ground level influenced the wind environment.
The results of the wind tunnel experiment verified the differences in the wind environment before and after the construction of skyscrapers in A district. The terms “Past model” and “Present model” refer to the conditions before and after skyscraper construction in A district, respectively.

In the present study, we set the wind direction to the east-southeast and the wind velocity to 2.77 m/s (land-surface roughness, $\alpha=0.10$).

8. Findings of the wind tunnel experiment

3 measurement points were set in A district and 7 in B district along a road undergoing redevelopment. We measured the velocity of the wind at each point at 5 heights: 30 m, 50 m, 100 m, 200 m, and 300 m.

8.1. Past model
(Before construction of skyscrapers in A district)

Fig.9. shows the Past model and its measurement points.

Fig.10. shows the measurement results of the wind velocity in the Past model.

8.2. Present model
(After construction of skyscrapers in A district)

Fig.11. shows the Present model and its measurement points.

Fig.12. shows the measurement results of the wind velocity in the Present model.

In B district, the wind velocity in the Present model was markedly decreased at each height examined up to 200 m.

Fig.13. shows the wind distribution chart in B district (750 m×750 m).
9. Analysis of the wind tunnel experiment

The wind environments of the Past and Present models were compared based on the findings of the wind tunnel experiment.

Fig.14. shows the wind velocity in the Present model divided by that in the Past model.

Compared with the wind velocity in the Past model, that in the Present model was reduced by half at heights from 50 to 200 m in B district. That is, a region was identified where the wind velocity was weak behind A district.

The results of the present study confirmed that there was an area of weak wind velocity in B district behind A district from the direction of the coastline.

We examined time change of temperature in both districts and temperature distribution in waterfront areas of Tokyo in another study

The differences in density of urban exhaust heat in A and B districts are also expected to have an impact on the differences in temperature.

10. Conclusions

It is possible that differences in the wind environment have an influence on temperature.

We confirmed that there was an area of weak wind velocity in B district behind A district from the direction of the coastline.

The results of the present study indicated that it is important to consider the heat island phenomenon in urban planning in order to make best use of the cooling effect of the breeze from the sea at waterfront areas.

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