EVALUATION OF VENTILATION RATE IN BUILT-UP AREA USING CONVECTIVE TRANSFER COEFFICIENT

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ABSTRACT

In this paper, measuring evaporation rate from the filter paper pasted on building model surface, convective mass transfer coefficient (*k*) at outside surface was examined by wind tunnel experiments. Because (*k*) is closely related to air flow near the building surface, it is possible to estimate ventilation rate of urban street canyon from the distribution of it. This time, (*k*) of several kinds of city block with different building arrangement were examined, and some well-ventilated city design were proposed.

1. INTRODUCTION

Effective land-use is, of course, one of the important policy in an urban area everywhere. In Japan, because of the steep rise in land-price, many building sites were broken into small pieces, and slender pencil-like buildings were standing without enough space between surrounding neighbors. In these built-up area, environment near the ground is far from comfort. The stagnation of air mass with low wind velocity leads severe air pollution by the motor-traffic emission and also creates unbearable thermal environment for the pedestrians in summer.

The purpose of this paper is to clarify the criteria of street canyon geometry or density of buildings for the desirable healthy ventilation rate. According to the real scale measurements about convective transfer coefficient at outside building surface, it was closely related to the air flow near the building. Therefore, this time we tried to evaluate ventilation rate in built-up area using the convective transfer coefficient in wind tunnel model experiments.

2. MEASURING TECHNIQUES

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

Then, the convective mass transfer coefficient (k) was calculated by

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

where E is evaporation rate, e_s is saturated vapor pressure of evaporating surface temperature, and e_a is vapor pressure of approach flow.

The dimensions of wind tunnel outlet are 900 mm in height and 1800 mm in width. By means of several kinds of roughness elements between outlet and working section, vertical profile of mean velocity was fitting to power law of 1/4 and turbulence intensity at roof level of the typical building model was set to 20 %.

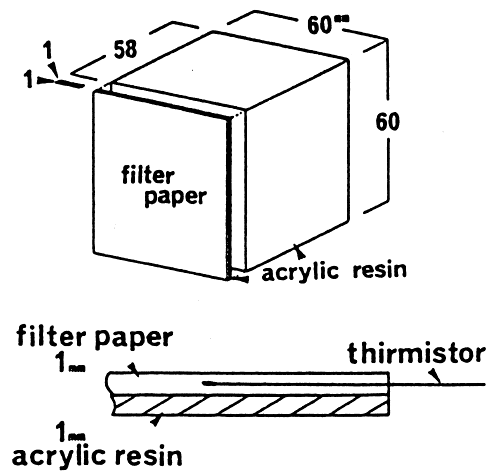

Figure 1. Building model

3. FULL SCALE OBSERVATIONS

It is necessary to describe some results of our full scale observations before going into the main subject in wind tunnel experiments. The real scale measurements of (k) were conducted at the window facing north on the seventh floor of eight-story building. The same filter paper (710 x 710 mm) was pasted on the windowpane surface and moistened overall. Measuring the weight loss of its center part piece (60 x 60 mm) by evaporation, (k) was calculated in the same manner. The relations between convective transfer coefficient (k) and wind velocity were determined in the different sites within the same floor, for example center part or edge, with balcony or not, and so on. In these observations, fine wind structures near the window were also measured with three dimensional ultrasonic anemometer (5 cm span).

Figure 2 shows the example of relations between (k) and the 30-minute means of wind speed at 15 m above the roof. These relations change due to the upper stream direction, that is, in the case of windward or leeward surface. On the other hand, (k) has the linear relation to the mean wind in the vicinity of the window regardless of the upper stream direction (Figure 3).

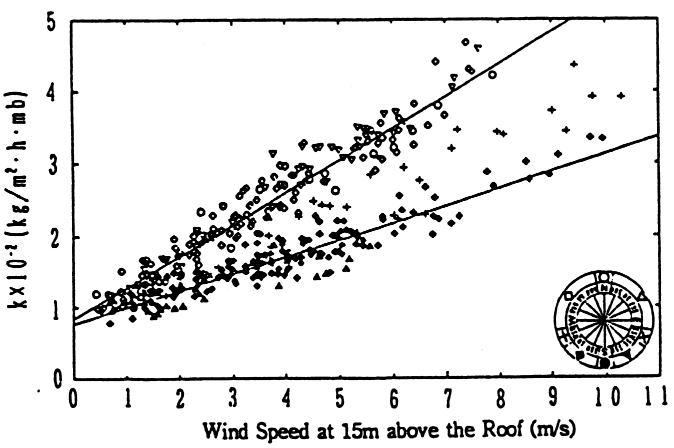

Figure 2. Relations between convective transfer coefficient and wind speed above the roof.

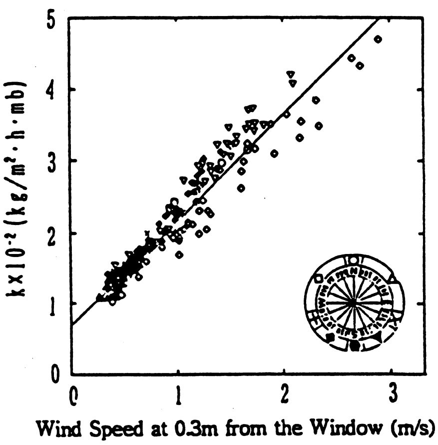

Figure 3. Relations between convective transfer coefficient and wind speed near the window.

This result suggests that it is possible to estimate ventilation rate of urban street canyon from the distribution of convective transfer coefficient.

4. WIND TUNNEL EXPERIMENTS

The relations between (*k*) of two dimensional urban canyon and canyon geometry are shown in Figure 4. In this figure, (*k*) is standardized by that of horizontal plate (k_o) which has same dimension as the model surface and located near the outlet. These values are the average of three measurements at the wind speed of free stream **U** = 2, 4 and 6 (m/s). In the range between **L/H** = 1 and 2.5, which corresponds to the flow pattern of wake interference, the value (*k*) of windward is decreased while that of leeward is increased. These values of windward and leeward decrease rapidly in the range of **L/H** < 1 (skimming flow pattern), then converge same value in the end. On the contrary, the value (*k*) of roof surface is almost constant within the limit of this experiment.

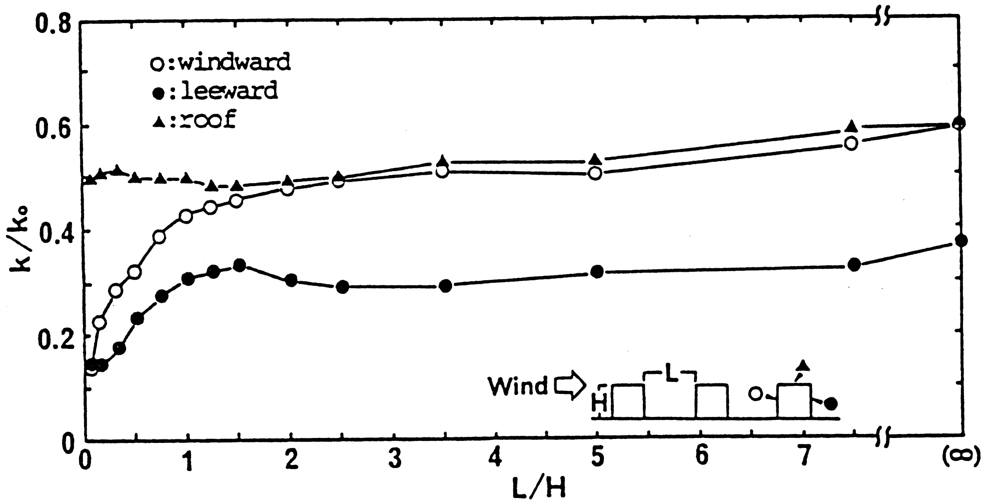

Figure 4. Change of convective transfer coefficient of two dimensional urban canyon due to canyon geometry.

Figure 5 shows the perspectives of city block model tested as a case study of ventilation rate. 5 x 5 of cubic models are set with interval 1/6 of model height. Though it is omitted in the figure, sampling was carried out in the half part of center block in the 3 x 3 of block arrangement. The street width between each block is equal to the height of cubic model. Here, the effect of open space **(type-B)** and the effect of building shape change under the condition that rate of building volume to lot is constant **(type-C)** were investigated in comparison with standard arrangement **(type-A)**.

The distributions of (k) in **type-A** are shown in Figure 6. Because each path forms relatively narrow and deep street canyon within the inside of blocks, the value (*k*) of vertical surface (●O▲) are only 40 to 50 % as compared with that of roos surface (◆). Within the block, the (*k*) of vertical surfaces tend to decrease slightly toward the center of it. In this area, the difference of (*k*) due to the surface direction against the wind is not so obvious. As for the peripheral surfaces facing the wide street (Δ) the (*k*) of these surfaces amount to about one and a half times as that of inside area.

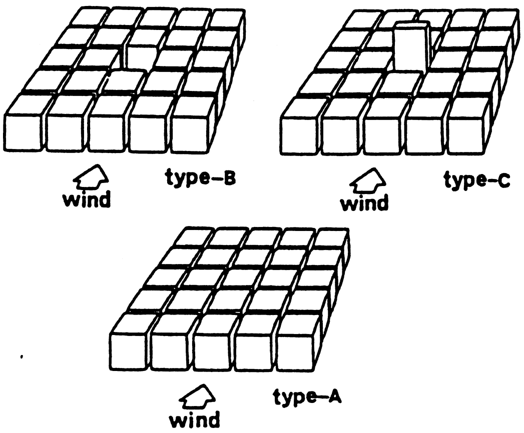

Figure 5. Perspectives of city block model.

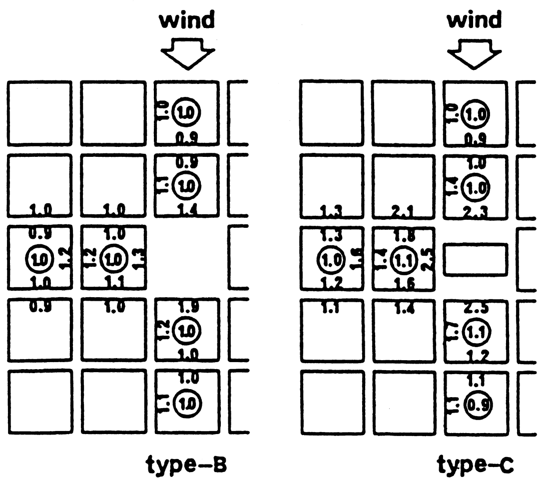

Figure 7. Ratio of convective transfer coefficient in type−B and type−C to that of type−A.

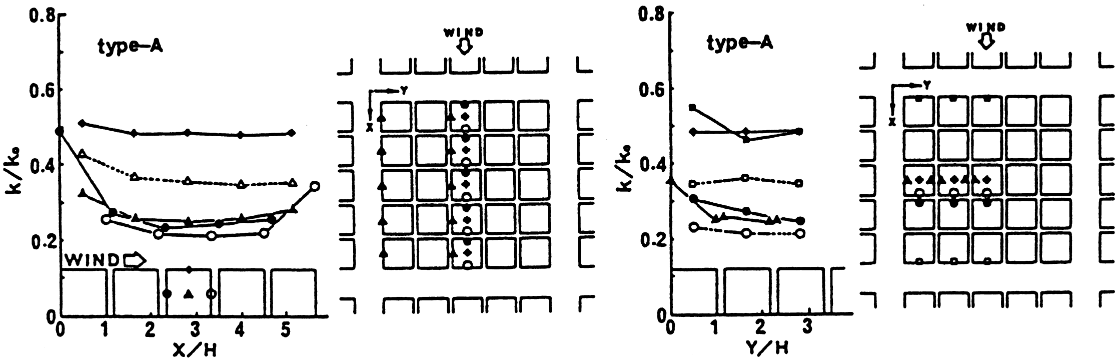

Figure 6. Distribution of convective transfer coefficient in type−A model.

Finally, figure 7 is the results of case study, expressed by the changing ratio of convective transfer coefficient. The numbers within the circle mean the value of roof surfaces, and the others do that of vertical surfaces. In the case of **type-B**, large increment of (*k*) is restricted within the vertical surfaces facing open space in question. On the other hand, in **type-C**, (*k*) is increased remarkably not only around high-rise building created but also the inside streets beyond the low-rise cubic models surrounded.

5. CONCLUSION

In this paper, we proposed the new technique to evaluate ventilation rate using convective transfer coefficient. Generally, wind velocity has a strong locality in its distribution, particularly in built-up area. Therefore, even if a very fine hot wire is used as a sensor, it is not so easy to know the space-averaging wind velocity within a street canyon. In this experiments, it is possible to evaluate the ventilation rate of whole street-space without difficulty, and also there is no disturbance by any kinds of sensor in air flow during the measurements. These are advantage of this technique and it is considered to be quite a convenient method for short-time investigations on the spatial distribution of wind environment in city planning.

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