9.2 CANOPY ALBEDOS AND REPRESENTATIVE TEMPERATURES FOR REGULARLY DISTRIBUTED RECTANGULAR OBSTACLES

Manabu Kanda * and Shigero Katsuyama
Tokyo Institute of Technology, Tokyo, Japan

1. INTRODUCTION

Urban canopy structures could make influences on the upper atmospheric boundary layer through energy exchanges. The radiation and turbulence within and above urban canopy layer are dominant processes for surface energy budgets.

The purposes of this study are the followings. (1) The first is to make a database of canopy albedos corresponding to a wide range of urban geometries and season. A numerical scheme of radiation transfer within a 3D urban canopy is developed and validated in comparison with the experimental data. (2) The second is to investigate the relationship between surface geometries and representative urban surface temperatures. (3) The third is to estimate the energy balance and heat transfer coefficient at six different surfaces (roof, floor and four wall surfaces), and to investigate their dependency on urban geometries.

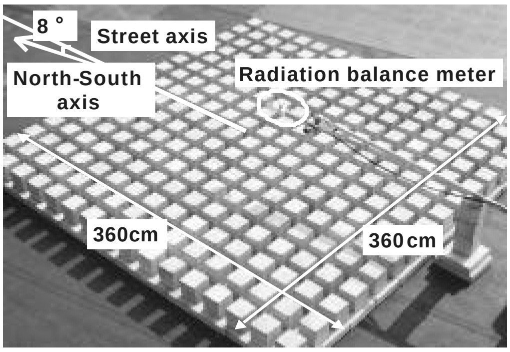

Fig.1 A photograph of experimental set up

2. SCALE MODEL EXPERIMENTS

Although the basic manner of scale modeling follows that by Aida(1982), a range of surface geometry is wider and additional measurements related to energy balance analysis are performed. The urban geometry is generated by the combination of 15cm cubic concretes regularly distributed on concrete flat plates (Fig.1). Experiments have been performed with seven different plain aspect ration and a obstacle height of 1 or 2 stories. The inclination between the N-S direction and the street axis is 8 degree. Up and downward short-wave and long-wave radiation are measured separately using a radiation-balance meter (Eiko MR-40) at 55cm above the canopy top. The surface temperatures are measured by a thermal-imager (NEC TH3102) and are continuously calibrated with thermo-couples distributed at every 7.5cm^2 on the surfaces. The conductive heat fluxes into the surfaces are measured using a number of 5cm x 5cm heat plate filled with the specified surfaces. Air temperatures are measured using 0.5mm thermocouples at the middle of the canopy and at 1.8 cm above the canopy. A 3D sonic anemometer (Kaijo WAT-395) is installed at 1.8cm above the canopy top for measuring the referenced wind velocity.

3. RADIATION TRANSFER MODELING

In this study, a numerical model based on finite different method considering mirror-reflection and multi-reflection effects has been developed and validated in comparison with the scale model experiments. This numerical scheme is applicable for 3D geometries consisting of regularly distributed rectangles at any times and positions. The grid spacing is chosen as 1.5cm, so that a 15cm x 15cm surface is divided into 100 small grid cells.

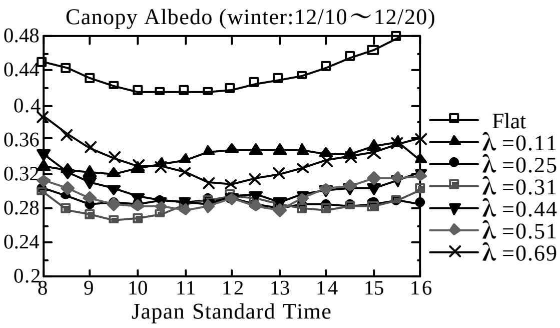

Fig.2 Albedos depending on plain aspect ratio
plain aspect ration λ = (roof area)/(total lot area)

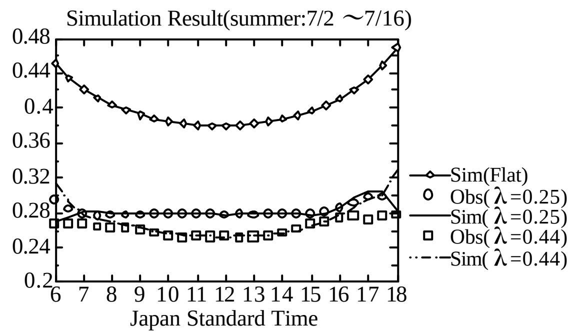

Fig.3 Simulated and observed albedos

* Corresponding author address: Manabu Kanda, Tokyo Institute of Technology, Dept. of International Development Engineering, Meguro-ku, O-okayama, 2-12-1 Tokyo, 152-8552 JAPAN; e-mail: kanda@fluid.cv.titech.ac.jp

4. CANOPY ALBEDO

Compared with the flat concrete (no obstacle), the canopy albedos of 3D geometry are significantly reduced for any seasons and any plain aspect ratios (Fig.2). This tendency supports the experiments by Aida(1982). The anti-symmetric trends of albedo in the morning and the afternoon are due to the inclination of street axes against the north-south direction. The diurnal changes of albedo significantly depend on the season. Particularly, the winter albedos show the distinctive "W" shape trend. 2-story canopies show smaller albedos than single story canopies with the same plain aspect ratio. The numerical model introduced in Chap.3 simulates well the anti-symmetric trends and quantitative value of observed albedos except only near sunrise/sunset time (Fig.3) .

5. REPRESENTATIVE SURFACE TEMPERATURES

Although great care should be needed for interpretation of model temperature since the thermal inertia of the model is not similar to the reality, qualitative discussions can be done. Several definitions of representative surface temperature are possible; (a) aerodynamic, (b) complete, (c) bird's-eye view, (d) long-wave radiation. Each surface temperature can be interpreted physically as the sum of six facets temperatures (roof, floor and four vertical walls) with different weighting factors as shown in Table 1. The aerodynamic temperature is calculated from the heat transfer coefficient at each facet based on the energy balance analysis as described in Chapter 6.

2-story obstacles give lower surface temperatures than those of 1-story obstacles, both for dense and sparse canopies, in terms of any representative temperatures (Fig.4). The complete temperature and long-wave radiation temperature are fairly well follow the aerodynamic temperature except for the 2-story dense canopy, while the bird's-eye view temperature systematically underestimate the aerodynamic temperature. Thus, upward long-wave radiation, if it is measured, can be used as the first approximation of aerodynamic temperature.

Table 1 representative surface temperatures

	Name	Physical meaning
Ta	Aerodynamic	$Ta = \sum_{i=1}^{6} \left(C_H(i) / C_H \right) S(i)T(i)$
Tc	Complete	$Tc = \sum_{i=1}^{6} \left(S(i) / \sum S(i) \right) T(i)$
Tb	Bird's-eye view	$Tb = \sum_{i=5}^{6} S(i)T(i)$
Tr	Long-wave radiation	$Tr = \sum_{i=1}^{6} V_{sky}(i)S(i)T(i)$

S(i):facet area normalized by lot area, i:facet number, T(i):facet temperature, Vsky(i):facet sky view factor
Approximations using Taylor expansion are used for the above Tb and Tr formulation.

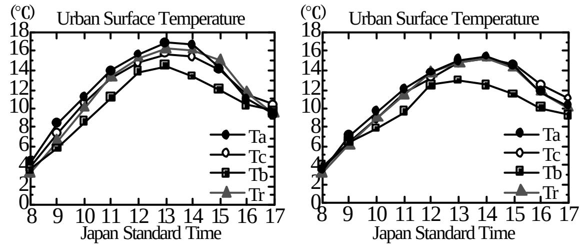

Fig.4 Comparison of representative temperatures
left: 1-story λ=0.25, right: 2-story λ=0.25

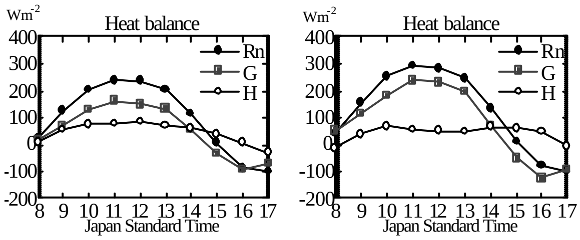

Fig.5 Comparison of total energy balance
left: 1-story λ=0.25, right: 2-story λ=0.25

6.ENERGY BALANCE AND HEAT TRANSFER COEFFICIENT

Ignoring latent heat, the energy balance at each facet requires that net radiation (Rn(i)) should be equal to the sum of sensible heat (H(i)) and conductive heat (G(i)), where i is facet number. G(i) is directly measured using heat plates, Rn(i) is estimated from the numerical model described in Chap.3 including the measured radiations and surface temperatures, and thus H(i) is obtained as the residual. The heat transfer coefficient ($C_H(i)$) between the facet and a reference height is calculated by $C_H(i) = H(i)/[U(T(i)-T_{ref})]$, where U and T_{ref} are velocity and air temperature at the reference height, and T(i) is the facet temperature. 2-story canopies show larger Rn(i) and G(i), and smaller H(i) than 1-story canopies. This suggests that larger volumetric heat capacity of high obstacles is a dominant factor to decrease the representative temperatures and air temperature in daytime. Table 2 shows the daytime-averaged heat transfer coefficients. The south walls show larger values than north walls. This suggests that local atmospheric stability near the surface is significantly affect transfer processes.

Table 2 heat transfer coefficients

	North	East	South	West	Floor	Roof	Total
1-story	0.002	0.023	0.054	0.014	0.028	0.031	0.052
2-story	0.008	0.027	0.030	0.016	0.020	0.035	0.064

REFERENCES

Aida,M,1982: Urban albedo as a function of the urban structure – A model experiments', Boundary-Layer Meteorology, **23**, 405-413.

Voogt,J.A. and T.R.Oke,1997: Complete urban surface temperatures, **36**,1117-1132.