THE EVALUATION OF THE INTRODUCTION EFFECT OF URBAN HEAT ISLAND MEASURE TECHNOLOGY IN THE CENTRAL BUSINESS DISTRICT OF OSAKA CITY
Hideki Takebayashi*, Masakazu Moriyama*
*Kobe University, Hyogo, Japan

Abstract
The outdoor thermal environment of Osaka city is extreme during summer. Therefore, the Osaka city government is considering the introduction of an urban heat island mitigation technology into the central business district. They are evaluating the effect of introducing various mitigation technologies before adopting any one of them as a policy. The Osaka city government and some research organizations are carrying out observations of the actual thermal environment and carrying out simulations of the effect of introducing the mitigation technologies. Sea breeze blows from the Osaka bay into the central business district of Osaka city during summer daytime; therefore, the introduction of sea breeze into the urban canopy layer over pedestrian spaces is one of the possible mitigation technologies. We have compared calculation results with observation results and have carried out the simulation of the effect of introducing a mitigation technology.

Key words: urban heat island mitigation technology, sea breeze, central business district

1. INTRODUCTION
In Osaka city, sea breeze blows from the Osaka bay into the central business district during summer daytime; therefore, the introduction of sea breeze into the urban canopy layer over pedestrian spaces is one of the possible urban heat island mitigation technologies. In this study, the effect of introducing this urban heat island mitigation technology in Osaka city is examined. The relationship between the amount of ventilation in street canyons and street forms, distance from the bay, and air temperature are investigated by carrying out observations and calculations. The simulation of the effect of introducing the above mentioned mitigation technology is carried out. Some projects are going to be carried out in several years. And we will inspect the introduction effect of each mitigation technology after the projects are carried out.

2. OBSERVATIONS
Observations were carried out from 10:00 to 20:00 on August 3 and 5, 2008. Observation points were set in Horie district on narrow, reasonably wide, and very wide streets, which are either perpendicular or parallel to the direction of the sea breeze. Three observation points were set about 1.5 km apart on Nagahori street, which is a wide east-west street (observation points A, B, and C). The wind direction and velocity and air temperature were observed at each observation point at heights of 2 m and 1.5 m above ground level. Data was sampled every 5 min. The observation points and calculation area are shown in figure 1. The wind velocity ratio was calculated by dividing the wind velocity recorded in the street canyon by the upper wind velocity recorded at the Osaka observatory, which is located 47 m above the observation points. The air temperature difference was calculated by subtracting the air temperature recorded in the street canyon from the air temperature recorded at the Osaka observatory. In this study, only the observation results obtained on August 3—when the weather conditions were fine and the sea breeze blew from the Osaka bay into the central business district in the daytime—were mainly examined.

The wind velocity ratio calculated in the case of the street that is parallel to the direction of the sea breeze was larger than that calculated in the case of the street that is perpendicular to the direction of the sea breeze. Few differences were observed in the wind velocity ratio calculated in the case of the narrow and reasonably wide streets. Correlation coefficients of the wind velocity ratio and air temperature on the streets that are parallel and perpendicular to the direction of the sea breeze are shown in table 1. Every one minute average values are used for. Negative correlation was observed between the wind velocity and air temperature, except in the case of the narrow (5 m width) street that is perpendicular to the direction of the sea breeze. The relationship between the distance from the Osaka bay and the wind velocity ratio is shown in figure 2. The error range expresses standard deviation of wind velocity ratio. The average observation period was 10 min. The wind velocity ratio calculated at the observation point A, which is located nearest to the Osaka bay, was larger by a value of about 0.2 than that calculated at the observation points B and C. However, the weather conditions at each observation point may have been affected by roadside trees, neighboring buildings, anthropogenic heat release, etc., although the observation points were selected in consideration of various conditions.
3. CALCULATIONS

3.1. Calculation conditions

CFD simulation is carried out for the districts neighboring Nagahori street. A map of the calculation area is shown in figure 3. The size of the calculation area was 5000 m (length) × 4000 m (breadth) × 570 m (height), including the analysis area whose length was 1500 m in the east–west direction and breadth was 1250 m in the north–south direction. The length of the mesh in the analysis area was 5 m and wider in outer analysis area; the height of the mesh was 1 m above ground level and wider in upper area. Only the buildings and streets in the calculation area were considered, while roadside trees and the highway were not considered. A standard k-ε type turbulence model was used for the calculation.

An inflow boundary condition was set on the west side of the calculation area, because the wind direction in this area was westward on a typical summer daytime. The wind velocity at the Osaka observatory was estimated as 4.5 m/s at a height of 47 m by the 1/4 exponential law. The air temperature at the Osaka observatory was calculated as 32.5°C. A free-slip boundary condition was set at the upper and side surfaces, a no-slip boundary condition was set at the bottom and wall surfaces, and a free outflow boundary condition was set at the outflow boundary of the model. The convection heat transfer coefficient was 11.6 W/m²K [Tsuchiya, et. al.]. The wind velocity ratio was estimated as the wind velocity observed at a height of 2 m divided by the upper inflow wind velocity (4.5 m/s) observed at the height of 47 m. The air temperature at the height of 2 m was used for the following examination. The wind velocity at the height of 2 m is shown in figure 4. It is confirmed that the wind velocity tended to be larger on the street with a large width and on the outskirts of the high-rise buildings.
3.2. Calculation results

The relationship between the width of the street and the wind velocity ratio calculated in the case of streets that are parallel and perpendicular to the wind direction is shown in figure 5. The error range expresses standard deviation of wind velocity ratio. The average wind velocity ratio increased with the street width. The wind velocity ratio calculated in the case of the street parallel to the wind direction was larger than that calculated in the case of the street perpendicular to the wind direction. The correlation coefficients between the wind velocity ratio and air temperature in the case of streets that are parallel and perpendicular to the wind direction are shown in table 2. Negative correlation was observed between the wind velocity and air temperature. The relationship between the distance from the west side of the analysis area and the wind velocity ratio at heights of 2 m and 47 m is shown in figure 6. The error range expresses standard deviation. The difference in the average wind velocity ratio calculated at the heights of 2 m and 47 m in the analysis area was around 0.5, except in the region between 600 m and 800 m from the west side.

![Figure 3 Map of calculation and analysis area](image1)

![Figure 4 Calculation result of wind velocity at height of 2 m](image2)

![Figure 5 Relationship between width of street and wind velocity ratio in case of streets that are parallel and perpendicular to wind direction](image3)

![Figure 6 Relationship between distance from west side of analysis area and wind velocity ratio](image4)

Table 2 Correlation coefficient between wind velocity ratio and air temperature

<table>
<thead>
<tr>
<th>Width of the street [m]</th>
<th>Correlation coefficient</th>
<th>Sample number</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ~ 10</td>
<td>-0.36</td>
<td>3116</td>
</tr>
<tr>
<td>15 ~ 30</td>
<td>-0.56</td>
<td>1440</td>
</tr>
<tr>
<td>35 ~</td>
<td>-0.57</td>
<td>2617</td>
</tr>
<tr>
<td>0 ~ 10</td>
<td>-0.19</td>
<td>4042</td>
</tr>
<tr>
<td>15 ~ 30</td>
<td>-0.49</td>
<td>459</td>
</tr>
<tr>
<td>35 ~</td>
<td>-0.28</td>
<td>3068</td>
</tr>
</tbody>
</table>
west side of the analysis area. The average wind velocity ratio calculated at the height of 2 m in the region between 600 m and 800 m was larger than that in the other regions, and the average wind velocity ratio at the height of 47 m in the region between 600 m and 800 m was smaller than that in the other regions. Midosuji is a wide north–south street, which is perpendicular to the wind direction, lying in the region between 600 m and 800 m, and it has high-rise buildings. Therefore, it is thought that the upper strong wind is introduced into the street by the high-rise buildings located along the wide north–south street.

3.3. Simulation

The effect of introducing a heat island mitigation technology was evaluated by carrying out a numerical simulation. The calculation results of surface temperature distribution on the wide east–west (Nagahori) street at 14:00 on a fine summer day are shown in figure 7. The calculation results obtained without introducing any mitigation technology were compared with those obtained from a thermal image observed using an infrared camera. The solar reflectance, emissivity, thermal conductivity, heat capacity, and evaporative coefficient of each building material were set according to previous studies [Takebayashi, et. al.]. The shade provided by roadside trees and buildings, as well as high solar reflectance, is the most important factor behind the reduction of street surface temperature. The air temperature and wind velocity distribution at 14:00 on a fine summer day are shown in figure 8. The decrease in the surface temperature led to a reduction in the air temperature above the wide east–west (Nagahori) street.

4. CONCLUSION

The examination concerning the method of urban heat island mitigation using sea breeze effectively is carried out. The relationship between the amount of ventilation in street canyons and street forms, distance from the bay, and air temperature was investigated by carrying out observations and calculations. The average wind velocity ratio increased with the street width. The wind velocity ratio calculated in the case of the street that is parallel to the wind direction was larger than that calculated in the case of the street that is perpendicular to the wind direction. Negative correlation was observed between the wind velocity and air temperature. Upper strong winds were introduced into the wide north–south street by the high-rise buildings located along the street. The simulation of the effect of introducing the above mentioned mitigation technology was carried out. It was estimated that this urban heat island mitigation technology can contribute to the decrease in the surface temperature and air temperature.

References