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SESSIONS 1 AND 2

OBSERVATIONS OF HEAT FLUX IN AN URBAN AREA WITH A LARGE POND BY KYTOONS

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ABSTRACT

There are few studies on the thermal environment in urban areas, considering the convective heat flux by natural wind and covering materials on the ground surface. In this paper, the heat flux is calculated from the profiles of the wind speed and the air temperature, which are simultaneously observed by kytoons at three points in an urban area with a large pond, to examine the difference between the built-up area and the water surface, and to make clear the relation between the convective heat transfer and the wind speed.

INTRODUCTION

An increase in population and pavement of ground surface affect the thermal environment in urban areas. To improve it, at first, it is necessary to grasp the convective heat flux on the ground surface by natural wind and the effect of covering materials e.g. pavement, bare ground or water on the heat flux through the field observation. The eddy correlation method and the gradient method are used as simple methods for calculating the heat flux on the ground (ref.1). These methods can be applied well to a plain field. In a built-up area, however, it is difficult to select an appropriate measurement point. Recently, another calculation method, called the traverse method was proposed (ref.2). Although it is more complex method than the formers, because it needs the profiles of the wind speed and the air temperature at two points, which are separated in the direction of the wind, it is possible to apply it to the built-up area, and the region where the heat flux is calculated is clear.

In this paper, the heat fluxes in an urban area are calculated by the traverse method from the profiles at three points, which are located in a line in the direction of the wind. The profiles of the wind speed and the air temperature are observed by kytoon systems simultaneously at three points. Three points mean contiguous two areas, one is a built-up area, and the other is a park with a large pond. Comparing the heat fluxes in the two areas, the effect of the water surface in the urban area is examined.

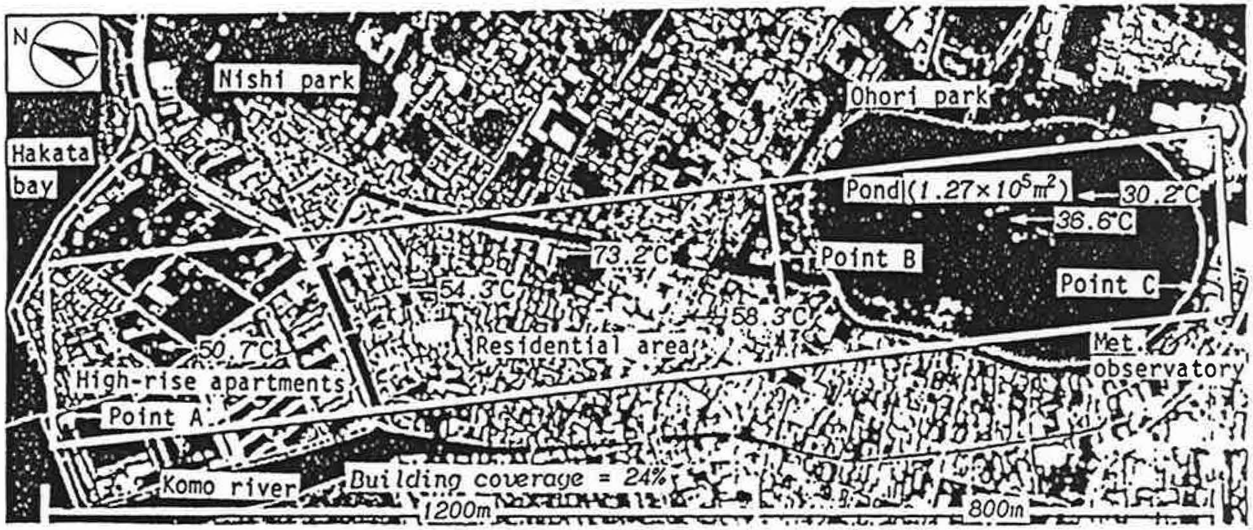

Fig. 1. Thermogram of the observation area by the remote-sensing data (11:37a.m. July 27, 1985)

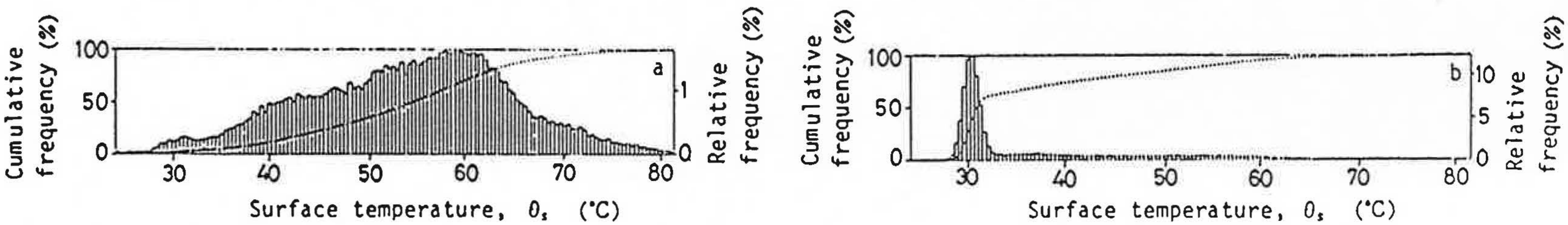

Fig. 2. Histograms of the surface temperature (a) Point A ~ Point B (b) Point B ~ Point C

OBSERVATION AREA

The observation is carried out in Fukuoka City, Japan. In the daytime of summer, sea breeze is frequently blowing above the city, of which direction is N~NW, normal to the coastline (ref.3). There is a large pond of 127000 m^2 in the Ohori Park, which is located in the center of the city. The region from the coastline to the southern end of the park is selected for the observation area. The profile data are observed at three points, shown in Fig. 1. Point A is near the coastline. Point B is about 1200 m inland from Point A. Point C is about 800 m from Point B. They are located almost in a line, normal to the coastline. The area between Point A and Point B is a built-up area, where the average building coverage is 24% and between Point B and Point C is the Ohori Park.

The distribution of the surface temperature in this area is shown in Fig. 1. The photograph is a thermogram made from the remote-sensing data, which are taken by an airplane at a height of 800 m on July 29, 1985. The histograms of the surface temperature are shown in Fig. 2. (a) and (b) indicate the built-up and the park area, respectively, shown as rectangles in Fig. 1. The surface temperature of the built-up area is clearly higher than that of the park area.

OBSERVATION METHOD

The profiles of the wind speed and the air temperature are simultaneously observed at three points by using three kytoon systems (ref.4). The kytoon system is shown in Fig. 3. Its senser box has a 3-cup anemometer and thermistor thermometer, and sends the data by wireless to the groung station. The profile data are observed at 11 points of which heights are 5, 10, 15, 20, 25, 30, 35, 40, 50, 60 and 80 m. The profile is observed from lower point to upper one, 5-minute measurement at each height and 1-minute interval. It takes 65 minutes for a profile. A profile was observed every two hours from Aug. 27, 10:00a.m. to Aug. 28, 9:05a.m., 1985.

The diurnal variations of the global solar radiation, the air temperature and the the wind direction at the Fukuoka meteorological observatory near Point C are shown in Fig. 4. It was clear weather during the observation. In the daytime, sea breeze blows, and after 19:00 the wind direction turns to W and to S, that is land breeze.

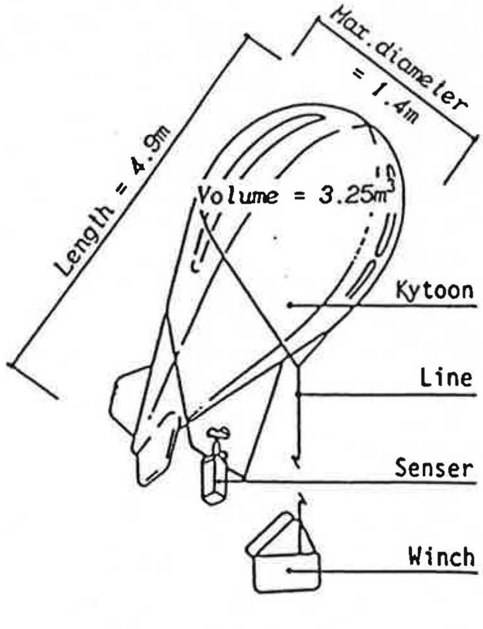

Fig. 3. Kytoon system

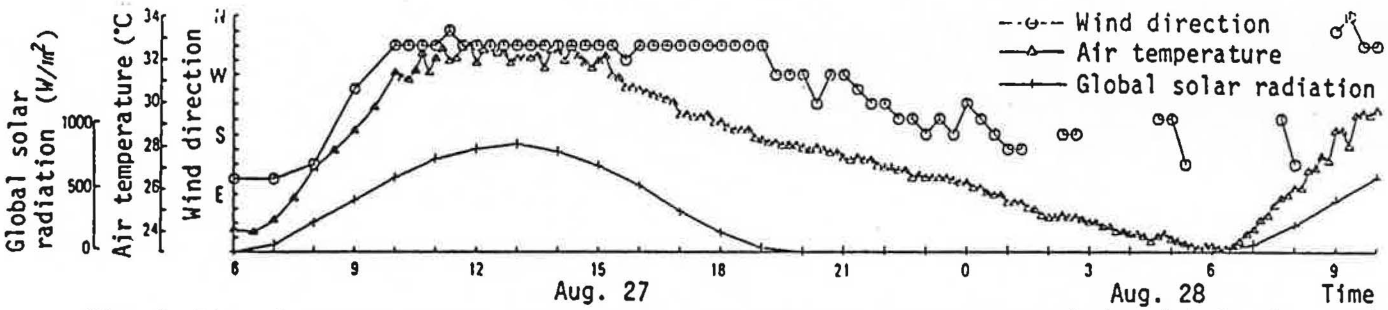

Fig. 4. Diurnal variations of the wind direction, the air temperature and the global solar radiation

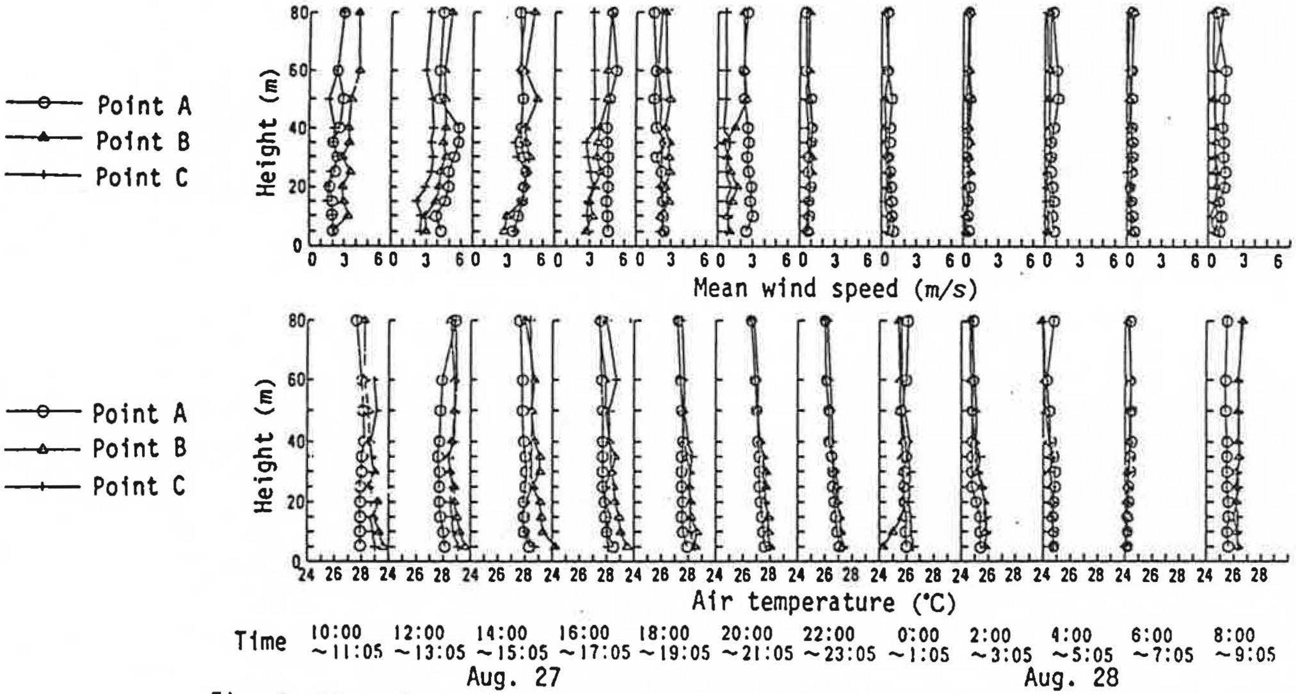

Fig. 5. Diurnal variations of the profiles of the mean wind speed and the air temperature

DIURNAL VARIATION OF THE PROFILE

The profiles, the vertical distributions of the mean wind speed and the air temperature at three points are shown in Fig. 5. The higher the measurement level, the stronger the wind speed in the daytime at Point B and Point C. The wind speed at Point A is almost constant in all heights and is stronger than that of the other two points. In the daytime, air temperature is the highest at Point B and the lowest at Point A. After 20:00 the air temperature at three points are almost the same and the lapse rate becomes smaller, neutral at dawn.

ESTIMATION OF THE WIND SPEED PROFILE

Since it is rather long time to measure a profile data, these data include the long period fluctuation of the wind speed. To eliminate the long period fluctuation, a 3-cup anemometer is set at each point to measure the reference wind speed. It is verified that the mean wind speed measured by the kytoon, $\overline{U}$ is in proportion to the reference mean wind speed, $\overline{U}_r$ (ref.4, ref.5). The mean speed indicates the wind speed averaged in the measurement time, 5 minutes. The mean wind speed is estimated from the nondimensionalized wind speed, $\overline{U}/\overline{U}_r$. The profiles of $\overline{U}/\overline{U}_r$ averaged in the daytime when sea breeze is blowing are shown in Fig. 6. They are semi-log scale graphs to apply the logarithmic law. From these figures, the roughness parameter, Z_0 can be estimated by extrapolation. Z_0 at Point A is the smallest, almost zero, because the windward of Point A is the sea of which surface is plain. Since there is the built-up area in the windward of Point B, Z_0 at Point B is the largest. Z_0 at Point C is smaller than that of Point B, because of the smooth surface of the pond.

The profiles of the turbulence intensity, $\sqrt{\overline{u^2}}/\overline{U}$ averaged in the daytime are shown in Fig. 7. Here, $\sqrt{\overline{u^2}}$ is the standard deviation of the wind speed. Corresponding to the value of Z_0, turbulence intensity in the lower layer is the largest at Point B, and the smallest at Point A (ref.6). The turbulence intensity below 30 m at Point C is smaller than that of Point B. The reason is thought to be the influence of the smooth surface of the pond.

THE TRAVERSE METHOD

Basic idea of the traverse method is explained here (ref.2). The heat flux from the ground surface to the air is simply modeled in Fig. 8. Here, $Q(W/m^2)$ is the heat flux from the ground surface, $\overline{U}(z)(m/s)$ and $\theta(z)(°C)$ is the mean wind speed and air temperature. L and W indicate leeward and windward, respectively. Supposing that when a block of air, of which the base area is 1 m^2 and the height is $dz(m)$ at the height of $z(m)$, traverses horizontally the length of $X(m)$, it gets the heat flux $dQ(z)\cdot\tau(J/m^2)$ and its temperature changes from $\theta_W(z)$ to $\theta_L(z)$, this relation is expressed as follows;

$$\rho c_p\theta_L(z)dz - \rho c_p\theta_W(z)dz = dQ(z)\cdot\tau \qquad (1)$$

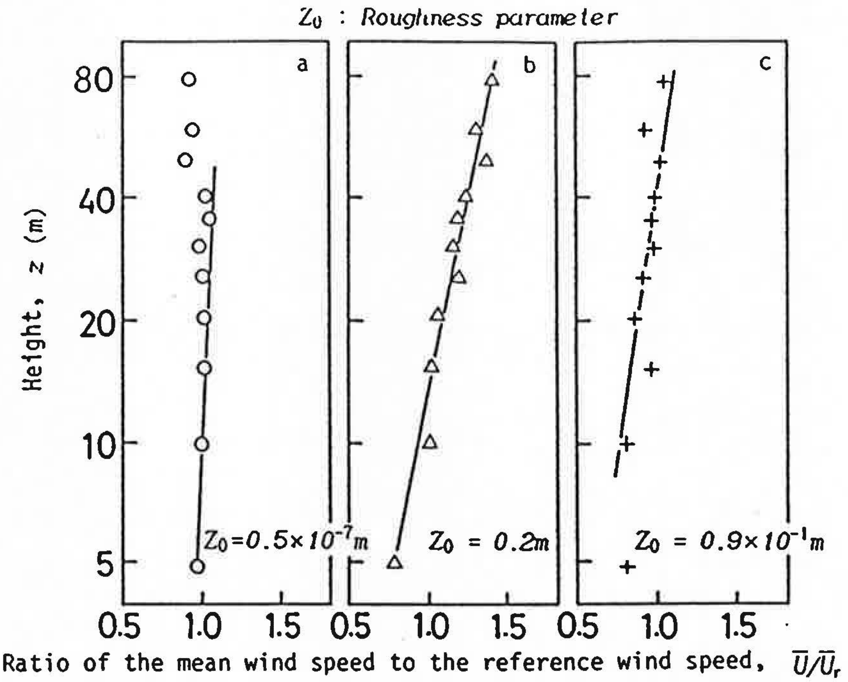

Fig. 6. Mean wind speed profiles in the logarithmic law
(a) Point A (b) Point B (c) Point C

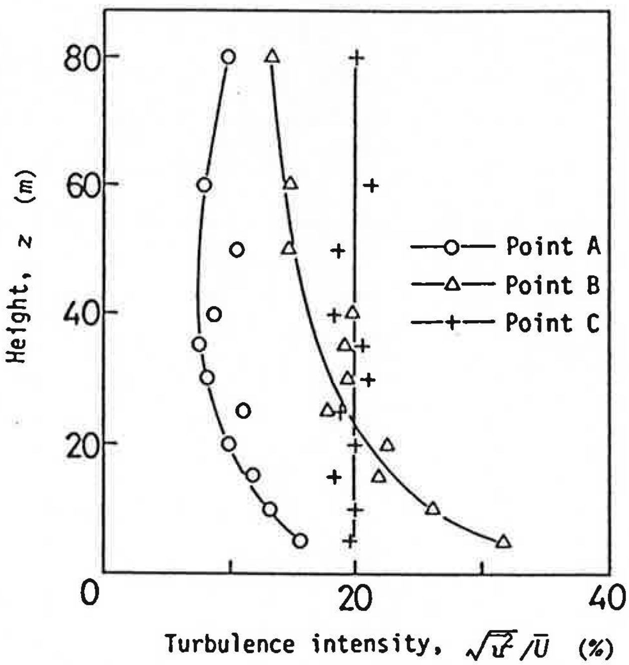

Fig. 7. Turbulence intensity profiles

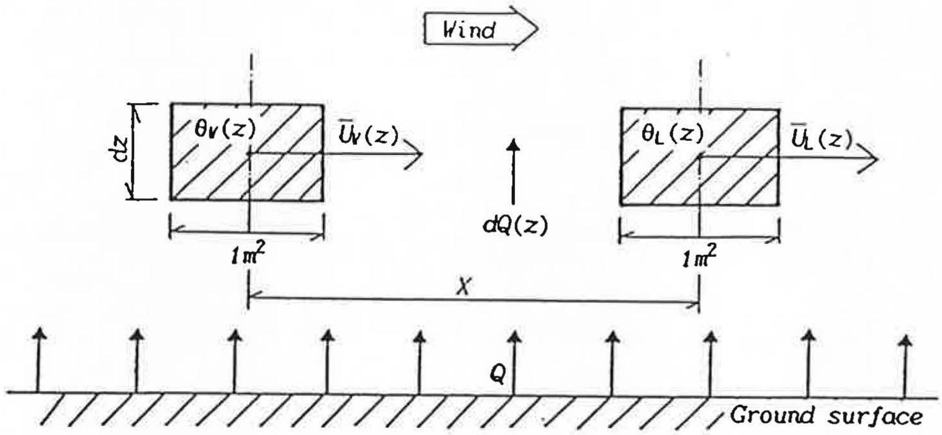

Fig. 8. The traverse method

where, $\rho(kg/m^3)$ and $c_p(J/kgK)$ is the specific weight and the specific heat of air, respectively. $dQ(z)(W/m^2)$ is the heat flux at the height of z, which is thought to be a part of Q, the difference between the heat flux flowing into the bottom of the block and the heat flux flowing out from the top. $\tau(sec.)$ is the time to traverse the length X. Supposing that the mean wind speed is varying linearly through the length X, it is expressed as follows;

$$\frac{\bar{U}_V(z)+\bar{U}_L(z)}{2}\cdot\tau = X \qquad (2)$$

Substituting eq.(2) for eq.(1), it becomes a differential equation of Q. Integrating the differential equation by z, Q is expressed as follows;

$$Q = \frac{\rho c_p}{X}\int_0^Z [\theta_L(z)-\theta_V(z)]\,\frac{\bar{U}_V(z)+\bar{U}_L(z)}{2}dz \qquad (3)$$

The upper limit of the integration Z is the height where the $\theta_L(z)$ is equal to $\theta_V(z)$. Using the profile data of the mean wind speed and the air temperature, eq.(3) is integrated numerically and the heat flux between Point A and Point B, Q_{AB} and between Point B and Point C, Q_{BC} can be calculated.

ESTIMATION OF THE HEAT FLUX

The diurnal variations of Q_{AB} and Q_{BC} are shown in Fig. 9. Q_{AB} is about 1/3 of the global solar radiation in the daytime, and almost zero in the nighttime. Q_{BC} is negative, because the air temperature of Point C is lower than that of Point B. It is thought to be the cooling effect of the pond.

The diurnal variations of the surface temperature of the asphalt pavement and the bare ground between Point A and Point B and of the pond water between Point B and Point C are shown in Fig. 10. In the daytime, the temperature of the pavement is over 55°C and that of the bare ground also ascends to 40~47°C, while the water surface temperature remains about 30°C, which changes little during a day, and is different from the air temperature no more than 1°C. Since the ground

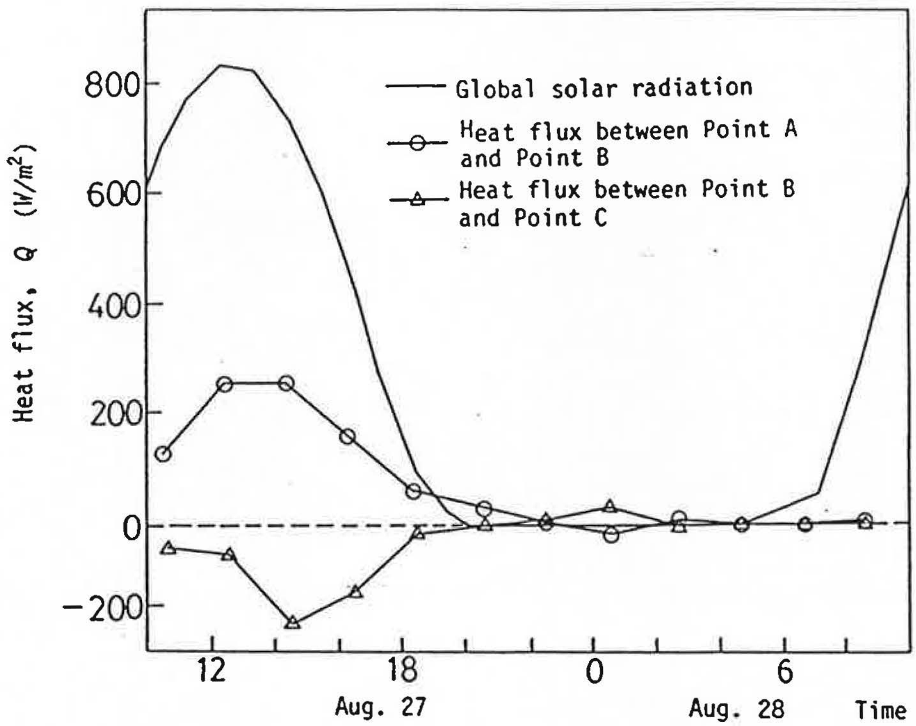

Fig. 9. Diurnal variations of the heat fluxes calculated by the traverse method

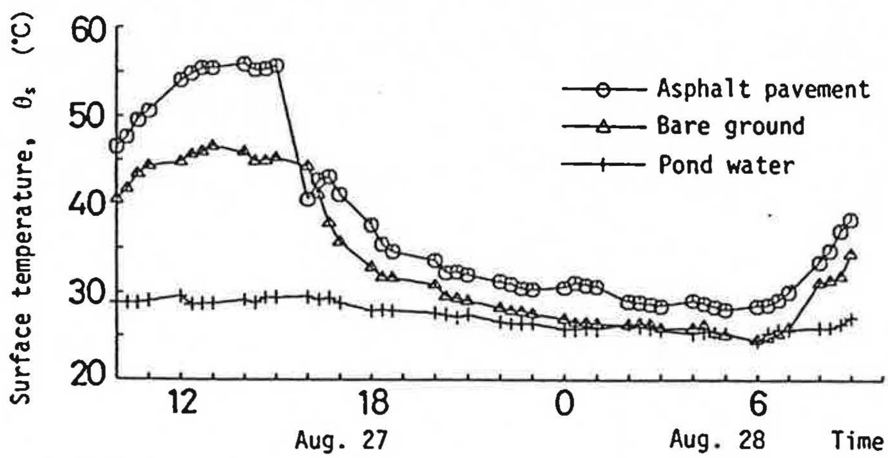

Fig. 10. Diurnal variations of the surface temperature of the asphalt pavement, the bare ground and the pond water

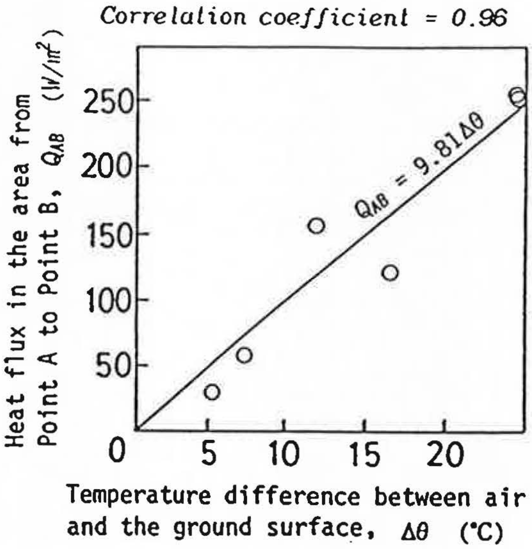

Fig. 11. Relation between the heat flux in the area from Point A to Point B and the temperature difference between air and the ground surface

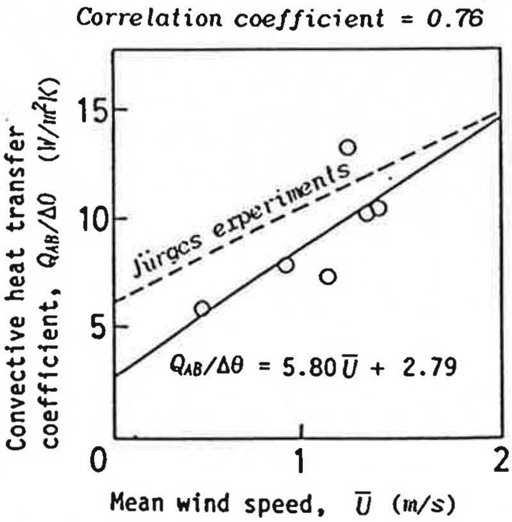

Fig. 12. Relation between the mean wind speed and the convective heat transfer coefficient in the area from Point A to Point B

surface is covered by the various materials, which have unique specific heats, it is difficult to estimate the average ground surface temperature correctly. It is supposed that the pavement surface temperature is equal to the average surface temperature, and the average of the air temperature of 1m above the ground at Point A and that of Point B is equal to the average air temperature in the built-up area. The correlation between the heat flux Q_{AB} and the difference between the surface and the air temperature $\Delta\theta$(°C) is shown in Fig. 11. The correlation coefficient is so high that Q_{AB} is thought to be in proportion to $\Delta\theta$. Estimating the mean wind speed of 1m above the ground from Fig. 6, the relation between $\bar{U}$ and $Q_{AB}/\Delta\theta$, which means the convective heat transfer coefficient, is shown in Fig. 12. The correlation coefficient is high. The heat transfer coefficient is a little smaller than that of the Jürges experiments.

CONCLUSIONS

(1) When sea breeze is blowing, roughness parameter Z_0 is very small near the coastline, while Z_0 in the built-up area is about 0.2 m. After the wind passes the pond, Z_0 becomes smaller again. The turbulence intensity near the ground in the built-up area is about 30%, while it decreases to 20% in the leeward of the pond. It is thought to be the effect of the smooth surface of the pond.

(2) The air temperature in the built-up area is higher than that of the coastline in the daytime. In the nighttime, however, the difference is very small.

(3) In the daytime, the surface temperature in the built-up area widely ranges 30~80°C, on an average 53°C, while the water surface temperature remains 30°C, which is near to the air temperature.

(4) The heat flux from the ground surface to air in the built-up area is about 1/3 of the global solar radiation, while the heat flux on the pond is negative, which indicates the cooling effect of the water surface.

(5) The convective heat transfer coefficient on the ground surface in the built-up area is the linear function of the mean wind speed, and is a little smaller than that of the Jürges experiments.

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