EFFECTS OF A BODY OF WATER ON URBAN THERMAL ENVIRONMENT DEPENDENT ON THE TYPES OF ON-SHORE BUILDING DISTRIBUTION MEASURED BY WIND TUNNEL EXPERIMENTS

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ABSTRACT

A river has a good effect on the micro-climate of surrounding areas when natural cooling winds are needed in the hot summer season in Japan. In order to clarify the effective arrangement of buildings around the river, wind tunnel experiments were conducted.

The water channel in the wind tunnel is 2000mm long and 200mm wide in full scale. The effects of the body of water were detected through analysis of the humidity distribution around it. The results suggest that the location and direction to wind of buildings are important, as well as the building density around the water surface.

1. Introduction

A river, a precious natural resource, can be important in the passive control of the outdoor environment in a built-up area.

We have conducted field observations on these micro-climatic effects during the last few years in and around the rivers flowing through Hiroshima City, Japan. Figure 1 is the map of Hiroshima City located in the south-west part of Japan, which is developed on the delta of Ota River. Around here, cool sea-breeze is prevailing wind in the daytime on fine days. Because it flows along the rivers rather than in the built-

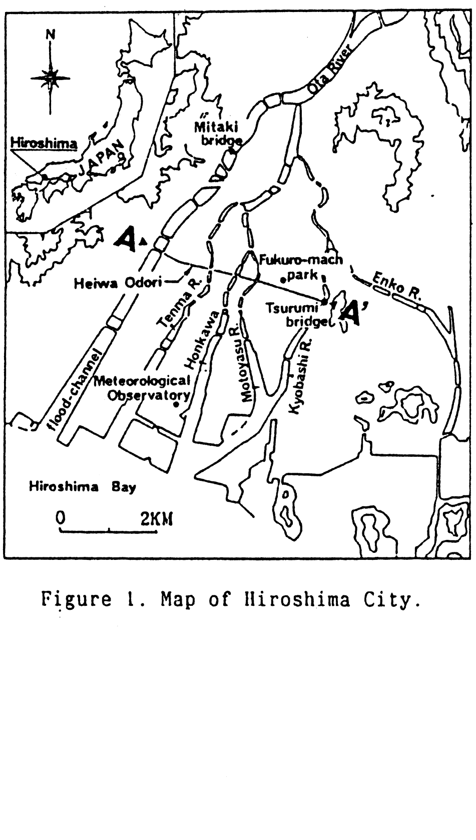


Figure 1. Map of Hiroshima City.

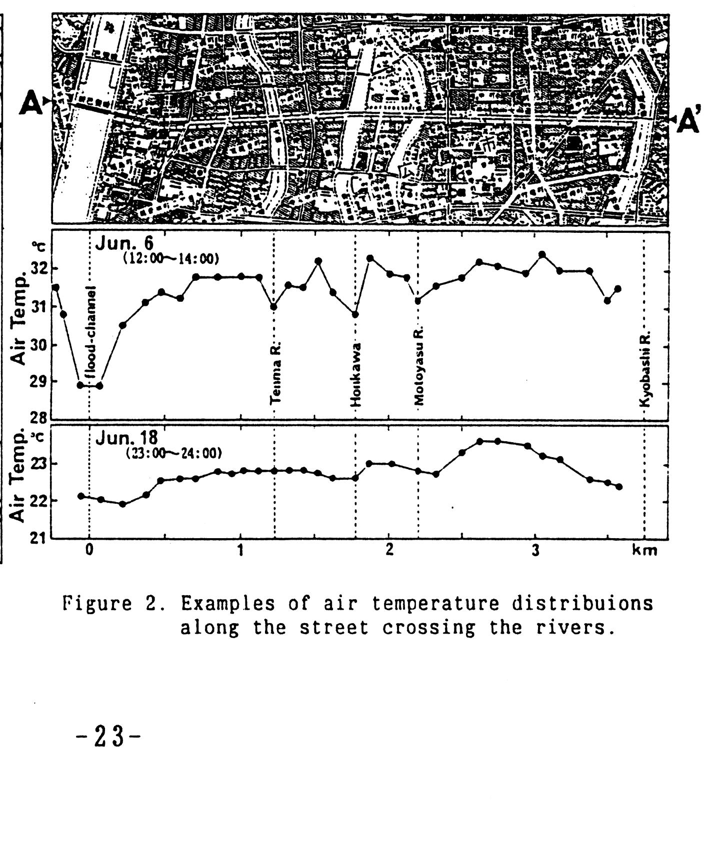


Figure 2. Examples of air temperature distribuions along the street crossing the rivers.

up area, heat-island is divided into topographical land units (FUKUOKA et al. 1979). Figure 2 shows the examples of air temperature distribution in warmer seasons along the street crossing the river. It is affected by rivers, particularly in the daytime, and in the case of the wide river, the effect extends in the perpendicular direction to neighboring built-up area. According to detailed observation, these extents of the river effects depend in part on the width of cross-streets and the rate of open space, that is, the density of surrounding buildings (MURAKAWA et al. 1990/91).

But in field measurements, the meteorological conditions are not always constant. Then, in order to confirm the effect of on-shore building arrangement, supplementary wind tunnel experiments were conducted.

2.Outline of the experiments

Figure 3 shows the outline of wind tunnel used in experiments. The dimensions of outlet is 900mm in height and 1800mm in width. By means of several kinds of roughness elements between outlet and working section, the vertical profile of mean velocity was fitting to power law of 1/4 and the turbulence intensity at the roof level of the typical building model was set to 20% at the upstream edge of working section. As for a wind speed, it was fixed on 3 m/s at the top of boundary layer, except for some special experiments testing the influences of wind speed.

In the part of working section, a simplified river model was set in parallel with wind, that is, the X-axis direction. The area of the water channel is 2000mm long and 200mm wide in full scale. On both sides of the river (shaded area in Figure 4), we set various kinds of model buildings.

The two pairs of thermometer and hygrometer were used. One was used for the stationary measurement of approach flow at the reference point,

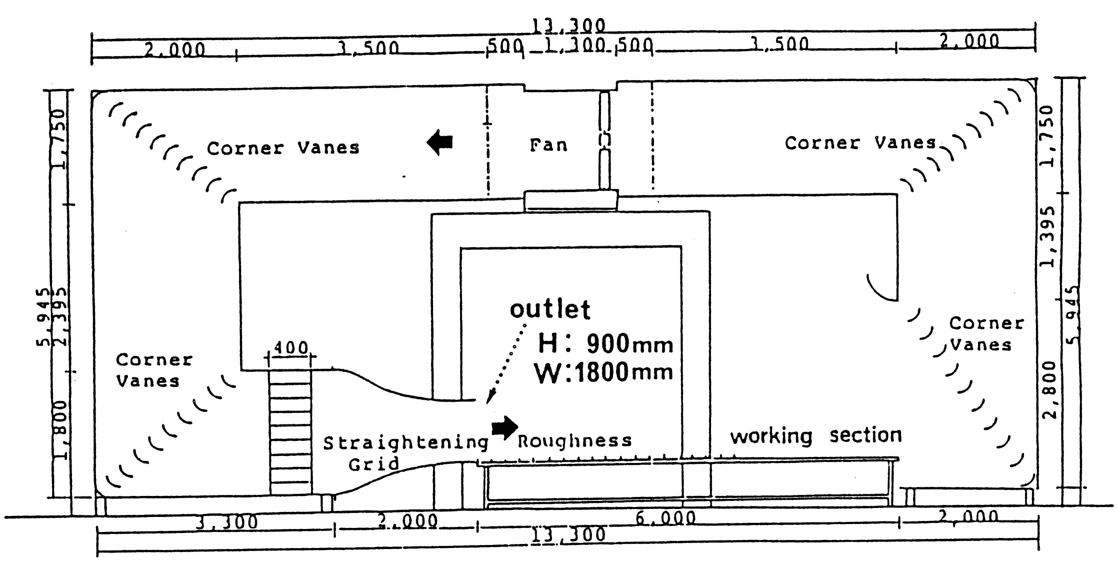
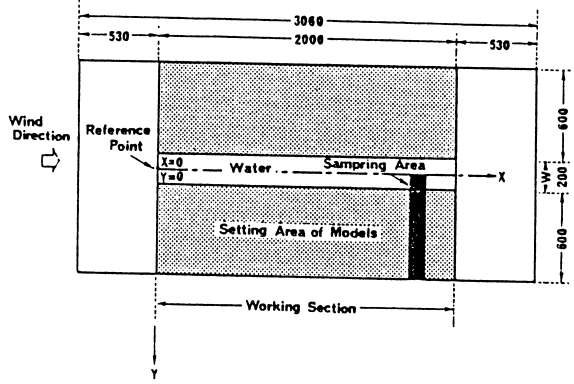


Figure 3. Outline of wind tunnel.



VP: standardized vapor pressure

$$\frac{e - e_o}{e_s - e_o}$$

e : vapor pressure at each point along the traverse line

e_o: vapor pressure of approach flow (measured at reference point)

e_s: saturated vapor pressure of water surface temperature

Figure 4. Water channel in working section and sampling area.

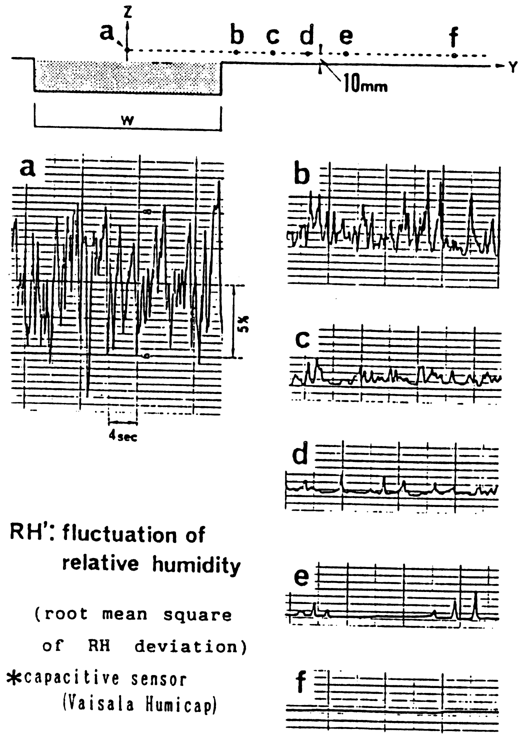


Figure 5. Examples of relative humidity output along the traverse line.

the other was used for the traverse measuring in the perpendicular Y-axis direction. Using these values and the water surface temperature, the standardized vapor pressures at each point along the traverse line were calculated. It is defined by the equation in Figure 4, and here we express it with the symbol "VP".

To detect the extent of the river effects, another index was introduced in addition to "VP". Figure 5 shows the fluctuations of relative humidity output measured by capacitive sensor at a height of 10mm above the surface along the traverse line. Figure-a is the fluctuation above the center of the river. As measuring position becomes further from the river, the variations in relative humidity diminish gradually. And at the position well away from the river, there is no fluctuations (Figure-f). Because upward peaks in these figures are caused by reaching of air-mass from the river, the standard deviation of relative humidity is considered to be available for river effect analysis. Therefor, the root mean square of relative humidity deviation, symbolized as "RH'", was used.

In order to detect humidity distribution with a high accuracy, it is necessary to keep some difference of vapor pressure between the air and the water surface. As our wind tunnel doesn't have a control unit of air temperature, the water temperature was controlled to be a little warmer than that of approach flow. But its difference is not so great that buoyancy effects are ignored in following analyses. Assuming a neutral condition, the remaining factor of similarity in a model experiments is a

Reynolds number. But, within fully developed turbulent flow, the flow pattern around a bluff body, like a building, is considered to be independent of Reynolds number. The lower limit of Reynolds number is 2,100 in these kind of model experiments, when the model height is a characteristic length (OHBA,M 1989). As the smallest model in the experiments is the cubic with 3cm long, this critical Reynolds number for similarity was satisfied enough.

3.Distribution of humidity without models

Previous to the experiments with building models, some experimental conditions were examined without models.

Figure 6 shows the distributions of "VP" and "RH'" along each traverse line having different distances from the upstream water edge. The horizontal axis means the distance from the center of the river in the perpendicular direction to the river. The change of "VP"-distribution is restricted to the point 1275mm from the edge. Though "RH'"-distribution is still shifting gradually, the sampling area of following experiments, about X=1755mm (refer to Figure 4), is considered to be stable in humidity distribution.

For the purpose of similarity test in experiments, "VP" and "RH'" distributions were compared with the ratio of measuring height, water level and distance from the upstream water edge to the channel width constant (Figure 7). The width of the water channel (W) was changed by

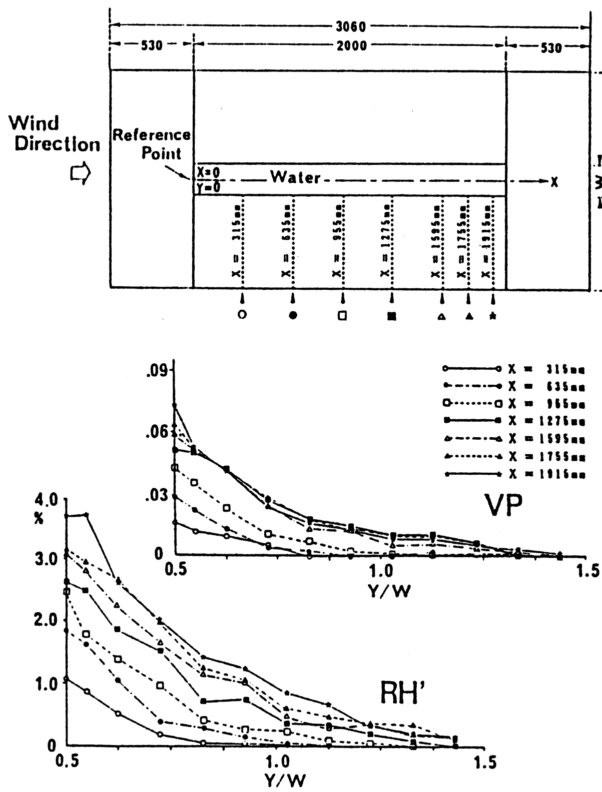


Figure 6. Humidity distributions without models.

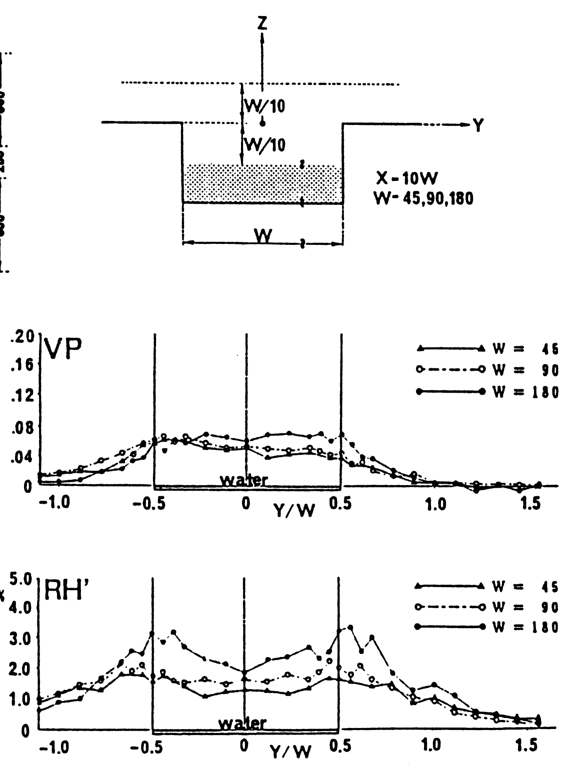


Figure 7. Test of similarity in experiments.

closing part of it with acryl plate. The distributions of "VP" are almost the same in spite of the model scale, while that of "RH'" are slightly large as the channel is wider. In the range of experiments, it can be considered that the similarity is approximately realized.

4.Effects of model arrangements on humidity distribution

Here, the experimental conditions were fixed as the channel width (W) was 200mm, the measuring height was 10mm, and the water level was -5mm from the shore, respectively.

Figure 8 shows the change of "VP" and "RH'" along the traverse line due to the density of buildings. The horizontal axis means the dimensionless distance from the center of the river in the perpendicular direction. As is evident from perspectives which show the part of model arrangements around the traverse line, the density decreases in the order, "S_1", "S_2", and "S_3". The building coverages of each arrangement were 56%, 36%, and 25%, respectively. It is clear that the river effects extend to the land direction more deeply as the building density is lower.

The next is the change due to the width of street crossing the river (Figure 9). The width becomes wider in the order, "S_1", "S1A", and "S2A". The traverse lines exist on the middle of each street. It can be read off the figures that the river effects spread wider as the street width becomes wider.

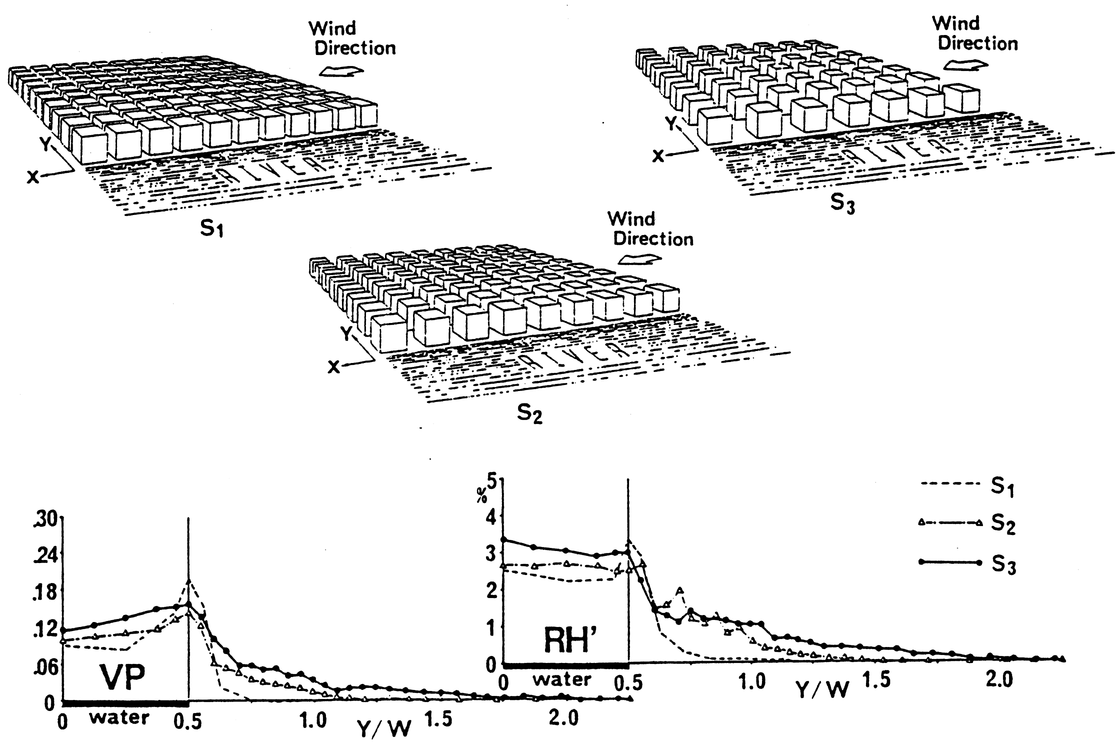


Figure 8. Change of humidity distribution due to the density of buildings.

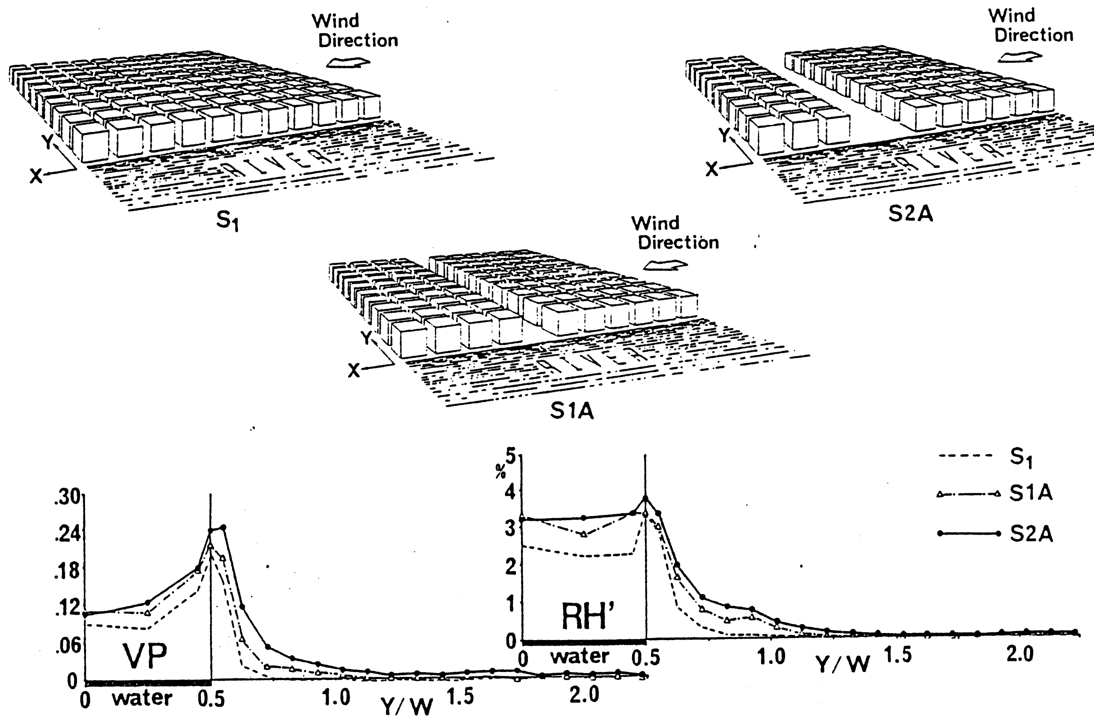


Figure 9. Change of humidity distribution due to the width of street crossing the river.

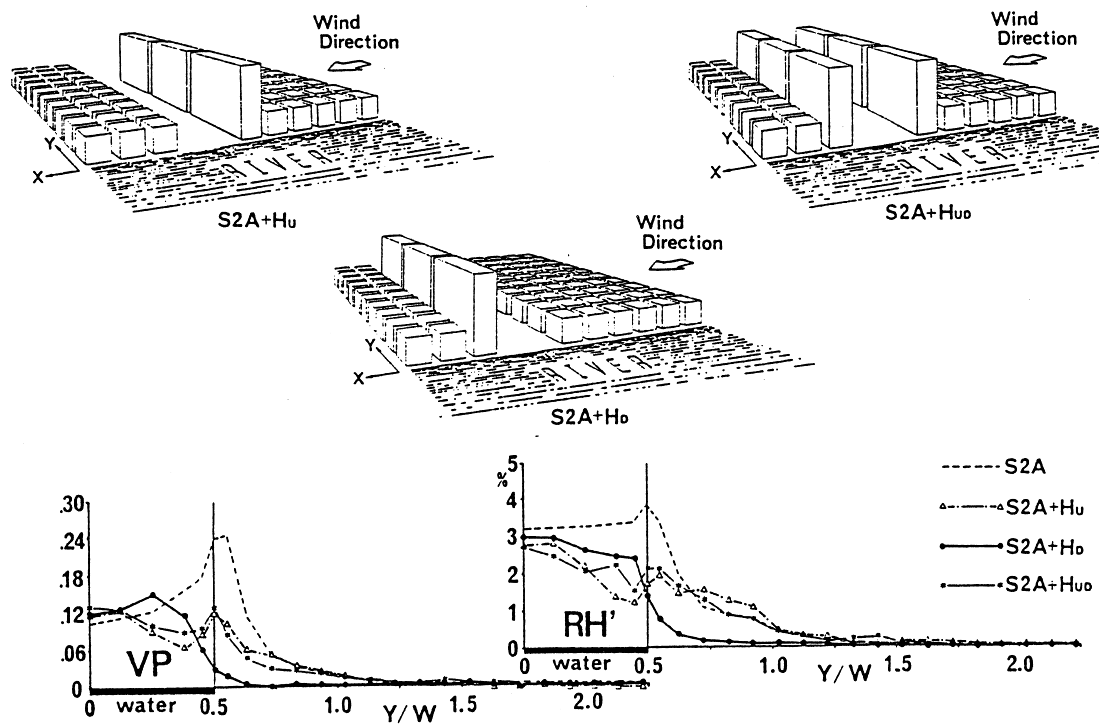


Figure 10. Change of humidity distribution due to the high-rise buildings along the street crossing the river.

These tendencies about the building density and the street width agree with above-mentioned results of the field observations.

Figure 10 shows the influences of high-rise buildings along the crossed street. The height of high-rise building models is three times as large as that of surrounding low-rise models. As a matter of course, the street width and the other experimental conditions were constant. If high-rise buildings stand on the leeward of the street ($S2A+H_D$), the introduction of the air-mass above the river is obstructed by the downward flow along the windward wall of the high buildings. On the contrary, when the buildings on the windward of the street are heightened ($S2A+H_U$), the air enters rather effectively from the river because the street is included in the cavity zone of high-rise buildings.

Figure 11 shows the change of making an open space around the river in low-rise dense arrangement. The change of humidity distribution is not so great only by making the open space (OP). But if we stand the high-rise building on the windward of the open space, the air above the river strongly invades into the open space ($OP+H_U$).

What is the most effective arrangement, under the condition that the rate of building volume to lot is constant? One of the examples is shown in Figure 12. By assembling four parts of the left arrangement horizontally, we can get the middle arrangement to have wider streets ($4S_H$). And by standing it vertically, we can get the right arrangement to have much more ground space ($4S_V$). It is obvious that the more open a

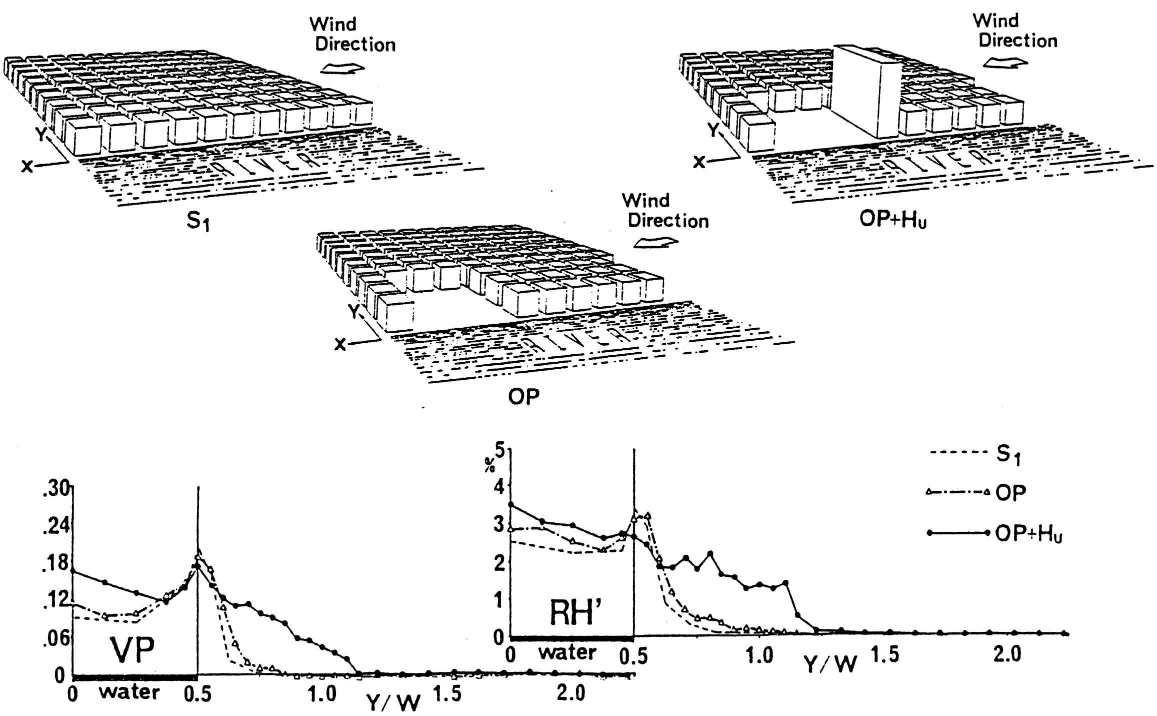


Figure 11. Change of humidity distribution due to making an open space.

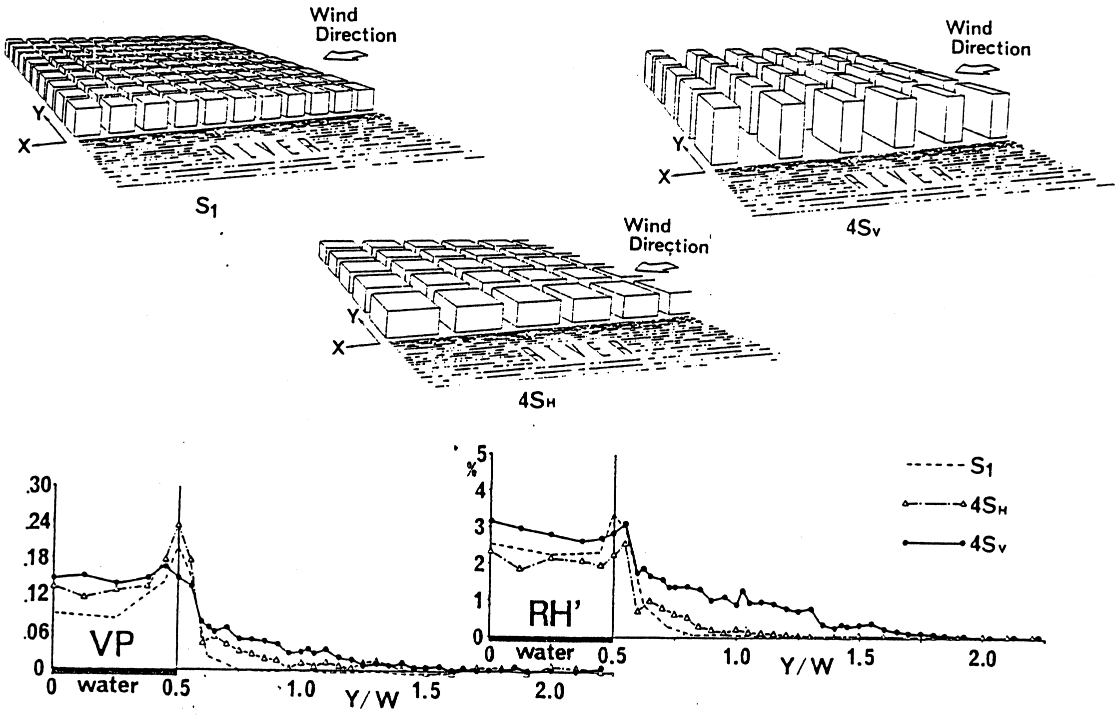


Figure 12. Change of humidity distribution due to the shape or size of buildings with the rate of building volume to lot constant.

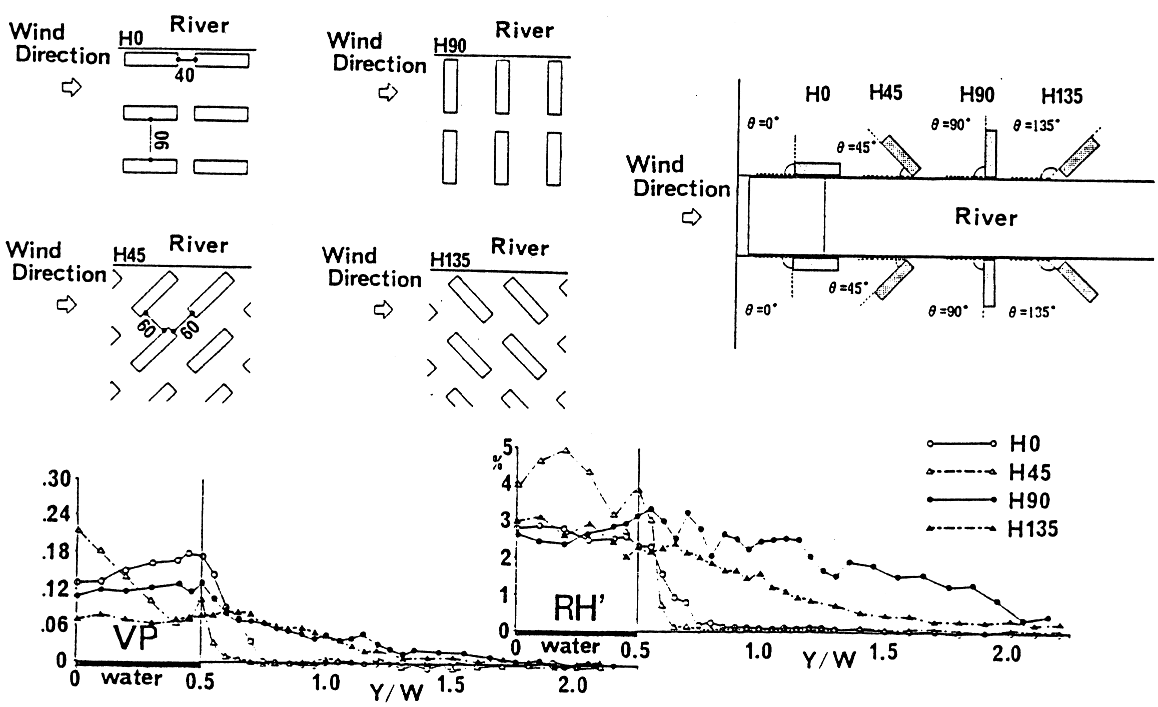


Figure 13. Change of humidity distribution due to the direction of high-rise buildings to the river.

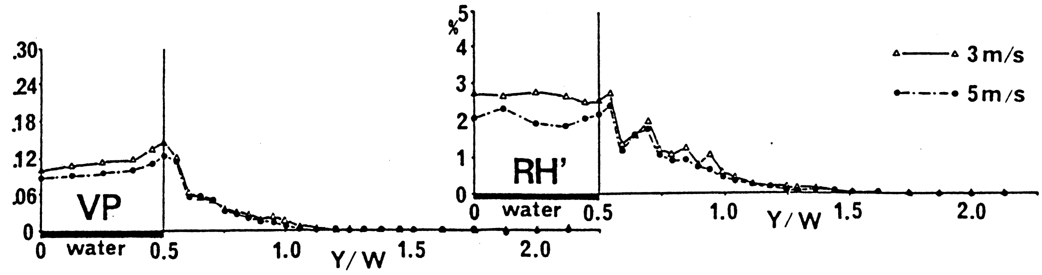


Figure 14. Effect of wind speed on the humidity distribution.

ground the more river effects spread.

Figure 13 shows the change due to the direction of high buildings to the river. In this case, the building model arrangement was symmetric with regard to the river. As for the left-hand two arrangements (H0 & H45), their results are described with open symbols, the diffusion of air-mass above the river is obstructed. On the other hand, the right-hand two arrangements (H90 & H135) lead the air-mass very effectively from the river to the land.

Last of all, Figure 14 shows the influences of wind speed on the humidity distributions in the case of S_2 arrangement. The results in 5 m/s are in agreement with that in 3 m/s.

In the case of the field observations, the air temperature distributions around the river were also affected by wind speed (MURAKAWA et al.). In general, the air temperature near the ground is strongly related to the ground surface temperature, in other word, a surface boundary layer whose thickness varies with wind speed. Because the air temperature around the river is influenced not only by "the river effect" but also by the ground just below, it is difficult to separate these two effects in air temperature distributions.

Regarding the present experiments, it is of great advantage to detect the river effect purely, since it deals with the simple diffusion phenomena using water vapor as a tracer gas. The results shown in Figure 14 mean that concerning this pure river effect, it doesn't change due to wind speed.

5.Conclusion

The present study has shown some ideas of on-shore building arrangement for the effective use of a water body, like a river. As already suggested by the field observations, the micro-climatic effects of the river are more widely spread when the density of buildings is lower and the streets crossing the river is wider. Besides, the location and direction to wind of high-rise buildings have influence on the extent of such river effects.

At any rate, in hotter climates of Japan, it should be emphasized that the planning of a well-ventilated city is most important for the effective use of a body of water as a cooling source.

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