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EFFECTS OF ROADSIDE TREES ON THE THERMAL ENVIRONMENT WITHIN A STREET CANYON

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Abstract: In this paper, the micro-climate and the sensible heat flux in a street with thick tree crowns was investigated from a series of observations during summer. The difference of air temperature is negligible throughout the day compared to a parallel street without tree crowns. However, for the radiation field, there is a clear shielding effect for solar radiation and downward long wave radiation, consequently the road surface temperature will differ. The sensible heat flux at three meters height above the road surface was measured by scintillation method. The heat flux in the street with tree crowns was similar to that without tree crowns, although there was a large difference in road surface temperature between them. The estimated exhaust heat was extremely large and the measured heat flux was dominated by this artificial heat flux. Such a large exhaust heat could partly be explained by the parked vehicles in both sides of the roadway which would keep the air conditioning running.

Key words: urban climate, green space, sensible heat flux, scintillation methods, cool island

1. Introduction

The annual average air temperature in Tokyo has risen 3 degrees Celsius during the last hundred years. Its rate is five times larger than that of global warming. The mitigating effect of green spaces in urban area has been expected to be comparable to that of water surfaces. In Japan, its cooling effect in hot and humid summer is especially important and it is considered as an important method available for city planning (Hamada and Mikami 1994, Hagishima *et al.* 2004, Narita *et al.* 2004, Sugawara *et al.* 2006, Hagishima *et al.* 2007). However, in built-up areas in Tokyo, it is difficult to find new space to create green areas like urban parks. A paved road surface is a major heat source during daytime in urban areas. Stored heat in paved materials is released after sunset, and it also contributes largely to the heat island phenomena in nighttime. Therefore, to plant roadside trees and to cover the road surface with tree crowns is an effective way to decrease the sensible heat flux from the ground surface and to create a more comfortable thermal environment for the pedestrians (Sakaida and Suzuki 1994, Hataya *et al.* 2007).

In this paper, results are shown from micro-climatological observations performed along a street with thick tree crowns, "Nakasugi Avenue”, during summer. “Nakasugi Ave.” (here after “G-street”) is located in Suginami Ward in Metropolitan Tokyo. It is almost straight in a north-south direction and tall zelkova trees are planted on both sides of street. These roadside trees

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create a “green tunnel” along the street in summer. They are deciduous trees, so in winter time the sun light reaches the street surface. To identify the thermal effects of these trees, measurements were also made along another street, parallel to the “G-street”. This reference street is “Koenji-ekimae Avenue” (here after “non-G-street”) which has almost the same dimensions and is located about 1 km east of “G-street”. It has only got a few small trees along the street and there are no conspicuous shaded areas by the tree crowns on the road surface (Fig. 1). The measurements were made during two days, September 17 and 18 in 2003.

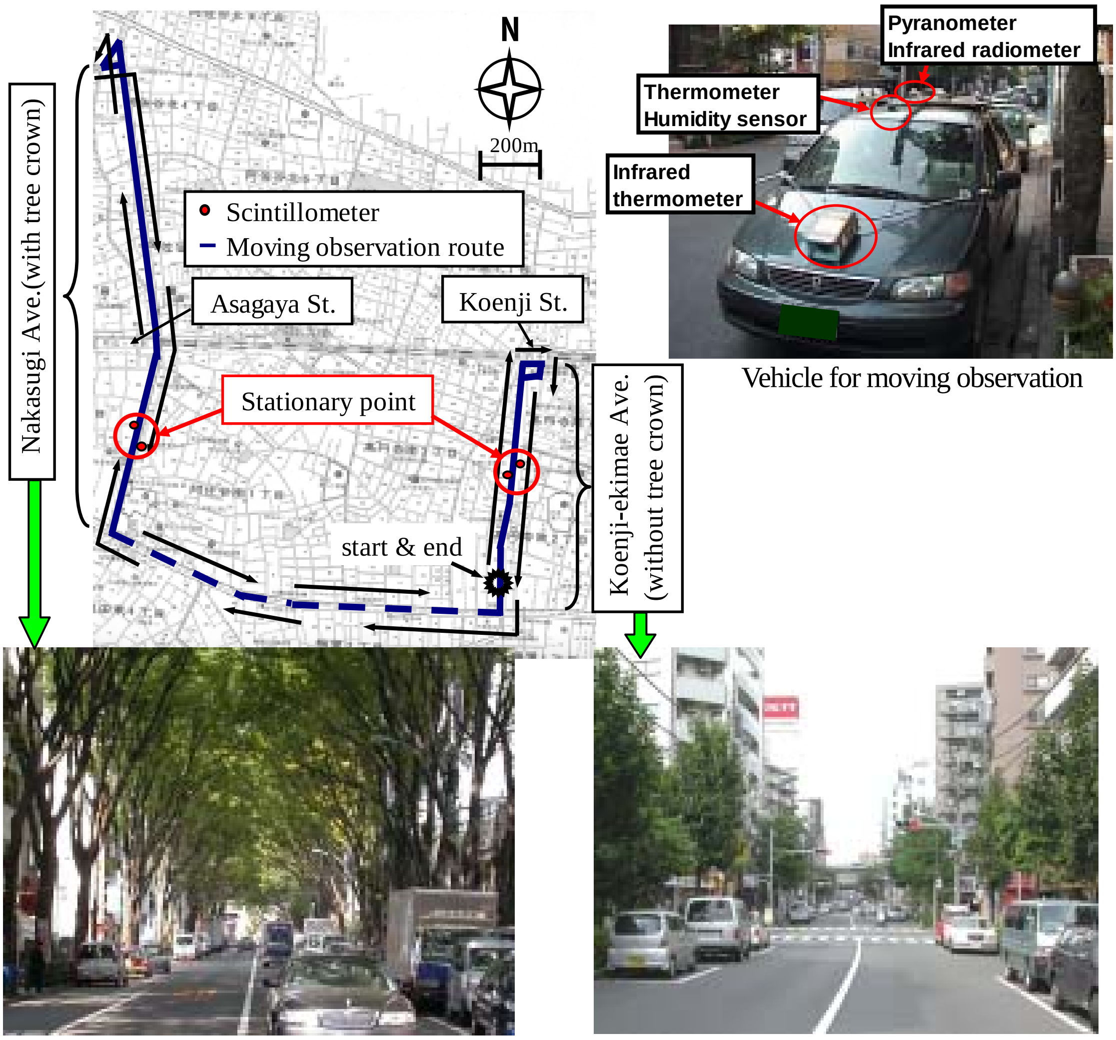

Fig. 1 Map of observation area and route of moving observation.

2. Measurement Methods

2.1 Stationary Observations

The downward shortwave and longwave radiations were measured with pyranometer and infrared radiometer at a stationary point in both streets. A three-cup anemometer and an Assmann’s aspiration psychrometer were also set up at 2 m height for the measurement of mean wind speed, air temperature and humidity. To evaluate the sensible heat flux from the road surface directly, the scintillometers were set across the street diagonally, near the stationary points. The transmitter and the receiver were set on the boundary between the roadway and the sidewalk. The laser beam height was 3.1 m above the ground and path length was 93 m in "G-street" and 75 m in "non-G-street".

2.2 Moving Observations

The radiation under the tree crowns was not spatially uniform, and the scintillation method estimated the sensible heat flux as a weighted average along the laser path. Therefore, it was desirable to measure the heat flux difference between the streets as a spatially averaged value. So a pyranometer and an infrared radiometer were mounted on the rooftop of a vehicle, and moving observations were performed along the route including both target streets. In addition, an infrared thermometer was set at an inclined position at the front edge of the hood to monitor the road surface, and a thermistor thermometer and a capacitive humidity sensor were installed into a naturally ventilated radiation shield, mounted at the front edge of a protruding pole at the roof top level. The time required to perform each moving observation was 24 - 40 minutes in daytime and 17 - 19 minutes in nighttime. The interval of observation was one hour in daytime, and three hours in nighttime. The data sampling frequency was 1 Hz.

3. Results and Discussion

3.1 Comparison of the Microclimate within the Street Canyons

Figure 2 shows the variation of short wave radiation (S↓) and long wave radiation (L↓) in both streets. These plots were calculated from moving observation data. Based on the time records for several passing points along the measuring route, the data was picked up while driving the vehicle along the target street, and then an average was calculated for these data sets. Sometimes these included data registered during traffic lights stops within the target street. The downward short wave radiation over the street with tree crowns was about one-third of that without tree crowns in midday. It clearly shows the effect of shielding the solar radiation by the "green tunnel". On the contrary, the downward long wave radiation under the tree crowns was about 20 – 30 Wm^{-2} larger than that without tree crowns throughout the day.

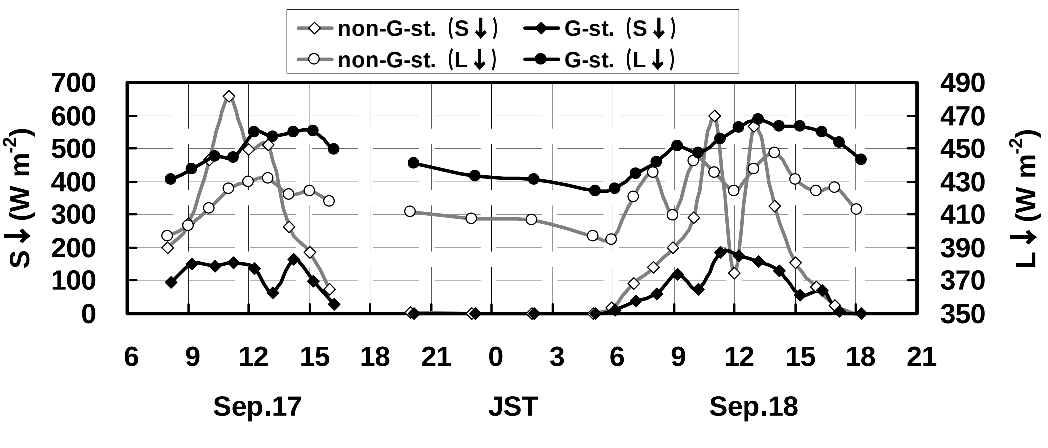

Fig. 2 Time variations of the downward short and long wave radiation in both streets.

The comparison of air temperature and humidity is shown in Fig. 3 and Fig. 4. The air temperature difference is smaller than expected; it is at most 0.7 degrees. As for the absolute humidity, the variation in both streets was quite similar; the difference was almost negligible. There are a few reports which imply that the increase of humidity in dense green areas has an adverse influence on human comfort. In this case, however, there is no evidence for such a negative effect by the tree crowns. Another possible negative factor of roadside trees for thermal sensation is to weaken the wind speed at pedestrian level. Although there was only data at stationary points, the wind speed difference between them was not so large (Fig. 5). It is partly because the observations were limited to rather calm condition.

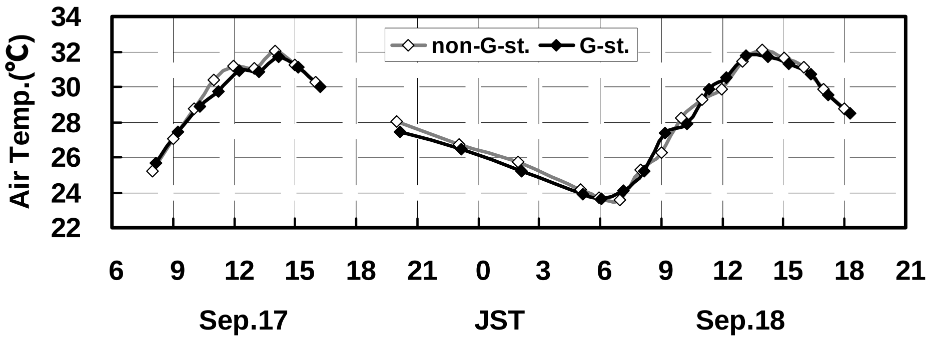

Fig. 3 Time variation of the air temperature in both streets.

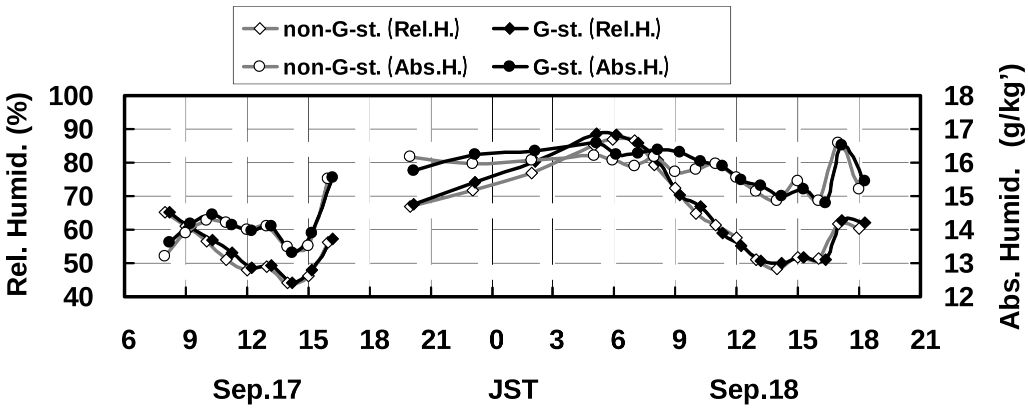

Fig. 4 Time variation of the relative and absolute humidity in both streets.

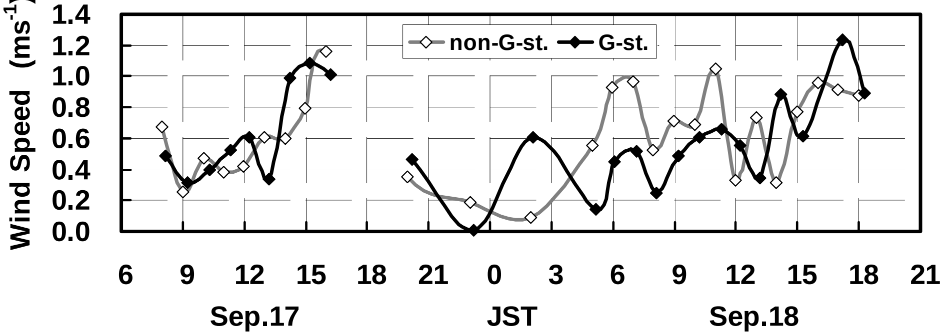

Fig. 5 Time variation of the wind speed at stationary points in both streets.

Figure 6 shows the comparison of temperature differences between road surface and the air at pedestrian level in both streets. Because of the shading effect of the tree crowns, the area-averaged road surface temperature in "G-street" was about 8 degrees lower than that in "non-G-street" in midday. During the night, however, the road surface temperature under the tree crowns was one or one and a half degrees higher than that without tree crowns. This is because the radiative cooling was diminished by the tree crowns in "G-street". In both streets, these temperature differences were always positive, it means that the road surface was a heat source for the air in the street canyon even under the tree crowns.

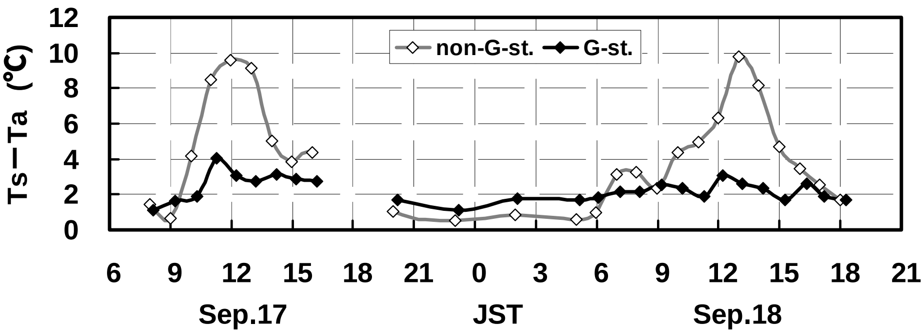

Fig. 6 Temperature difference between road surface and air in both streets.

3.2 Sensible Heat Flux within the Street Canyons

Sensible heat flux in both streets was estimated with two different methods; one a bulk method and the other a scintillation method. In the bulk method, sensible heat flux (H) [W m^{-2}] is expressed as follows:

$$H = c_p \rho C_H (T_s - T_a) \quad (1)$$

where c_p is specific heat of air at constant pressure [J kg^{-1} K^{-1}], ρ is density of air [kg m^{-3}], C_H is bulk transfer coefficient, T_s and T_a are surface and air temperature [K]. Here, the spatially-averaged value of the temperature difference shown in Fig. 6 was used. As for the bulk transfer coefficient, the following experimental formula by Fukumoto and Hirota (1994) was used:

$$C_H = 0.0027 + 0.0031 U_{0.6} \quad (2)$$

Here, $U_{0.6}$ is the wind speed at 0.6 m height above the ground [m s^{-1}]. Assuming a logarithmic wind profile, $U_{0.6}$ was calculated from the wind speed at 2 m above the ground U_2 [m s^{-1}] at the stationary observation points.

$$U_{0.6} = \frac{u_*}{k} \ln \frac{0.6}{z_0} \quad (3)$$

$$u_* = \frac{k U_2}{\ln(2/z_0)} \quad (4)$$

where u_* is the friction velocity [m s^{-1}], k is the von Karman's constant and z_0 is the roughness length [m], here assumed to be 10^{-4} m.

In the bulk method, sensible heat flux only from the road surface was evaluated, so anthropogenic exhaust heat from the traffic was not taken into account. On the contrary, all sensible heat flux at the laser path level, including the exhaust heat, was detected when using the scintillation method (Fig.7).

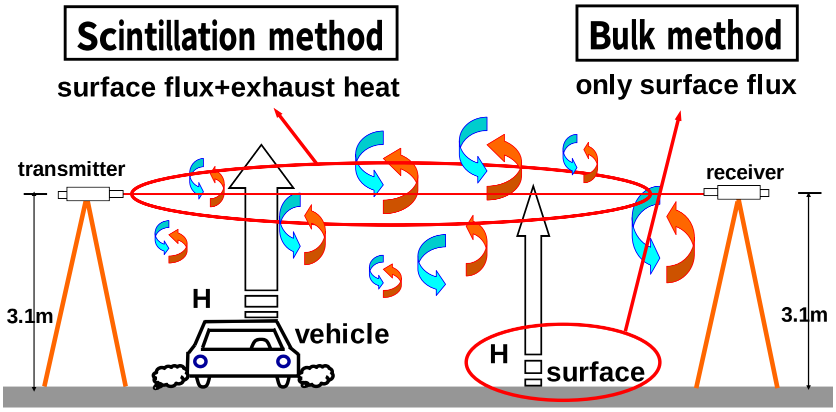

Fig. 7 Difference of the sensible heat flux for each evaluation method.

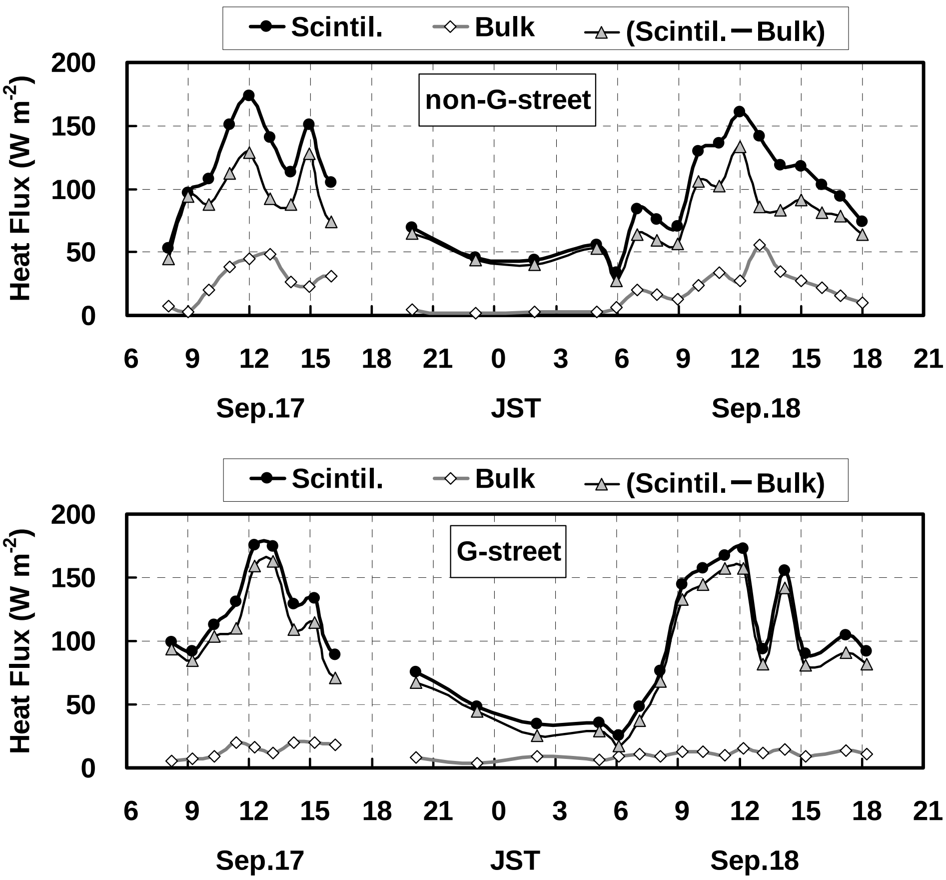

Fig. 8 Sensible heat flux for each evaluation method and the difference between them.

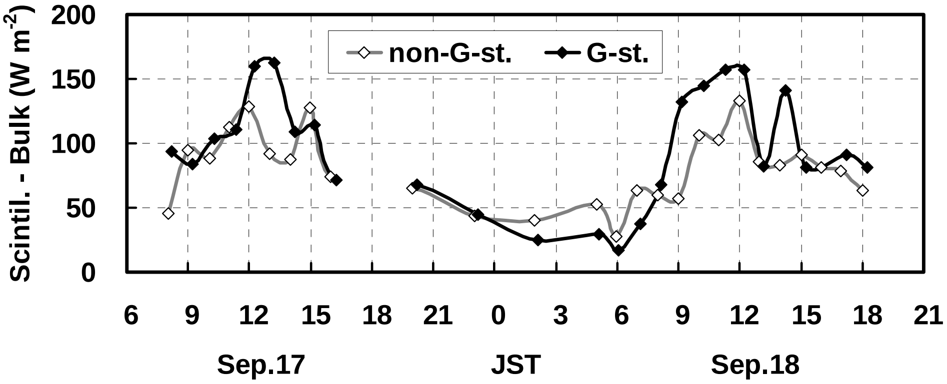

Fig. 9 Comparison of the estimated exhaust heat flux in both streets.

Figure 8 shows the sensible heat flux estimated by both scintillation and bulk methods. In these figures, the heat flux difference between the two methods, which is considered to be exhaust heat from traffic, is also illustrated. The peak of the scintillation method appeared at noon, and it amounts to 180 W m^{-2}. As for the street with tree crowns, the heat flux measured by the scintillation method was not as small as expected. The peak value in the G-street is almost the same as that in the non-G-street. Concerning the heat flux estimated by the bulk method, it was quite low, even in the non-G-street. The peak value was 50 W m^{-2} for the non-G-street, and 20 W m^{-2} for the G-street. Such a small heat flux was partly due to the weakness of the wind speeds measured at the sidewalk at the stationary points. Over the road, the traffic produces turbulence. It means that the calculated bulk transfer coefficient C_H in equation (2) was underestimated compared to the real situation near the road surface.

Consequently, the exhaust heat flux estimated as the difference between the scintillation method and the bulk method was remarkably high in both streets (Fig. 9), particularly in the G-street. The peak in the G-street exceeded 150 W m^{-2} in midday, and it contributed to most of the heat flux at the Scintillometer level. One possible reason why the exhaust heat was larger in G-street was the existence of parked vehicles along the roadside. In this hot season, many drivers have short rests in shaded lots, so the number of parked vehicles was significantly different from the non-G-street. In addition, these vehicles did not run air conditioning while idling.

According to some experiments, the fuel consumption during such idling is about 65 mℓ / 5 min for a 2-ℓ displacement car. As the calorific value of gas is 34.6 MJ / ℓ, the heat release from a car is estimated to about 7500 W. A car occupies an area of about 7.5 m^2 and therefore the exhaust heat flux from the area occupied by parked vehicles amounts to approximately 1000 Wm^{-2}. Supposing 10% of the road surface is occupied by parking vehicles, the area averaged exhaust heat flux amounts to 100 W m^{-2}. Adding this to the exhaust heat from the passing traffic, the calculated value for the G-street is not so improbable.

4. Conclusions

In this paper, the micro-climate and the sensible heat flux in a street with thick tree crowns was investigated from a series of observations during summer. Though roadside trees were expected to have an important mitigating effect on the heat island, the difference of air temperature was negligible throughout the day compared to a parallel street without tree crowns. Also, the increase of humidity and the decrease of wind speed were not discernible. As for the radiation field, there was a clear shielding effect for solar radiation and downward long wave radiation, consequently the road surface temperature was reduced. That means that the main reason to feel comfortable under the tree crowns is not the air temperature but the radiation effects.

The sensible heat flux three meters above the road surface was measured by the scintillation method. The heat flux in the street with tree crowns was quite similar to that without tree crowns, although there were large differences in road surface temperature between them. To separate the anthropogenic exhaust heat from the heat flux measured at three meters, the heat flux from the road surface was calculated using the bulk method. The estimated exhaust heat was extremely large and the heat flux at three meters was mainly occupied by this artificial heat flux. Such a large exhaust heat could partly be explained by the parked vehicles on both sides of the road, which were running their air conditioning while idling.

For future considerations, there are still some problems in the estimation of the sensible heat flux. One is whether the scintillation method can be applied to measurements within the urban canyon without any adjustment. Another is how to determine the road surface transfer coefficient including the traffic induced turbulence. Also the heat flux above the tree crowns has to be clarified in order to evaluate its effects as a countermeasure to the heat island.

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