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Wind Protection on the Housing Estate in Hokkaido
– Model Test in Wind Tunnel –

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北海道における住宅団地の防風
— 風洞内模型実験による検討 —

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Summary

The effects of windbreaks as a means of wind protection on a housing estate were investigated using models in a wind tunnel. The results indicated that the windbreaks were highly usefull to protect buildings from high velocity winds in the housing estate. But somewhat stronger winds were observed in several regions such as flats broad exposed without wind protection, especially along main highways laid out in parallel to the prevailing wind direction and along the sides especially in the leeward areas of tall buildings and structures.

Introduction

One of the important elements that must be considered at all levels of planning of housing estates is extreme climatic conditions. The problems of high velocity winds blowing over sand dune and into a township have been considered by Bitan (1977) in the planning of Di-Zahav, Israel. Windbreaks and shelterhedges are known to be usefull to protect detached houses from strong and cold winds (Yazawa, 1953; Caborn, 1965).

In the present study Shinoro was selected as a study site. Shinoro district is located 12 km north of the center of Sapporo City and is adjacent to Ishikari Town. Distinctive climatic features of Shinoro are the high velocity winds from Ishikari Bay in winter and from the Pacific Ocean in the spring season. In particular, the strong winds in winter are accompanied

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with blowing snow. Strong wind reduces effective temperature and increases the chill factor felt by pedestrains on the street. Blowing snow obscures vision and makes everyday life hazardous. Transportation and communications are often disrupted by the effects of strong wind and blowing snow.

An extensive windbreak system was included in the planning as a preventative measure against the effects of extreme climate, strong winds and blowing snow, in the Shinoro Housing Estate by the Japan Housing Corporation. A windbreak system is a new method to modify the extreme climate in a housing estate. The effeets of windbreaks on modification of climatic environment in a housing estate have not been clarified in spite of the various reports on windbreaks.

In this paper, optimum intervals of windbreaks and adequate arrangement of buildings in the windbreak system were investigated using models of Shinoro Housing Estate in a wind tunnel.

Outline of Shinoro Housing Estate and climatic background

Shinoro Housing Estate is 394 ha in area, about 2.5 km in length from east to west and with a width of about 1.7 km. The boundaries to the east and the north of Shinoro Housing Estate lie along the Ishikari R. and Barato R. respectively. The region lies on a flat plain consisting of alluvial

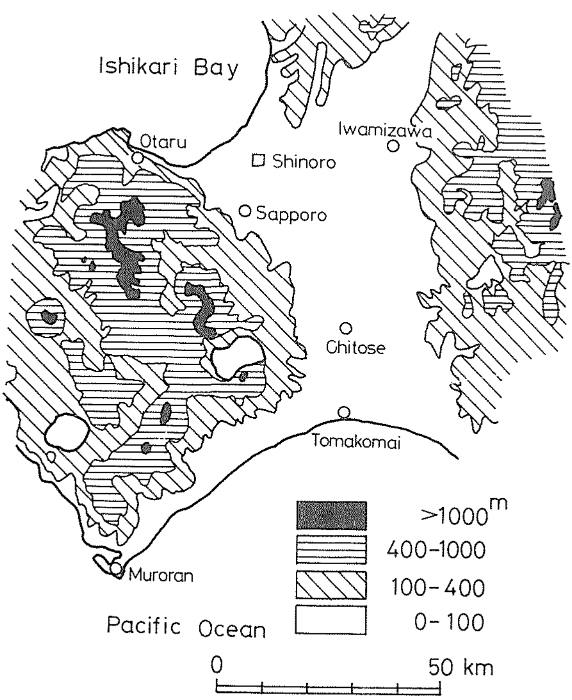


Fig. 1. Location of Shinoro Housing Estate.

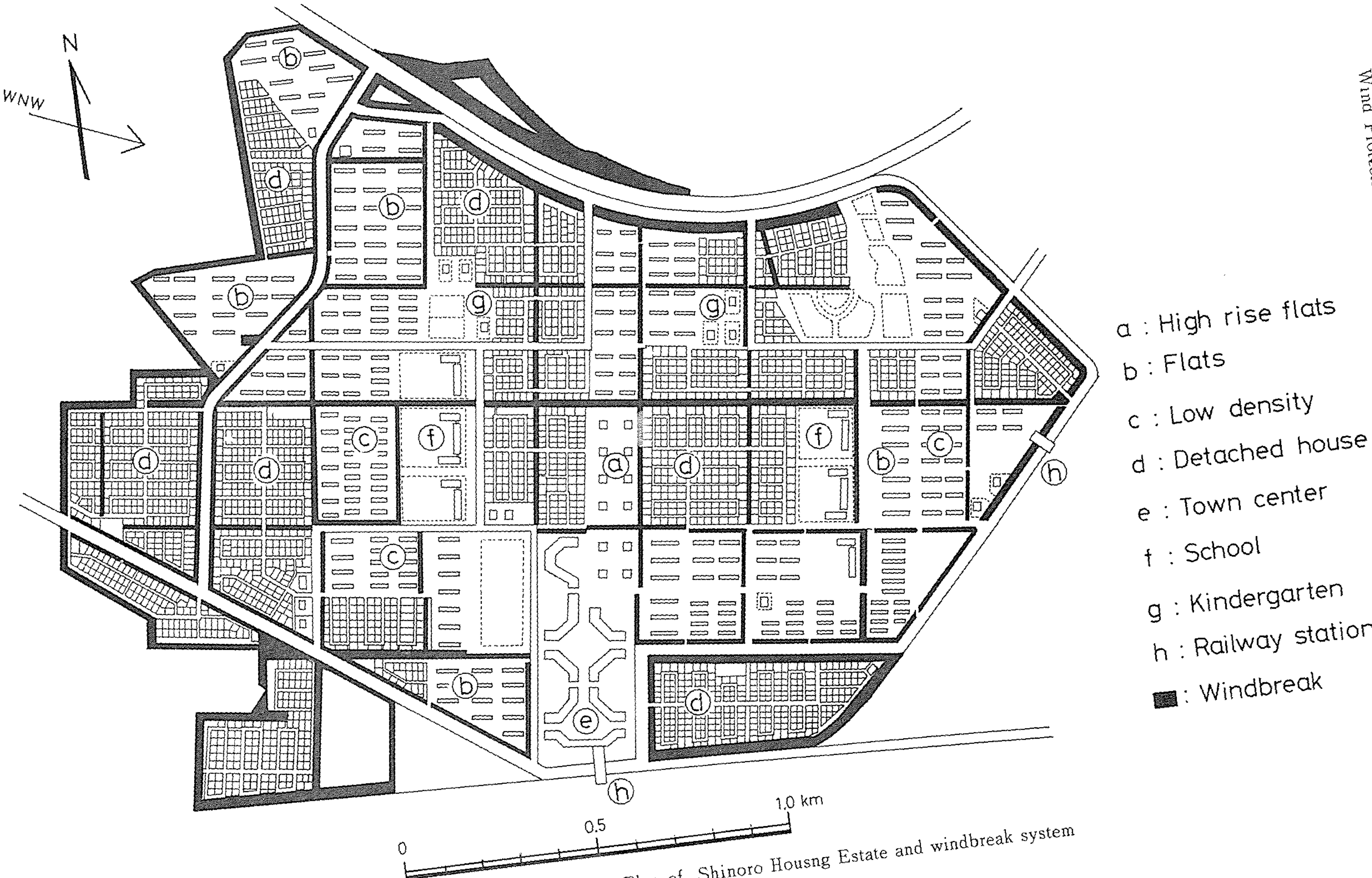


Fig. 2. Plan of Shinoro Housng Estate and windbreak system

soil originating in floods of Ishikari R.. Mean gradient of groud from south to north at the region is smaller than 2 %. Various types of buildings and structures are being planned for construction in Shinoro Housing Estate such as detached houses (8 m in height), low densities (7 m in height), flats (15 m in height), high rise flats (35 m in height), town centers (35m in height), schools (13 m in height), railway stations (7 m in height) and windbreaks (15 m in height).

Two types of windbreaks which differ in width are used in this plan. The wider one is 20 m in width and the other is 10 m in width. Porosity of these windbreaks is about 40 %. Intervals of windbreaks are about 275 m.

Fig. 3 shows the annual changes of wind velocity at the Ishikari Agricultural Station located about 9 km north of the Shinoro Housing Estate and the Sapporo District Meteorological Observatory located 12 km south of the housing estate. The wind velocity at Ishikari is high in winter especially from November to February. But at Sapporo, wind velocity is lower in winter than in spring. Patterns of the annual change of wind speed at Shinoro Housing Estate were assumed to be roughly similar to that at Ishikari Agricultural Meteorological Station. Because the regin of Shinoro Housing Estate is topographically more similar to Ishikari than Sapporo.

High winds in winter blow at Shinoro when the synoptic pressure pattern develops to the typical west-high / east-low pressure pattern. The prevailing direction of wind over Hokkaido is northwesterly in winter (Maejima, 1954). But at Ishikari, the privailing wind blows from west northwest. This is a result of topographical influence. A west northwest wind was selected as the privailing wind in this model test.

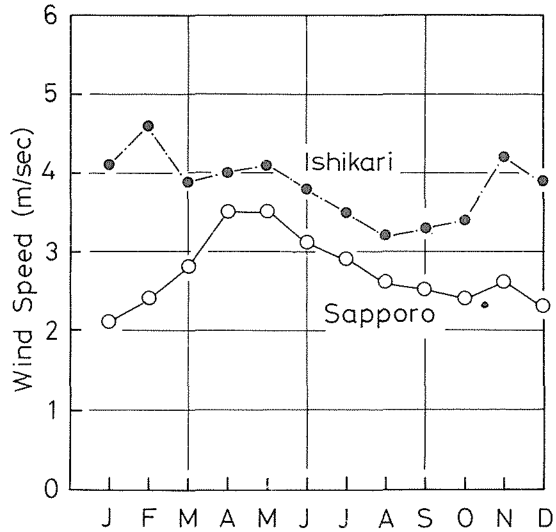


Fig. 3. Annual changes of wind speed at Ishikari and Sapporo.

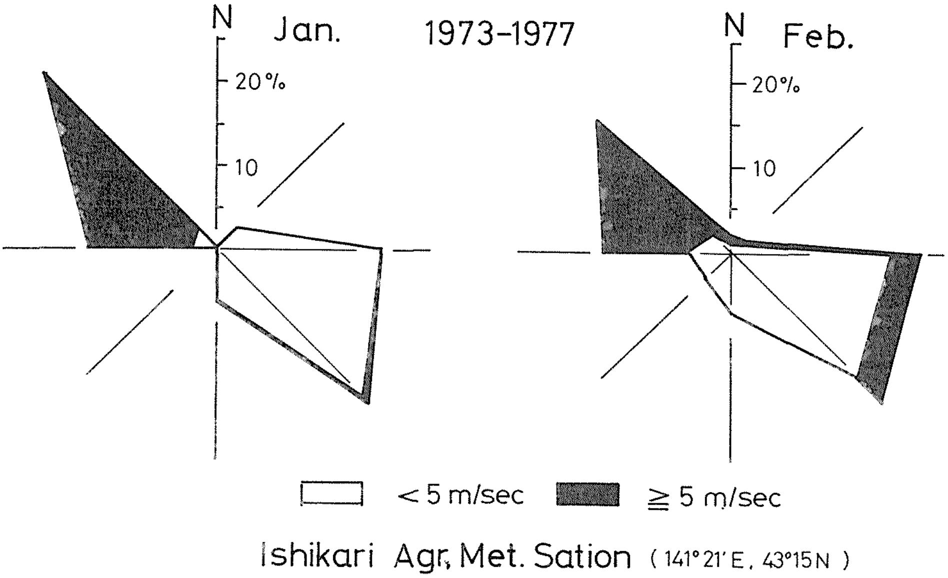


Fig. 4. Wind roses of Ishikari.

Blowing snow occurs under the following conditions. Wind speed at 1.0 m height is larger than 5 m/sec on a new snow cover and larger than 10 m/sec on a snow cover without a cover of new snow (Kobayashi et al., 1975).

At Ishikari, strong winds higher than 5 m/sec blows frequently in winter. This indicates that high velocity winds and blowing snow are often detrimental to the living environment at Shinoro Housing Estate.

Methods

a. Wind tunnel

Experiments were conducted in a low-speed wind tunnel of open circuit type. This wind tunnel is about 550 cm in length and 170 cm by 170 cm at its cross section, with a flow regulator at the inlet bell mouth. This wind tunnel can generate wind speed ranging from 50 to about 500 cm/sec. A hot wire anemometer was used to measure wind speed in the wind tunnel. The hot wire consists of a fine tungsten wire. The wire is 0.5 micron in diameter and 2 mm in length. The wire was set perpendicular to the air flow and parallel to the floor of the wind tunnel. Thus some amount of error in wind speed may occur by changing of the wind direction. Wind speed was measured at a height of 0.5 cm. Standard wind speed in this test was at a distance of 60 cm windward of model housing estate. The wind speed in the housing estate was indicated by the rate of the standard speed.

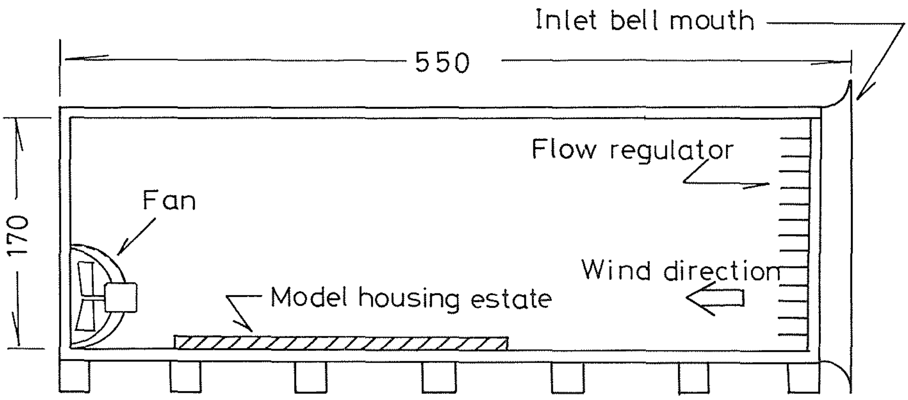


Fig. 5. Experimental arrangement in wind tunnel.

b. Model of housing estate

A reduced scale of the model housing estate is 1/1000. Dimension, shape and material of the model buildings and model windbreaks are shown in Table 1. The test was carried out using three separate models of housing estate as follows.

Model A : without windbreak
Model B : with windbreaks at intervals of 275 m
Model C : with windbreaks at intervals of 550 m

c. Similarity laws

Similitude between natural wind in the atmosphere and model wind in a wind tunnel was approximately expressed by the following relations proposed by Inoue (1952) and Nemoto (1961 a) for wind profile in the surface air layer under the limiting conditions that the molecular viscosity may be neglected and variation of the hydrostatic pressure, the Coriolis force and the effect of thermal stratification of the air layer are not taken into account.

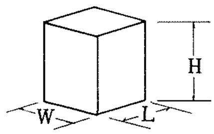
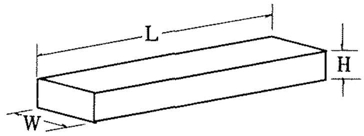
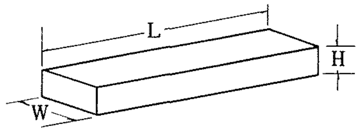
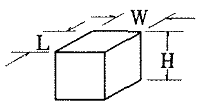
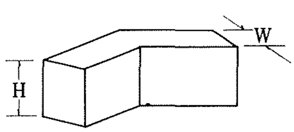
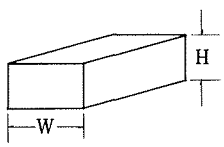
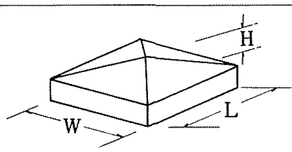
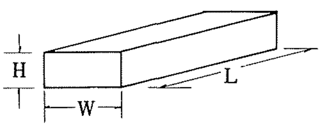
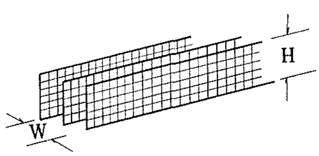
$$Z_{OM}/Z_{ON}=L_M/L_N \tag{1}$$

$$U_M/U_N=(L_M/L_N)^{\frac{1}{3}} \tag{2}$$

where L_M and L_N are the representative scale, U_M and U_N are representative wind speed in model flow and natural flow, respectively.

Nemoto (1961 b) successfully applied the above two laws to the natural air flow at Enoshima Light-house Tower and model air flow with a 1/600 reduced scale model. Yokota et al (1972) applied the above two laws to model test of windbreaks with a 1/1000 reduced scale on the field, and obtained approximately the same pattern of wind speed distribution around model windbreaks as that around natural windbreaks. It thus appears that the wind speed distributions in the housing estate obtained in this model may be applied to the actual housing estate.

Table 1. Dimension, shape and material of the model buildings and model windbreaks.

Building	Shape and dimension (mm)	Material
High rise flats	 H＝35.0 W＝30.0 L＝30.0	Wood
Flats	 H＝15.0 W＝13.0 L＝45.0～70.0	Wood
Low density	 H＝ 7.0 W＝13.0 L＝45.0	Wood
Detached house	 H＝ 8.0 W＝ 8.0 L＝ 8.0	Wood
Town center	 H＝30.0 W＝25.0	Wood
School	 H＝13.0 W＝20.0	Wood
Kindergarten	 H＝ 7.0 W＝18.0 L＝20.0	Wood
Railway station	 H＝ 7.0 W＝30.0 L＝60.0, 100.0	Wood
Windbreak	 H＝15.0 W＝20.0, 10.0	Vinyl net

Results and Discussions

a. Profile of wind speed in the wind tunnel

Vertical profile of wind speed in the wind tunnel obeyed the logarithmic law (Fig. 6). Roughness length Z_{OM} obtained from the wind speed profile was 0.0008 cm in this wind tunnel. Corresponding roughness length was 0.8 cm calculated from eq. (1) and above value of Z_{OM}

West northwest to the windward of Shinoro Housing Estate is an open flat field up to about 3 km to the windward. Roughness length for various surfaces have been given by Deacon (1949) shown as Table 2. Corresponding roughness length Z_{ON} is somewhat larger than that of the snow cover. It is considered that such asdifference of roughness length does not greatly influence the results of this model test.

Table 2. Roughness length of various surfaces.

Ground surface	Roughness length (cm)
Downland (summer)	2.0—4.0
Downland (winter)	1.0—2.0
Mown grass (length 3 cm)	0.7
Mown grass (length 1.5 cm)	0.2
Natural snow surface	0.1
Smooth mud flats	0.001

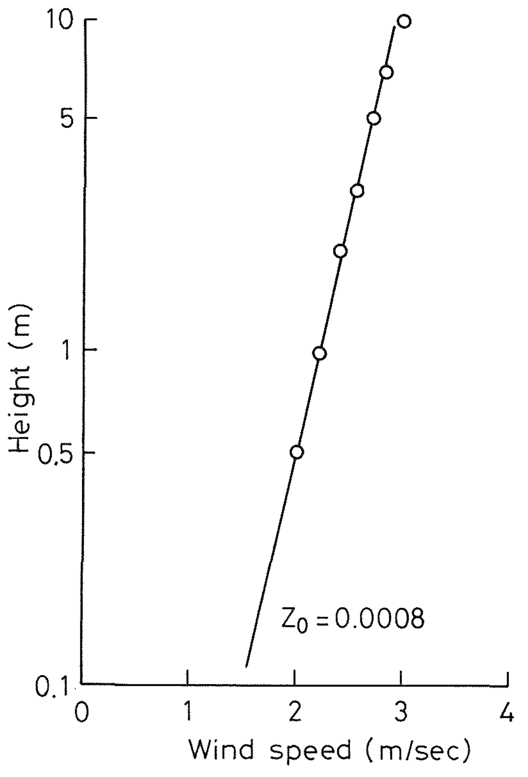


Fig. 6. Vertical profile of wind speed in the wind tunnel.

b. Wind speed distribution to the lee and windward of model breaks

The wind speed distributions toward the windward and leeward sides of the model windbreak are shown in Fig. 7. Wind speed was normalized by the undisturbed wind speed measured at 10 H windward (H being the height of the windbreak). The pattern of wind speed distribution on the lee and windward side of the model windbreak was similar to that of a windbreak with a porosity 40 % measured by Smariko (1963) in the field. Very strong winds, larger than 70 % in wind speed ratio, were observed at the area removed further than 20 H in the model test. Strong winds, between 50–70 % in wind speed ratio, were observed between 13 H and 20 H. The weak wind area and calm area, 30–50 % and smaller than 30 % in wind speed ratio respectively, were obtained in the region nearer than 13 H.

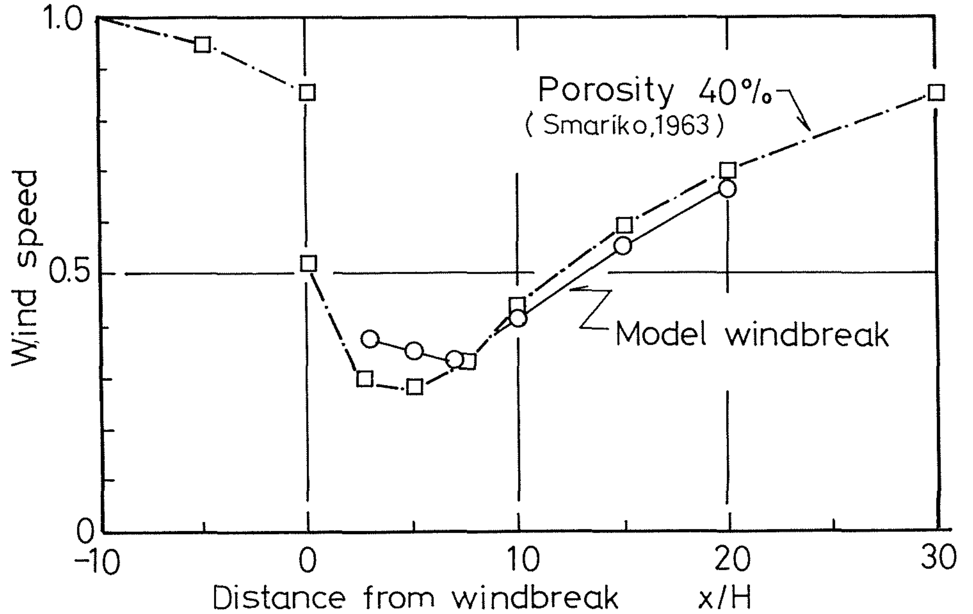


Fig. 7. Wind speed distributions on the lee and windward side of windbreaks.

c. Wind speed distribution in Shinoro Housing Estate

(i) Test on model A of the housing estate

Strong winds and very strong winds blow at the major part of the housing estate as shown in Fig. 8. Particularly, winds at A–1 region shown in Fig. 8 are very strong. Thus heavy blowing snow is presumed to arise there. Wind speed is strong also at A–2 region, but not so strong as at A–1 region. The fact indicates that the effect on reduction of wind speed by detached houses themselves is larger than that by flats themselves which have east-west ridges. The wind becomes weak as the distance recedes further away from the western part (A–2 region) to eastern part (A–3, A–4 regions) of the housing estate.

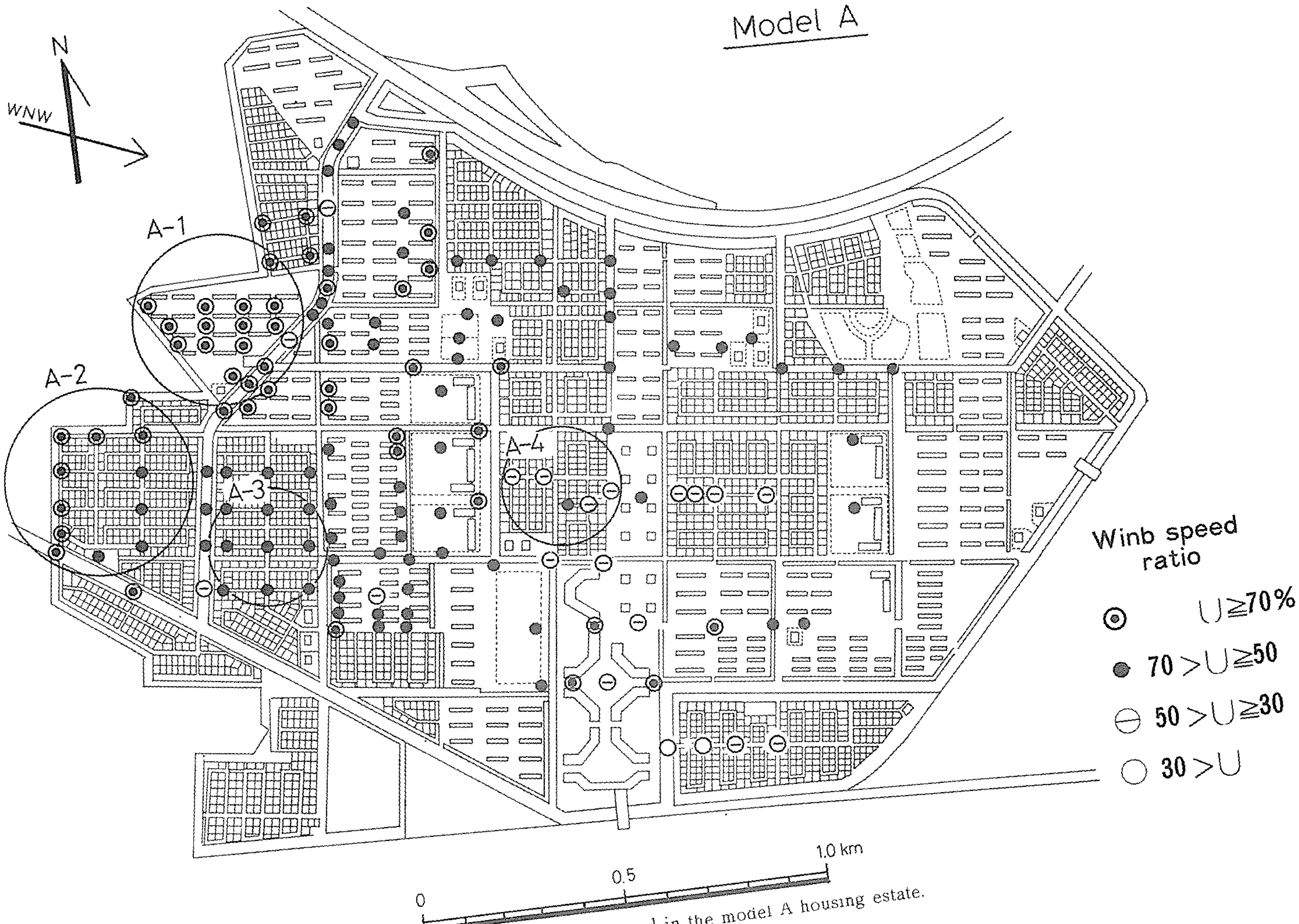


Fig. 8. Wind speed in the model A housing estate.

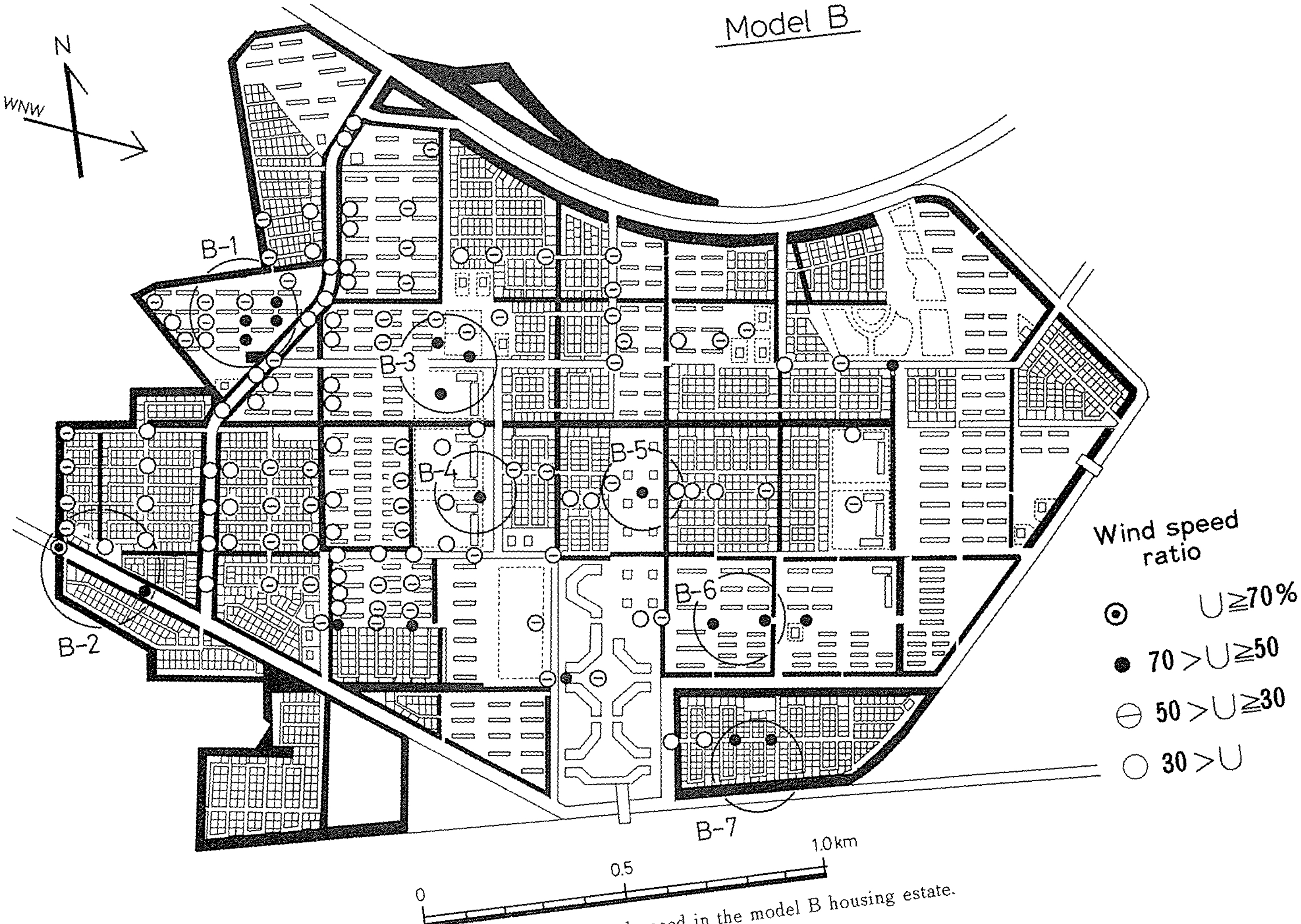


Fig. 9. Wind speed in the model B housing estate.

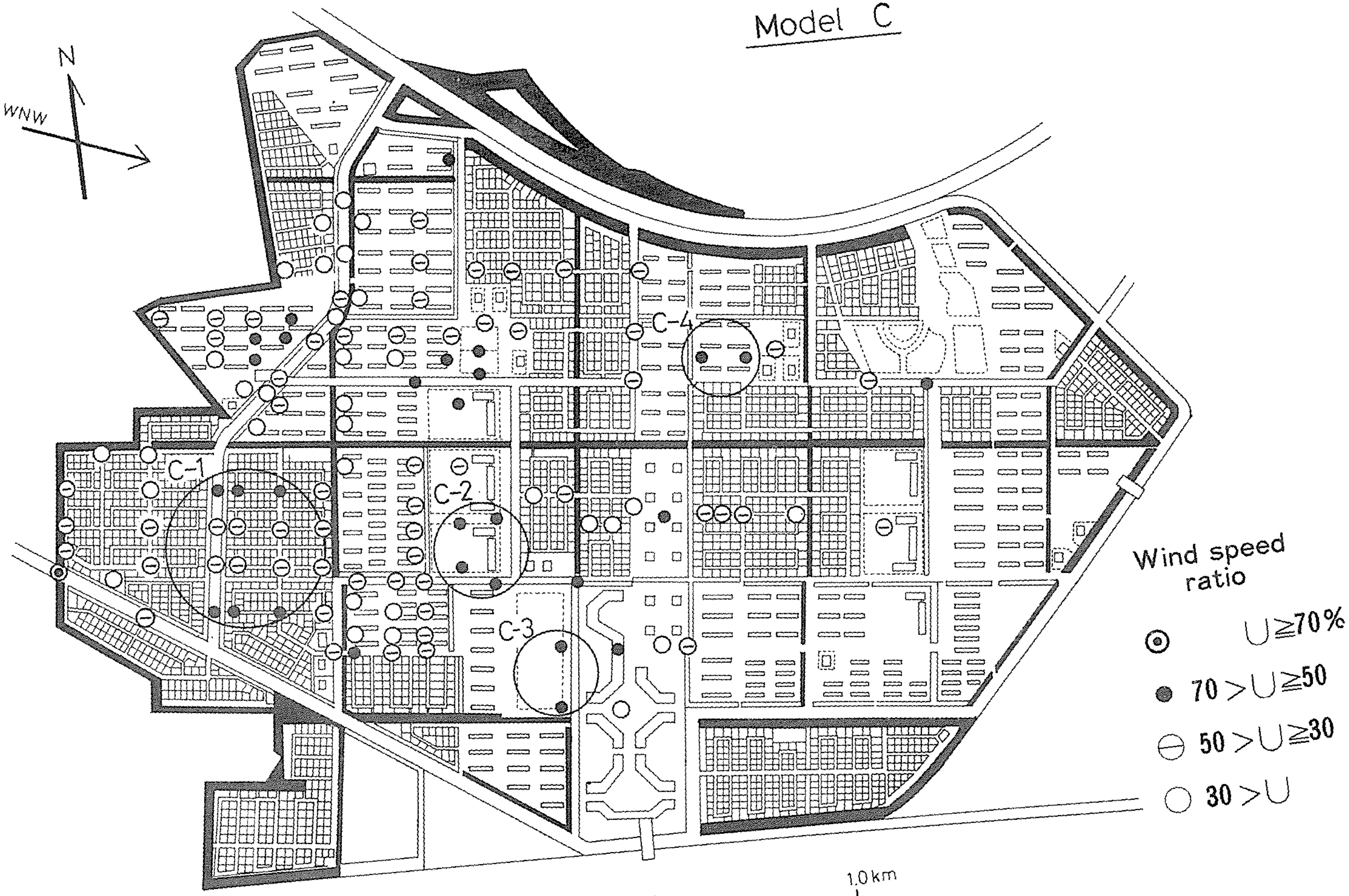


Fig. 10. Wind speed in the model C housing estate.

(ii) Test on model B of the housing estate

Over most of the area of the housing estate with windbreaks of 275 m interval, the wind speed was reduced to lower than 50 % in wind speed ratio. But some strong wind regions were observed partially in the model B housing estate as follows.

In the B–1 region, a strong wind blew because the direction of windbreak windward of the region was not rectangular to the windbreak and the buildings in the region were the flats with east-west ridges. In the B–3 region, the wind became partially strong because the distance from the windward windbreaks were more than 275 m in this region. Very strong winds entered along the main highways into the housing estate (B–2 region).

Wind blowing between two buildings was accelerrated with the convergence of those two buildings (B–4, B–6 regions). To the side and leeward area of the tall buildings, the wind speed was accelerated, and the turbulence was increased (B–7, B–8 regions). Those phenomena are the so–called "Monroe Effect".

(iii) Test on model C of the housing estate

In the model C housing estate with windbreaks of 550 m interval, the strong wind area was enlarged, for example, at C–1, C–2, C–3 and C–4 regions. These regions were on the leeward area of the removed windbreaks. Those fact indicated that the sufficient effects of windbreaks for the protection against strong winds and blowing snow may not be expected in the model C housing estate.

Conclusion

Windbreaks are highly usefull for protect against strong winds in a housing estate in winter. It is necessary to provide protection against strong winds for maintenance of comfortable living environment in a housing estate.

Effects of wind protection of windbreaks in model B (interval of windbreaks were 275 m) were larger than that in model C (interval of windbreaks were 550 m). But somewhat stronger winds were observed at several regions such as the region of flats with insufficient wind protection, the main road parallel to the prevailing wind direction and the side and leeward regions of tall buildings. Some suitable measures should be considered for such strong wind areas in next detailed plans.

In the planning of housing estates and industrial centers, such extreme climatic conditions as strong wind or blowing snow in winter should be studied with a model in a wind tunnel.

Photo 1. Blowing snow in Hokkaido.

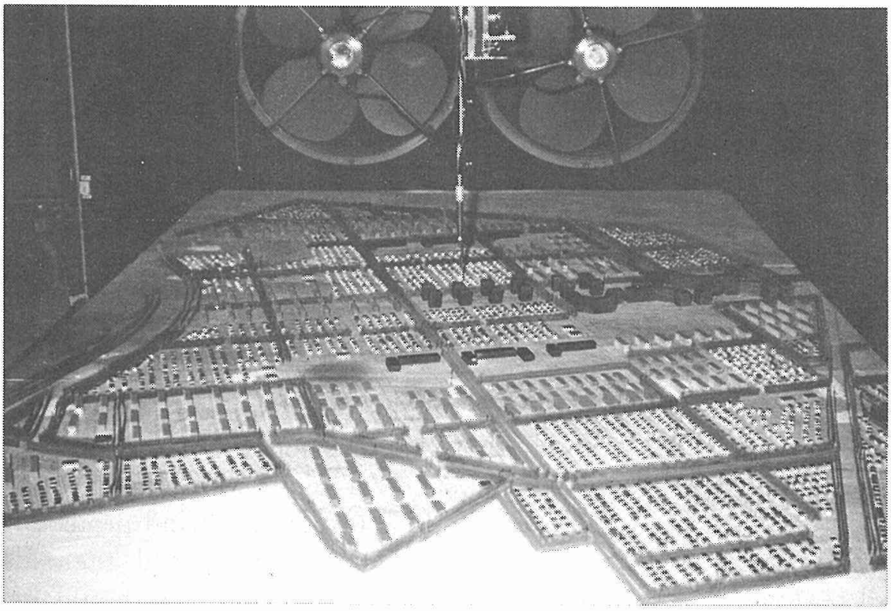


Photo 2. Model test in a wind tunnel.

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References

Bitan, A. (1977) : Planning and climate – The case of Di-Zahav. Geoforum, **8**, 249–265.

Caborn, J. M. (1965) : Shelterbelts and windbreaks, Faber and Faber LTD, 288 pp.

Deacon, E. L. (1949) : Vertical diffusion in the lowest layers of the atmosphere Quart. Jour. Roy. Meteor. Soc. **75** 89–103.

Inoue, E. (1952) : On the structure of wind near the ground. Bull. Nat. Inst. Agr. Sci., A–2 93 pp.**

Kobayashi, D. and Kinoshita, S. (1975) : Blowing snow and snowdrift. Scientific Research (Natural hazard) of Japanese Ministry o f Education, A–50–1, 89–100.

Maejima, I (1954) : A synoptic climatological study; on the precipitation of Japan in winter. Tokyo Univ. Chirigaku Kenkyu (3), 127–148.*

Nemoto, S. (1961 a) : Similarity between natural wind in the atmosphere and model wind in a wind tunnel –Modeling criteria for a local wind –. Pap. Meteor. Geophys., 12, 30–52.

Nemoto, S. (1961 b) : Similarity between natural wind in the atmosphere and model wind in a wind tunnel – Modeling criteria for a local wind – Part Ⅲ. Some example of experiments. Pap Meteor. Geophys ., 12, 129–153.

Smariko, J. A. (1963) : Vetrozashitnye osobenosti lesnykh polos raznykh konstrukcij (Bofurintai no kosei to kino, translated into japanese by Hiroo Matsuoka). Bosai Shiryo of Gov. For Expt Sta., 11, 123 pp.*

Yazawa, T (1953) : Climatic landscape. Kokindo, Tokyo, 227 pp.*

Yokota, R. and Takahashi, H. (1972) : The measurements on effects of complicated configuration and its model-test in wind tunnel. Jour. Agr. Meteor. Soc., **27**, 123–128.**

* In Japanese.

** In Japanese with English abstract.