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KOBE UNIVERSITY

CLIMATE ANALYSIS FOR URBAN PLANNING IN FUKUOKA

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Tadahisa Katayama 2)

Abstract: According to urbanization, the urban environment, particularly the thermal one in hot and humid summer, is getting worth in Japan. Fukuoka City, where 1.23 million residents lives, and Kitakyushu City, where 1.01 million residents lives, in Kyushu Island, Japan, are without exception. This paper describes surveys land cover and energy consumption in Fukuoka City. And it is cleared that cooling effects of natural covering, the sea breeze, a river and a pond. Its basic data are used for making a clima atlas. And we make a proposal of urban planning for changing as ecological city.

Key words: Clima atlas, Urban thermal environment, Fukuoka City, Kitakyushu City

1. DISTRIBUTIONS OF LAND-USE, HEAT LOAD DENSITY AND AIR TEMPERATURE IN FUKUOKA CITY

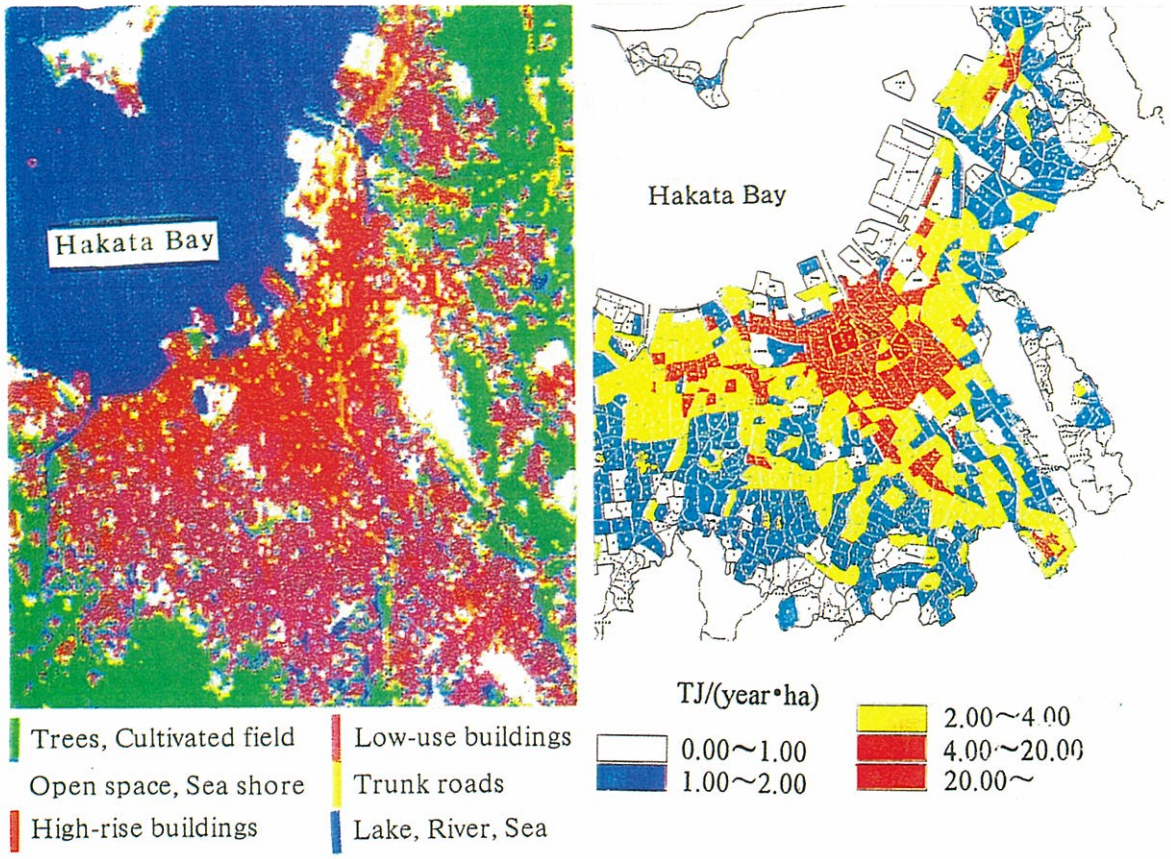
The increase in temperature in a hot urban area is mainly attributed to the ground surface being covered with artificial materials instead of natural ones. Therefore, in the city, studying the distribution of land-use for natural elements is the most important source of data for the analysis of the urban thermal environment. Currently, the land-use in many major cities can be quantified in the database of the National Land-Use Digital Information. The land-use is mapped in a grid of cells of 100 m^2 and the ratio of the surface area of man-made artificial construction to natural material and water is calculated.

According to data of 1995, the area of Fukuoka City is about 340 km^2 and the population is about 1.2 millions. Figure 1(a) indicates the distribution of land-use in Fukuoka City, based on the data of 1990.[1)] The original data consisted of nineteen categories of land use. These were later consolidated into six categories as follows: 1) high-rise buildings; 2) low-use buildings; 3) trunk roads; 4) open spaces, sea shore; 5) trees, cultivated fields; and 6) lake, rivers, and sea.

Because Fukuoka City faces Hakata Bay, it was developed as the largest commercial city on Kyushu Island. Accompanying this growth, an area of high-rise buildings developed along the coast line from NE to SW, and along a private railway which runs through the center of the city, inland. Structurally, Fukuoka City environment forms three zones: the high-rise buildings in the center, surrounded closely by low-use buildings, and these two, enclosed by a zone of vegetation and cultivated fields.

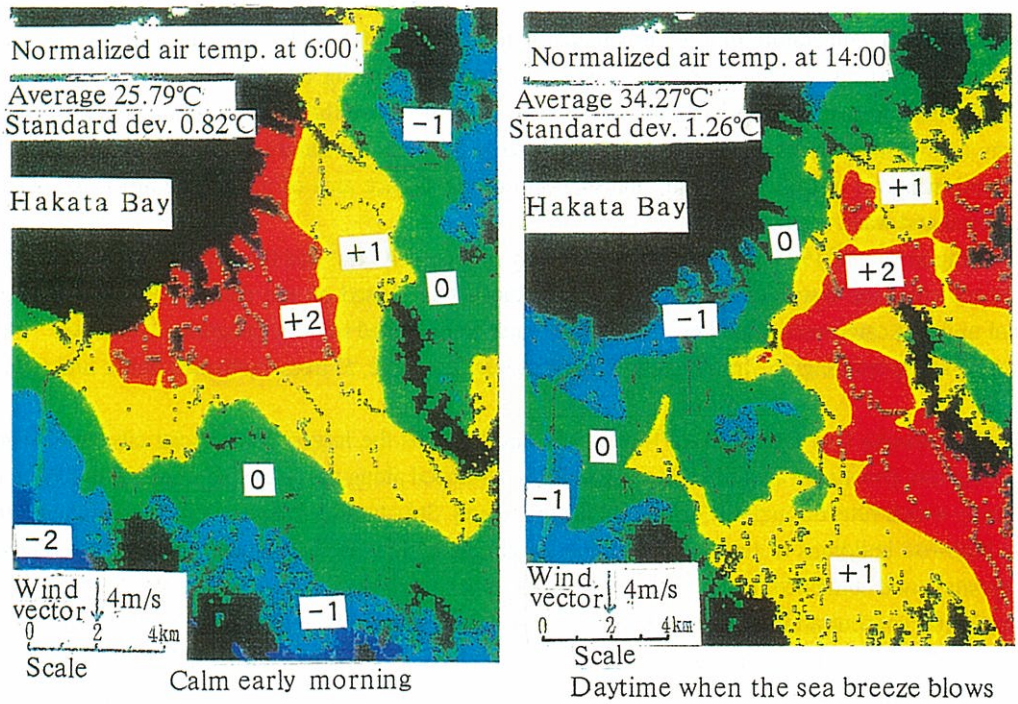
Growth and concentration of population in an urban area cause urbanization and a great amount of energy consumption. A greater amount of waste heat generated by a large quantity of energy consumption is exhausted into exhausted into the atmosphere and increases air temperature directly. Figure 1(b) shows heat load density per town using building survey.[2)]

Measurements of air temperature distribution in Fukuoka City in summer were taken in the calm early morning and daytime when the sea breeze blows. Air temperatures were measured by thermistor thermometers with sunshades mounted on eight cars. The measurement points were selected on the roads where the cars would drive and



(a) Land-use classified into six categories

(b) Heat load density



(c) Normalized air temperature and wind vector in summer

Figure 1 Distributions of land-use, heat load density and air temperature in Fukuoka City

distributed uniformly over the city. About 120 measurement points were passed by each car within two hours. The total number of measurement points was 958. The difference of air temperatures occurred by a time lag between measurements points, with the base temperature reading taken at 06:00 in the early morning and the high point reading taken at 14:00 in the daytime. The assumption was made that the change of air temperature at each measurement point was similar to that at Fukuoka Observatory. The results are illustrated in Figure 1(c).[3] Numbers in the figure are the normalized air temperatures calculated by the following equations:

$$(t_i - \langle t \rangle)/\sigma \qquad (1)$$

where $\langle t \rangle = (1/n)\Sigma\, t_i$

$\sigma = \{(1/n-1)\Sigma(t_i-\langle t \rangle)^2\}^{1/2}$

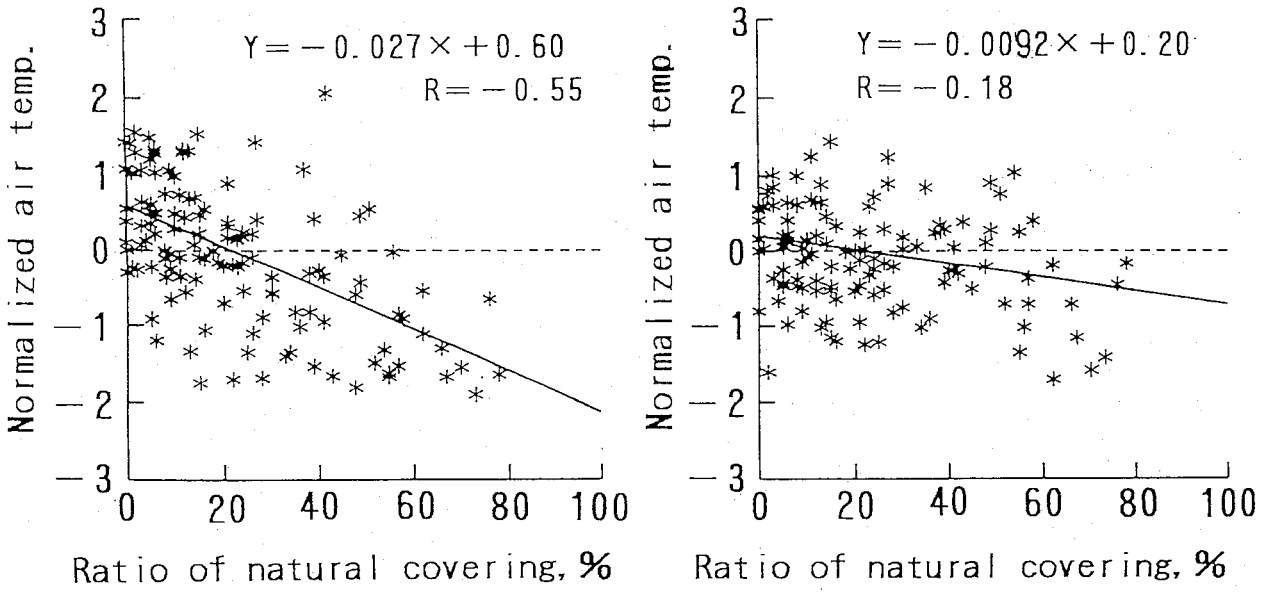
t_i = corrected value of air temperatures at point i

n = number of measurement points(958)

The wind vectors at eight points are represented by the arrows. In the early morning, wind speeds at these eight points are less than 2 or 3 m/s and the contour lines of normalized air temperature correspond well to the distribution of land-use. That is, the air temperature in the center of the city, where the prevailing ratio of high-rise buildings is the highest, is contrasted to that in the suburbs with varied vegetation where the air temperature is lowest. On the other hand, in the daytime, wind blows from the sea toward inland at a speed of about 4 to 8 m/s and the high air temperature region moves from the center of the built-up area to the leeward side of land.

2. COOLING EFFECTS OF NATURAL COVERING

The investigation area was divided into a 1 km square grid and the measured values of air temperature were averaged in each cell. The ratios of the natural covering such as trees, cultivated fields and surfaces of bodies of water were calculated in each cell of the 1 km square grid to examine the relation to the air temperature. Figure 2 shows that the larger the natural covering, the lower the air temperature and that the absolute values of both the correlation coefficients and the regression coefficients in the calm early morning are larger than those in the daytime when the sea breeze develops.[3] This tendency reverses when the ratios of the artificial covering such as building and pavement are increased.[4]



(a) Calm early morning

(b) Daytime when the sea breeze blows

Figure 2 Relation between natural covering ratio and averaged air temperature in the cell of 1 km square grid

3. COOLING EFFECTS OF THE SEA BREEZE

The distribution pattern of air temperature over the city is influenced greatly by the wind as was previously indicated in Figure 1(c). Part of the monitoring system of atmospheric contamination concentration in Fukuoka City includes six observation stations of wind speed and wind direction, and these were used to study the effects of the sea breeze over the city. The observation stations ranged in height from 18 to 43 meters above ground. Data on the wind was gathered for two years at six stations and analyzed to obtain the windroses and the frequency distributions of wind speed, illustrated in Figure 3. It became clear at that the sea-land breeze develops well across the city and wind speed in the daytime is stronger than that in the night. At each point, wind blows from the sea in the daytime and the prevailing wind direction is approximately perpendicular to the coast line.

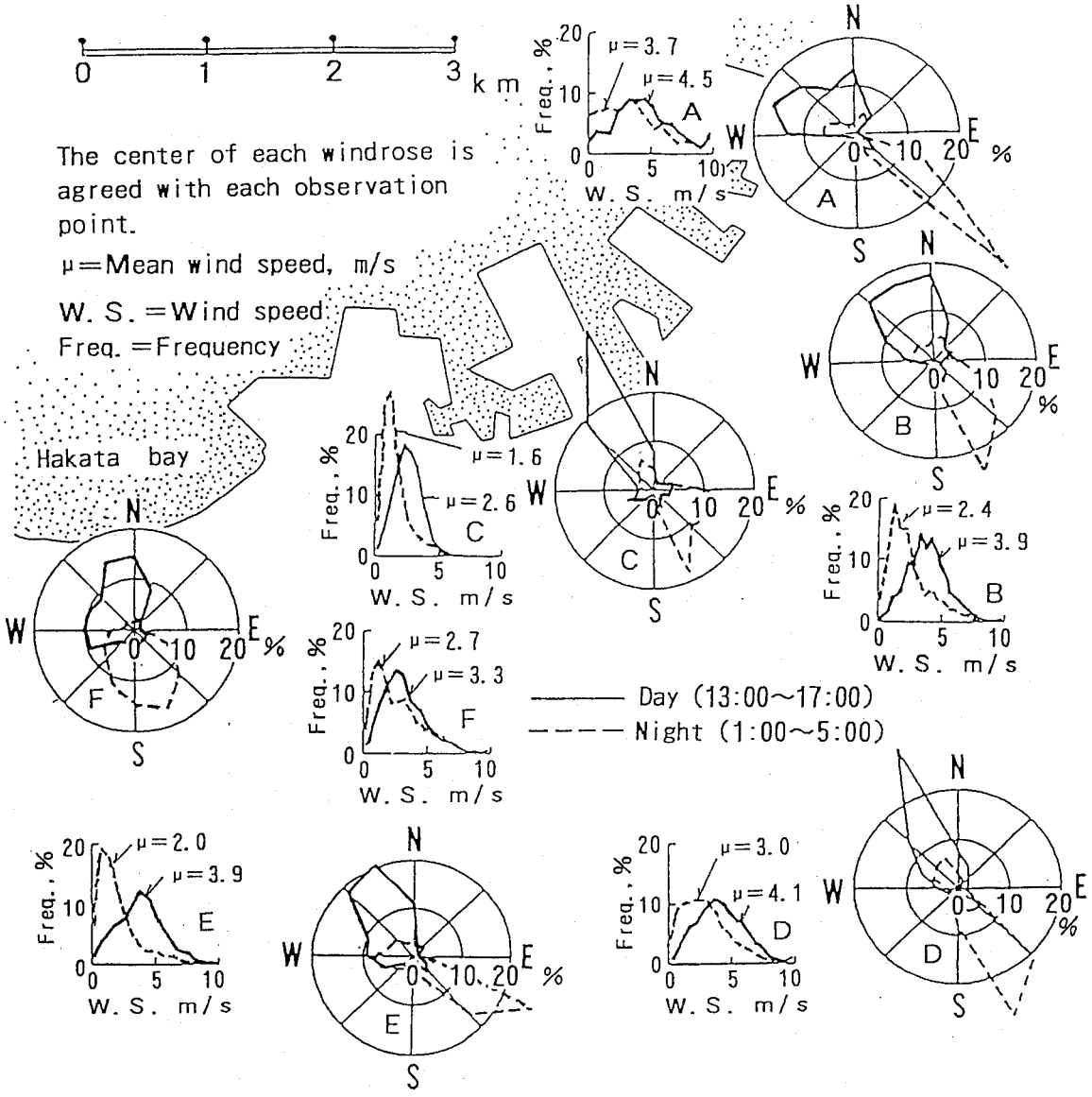
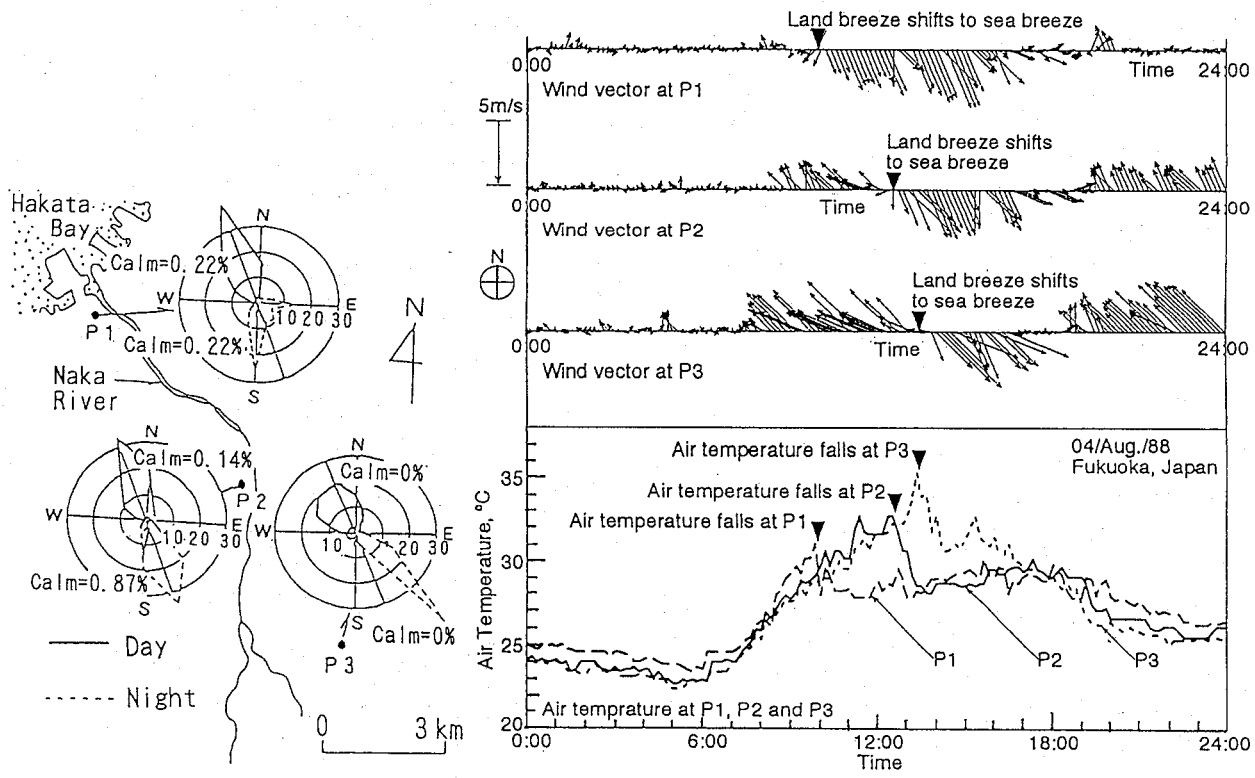


Figure 3 Windroses and frequency distributions of wind speed during the day and night for two years

Because of its thermal convection, the sea breeze is a natural cooling resource that mitigates the rise of air temperature in summer. Wind direction, wind speed and air temperature were observed simultaneously at three stations located almost in a line to the direction of the sea breeze as shown in Figure 4(a). The distances from the coast line to the three stations were about 1 km, 5 km and 11km. respectively. Propeller-type anemometers and vanes were used to observe wind speed and wind direction. Air temperatures were measured by thermocouples with sunshades at 10-minute intervals. The days used for the analysis were limited to days with a noticeable sea-land breeze, with changes in wind direction and wind speed, and where there existed solar radiation. The criteria for the selection were the following; 1) no precipitation during the daytime; 2) an obvious shift in the wind direction from landside to seaside in the daytime; 3) a wind speed that was neither too strong nor too weak; 4) and, where there was a reasonable degree of solar radiation. Figure 4(b) indicates a sample of the diurnal fluctuations of wind vector and air temperature.[5] The wind shift from the land breeze to the sea breeze was delayed at the landward station. The air temperature fell noticeably when the wind shifted from the land breeze to the sea breeze, and remained low while the sea breeze was blowing. The temperature was lowest at the station nearest to the coast-line where the wind shifted from the land breeze to the sea breeze faster and where the air temperature was lower than the other two landward stations.

The results of the diurnal fluctuations of the averaged air temperatures for the sea-land breeze days during four months from June to September (the number of which was thirty-three according to the previously stated criteria) indicate that the air temperature at the seaward station was lower during the daytime. However, there was little difference among the air temperature data at the three stations in the nighttime as indicated in Figure 5.[5]



(a) Observation points and windroses in summer

(b) Diurnal fluctuations of wind vector and air temperature

Figure 4 Relation between diurnal fluctuation of wind vector and that of air temperature related to the distance from seashore

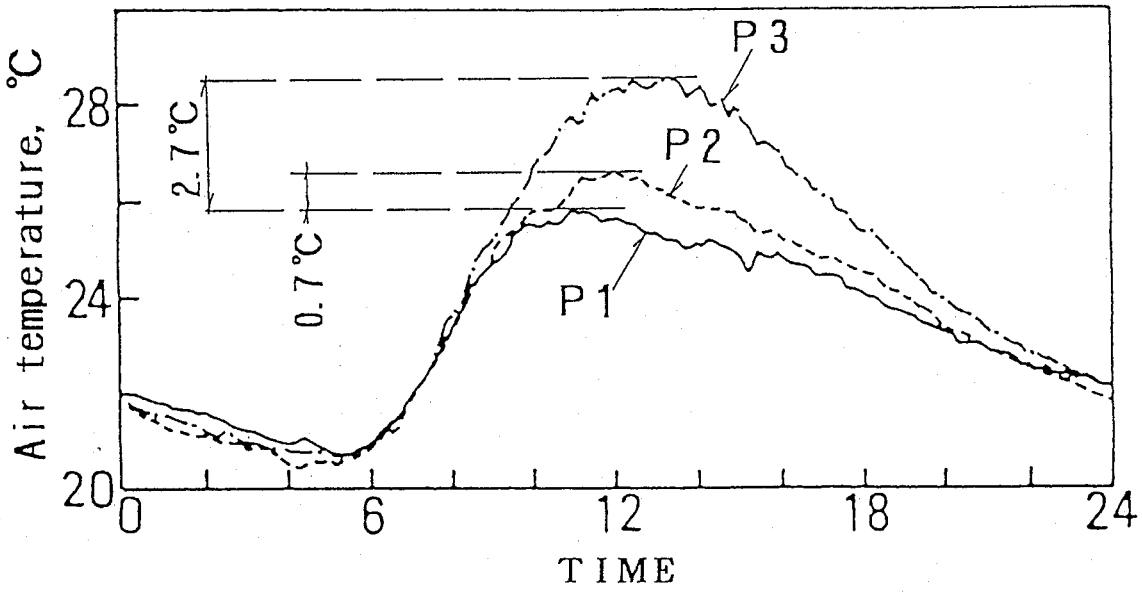


Figure 5 Comparison of diurnal fluctuations of averaged air temperature for sea-land breeze days in relation to the distances from the sea shore

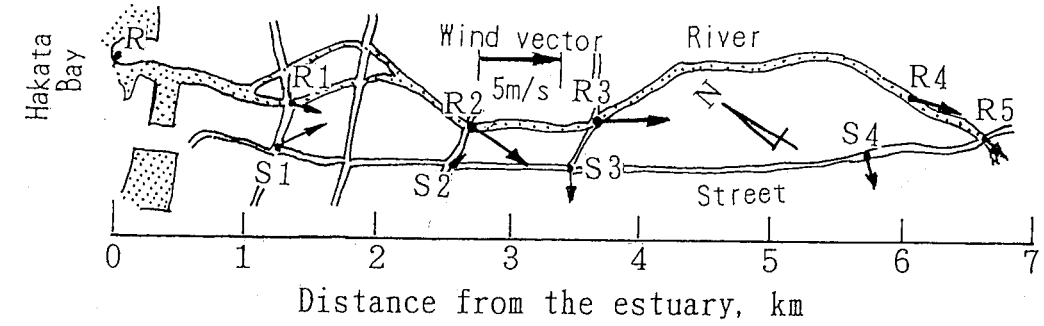
4. COOLING EFFECTS OF A RIVER

Most of the seaside cities in Japan have rivers which usually run almost perpendicular to the coastline and empty into the sea. These rivers become an open space through which sea breezes blow freely. Thus, rivers in built-up seaside cities support the cooling effects of the sea breeze and improve their nearby thermal environment.

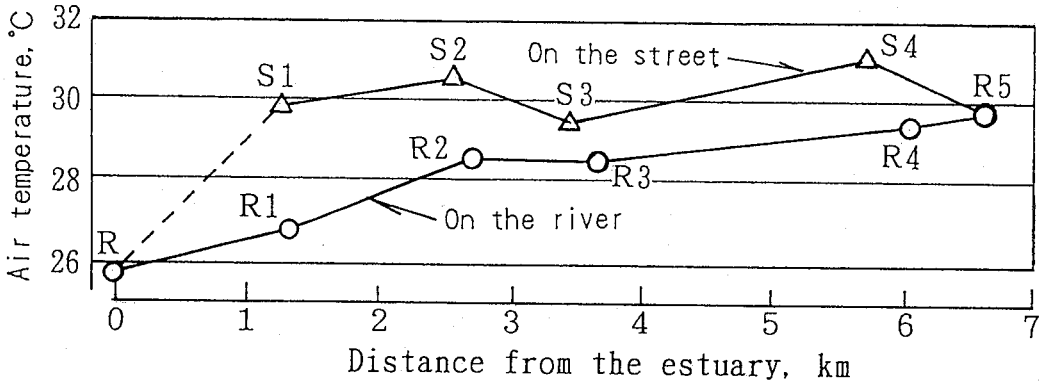
The Naka River, which is about 100 m wide, flows from SE to NW through the downtown area of Fukuoka City. One of the streets, with a width of about 40 m is nearly parallel to the Naka River for a distance of about 400 m. The street crosses the river at a point about 6 km upstream from its estuary. Measurement points were set at the coast and at the cross-point. Between these points, there were four additional pairs of measurement sites, each on the river and on the street as shown in Figure 6(a).[6)]

The measurements were carried out on a clear day in August. In northern Kyushu District, a typically good day in summer is clear both in the morning and in the evening but is sometimes cloudy during the daytime. When the sea breeze blew, the wind speed increased more over the river than over the street. The wind direction above the river remained fairly constant while the wind direction over the street became irregular and was strongly influenced by various obstacles such as buildings and road-side trees as indicated in Figure 6(a). When the intensity of the sea breeze increased, the air temperature above the river was clearly lower than that above the street in the daytime as shown in Figure 6(b).[6)] The air temperature above the river increased gradually from the estuary upstream. This indicates that the cooler air of the sea breeze blown inland above the river mixes with nearby hot air and cools the neighboring area of the river.

The surface temperature of the river water was lower than that of the asphalt pavement of the street during the daytime. Water surface temperatures fluctuated gently between 21℃ and 27℃, as opposed to the surface temperatures of the pavement in the sunshine, which changed from 25℃ at 07:00 to 60℃ at 13:00 according to the amount of solar radiation. The difference in surface temperature between the water and the pavement reached more than 25℃ at about 13:00 as indicated in Figure 7.[6)]



(a) Measurement points and wind vectors



(b) Distributions of air temperature

Figure 6 Comparison of the distributions of air temperature and wind vector along the river with those along the street at 13:00 in the clear summer day

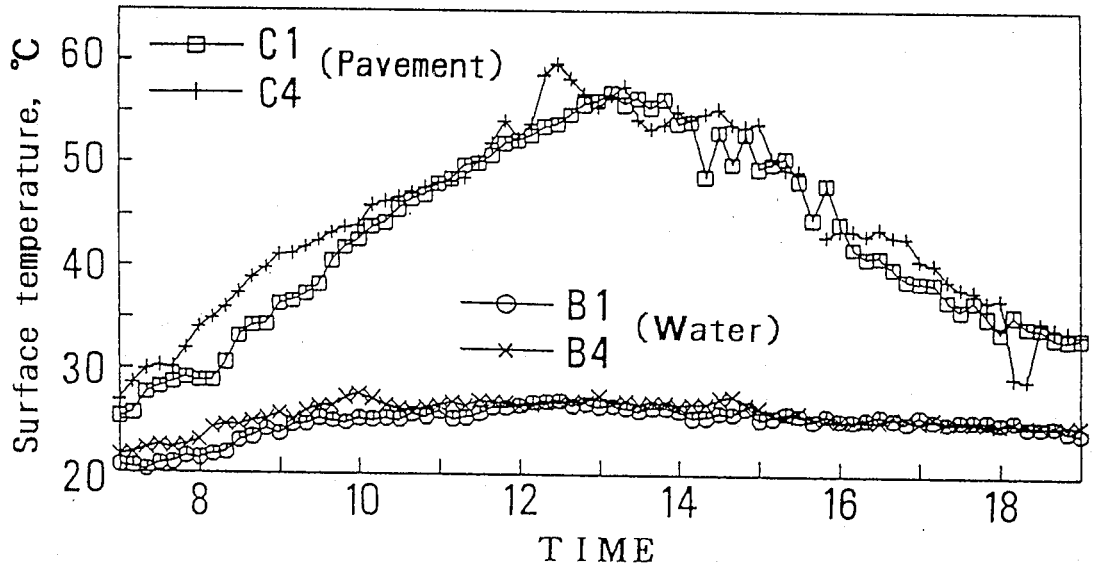
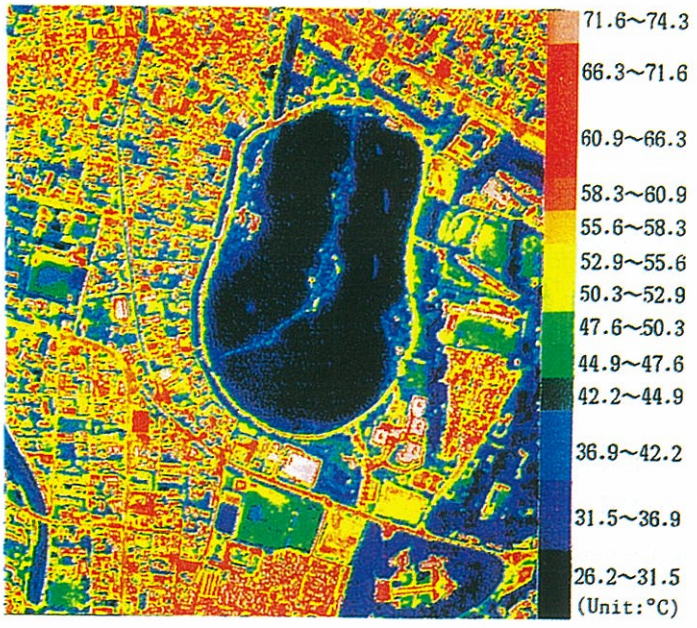


Figure 7 Comparison of surface temperatures of the river water with those of the asphalt pavement

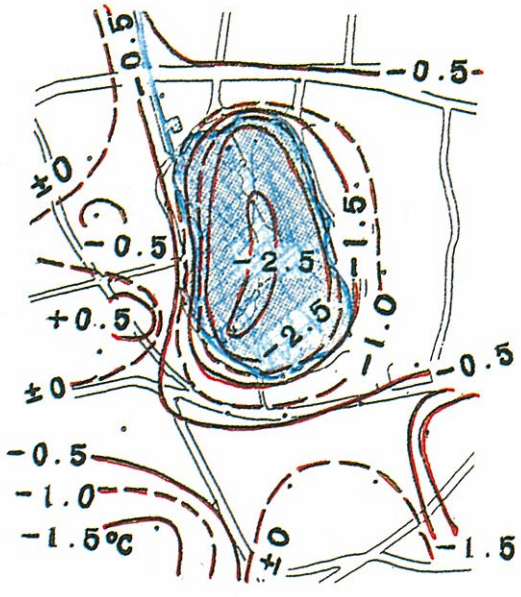
5. COOLING EFFECTS OF A POND



Figure 8 Aerial photograph of the pond



(a) Thermogram at midday by remote-sensing from the height of 800 m above the ground



(b) Air temperature distribution in the early afternoon

Figure 9 Thermogram and air temperature distribution on and around pond in a built-up area in clear summer day

Water surface of a pond also remains at a lower temperature similar to that of a river. Fukuoka is one of the rare cities that has a park in its center with a large pond of about 240,000 m^2, as indicated in Figure 8. It was artificially constructed about seventy years ago.

The distribution of surface temperature on and around the pond was measured by sensing from the height of 800 m above the ground at midday in clear summer day. Figure 9(a) shows its thermogram.[7] In the daytime, the pond forms a cooling spot. The surface temperature difference between the pond water and its surroundings is very large, and the air temperature on the pond becomes 2.5℃ lower than that of the distant streets as indicated in Figure 9(b).[8] The isometric lines of -1.5℃, -1.0℃ and -0.5℃ can be drawn around the pond in an area of about 700 m × 1,000 m. This air temperature distribution demonstrates that a clear "cool island" is caused by the pond, and the cooling effect of the pond on the surrounding built-up area is considerably large. The thermal effect of the pond gradually decreases in the evening and at night, because the surface temperature difference between the pond water and its surroundings also becomes smaller, as in the morning. The air temperature differential between 39 measuring points in an area of about 700 m × 1,000 m, including the pond, is small in the early morning and gradually increases, reaching a maximum in the early afternoon and decreasing at night. This temperature differential seems to be highly related to solar radiation, and the standard deviation of the air temperature differential is nearly proportional to solar radiation (Figure 10).[8]

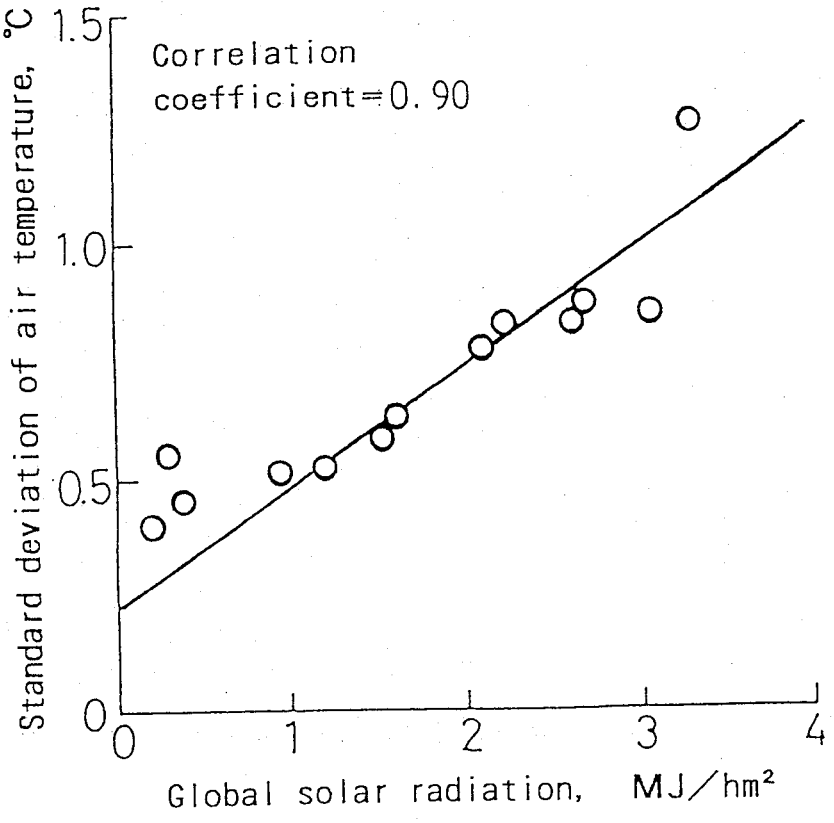


Figure 10 Relation between solar radiation and deviation of air temperature distribution

6. PROJECTS IN FUKUOKA CITY

Fukuoka City is divided among the Tatara River flows the eastern, the Naka River flows the city center and the Muromi River flows the western. It is expected that to redevelopment of avenues along these rivers will help the city breathe and function as having the effect of the urban cool island phenomenon. Green zones from seaside to inner area will be connected and city area between the Naka River and the Muromi River will be divided by the green belt. Furthermore, the Ishido River side nearby Hakata Station, in the business area, and the Hii River side through Nisijin will get improved. According to a broken line in Figure 11, the urban heat island phenomenon is divided by rivers and green belt.

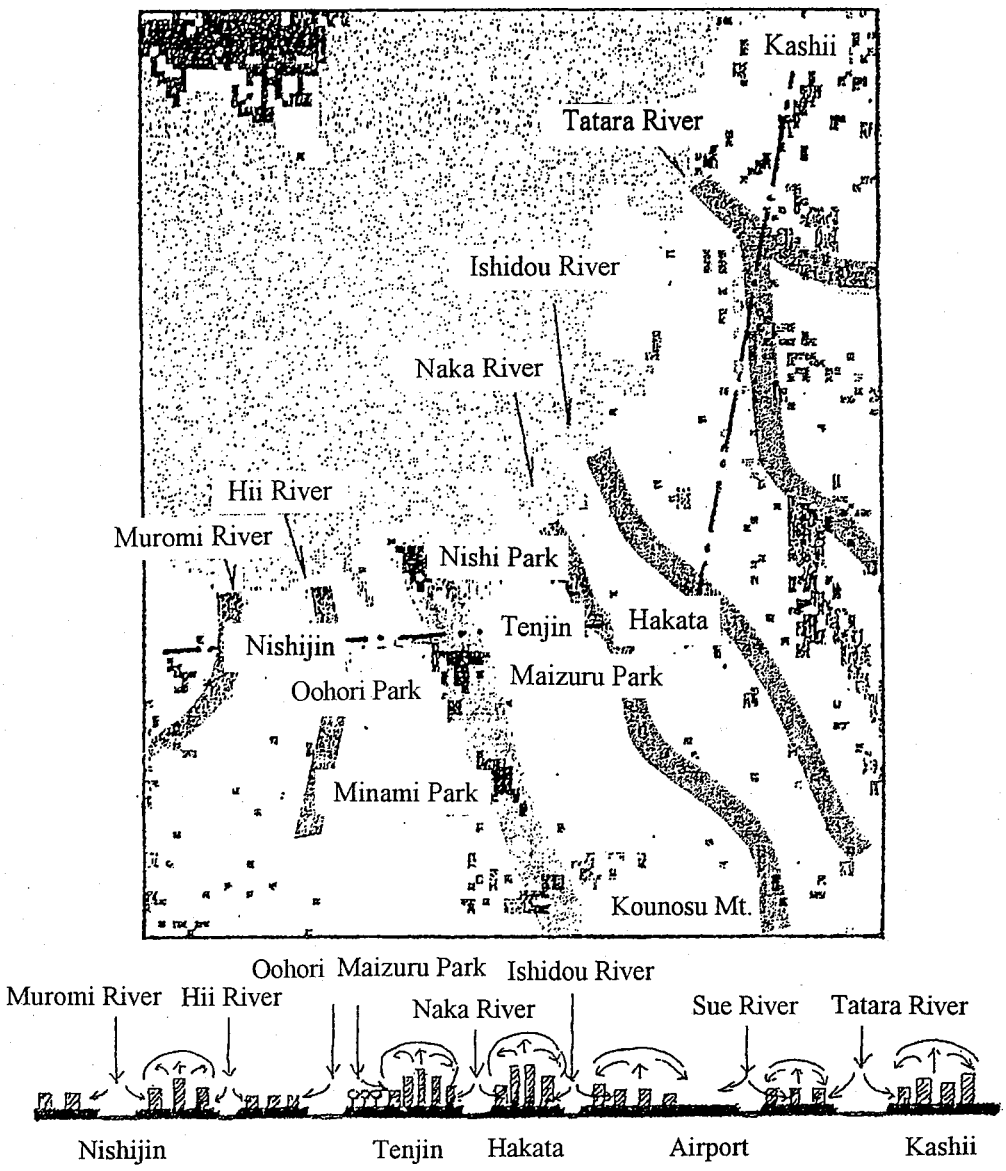


Figure 11 Division of heat island by cool island in Fukuoka City

7. PROJECTS IN KOKURA CITY-CENTER AREA AND KUROSAKI SUB-CENTER AREA, KIKAKYUSHU

Kitakyusyu City is a government ordinance designated city located at a Northern latitude of 34 degrees and on Eastern longitude of 131 degrees at the entrance of Kyushu. It was founded by a merger on equal terms of 5 cities. It is a coastal city with a long coastline and undulating mountains closing in from both sides. In the flat area between the seas and mountains lies an urban belt consisting of Kokura, the city center, and Kurosaki, the sub-center, as the core of the city.

The present situation in the urban environment and the basic policies to create the urban environment for years to come have been presented according to the urban environmental plan (Urban Green Kitakyushu), drawn up by Kitakyushu City.

From the following viewpoints, urban environmental projects will be implemented in two areas of Kokura city center and Kurosaki sub-center, which are designated as the priority renovation areas.

1) This city is already endowed with a superb natural environment. The two areas, Kokura city center and Kurosaki sub-center, where currently a variety of projects are actively pursued, carry great weight in this city's urban development. The creation of the city identity is being promoted through improvement of the city's image, by bettering its bases where the citizens can live in harmony with the environment.

2) As stated before, these areas are considered to be the most important from the viewpoint of the urban environment, because the effects of city-life-type pollution such as automobile exhaust are causing grave concern in the city center and sub-center areas.

3) From the viewpoint of drawing the attention of its citizens, it is hoped that by implementing projects in the central areas which are familiar to them, a ripple effect of such projects to other areas will be produced.

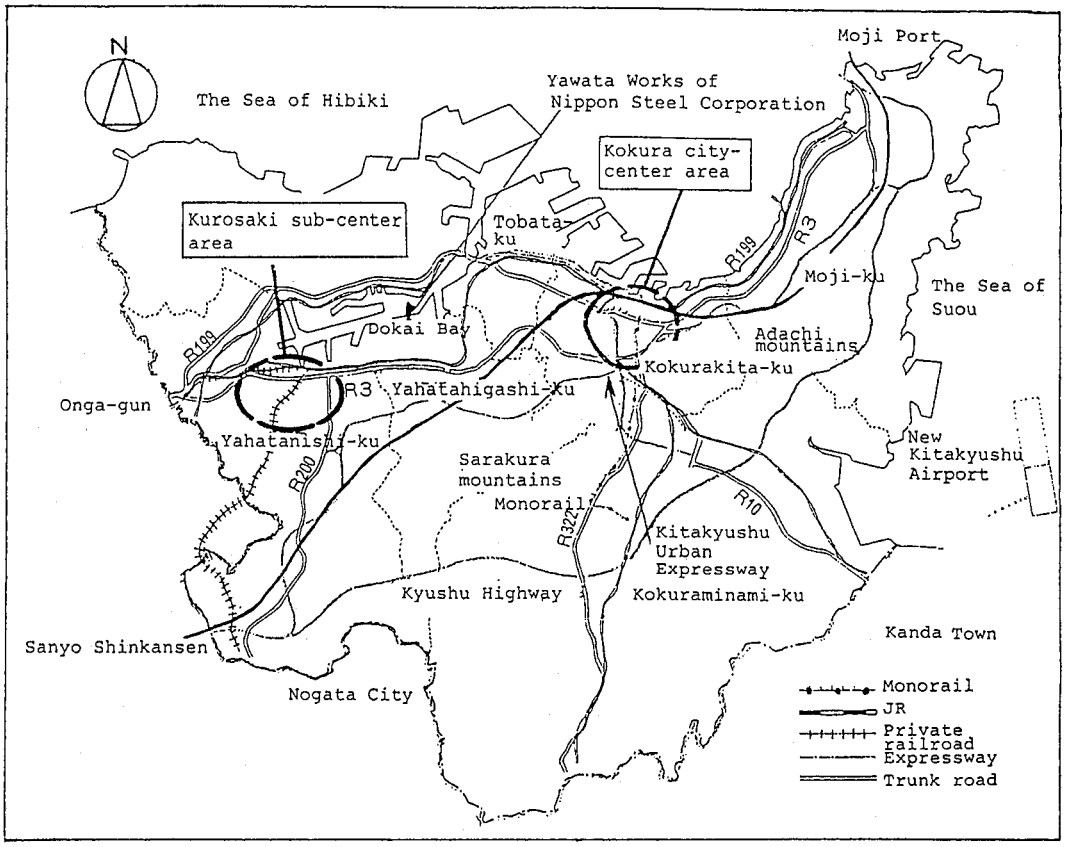
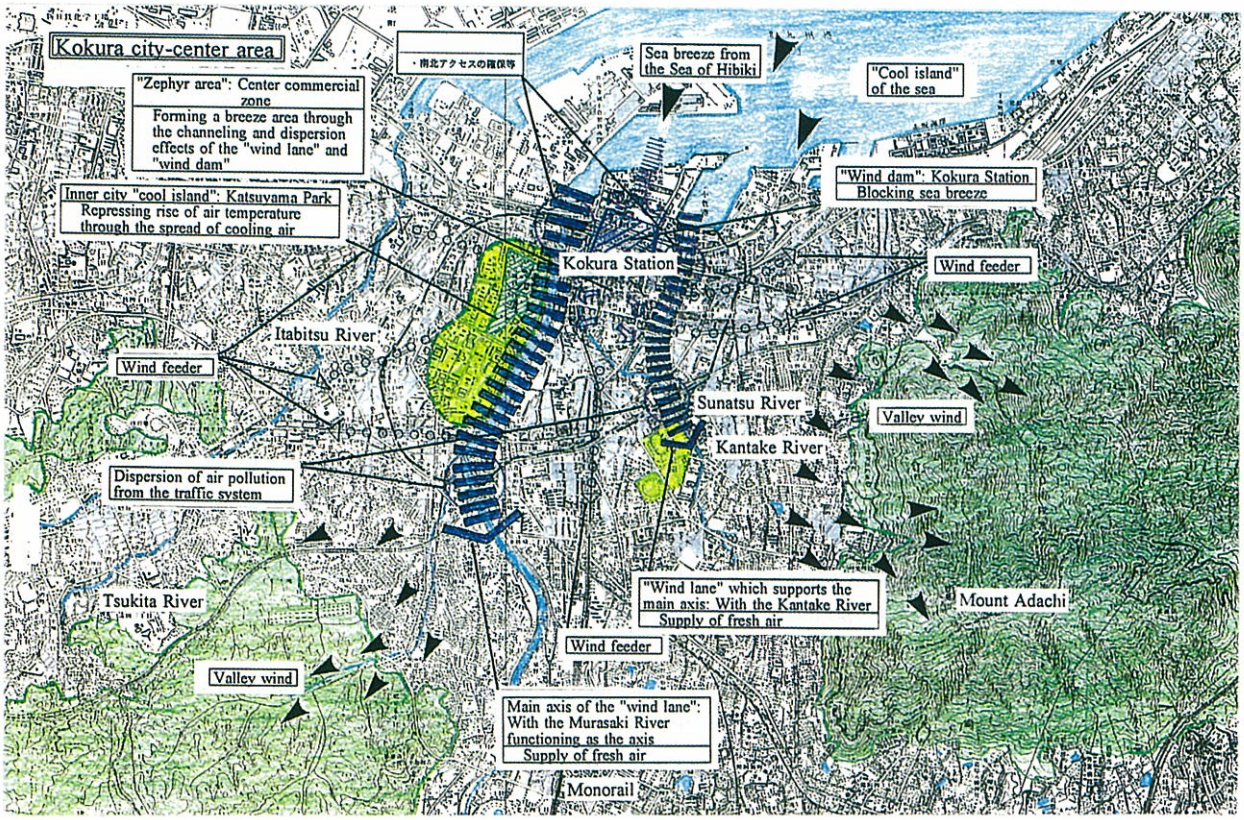
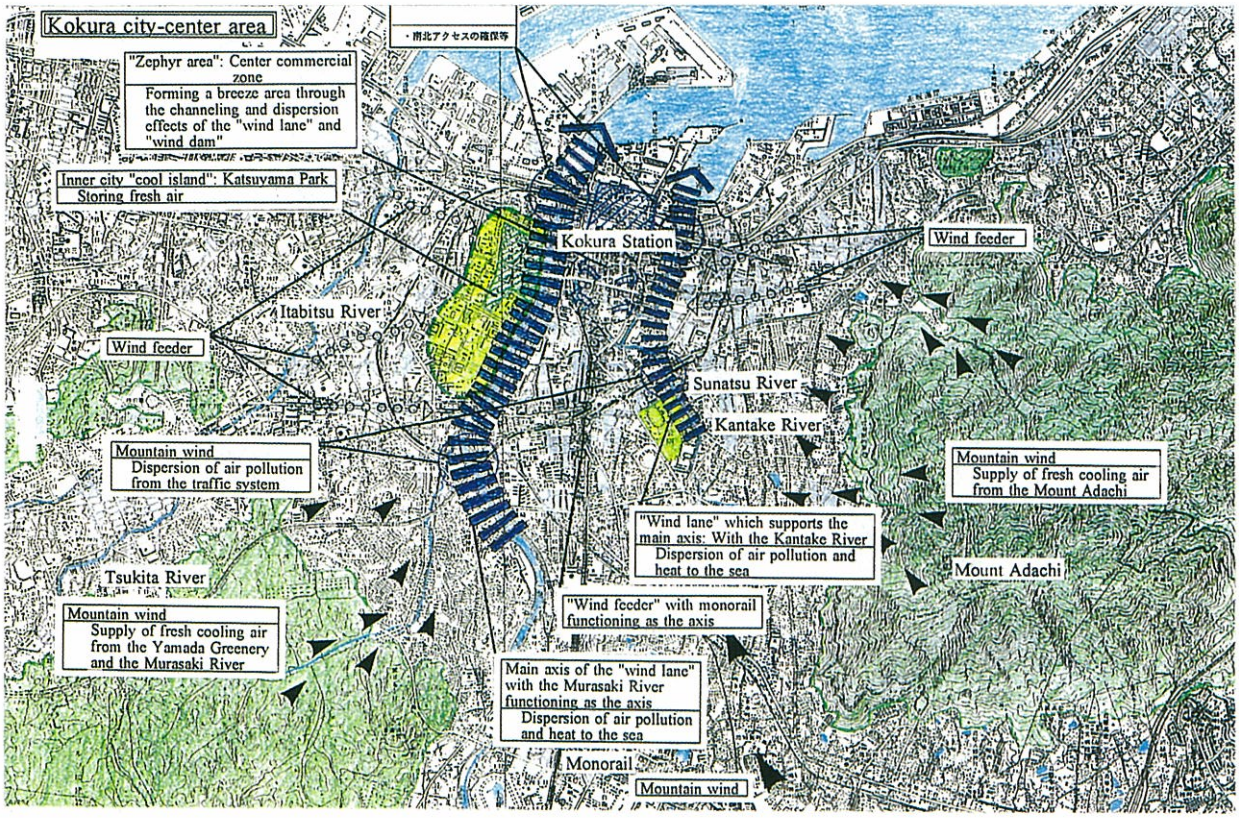


Figure 12 Drawing of the present condition of Kitakyushu City

(1) PRIORITY RENOVATION PROJECTS IN THE KOKURA CITY-CENTER AREA



(a) daytime pattern



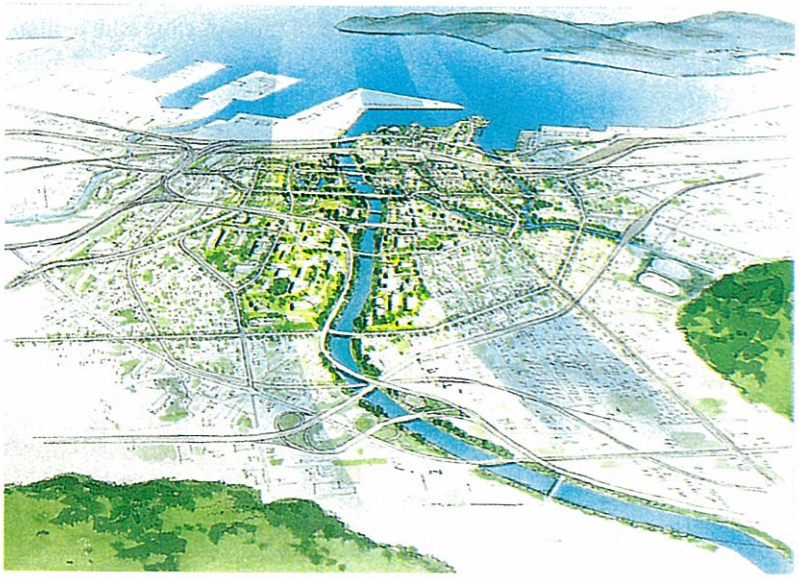
(b) nighttime pattern

Figure 13 Conceptual diagram of the "Kokura City"

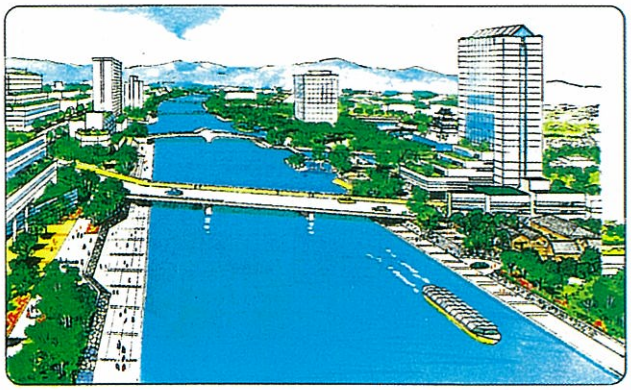
Considering the urban and natural environmental characteristics, trends in urban improvement and so forth, it is more appropriate to actively utilize natural features for improvement such as those offered by the Murasaki River which flows through the center of this area from south to north as in the case of the Kokura city-center renovation project. In this way, it is intended to achieve improvement of the urban environment without spending additional energies or costs, and to diffuse the environmental impact on the city center by making use of the Murasaki River and the open space along it, parks, green zones, and trunk roads and furthermore, by introducing the natural "breezes" into the city through the creation of urban environmental axes abundant with water and greenery.

Mostly, the wind blows from south to north due to the geographical characteristics of Kokura city-center. It is assumed that during the daytime the sea breeze blows from the Sea of Hibiki, while during the night the land breeze blows from the mountains. Therefore, the creation of the "Lane of Zephyr" will be promoted through formation of two principal axes; the Murasaki River forms the principal axis as a wind path connecting the city center with the suburbs and the littoral areas by continuously linking a series of open spaces abundant with water and greenery, while the Kantake River forms an auxiliary axis as a wind path supporting the principal axis.

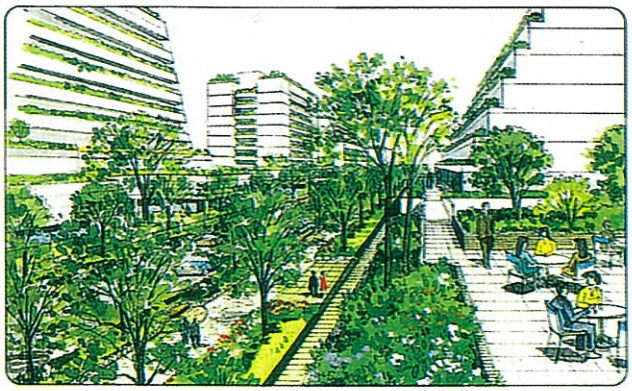
The trunk roads running in the radial direction and in loops throughout the area will be planned as feeders for the wind branching off the two wind path axes. It is expected that the "Lane of Zephyr" will help the city breathe and function as having the effect of preventing the urban heat island phenomenon and diffusing the impact of waste heat and air pollution on the city center.



(a) A bird's-eye view



(b) Image of a renovated Murasaki River: "lane of zephyr"



(c) Image of an innovated city center with abundant greenery; via afforestation, etc.

Figure 14 Images of the renovated city, Kokura

(2) PRIORITY RENOVATION PROJECTS IN THE KUROSAKI SUB-CENTER AREA

Considering the urban and natural environmental characteristics, trends of urban renovation, etc., it is more appropriate to aim at the creation of a compact urban zone where jobs, housing, leisure, and nearby natural features are integrated into one body, and to implement urban environmental renovation aiming at harmony between "reduction or environmental impact and symbiosis with nature" and "compound urban development", when implementing the Kurosaki sub-center renovation project. The principal object in view is to create a "Lane of Amenity" which is comfortable for humans and other living things. This is achieved in the following way; the trunk roads are utilized as a "green axis" (eco-boulevard) linking the green zones within the area with each other, and the rivers that flow through each part within the area are utilized as a "glue". In this way, the areas are linked with each other in an organic network so that they can exist in harmony.

From the viewpoint of wide area, it will be necessary to share the urban functions with Kokura city-center through the linkage by means of a green axis extending to the city-center area, Kokura.

The ecological city will be realized only when the areas where environment-improving measures have been carried out independently are linked by an organic network, the "Lane of Amenity", so that they can exist in harmony with one another. The "Lane of Amenity" is a "corridor" through which people, commodities, information as well as wild birds can come and go. It is also a road of "excursion" which supports the life, exchange, and leisure of the citizens. At the same time, it is the "pleasant" pedestrian space rich in greenery where the citizens can experience pleasant relaxation and recreation, and is the most important urban infrastructure which offers a beautiful cityscape symbolic of the image of the area. "Lane of Amenity" will consist of three roads which will be designated as the green

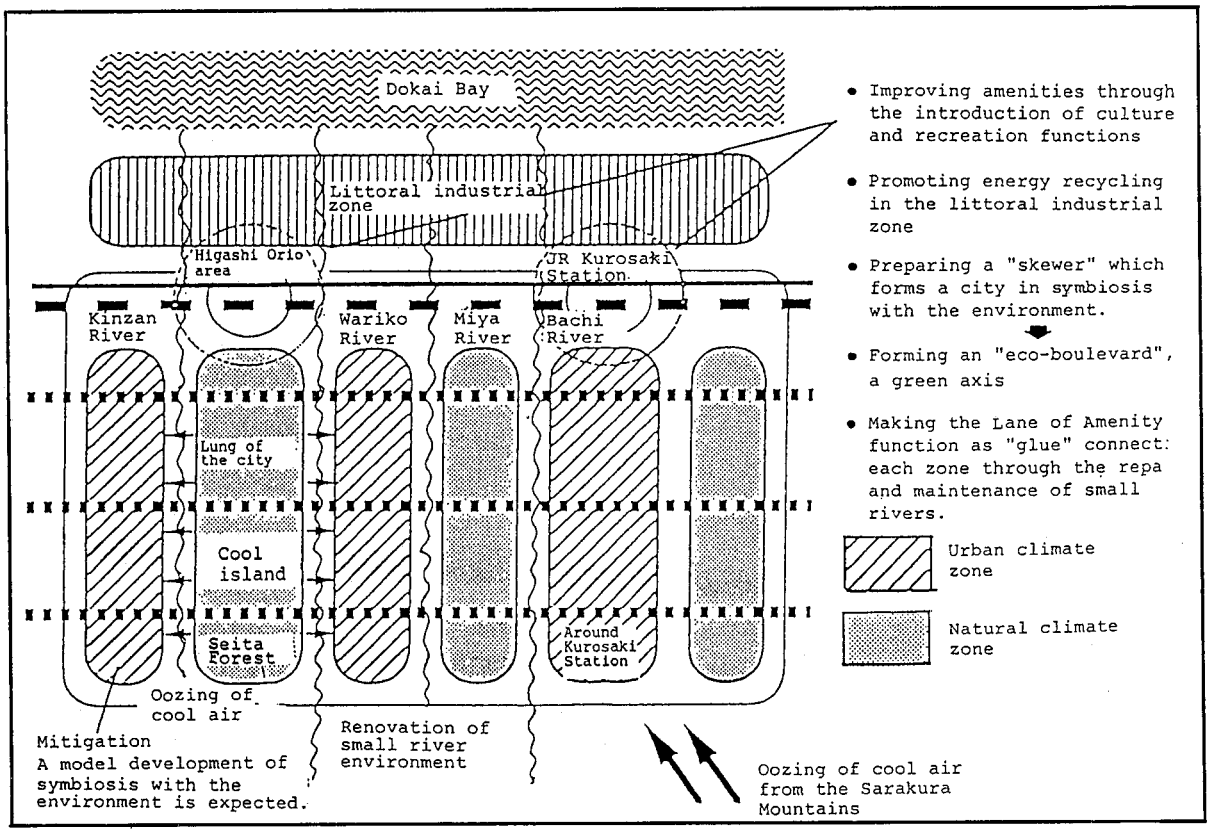
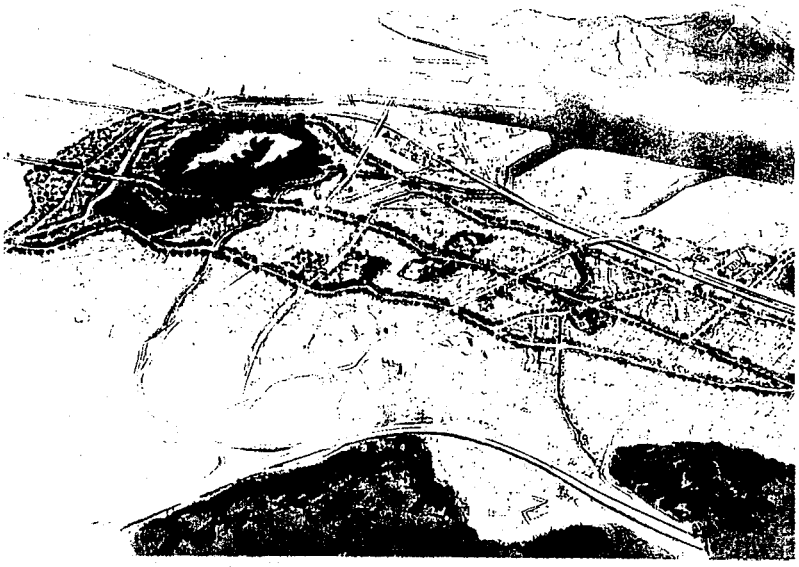


Figure 15 Schematic diagram of the "lane of amenity"

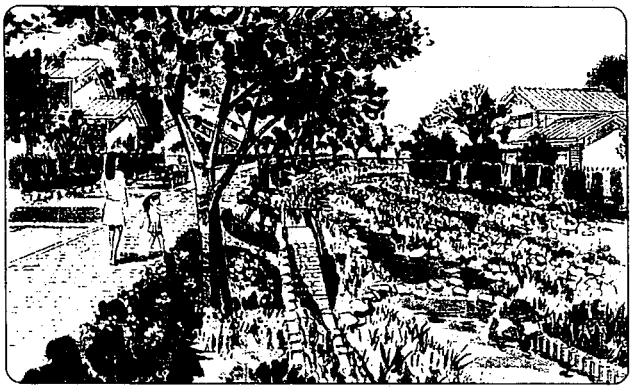
axis linking each area and four rivers which will be designated as the glue connecting the areas with each other. The image of the eco-boulevard is of the creation of an ecologically open space not only through the expansion of broad and richly tree-lined roads and a pedestrian space providing the setback, but also by securing a large roadside space when developing the roadside plot so that it will become a biotope which attracts wild birds and insects. As for the rivers that work as glue, the renovation of the river environment where people can live in harmony with nature is envisaged through the adoption of "nature-conscious" conservation, and the construction of promenade along them. The "Lane of Amenity" aims at the creation of an urban zone where jobs, housing, leisure and nearby natural features integrated into one body, and contributes to the compatibility and convenience of the city with efficiency in traffic and energy.



(a) A bird's-eye view



(b) Image of an improved arterial road, a "lane of amenity"



(c) Image of an improved river forming a network

Figure 16 Images of the renovated city, Kurosaki

4. CONCLUSION

A high temperature zone is observed in the center of the built-up area where the coverage of the ground surface with high-rise buildings is dominant. However, in a warm climate, the sea breeze and natural covering have a positive cooling effect on these urban zones.

The cooling effect of the sea breeze is notably greater at its time shift from the land breeze to the sea breeze and results in a fluctuation in air temperature. The sea breeze also carries the hot air from the center of the built-up zone to its leeward side. These measurement results indicate that the sea breeze has great potential in controlling the thermal environment in urban areas. When the wind is gentle, the relation between the ratio of natural covering and the averaged air temperature in a 1 km square grid is high. But an increase in the ratio of natural covering from 0 % to 100 % corresponds to a decrease in air temperature of up to 2.7℃. This suggests that natural covering plays a large role in mitigating urban heat.

In the "heat island" of an urban center, therefore, natural ventilation by the sea breeze plays one of the most important roles in improving the thermal environment, particularly in hot-humid summers of Japan. Natural coverings such as water and vegetation also create clear "cool islands" within hot urban areas. It is clearly found that the larger the ratio of natural covering, the wider and the stronger is the "cool island". Mitigation of urban heat requires consideration of climatic effects in environmental design for the efficient usage of natural cooling resources. Natural covering should also be recognized as a significant and integral part of urban planning and site selection.

For the creation of an ecological city, it is important to promote renovation of the urban environment through a harmonious sharing of roles between the governmental and private sectors. Particularly, in the initial stage of a project, as the overall project is led by more mature projects, the government institutions are required to take the initiative to a certain extent in promoting the renovation project. On the other hand, for the realization of an ecological city, it is important to obtain the cooperation of private entrepreneurs and citizens who are the principal bearers of town-creation activities and to implement the project on a continuous basis. Therefore, it is necessary to assist private entrepreneurs with their town-creation efforts through the establishment of a financing system, etc., and to assist the citizens with their efforts to create an ecological city by expanding the existing subsidy system for the improvement of the citizens' residential environment.

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