J9.2 OUTDOOR SCALE MODEL EXPERIMENTS FOR THE EVALUATION OF URBAN MODELING STUDIES

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1. INTRODUCTION

For understanding the unique features of urban climates, there have been many studies in real cities. However, such full-scale studies have not yet provided a comprehensive understanding of the complicated physical processes that contribute to urban climate. As a complementary method, we have done studies using a reduced-scale model. Such a model has the advantages of allowing us to make complete measurements and to obtain data on a relatively uniform area. By working with a uniform area, the results are easier to interpret and more suitable for urban modeling than data from real cities. Previous outdoor scale model experiments using relatively large obstacles are mainly focused on dispersion processes (e.g. Kit FOX(Hanna and Chang, 2001)) and did not analyze the energy balance. Thus, our main purposes are to make a detailed analysis of the urban energy balance, and to provide datasets which can use the evaluation of urban energy balance models (e.g. SUMM(Kanda et al, 2005)). In this paper, in addition to introduce the model equipments, basic performances of the scale models are examined.

2. SCALE MODEL EXPERIMENTS

2.1 Site

Larger and smaller reduced-scale models both which have 1/5 and 1/50 geometrical scale compared with typical residential area of Tokyo are built up on the campus of Nippon Institute of Technology, Saitama prefecture, Japan (36º01'N, 139º42'E) (Figure1). The 1/5 and 1/50 models are located next to each other in order to ensure same meteorological conditions. The dominant seasonal wind is from NW in winter while from SE in summer. In terms both of the landscape and wind, we designed our scale models in such a way that the longer axes roughly coincide with the NW-SE line, which provides an appropriate fetch condition for producing sufficient internal boundary layers (Figure 2).

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Figure 1 1/5 and 1/50 outdoor scale models

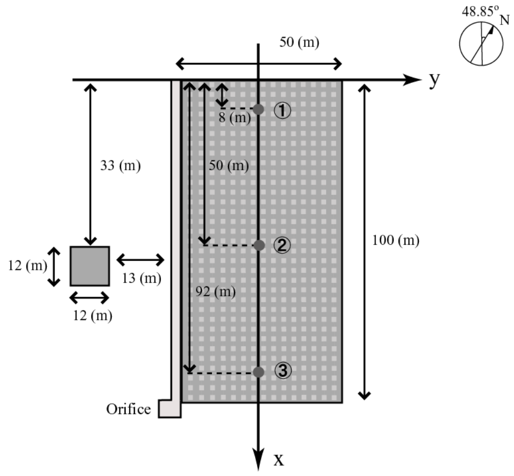

Figure 2 Model set up

2.2 1/5 Larger Scale Model

The 1/5 scale model surface geometry consists of cubic concrete blocks 1.5-m on a side with 0.1-m thick walls. Inside blocks are vacant. The blocks are distributed in an array on concrete pavement that has a total area of 100 x 50 m^2. The cubes are aligned in a square array with plane area density 0.25. The same concrete material was used for cubic block and basement. Three towers were constructed at X=8m, 50m and 92m along the central X-axis (Y=0). Air temperatures were measured at heights of 0.3, 0.75, 1.5, 2.25, 3, 3.75, 4.5, 5.25, 6, 7.5, 9 m of three towers using unshielded, 20-μm-thick bare thermocouples. We judged from the observed vertical temperature profiles that the depth of IBL ranged from Z/H = 2.5 to 4.0 at the distance of central tower, where H is the cube height. Considering the minimum IBL height, a compact sonic anemometer with 0.05 m sensor-span and 50 Hz sampling frequency (Kaijo TR90-AH), and an infrared CO_2/H_2O open-path analyzer (LI-COR LI-7500) were installed at a height of 3 m (Z/H = 2) of the central tower. They were used for the estimation of sensible and latent heat fluxes through the eddy covariance (EC) method. Upward and downward shortwave and longwave radiation were measured separately using a radiation balance meter (Eiko MR-40) 4.5 m above the ground (Z/H = 3). The energy balance residual of the net radiation minus the turbulent fluxes cannot be used instead of the conductive flux measurements due to the energy imbalance problem with the EC method (Kanda et al., 2004)(section 3.4). This is a serious problem in real cities since the direct measurement of heat storage is quite difficult. To precisely close the energy balance, the conductive heat fluxes of all facets in a unit area should be measured. As a great advantage of scale models, this is possible using very thin and highly-accurate heat plates (Captec HF-300 with 0.3 m x 0.3 m size and 0.4-mm thickness). A total of 164 heat plates cover a unit of constituent surfaces including four vertical walls, roof, and floor (Figure 3). The heat sensor can also measure the surface temperature as well as the conductive heat flux. The whole surface is painted with same color to uniform the surface radiative properties.

Figure 3 Direct measurements of conductive heat flux (G) using very thin heat plates

2.3 1/50 Smaller Scale Model

The model surface geometry consisted of cubic concrete blocks 0.15 m on a side, regularly distributed on flat concrete plates with a total area of 12 x 12 m^2. The surface geometry was similar to and the material was the same as those of the 1/5 model, except that the inside cube was filled with concrete. To capture a sufficiently developed IBL, all sensors were installed 11 m downstream from the fetch. The same instruments of radiometer (Eiko MR-40), compact sonic anemometer (Kaijo TR90-AH), CO_2/H_2O open-path analyzer (LI-COR LI-7500) were installed at the same heights relative to cube (Z/H), as in the 1/5 model. A total of 72 heat plates, each of which has 0.05 x 0.05 m^2 area and 0.4-mm thickness (Captec HF-50) cover a unit of constituent surfaces.

3. BASIC PERFORMANCES OF THE MODEL

To accurately reflect real urban settings, scale modeling requires dynamical similarity to the real world. In this section, the dynamical similarity including (1) the similarity of radiation, (2) the similarity of flow, and (3) the similarity of thermal inertia are investigated (3.1, 3.2, 3.3). In addition to physical scale similarities, the ratio of the energy balance residual of the directly measured net radiation minus conductive heat to sensible heat plus latent heat derived from EC method is examined (3.4).

3.1 Similarity of Radiation

As long as the same surface material is used and the same meteorological condition is given, the similarity of radiation always occurs because the linear dimensions of scale models are much larger than the relevant radiation wavelengths. Albedo of shortwave radiation is the best index to examine the radiation similarity since long wave radiation balance is influenced not only the radiation process itself but also by surface temperature which strongly depends on the thermal inertia. The albedos of 1/5 and 1/50 models correlate very well (Figure 4), which is the evident of the radiation similarity.

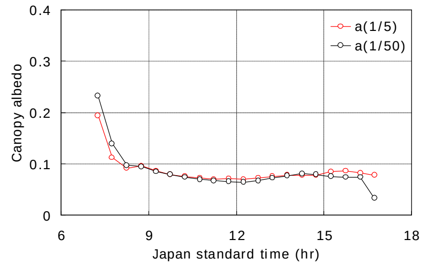

Figure 4 Canopy albedos of 1/5 model and 1/50 model (25, Oct, 2005)

3.2 Similarity of Flow

We compare the local drag coefficients (Cd) in the roughness sublayer at Z/H=2 as an indirect measure of flow similarity, since it is well known that neutrally-stratified fully developed turbulences with the same geometrical condition have a constant Cd, independent of the Reynolds numbers. Figure 5 shows the Cd versus the wind velocity at Z/H=2 of each model, in which only the data with NW±5°wind direction (almost parallel to street direction) are plotted. From Figure 5, it is evident that more than 1(m/s) wind conditions produce almost a constant value of Cd both for 1/5 and 1/50 models.

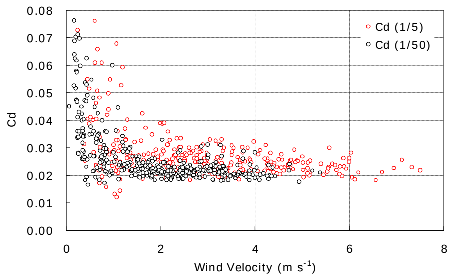

Figure 5 Drag coefficient (Cd) and wind velocity

3.3 Similarity of Thermal Inertia

The ratio of heat storage (G) to net radiation (Rn) has been often used as a good index of the thermal inertia (Grimmond and Oke, 1999). An example of energy balances of 1/5 model and 1/50 model and corresponding diurnal loop of Rn and G are shown in Figure 6 and 7. While the ratio of G to Rn of both models are almost the same before sunrise and early morning (until about 8:00 o'clock), after 8:00 o'clock more heat are stored in 1/5 model than in 1/50 model due to its larger volume. Continuous release of sensible heat after sunset as observed for 1/5 model is attributed to the fact of this lager heat storage at daytime.

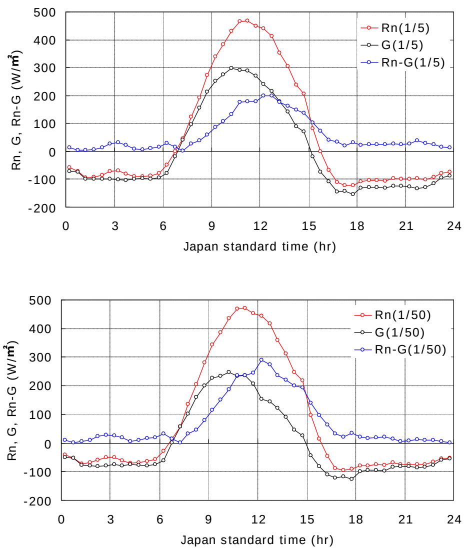

Figure 6 Typical energy balance of 1/5 and 1/50 model in autumn (25, Oct., 2005)

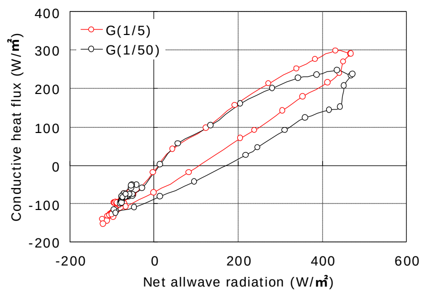

Figure 7 Ratio of heat storage (G) to net radiation (Rn) of 1/5 and 1/50 model (25, Oct, 2005)

Surface temperature is another measure of thermal inertia. Figure 7 shows diurnal courses of radiative surface temperature (Tr) derived from the measured upward longwave radiation in which emissivity of facet value (=0.88) is assumed as a effective value represents on whole surface. In addition to Tr, complete surface temperature (Tc) which is the average surface temperature weighted by the constituent surface areas (Voogt and Oke, 1997) and aerodynamic surface temperature (TH) which is the average surface temperature weighted by local transfer coefficients (Kanda et al, 2005) are also plotted in the same figure. Tr always overestimates both Tc and TH in the present morphology, meteorological conditions and surface radiative properties due to a complex multi-reflection process among the constituent roughness elements. While the difference between Tr, Tc and TH have no significant dependency on physical scale, in each temperatures, the maximum temperature of 1/5 model is lower and later than that of 1/50 model.

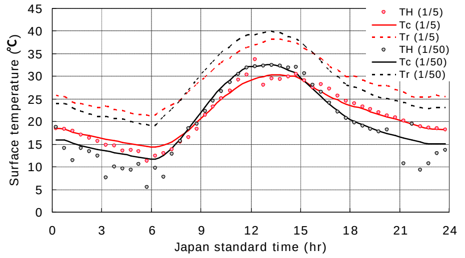

Figure 8 Radiative surface temperature (Tr), complete surface temperature (Tc) and aerodynamic surface temperature (TH) of 1/5 and 1/50 model (25, Oct., 2005)

These results suggest that the thermal inertia mismatch actually exists. However, the energy partition of heat storage and net radiation is less sensitive to the volumetric heat capacity than the surface temperature is. One of the possible reasons for this is that the thermally active layer of concrete which influence on largely on energy partition is not so deep in this season. On the other hand, the surface temperature is thought to be influenced by the temperature of whole buildings including inside the obstacles. The active layer can be variable according to the forcing of net radiation and thus further investigation using summer and winter time data is needed.

3.4 Energy Imbalance

The accumulation of data in a number of forests has revealed that the sum of sensible and latent heat fluxes H+LE estimated by the EC method is often less than the difference between the net radiation and the heat storage Rn-G (e.g., Lee and Black, 1993). This is the so called energy imbalance problem. In urban fields, however, energy balance closure has never been investigated so far due to the lacking of direct measurement of heat storage term. Figure 9 shows the relationship between H+LE and Rn-G for the present models, in which energy imbalance is obvious. The inclination of H+LE vs. Rn-G is about 0.7-0.8, which is close to the value observed in a forest region (Lee and Black, 1993).

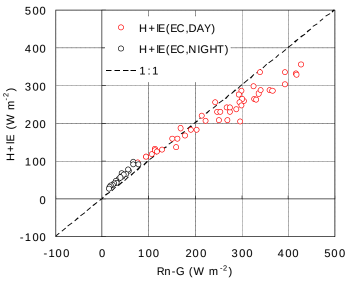

Figure 9 Ratio of direct measured net radiation minus conductive heat to sensible heat plus latent heat estimated from eddy covariance method

4. CONCLUSION

1/5 and 1/50 outdoor scale models designed for studying urban climate were introduced, and their basic performances including physical scale similarities were evaluated. As for the physical scale similarities, those of radiation and turbulence were well scaled, whereas that of thermal inertia mismatched in a lower magnitude than we expected. And the significant surface energy imbalance was observed from the direct measurement of heat storage term. We are optimistic to scale up the volumetric heat capacity to that of real on numerical model sides, since the thermal conductive process into obstacles obeys a simple liner equation different from non-linear processes like turbulence.

ACKNOWLEDGEMENTS

This research was financially supported by Core Research for Evolution Science and Technology of the Japan Science and Technology Cooperation, and by a Grant-in-Aid for Developmental Scientific Research from the Ministry of Education, Science and Culture of Japan.

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