WIND TUNNEL EXPERIMENT ON CONVECTIVE TRANSFER COEFFICIENT IN URBAN STREET CANYON

Ken-ichi Narita*
*Nippon Institute of Technology, Saitama, Japan

Abstract

How heat fluxes from different surfaces within canyon are affected by canyon flow is one of the remaining problems in urban climate modeling. In this paper, water evaporation technique was developed to study the distribution of convective transfer coefficient in urban street canyon. Evaporation rate from the filter paper pasted on building model was measured by electric balance about 2D street canyon models and 3D model arrangements. In this technique, it is easy to restrict flux within an arbitrary surface in question. Then by dividing filter paper, detailed distributions within each surface were also clarified about all active surfaces of 2D street canyon models.

Key words: urban canopy layer, evaporation, spatial heterogeneity

1. INTRODUCTION

To simulate the heat balance of urban area, it is important to know turbulent transfer from all active surfaces. Recently urban canopy models, like well-known TEB model, are developed, in which turbulent transfer is expressed as a network of resistances between the surface and air. However, there are very few reports about the values of these resistances (or transfer coefficients) for urban geometry. In this paper, a newly contrived estimation method of convective transfer coefficient was applied for wind tunnel model experiments.

2. OUTLINE OF THE EXPERIMENTS - WATER EVAPORATION TECHNIQUE

By measuring evaporation rate from the filter paper pasted on building model surface, the convective mass transfer coefficient at outside surface was examined. The filter paper used in experiments is 1mm thick, and its side surfaces were treated with waterproofing agent. A very fine thermistor sensor was inserted from side surface just below the paper surface to measure evaporating surface temperature. The model was set in the wind tunnel for a half hour, and the weight loss during that period (about 200-400mg) was measured by electric balance (the accuracy was 0.1mg). Then, mass transfer coefficient (k) was calculated by following formula.

$$k = E / (e_s - e_a)$$

where E is the evaporation rate, e_s is the saturated vapor pressure of evaporating surface temperature, e_a is the vapor pressure of approach flow. The merit of this experiment is easiness to restrict the flux within an arbitrary surface in question. In the case of similar experiments about heat transfer, there are many kinds of inevitable heat flow except for the convective heat flux in objective surface. Evaporation process is supposed to be constant, which means evaporating surface is saturated through the experiments. If model surface is partially dry out, surface temperature will rise quickly. As experiments were conducted with monitoring the surface temperature, we can easily check whether filter paper dries or not. Within model arrangement, wetting part is always only objective surface of sampling building model.

Vertical profile of mean velocity at wind tunnel working section was fitting to power law of 1/4 and turbulence intensity at model roof level (60mm) was set to 20%. Air temperature and humidity of approach flow were not controlled unfortunately. Then, as a reference, evaporation rate from horizontal same size plate near the outlet was also measured simultaneously in every case. All results were analyzed as the ratio of (k) to this reference value (k_0).

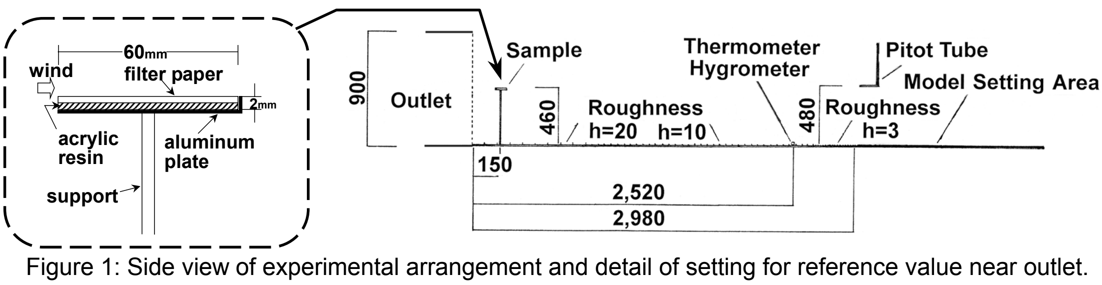

Figure 1: Side view of experimental arrangement and detail of setting for reference value near outlet.

* *Corresponding author address*: Ken-ichi Narita, Department of Architecture, Nippon Institute of Technology, Gakuendai 4-1, Miyashiro, Saitama, Japan; e-mail: narita@nit.ac.jp

3. RESULTS

3.1. Two-dimensional street canyon models

The relations between mass transfer coefficient (*k*) of two-dimensional street canyon and canyon geometry are shown in Figure 3 for the case of flow perpendicular to the street. The transfer coefficient of leeward wall is about 2/3 of windward wall in the range aspect ratio L/H is sufficiently large, which is considered *isolated roughness flow*. These values of wall decrease rapidly in L/H<1, then converge same value in the end (*skimming*). In the range of 1<L/H<2.5, leeward is increased while windward is decreased, that means the development of vortex flow within street canyon. This range corresponds to flow regime of *wake interference*.
On the contrary, the value of roof surface is almost constant within the limit of this experiment.

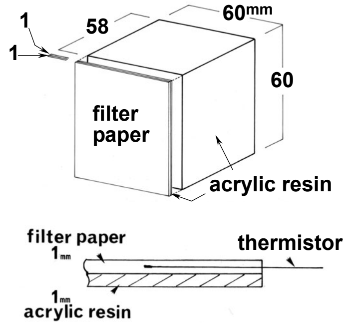

Figure 2: Building model for sampling.

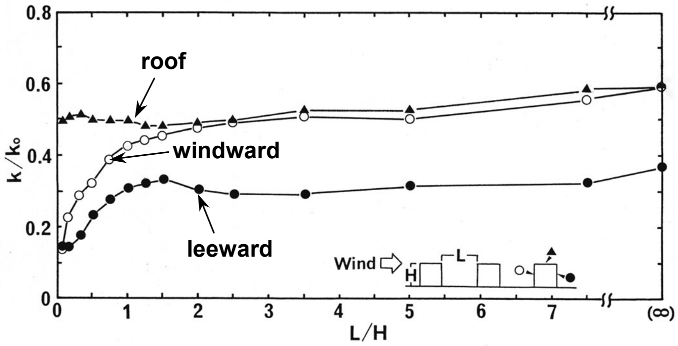

Figure 3: Relations between mass transfer coefficient (*k*) of two dimensional street canyon and canyon geometry.

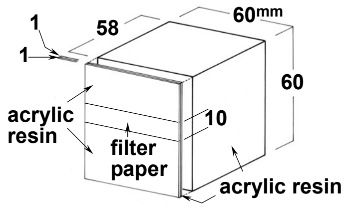

Figure 4: Building model for split measurement within surface.

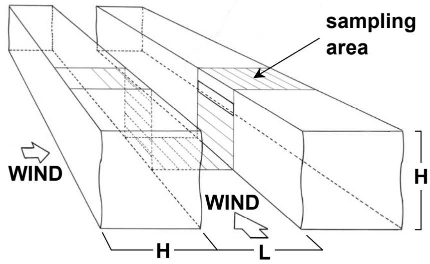

Figure 5: Sampling area of split measurement.

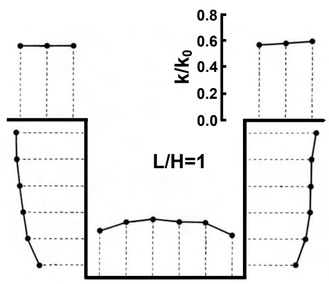

Figure 7:Distribution of (*k*) in parallel wind direction.

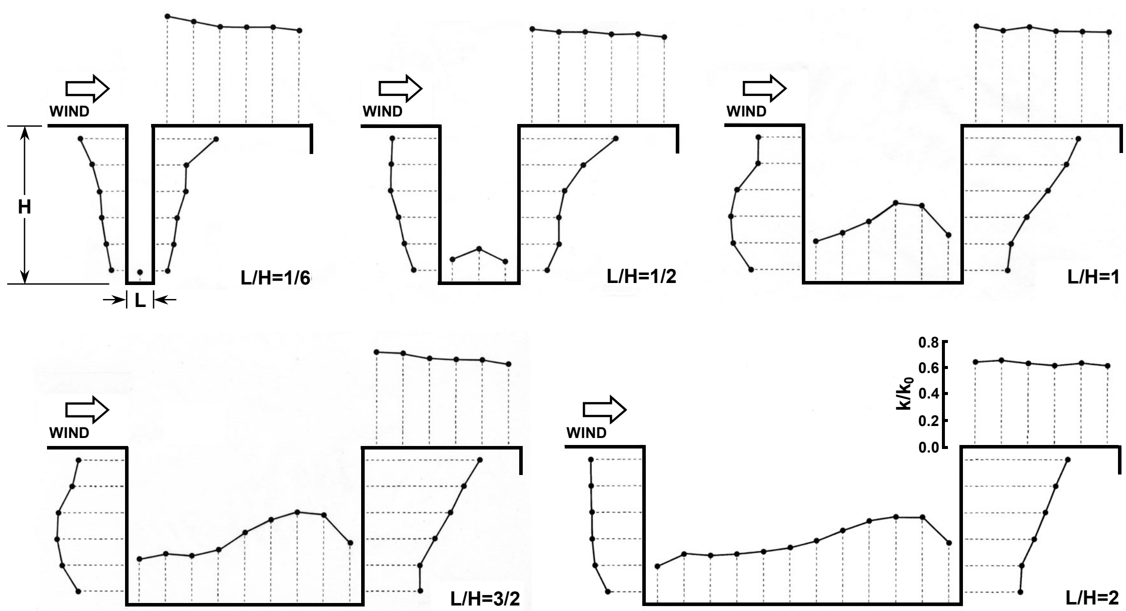

Figure 6: Distribution of (*k*) within each surface of 2-D street canyon in perpendicular wind direction.

In this technique, it is easy to restrict flux within an arbitrary surface in question. Then, by dividing filter paper, detailed distributions within each surface were also clarified about all active surfaces of two-dimensional street canyon models. Figure 4 shows the building model for such a split measurement, and sampling area is also shown in Figure 5. The results of different canyon geometry are shown in Figure 6 for the case of perpendicular wind direction. Within the windward wall, transfer coefficient always increases with height. In the case of L/H=1 and 3/2, leeward wall and ground have a peak in the middle part of surface due to the vortex flow. In skimming flow regime (L/H=1/6), the distribution of leeward wall is similar to that of windward wall.

3.2. Three-dimensional array

At first, change of mass transfer coefficient due to building density was investigated for simple cubic arrays (Figure 8). In sufficiently sparse condition, the order of transfer coefficient of each surface is roof > windward wall > side wall > leeward wall. The roof top value decreases gradually as building density increases. In the range of 1 < L/H < 5, windward wall has a highest value among surfaces. While the transfer coefficient begins to decrease around L/H=5 in other surfaces, that of leeward wall is almost constant up to comparatively dense condition. And there is no hilly increase by vortex flow between obstacles like two-dimensional street canyon.

Figure 9 shows wind speed dependency of transfer coefficient about single cubic model (L/H→∞). The variation of all kind of surfaces could be fitted by curves 4/5 power of wind speed (wind speed >1m/s).

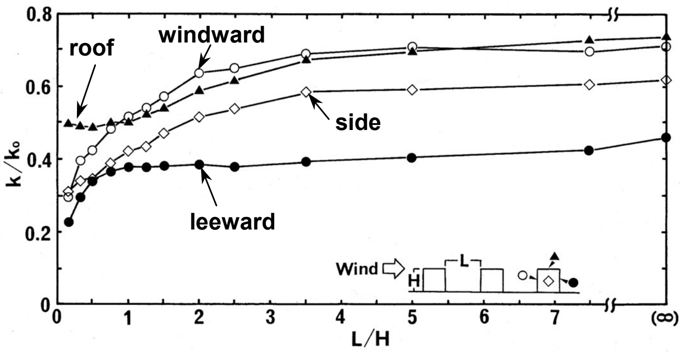

Figure 8: Relations between mass transfer coefficient (*k*) of regular cubic arrays and canyon geometry.

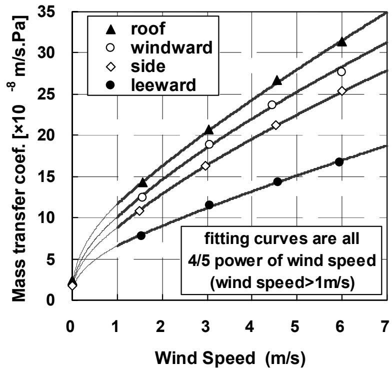

Figure 9: Change of mass transfer coefficient due to wind speed in single cubic model.

3.3. Change of transfer coefficient due to wind direction in three-dimensional array (case study)

In the experiments about simple cubic arrays, transfer coefficient of ground surface was not measured because the size of sampling area (part of wetting surface) changes with L/H concerning the ground. In this experimental technique, absolute value of transfer coefficient is affected by scale effect of sampling area. Then, we should compare the contribution of each surface under the condition of wetting area is equal to each other.

Figure 10 shows model arrangement for wind direction dependency of transfer coefficient. The model shape is 1:1:4, and interval between models is equal to model height. This makes building coverage ratio of 0.4. Here, sampling area is same square size and covered all surface including roof, wall and ground (Figure 11). The number of sampling location amounts to twenty. Transfer coefficient was measured for five wind directions at 22.5-degree intervals from right angle.

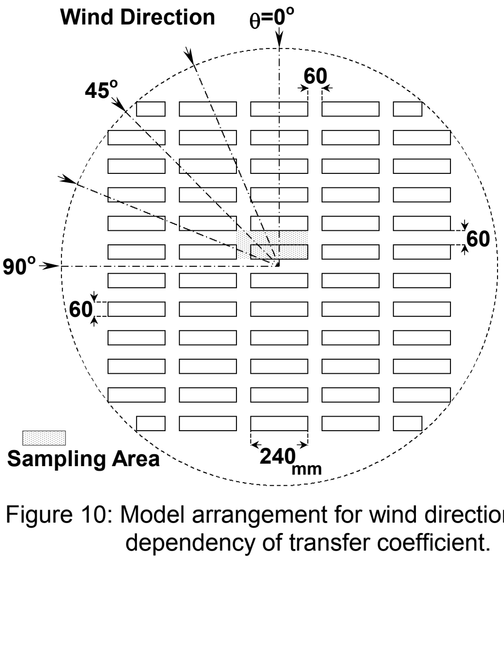

Figure 10: Model arrangement for wind direction dependency of transfer coefficient.

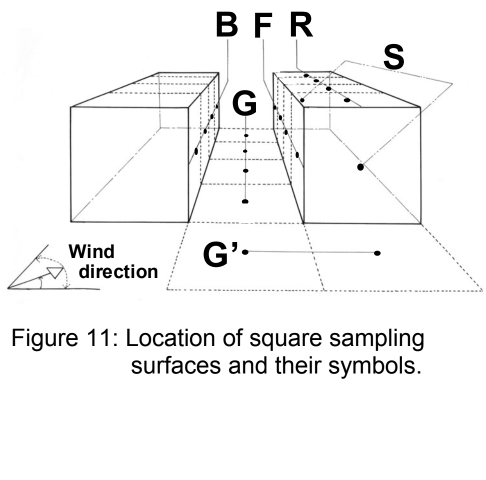

Figure 11: Location of square sampling surfaces and their symbols.

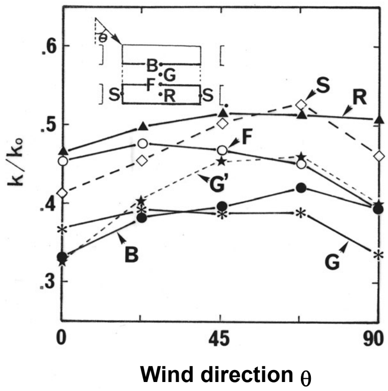

Figure 12: Change of (k) due to wind direction in each type of surface.

Table 1: Change of transfer coefficient due to wind direction and magnitude of deviation from spatial average .

Type of surface	Area (lot=100)	Wind direc.	0	22.5	45	67.5	90
Roof [R]	40	max.	0.49	0.53	0.57	0.58	0.56
		ave.	**0.47**	**0.50**	**0.52**	**0.51**	**0.51**
		min.	0.46	0.48	0.49	0.47	0.48
Ground [G+G']	60	max.	0.39	0.42	0.45	0.49	0.42
		ave.	**0.36**	**0.40**	**0.41**	**0.41**	**0.36**
		min.	0.32	0.38	0.37	0.34	0.31
Wall [B+F+S]	100	max.	0.50	0.51	0.61	0.64	0.55
		ave.	**0.40**	**0.43**	**0.45**	**0.45**	**0.41**
		min.	0.32	0.36	0.36	0.37	0.36
(Total)	200	ave.	**0.40**	**0.44**	**0.45**	**0.45**	**0.41**
		(Total ave.=1)	***0.94***	***1.01***	***1.04***	***1.05***	***0.96***
		max./ave.	***1.23***	***1.21***	***1.36***	***1.41***	***1.36***
		min./ave.	***0.79***	***0.82***	***0.79***	***0.75***	***0.74***

Figure 12 shows variations of transfer coefficient in each type of surface with wind direction. In the case of right angle (θ=0), the value of ground surface between models (G) is larger than that of street ground parallel to wind direction (G'). Spatial average and magnitude of deviation in each wind direction are summarized in Table 1. Concerning total average of all surfaces, its variation due to wind direction is small, less than 10%. As for this arrangement, the rank of transfer coefficient among surface types is constant, that is roof > wall > ground in all wind directions. The magnitude of locality, however, comes at most from –25% to +41% of spatial average.

3.4. Effect of spatial heterogeneity - representativeness of uniform cubic array (case study)

In many study, uniform cubic array has been used as a typical urban model. To check a representative-ness of this simple array, its transfer coefficient was compared with that of a clustered block array surrounded by rather wide streets. Figure 13 shows distribution of transfer coefficient of wall surface about clustered block array and uniform cubic array as a reference. Both arrangements have a same building coverage ratio of 0.51. About clustered array, transfer coefficient of wall surface facing wide streets are larger than that of core area. Maximum value appeared in windward corner of cluster, its ratio to spatial average of uniform array (0.695) is 1.53. On the other hand, spatial average of clustered array is 0.627, which is smaller than that of uniform array approximately 10%. Though we need to know the change in horizontal surfaces, it suggested that the contribution of wall is different between uniform and clustered arrays.

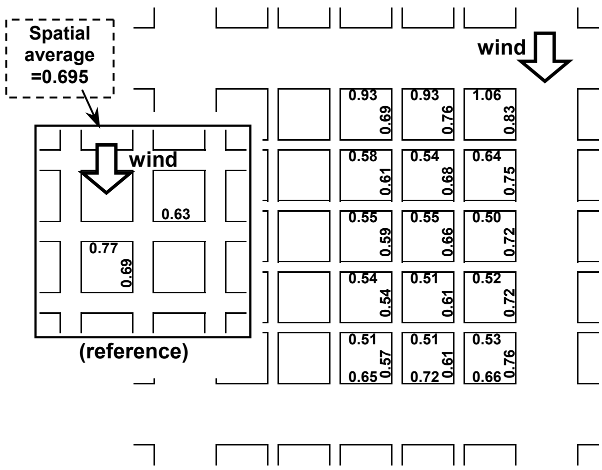

Figure 13: Distribution of (*k*) in clustered block array surrounded by rather wide streets – comparison with uniform cubic array with same building coverage ratio.

4. CONCLUDING REMARKS

Water evaporation technique using filter paper has been used to evaluate the transfer coefficient within a street canyon. Results suggest that concerning three-dimensional array, spatial average of transfer coefficient is not so sensitive to change of wind direction while its local deviation is considerably large and not negligible.

Acknowledgement
This research was financially supported by CREST (Core Research for Evolutional Science and Technology) of JST (Japan Science and Technology Cooperation) and by Grant-in Aid for Scientific Research from the Ministry of Education, Science and Culture of Japan.

References

Barlow, J.K. and Belcher S. E., 2002, A wind tunnel model for quantifying fluxes in the urban boundary layer, *Boundary-Layer Meteorol.*, **104**, 131-150.

Masson, V., 2000, A physically-based scheme for the urban energy budget in atmospheric models, *Boundary-Layer Meteorol.*, **94**, 357-397.