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Academic Article

Evaluation of the outdoor thermal environment in redevelopment buildings in front of Osaka Station based on observations

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ABSTRACT

Several technologies used as countermeasures against urban heat islands, such as green cover and water surfaces, are being applied to redevelopment buildings in front of central Osaka Station. In this study, we evaluated the outdoor thermal environment by focusing on the effects of wind velocity and MRT, which is reflective of solar radiation shielding, in an open plaza with water surfaces, a rooftop garden with plants, and a sunken garden placed between high-rise buildings. In the open plaza, SET* was high due to high MRT and reduced by slightly strong wind at some measurement points. In rooftop garden, SET* was high due to high MRT and not reduced so much by wind with a little variation in each measurement point. In the sunken garden, SET* was low due to low MRT, because solar radiation is shielded by plants and high-rise buildings at most of the measurement points, while wind velocity is low due to wind resistance offered by plants. To conclude, the improvement of MRT is the most significant factor for the improvement of the outdoor thermal environment during the daytime.

Key Words : Outdoor thermal environment, Wind velocity, MRT, SET*, Redevelopment buildings

1. Introduction

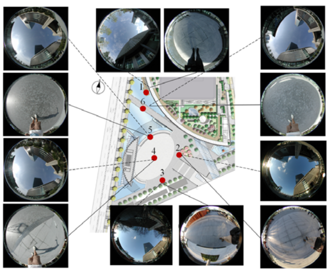
Several technologies used as countermeasures against urban heat islands, such as green cover and water surfaces, are being applied to redevelopment buildings in front of central Osaka Station. With regards to a previous study, Akagawa et al.(1) analyzed the outdoor thermal environment of a rooftop garden on a large commercial building. In subsequent research, Akagawa et al.(2) also compared standard effective temperature at an area shielded by objects, trees, and semi-open spaces in a large, artificial green space. standard effective temperature is transcribed into SET*. SET* was found to be lowest in semi-open spaces in the morning and evening, and in spaces shielded by trees in the daytime. As well, SET* was highest in spaces shielded by various objects, due to low wind velocities in the daytime and high air temperatures at night. The authors concluded that ventilation and solar radiation shielding can effectively improve the outdoor thermal environment. However, they did not discuss whether ventilation or solar radiation shielding was more important for the improvement of the outdoor thermal environment. In this study, we evaluated the outdoor thermal environment by focusing on the effects of wind velocity and mean radiative temperature, which is reflective of solar radiation shielding, in an open plaza with water surfaces, a rooftop garden with plants, and a sunken garden placed between high-rise buildings. Mean radiative temperature is transcribed into MRT.

2. Measurement

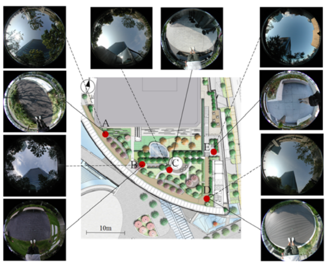
2.1 Measurement method

The selected measurement period was from July 22 to 26, 2013. Air temperature, relative humidity, surface temperature, wind direction and velocity, and thermal images were obtained by a thermistor, capacitive humidity sensor, infrared thermometer, windsock, hot-wire anemometer, and thermo-camera. Measurements were made at 10:00, 13:00, 17:00, and 20:00 in 5 or 6 measurement points in each of the following areas: open plaza, rooftop garden, and sunken garden. We selected these 3 areas in the redevelopment building complex because several urban heat island countermeasure technologies, such as green cover and water surfaces, had already been applied at those sites. The open plaza is located on the southern tip of the redevelopment building complex. There are two tall buildings to the northeast and south of the open plaza, while the western side of the plaza is open. There is little vegetation present, and open spaces and water surfaces are dominant. The rooftop garden (GL + 45 m) is on the roof of the southernmost building in the redevelopment building complex. The sunken garden, where plants are prevalent, is located between the northernmost and southernmost high-rise buildings.

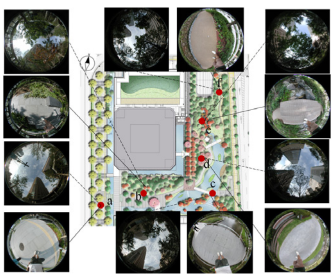
The measured variables and the measurement and analytical method are shown in Table 1. We carried out the measurements by moving between the measurement points. Figure 1 shows the measurement points and photos taken via fisheye lens in each area. The measurement points were selected with consideration of surface cover, ventilation, and solar radiation shielding. Six measurement points in the open plaza were numbered from "1" to "6," five measurement points in the rooftop garden were labeled "A" to "E," and six measurement points in the rooftop garden were labeled "a" to "f".



(a) Open plaza



(b) Rooftop garden

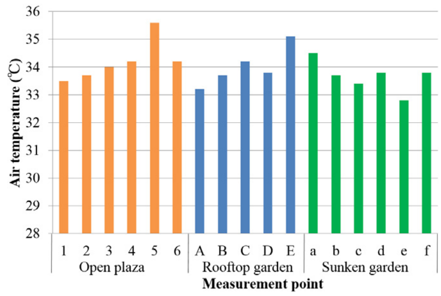


(c) Sunken garden

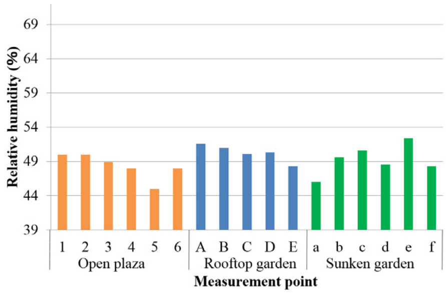
Fig. 1 Location of the measurement points and photos taken via fisheye lens

Table 1 Measurement elements, measurements, and analytical methods

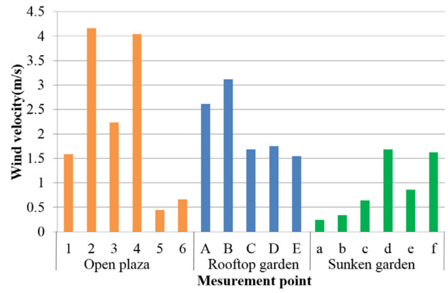
Element	Measureent and analysis method
Air temperature	Measured at 5 sec., averaged in 5 min.
Relative humidity	Measured at 5 sec., averaged in 5 min.
Surface temp.	Measured on ground and wall surface
Wind direction	Recored most frequent wind direction
Wind velocity	Measured at 1 sec., averaged in 30 sec.
View factor	Calculated by fisheye photo at 1.5m
Thermal image	Taken to capture panoramic view



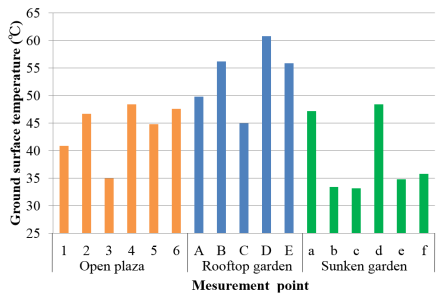
(a) Air temperature



(b) Relative humidity



(c) Ground surface temperature



(d) Wind velocity

Fig. 2 Air temperature, relative humidity, ground surface temperature, and wind velocity at 13:00 on July 25, 2013

2.2 Measurement results

In the daytime, the air temperature increased in the following order: open plaza, rooftop garden, and sunken garden. At night, the temperature was lowest in the rooftop garden. Differences in relative humidity were small; however, relative humidity values were greatest at the measurement points located near water surfaces in the open plaza and sunken garden. The wind velocity was high during the daytime at several measurement points in the rooftop garden. In the daytime, the artificial ground surface temperature in the open plaza and rooftop garden was high due to solar radiation absorption. Air temperature, relative humidity, ground surface temperature, and wind velocity in each measurement point at 13:00 on July 25, 2013, is shown in Figure 2.

3. Calculation of SET*

Measured values of four environmental elements; air temperature, surface temperature, relative humidity, and wind velocity, were used for calculating SET*. SET* is commonly used as an indicator of the outdoor thermal environment, particularly in Japan. Therefore, we have focused on SET* in this study. We set a metabolic rate of 2.0 Mets, with the assumption of a certain walking pace, and we set the amount of clothing at 0.6 clo, assuming the use of summer clothes. Through the sensitivity analysis of SET* for changes in four environmental elements, it was observed that MRT and wind velocity are the dominant factors in SET*.

Therefore, we evaluated the outdoor thermal environment by focusing on the effects of wind velocity and MRT. MRT was calculated with surface temperature, view factor, direct solar radiation, and diffuse solar radiation. We divided the measured global solar radiation into direct and diffuse solar radiation for this purpose.

MRT was an instantaneous value and wind velocity was averaged over 30-seconds, based on measurements taken at one-second intervals. The effects of MRT and wind velocity on SET* in all areas at 13:00 during July 25 is shown in Figure 3. The thermal comfort of SET* is shown in accordance with the study results of Ishii et al.(3). In the open plaza, MRT was high and the variation in wind velocity was large. In the rooftop garden, MRT was also high, while the wind velocity was generally high. In the sunken garden, the variation in MRT was large as well, but the wind velocity was low.

4. Discussion of SET*

4.1 Open plaza

The variation in SET* in the measurement points was about 4.5°C due to the differences between measured maximum and minimum MRT, and about 8°C due to the differences between measured maximum and minimum wind velocity. The effect of wind velocity on SET* was found to be greater than that of MRT.

MRT components at each measurement point are shown in Figure 4. MRT was primarily affected by ground surface temperature, wall surface temperature, and direct solar radiation. In particular, the ground surface temperature dominated MRT. The ground surface temperature was low at measurement points "1" and "3," where solar radiation was shielded in the morning.

The wind vectors are shown in Figure 5. Wind directions varied depending on the obstacles present around the measurement points.

The characteristics of the thermal environment at each

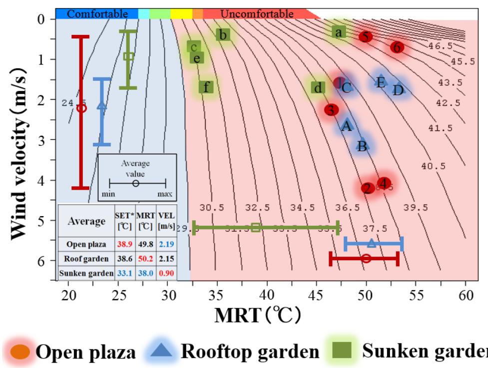


Fig. 3 Effects of MRT and wind velocity on SET* in all areas at 13:00 on July 25, 2013

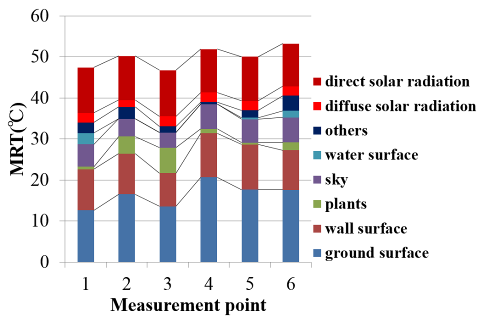


Fig. 4 Components of MRT in the open plaza at 13:00 on July 25, 2013

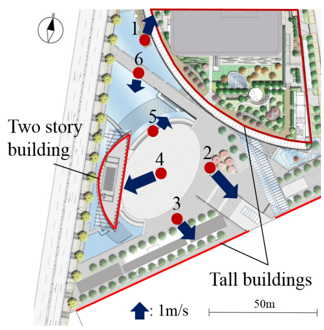


Fig. 5 Wind vectors in the open plaza at 13:00 on July 25, 2013

measurement point were as follows:

- At measurement point “2,” SET* was low because the wind velocity was high due to the wind passage in high-rise buildings.
- At measurement point “3,” SET* was high because the wind velocity was low, due to shielding by trees.
- At measurement point “4,” SET* was low because the wind velocity was high, due to a lack of obstructions in the center of the open plaza.
- At measurement points “5” and “6,” SET* was high because the wind velocity was low, due to the presence of a glass fence between the ground and water surfaces.

At measurement point “5” or “6,” any improvement of MRT derived from water surfaces was not observed. Therefore, we analyzed the relationship between the distance from the water surface boundary and MRT, using a view factor as an indicator. The relationship between the distance from the water surface boundary and MRT is shown in Figure 6. We calculated the view factor by the water surface by changing the distance from the water surface boundary, with a height of 0.88 m assuming a child’s stature, and a height of 1.5 m assuming an adult’s stature. If the distance was closer than 2 m and 3.5 m to the water surface boundary, the improvement of MRT by the water surface was confirmed at both 0.88 m and 1.5 m heights.

4.2 Rooftop garden

The variation in SET* in the measurement points was about 3°C, due to differences between the measured maximum and minimum MRT, and about 2.5°C due to differences between the measured maximum and minimum wind velocity. The effect of MRT on SET* was found to be more significant than that of wind velocity.

The MRT components at each measurement point are shown in Figure 7. The MRT was primarily affected by plant surface temperature, ground surface temperature, and direct solar radiation. The ground surface temperature dominated MRT, similar to the results obtained from the open plaza.

Wind vectors are shown in Figure 8. The primary wind direction on the rooftop garden was from the southwest. The wind velocity was high at measurement points “A” and “B” on the windward side, and slightly lower at measurement points “C,” “D,” and “E” on the leeward side, due to the wind resistance offered by plants and obstacles.

The characteristics of the thermal environment on each measurement point were as follows:

- At measurement points “A” and “C,” SET* was low because the MRTs were low, due to low ground surface temperatures on brick and stone.
- At measurement point “B,” SET* was low because the MRT was low, due to the large view factor of plants.
- At measurement point “D,” SET* was high because the MRT was high, due to high ground surface temperatures on the wood deck.
- At measurement point “E,” SET* was high because MRT was high, due to high ground surface temperatures on stone.

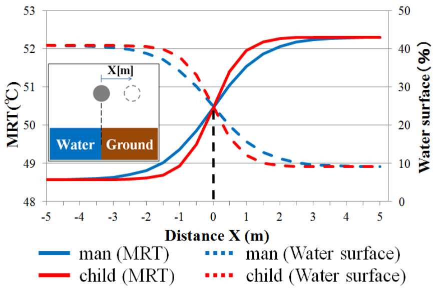


Fig. 6 Relationship between the distance from the water surface boundary and MRT, at 0.88 m (child) and 1.5 m (adult) height

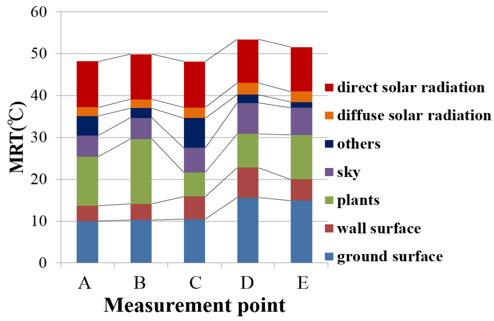


Fig. 7 Components of MRT in the rooftop garden at 13:00 on July 25, 2013

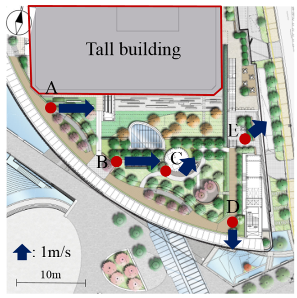


Fig. 8 Wind vectors in the rooftop garden at 13:00 on July 25, 2013

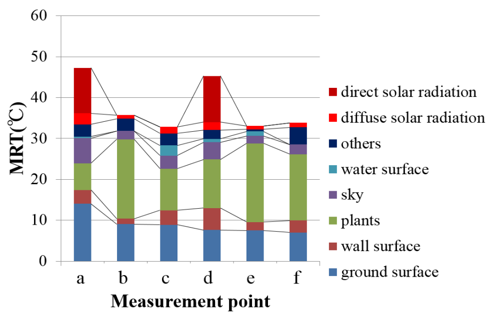


Fig. 9 Components of MRT in the sunken garden at 13:00 on July 25, 2013

4.3 Sunken garden

The variation in SET* in the measurement points was about 9.5°C due to the differences between the measured maximum and minimum MRT, and about 3°C due to the differences between the measured maximum and minimum wind velocity. The effect of MRT on SET* was dominant, as compared to wind velocity.

The components of MRT at each measurement point are shown in Figure 9. There were few plants at measurement point “a,” and more plants present at measurement point “f”. Solar orbital diagrams corresponding to the date of July 25 are shown in Figure 10. At the majority of the measurement points, the solar radiation was shielded by high-rise buildings and plants throughout the day.

MRT was primarily affected by plant surface temperatures, direct solar radiation, and ground surface temperatures. MRT was low at most of the measurement points because of the large view factor of plants, while MRT was high at measurement points “a” and “d,” due to the incidence of direct solar radiation. The wind velocity at each measurement point was low, due to the wind resistance offered by plants.

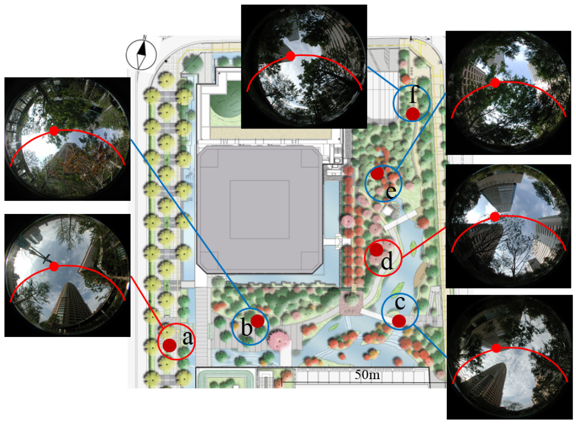


Fig. 10 Solar orbital diagrams from the sunken garden on July 25, 2013

Table 2 Averaged values of SET*, MRT, and wind velocity at 13:00 on July 25, 2013

	SET*	MRT	wind velocity
Open plaza	38.9 °C	50.0 °C	2.2 m/s
Rooftop garden	38.6 °C	50.3 °C	2.1 m/s
Sunken garden	33.1 °C	38.0 °C	0.9 m/s

Table 3 Variations in SET* due to differences in MRT and wind velocity at 13:00 on July 25, 2013

	due to difference in MRT	due to difference in wind velocity
Open plaza	4.5 °C	8.0 °C
Rooftop garden	3.0 °C	2.5 °C
Sunken garden	9.5 °C	3.0 °C

Table 4 Averaged values of SET*, MRT, and wind velocity at 10:00, 17:00 and 20:00 on July 25, 2013

		SET*	MRT	wind velocity
10:00	Open plaza	32.7 °C	41.9 °C	1.7 m/s
	Rooftop garden	31.3 °C	41.1 °C	2.6 m/s
	Sunken garden	30.8 °C	37.2 °C	0.8 m/s
17:00	Open plaza	38.9 °C	45.4 °C	0.7 m/s
	Rooftop garden	31.3 °C	38.5 °C	2.1 m/s
	Sunken garden	30.6 °C	36.3 °C	1.4 m/s
20:00	Open plaza	26.0 °C	30.0 °C	0.4 m/s
	Rooftop garden	24.2 °C	27.5 °C	1.3 m/s
	Sunken garden	25.3 °C	29.3 °C	0.8 m/s

5. Discussion and Summary

The averaged value of SET*, MRT, and wind velocity in each area at 13:00 on July 25, 2013, is shown in Table 2. The variation in SET* due to differences in MRT and wind velocity in each area at 13:00 on July 25, 2013, is shown in Table 3.

The averaged value of SET* in the sunken garden was the lowest out of the three measurement areas because the lowest MRT was present at this location, despite the fact that the wind velocity was also the lowest at the same site. The improvement in MRT due to solar radiation shielding by plants and high-rise buildings is more effective for the improvement of the outdoor thermal environment, rather than through ventilation enhancements.

The averaged value of SET*, MRT, and wind velocity in each study area for other measurement times and days, i.e., under alternative weather conditions, are shown in Tables 4 and 5. The tendency for SET* to be lower in the sunken garden during these measurement times and days is similar to the observations taken at 13:00 on July 25. However, the SET* in the rooftop garden at 17:00 and 20:00 is low due to the low MRT derived from radiative cooling and a slightly stronger wind.

To conclude, the improvement of MRT is the most significant factor for the improvement of the outdoor thermal environment during the daytime, although ventilation enhancements are also important for the improvement of the outdoor thermal environment during the evening.

Table 5 Averaged values of SET*, MRT, and wind velocity at 13:00 on July 22, 23, 24 and 26, 2013

		SET*	MRT	wind velocity
July 22	Open plaza	35.3 °C	46.8 °C	2.6 m/s
	Rooftop garden	34.8 °C	48.1 °C	3.4 m/s
	Sunken garden	29.7 °C	37.1 °C	2.0 m/s
July 23	Open plaza	30.4 °C	38.5 °C	1.7 m/s
	Rooftop garden	30.8 °C	39.2 °C	1.7 m/s
	Sunken garden	28.7 °C	36.3 °C	1.9 m/s
July 24	Open plaza	-	40.8 °C	2.3 m/s
	Rooftop garden	35.7 °C	47.6 °C	2.3 m/s
	Sunken garden	26.4 °C	32.9 °C	1.2 m/s
July 26	Open plaza	34.6 °C	43.6 °C	2.4 m/s
	Rooftop garden	34.6 °C	45.4 °C	3.0 m/s
	Sunken garden	31.8 °C	38.0 °C	0.9 m/s

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