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Analysis of the Distribution of Air Temperature and Wind Field on the Hillside Area

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Abstract: In Japan, residential development is expected to shift from the increasingly built-up plains to the sides of the many hills surrounding cities and towns, which still have a largely natural environment. Such hillside locations will offer microclimatic advantages, such as mitigation of the intense summer heat. Therefore, it is worthwhile investigating the local climate of hillsides with a special focus on environmental symbiosis and energy conservation. The site of this research study was a hillside area in the Hibarigaoka district, Hyogo. Testing was conducted to determine the air temperature distribution and wind field (wind velocity and direction) around the hill using both long-term and short-term measurement methods.

Key Word : hillside, residential area, air temperature, wind field, environmental symbiosis

1. Introduction

Over the last few years, with the rapid rise in awareness and interest in environmental protection there has been significant discussion and controversy relating to the concept of environmental symbiosis. Many recent large-scale residential developments claim to be symbiotic with the environment. However, in general the planning of these developments has not taken into account sufficient supporting data on the climatic characteristics of the local area. On the other hand, residential development is expected to shift from the plains, which are nearly fully exploited, to the sides of the many green hills surrounding cities and towns which have largely unspoiled environments. Such hillside locations will offer climatic advantages, such as mitigation of the intense summer heat. Given this inevitable trend, it is worthwhile investigating the microclimate of hillsides with a special focus on environmental symbiosis and energy conservation. By studying the microclimatic characteristics of hillsides it will be possible to make better use of our natural resources in planning of new residential estates.

So far we have conducted research on outdoor thermal environments on various scales [1) 2) 3)]. In conclusion these studies showed that air temperature distribution depends on the surroundings and on sensible waste heat, and that the closest correlation between air temperature and the surroundings is from 100 m to 200 m. For this reason, we should be careful about how we plan and manage land use, noting that the scale of our developments determines the local outdoor thermal environment. However, these results were mainly concerned with urban areas. In complex topographical areas such as hillsides, it is unclear that these results can be applied, because of the difficulties in quantitatively determining the climatic characteristics of hillside areas. Thus we conducted an investigation of the microclimate of a hillside in the Hibarigaoka district of Hyogo prefecture as a model case. This site remains a largely unspoiled natural environment. It is hoped that this study will provide basic data to help in the planning of more environmentally efficient (symbiotic) residential areas.

2. Materials and Methods

Our test hillside is located in the Hibarigaoka district, which is the eastern part of Hyogo prefecture, more or less around the center of Japan. The hillside is horizontally 1.5 km and vertically 160 m from the densely populated center of Kawanishi City, which has a population of approx. 150,000. The highest mountain in the Hibarigaoka district is Mt. Ishikiri (280 m). Fig.1 shows a classification of land use of the research area based on aerial photographs and on-site investigation. The land surface here has many complex topographical features and has been steadily under development from the outskirts of the city. However, the research area still contains largely unspoiled tracts of green land.

In this area, we carried out an investigation into the local climate of the area to produce some data that would be helpful in planning of new residential areas. At this point, it is necessary to make a few notes on the methodology used in the investigation. Firstly how reliable is the data? To produce results of high statistical confidence it would be necessary to conduct long-term measurements. In addition, ideally, more detailed data would be needed, i.e. more test points. It is not feasible due to both the labor and costs required to undertake detailed measurements over a long period. For this reason it was necessary to gather data by taking measurements on representative days for each season of the year. Thus in this study, measurements of the outdoor thermal environment were conducted using following two methods.

1) Short-term measurements

Dividing the research area into five zones, from A to E (refer to Fig.1), the air temperature and wind field were measured at the same time at points in each of the zones. Zone A is located in the northern part of Mt. Ishikiri and it's surface is mainly bare ground; Zone B is in the northeastern part of Mt. Ishikiri and is essentially a valley leading from Mt. Ishikiri to the residential area to the east; Zone C is in the eastern part of Mt. Ishikiri, on the top of a little hill that provides a commanding view over the center of Kawanishi City; Zone D is to the northeast of zone A and has been already developed into a residential area; and Zone E is to the east of zone B and has also been developed.

The measuring instruments used were as follows. Air temperature was measured using a custom made thermometer (Fig.2), with a platinum resistance-wire sensor fitted into a double tube made of PVC. Air is sucked into the tube using a fan. To minimize any measurement errors caused by solar radiation, the tube is covered with aluminum foil.

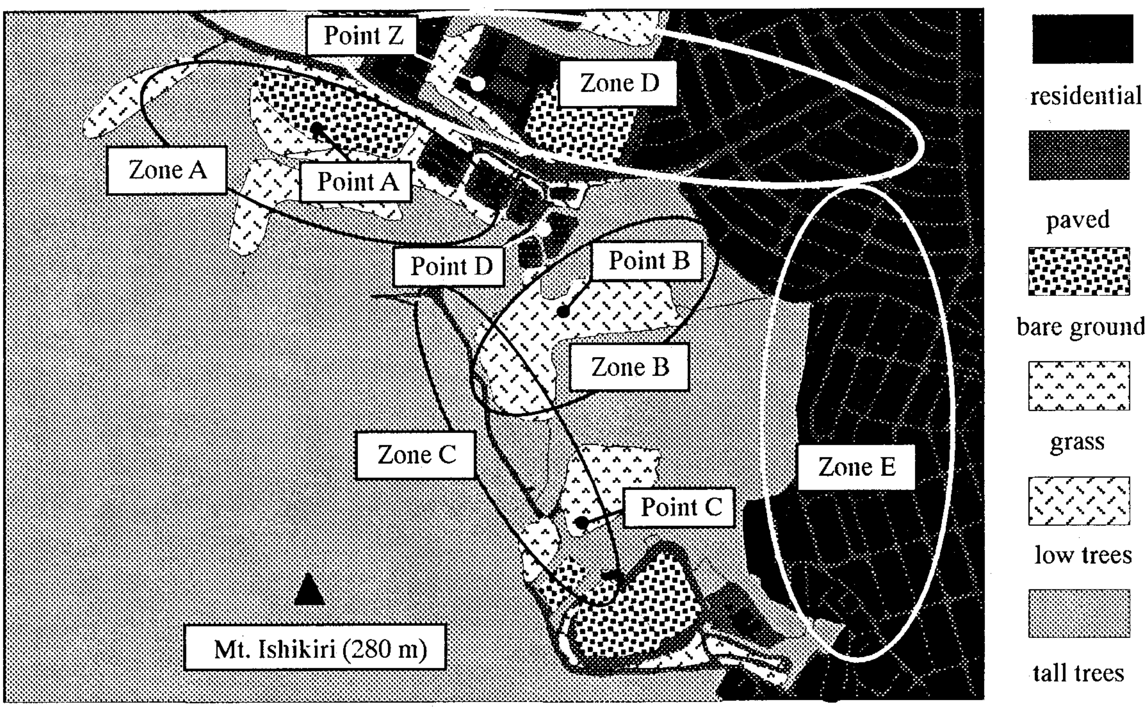

Fig.1 Classification of Land Use in the Study Area

Wind velocity was measured using a hot-wire anemometer (Kanomax MODEL-6061), and wind direction was evaluated using a smoke tester. Wind velocity measurements were conducted only at zones A, B and C. It took approximately 40 minutes to measure the air temperature at all points, after measuring the temperature at each point twice; once going and once returning along our measurement route. We then calculated the average of the two temperatures at each point to reduce any errors due to measurement time.

2) Long-term measurements

In the research area and it's outskirts, we measured the air temperature and wind field at seven permanent stations from Jan. 1997. The points A to D are each located in the above-mentioned zones A to D, respectively. Point X is in the nearly center of Kawanishi City. Point Y is on the roof of the Kawanishi-Meiho High School in Zone D. Point Z is on the roof of the Takarazuka University of Art and Design, located in the southern part of Mt. Ishikiri.

The measuring instruments used were as follows. Air temperature was measured using a thermistor-type thermometer in an instrument shelter, and wind velocity and direction were measured using a vane anemometer (Young KYG-05305).

Air temperature was measured up to a height of 1.5 m above the ground and the wind velocity was measured at 6.0 m above the ground, or on the roof. Measurements were conducted every ten minutes.

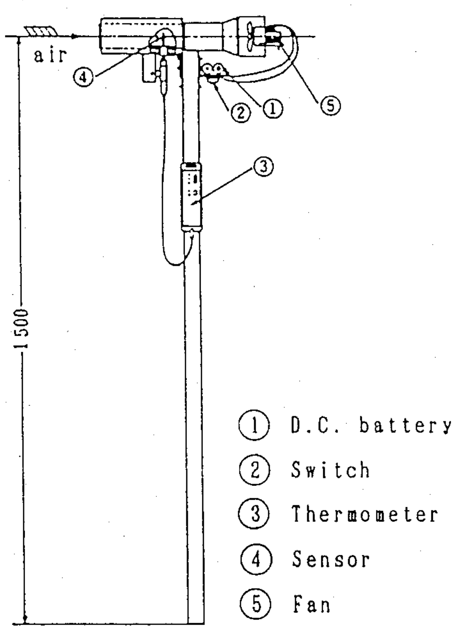

Fig.2 Measurement instrument of air temperature

3. Results and Discussion

3.1 Air Temperature Distribution

Fig.3 shows the daily maximum temperature according to our long-term measurements. The temperature difference between points C and X was 4 K, right throughout the range of recorded temperatures. The expected difference in the temperatures at points C and X due to lapse rate would be approx. 1.5 K (based on 0.6 K/100 m and an

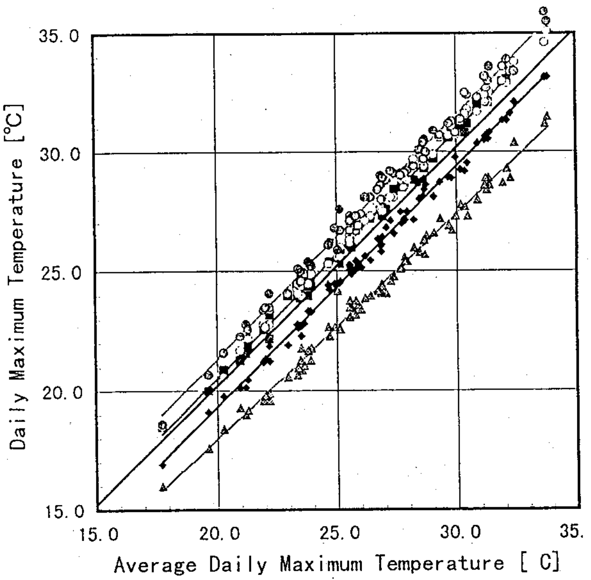

Fig.3 Daily Maximum Temperatures (May to July 1997)

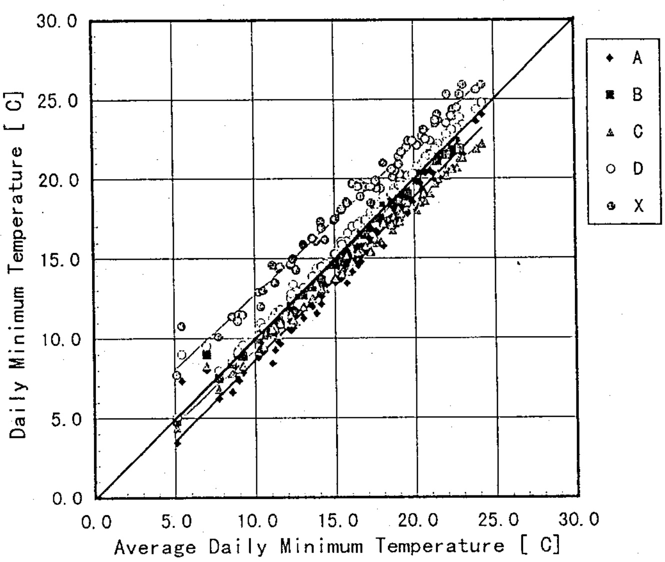

Fig.4 Daily Minimum Temperatures (May to July 1997)

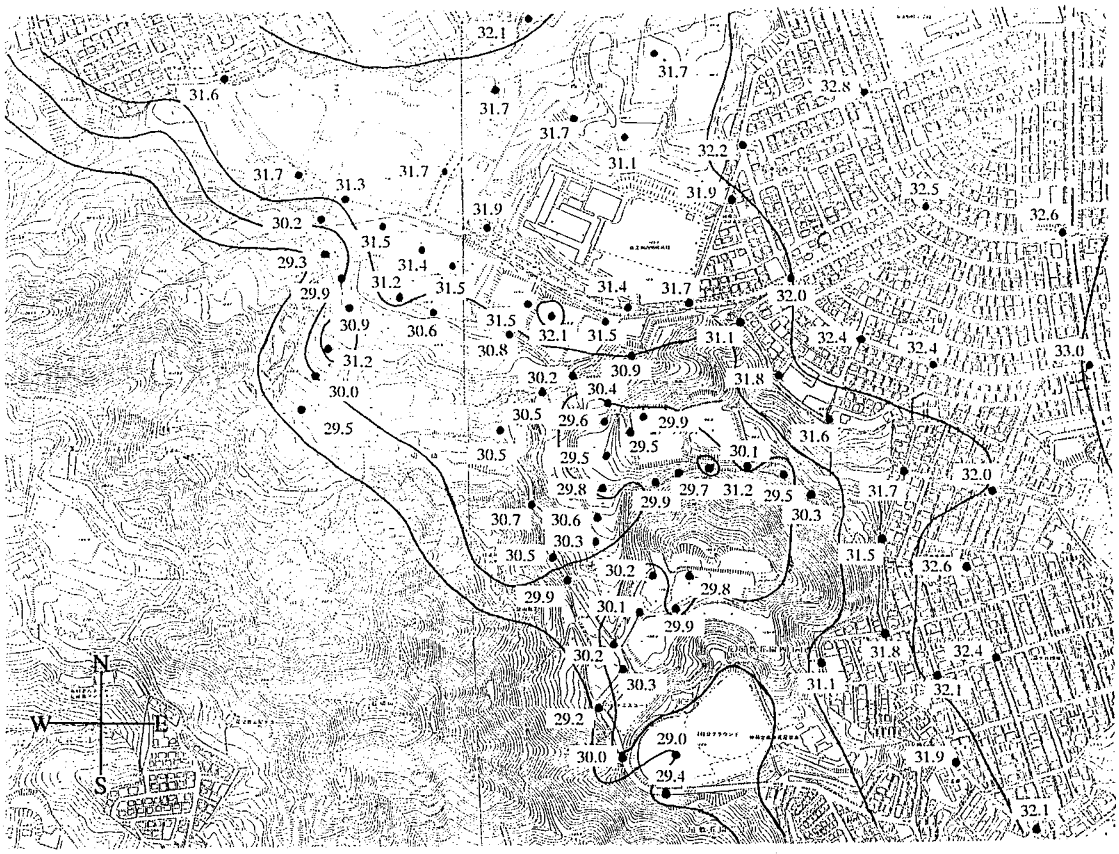

Fig.5 Daytime Air Temperature Contours in the Study Area

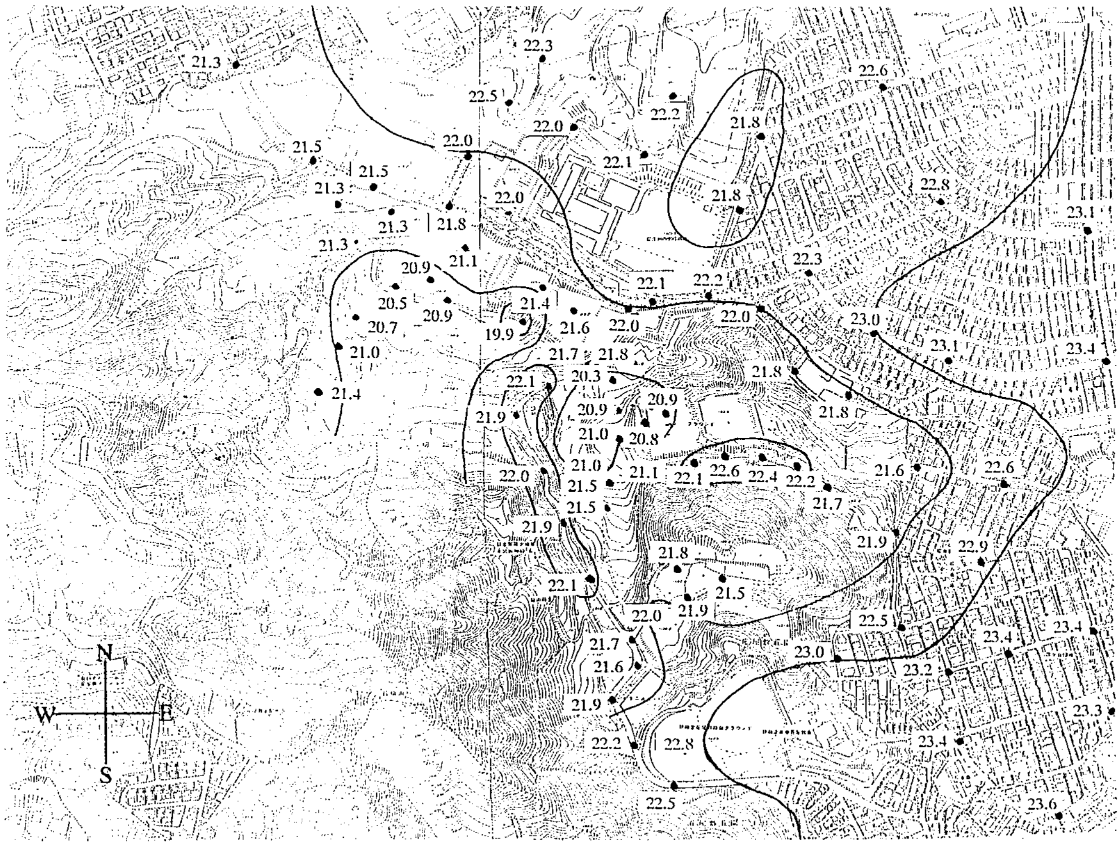

Fig.6 Nighttime Air Temperature Contours in the Study Area

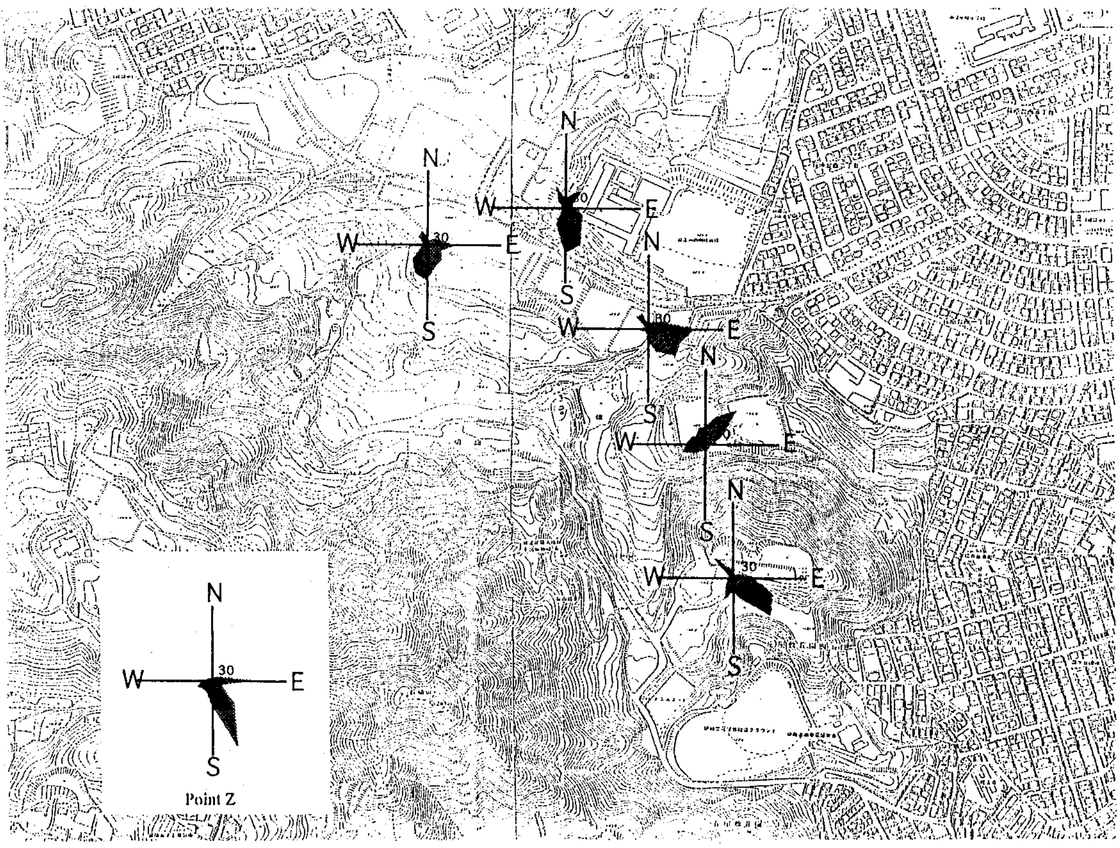

Fig.7 Wind roses in the research area in daytime (1997 August)

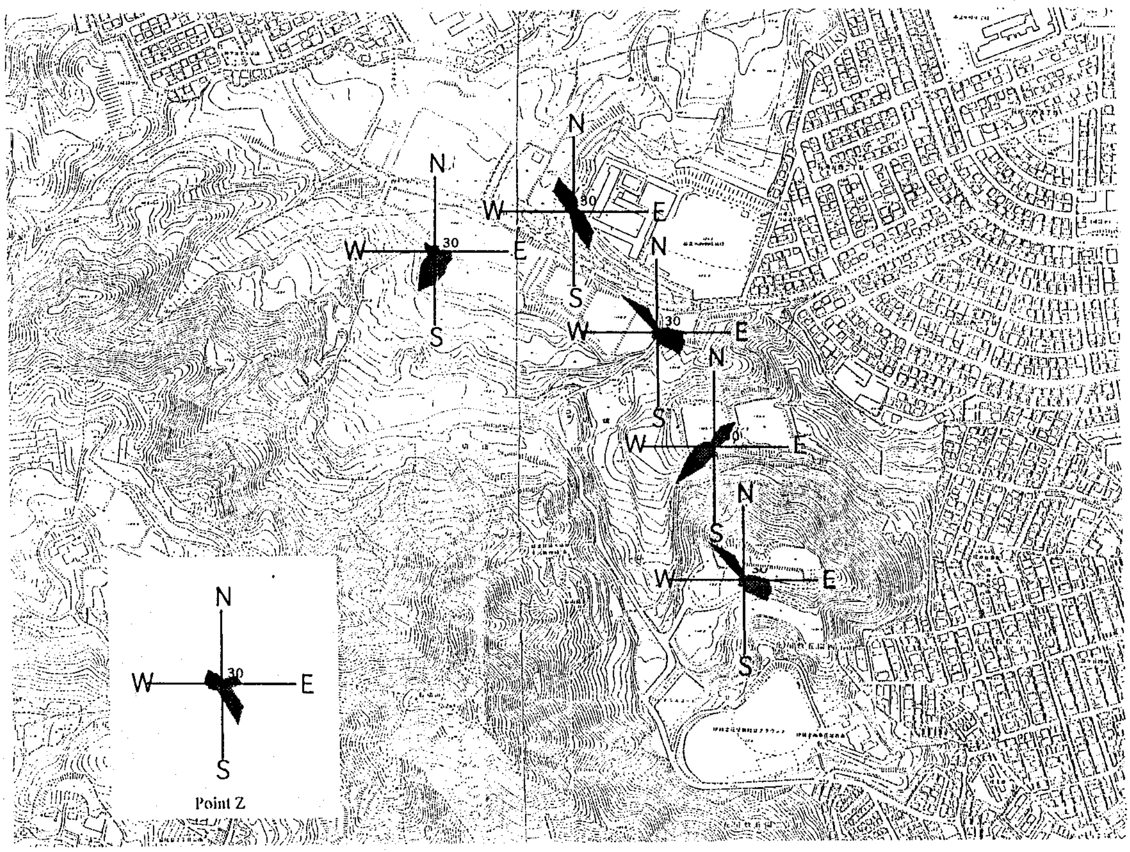

Fig.8 Wind roses in the research area in nighttime (1997 August)

altitude difference of approx. 160 m between the two points). The measured temperature difference (4 K) is much larger than can be explained by the temperature lapse rate. Thus, we conclude that the point C is not affected by an urban climate. Fig.4 shows a graph of daily minimum temperature. There is a clear difference in temperature between point X and the other points. It was around 2 K throughout the period of measurement. So far as the area under investigation, the maximum temperature difference was about 4 K during the day and 2 K throughout the night.

The temperature distribution in summer obtained through the short-term measurements is shown in Figs.5 and 6. Fig.5 shows daytime temperature contours for the area under study, while Fig.6 shows the night temperature contours. Measurements were carried out mainly under clear days with slight breezes. According to these results, temperature tends to fall as we approach a hill or mountain from an urban area. The maximum recorded temperature difference between all points was about 3 K. The daytime temperature distribution results seem to be in basic agreement with land use. The maximum temperature was observed in the eastern part of zone D while the minimum recorded temperature was in zone B. In the night-time results, There is clearly a much weaker correlation between temperature and location and land use. Furthermore, It seems that the warmer residential areas were influenced by the cooler hillside areas during the daytime. In particular, in the eastern and northern areas of the mountain, the cool area spreads out to the residential zone. From the point of view of the correlation of topographical features with temperature distribution, we suppose that cold air flowed down the hillside, especially through the valley in zone B. This cool air flow pattern was observed particularly at night.

3.2 Wind Velocity Distribution Results

Fig.7 and 8 show wind direction results from long-term measurements in August. Fig.7 shows daytime results, while Fig.8 shows nighttime results. During the day, wind generally seemed to blow from the south, according to the results from points C and Y. This general summer wind pattern may be explained as follows. Firstly, the hillside area under study is only 15 km away from the nearest sea coast (Osaka Bay), short enough that sea breezes can reach there. Secondly, as summer approaches winds tends to flow increasingly from the south during the day, and then switch to flow from the north during the night. The points most affected by this wind pattern were points C, D and Y. The other points seemed to follow different patterns. At point A the wind seemed to flow south regardless of whether it was day or night. We suppose that this is due to wind flowing down the slope of Mt. Ishikiri to the test point. At point B wind tended to flow from the southwest during the day and switch to the northeast during the night. This is probably explained by the local topography which features a valley oriented from the southwest to the northeast. In other words, during the day the wind flowed up the valley while at night the wind did the opposite, flowing down the slope. At present the results of all measurements and apparent phenomena are being considered in more detail. In further studies, we will attempt to clarify these mechanisms through conducting more microcli-

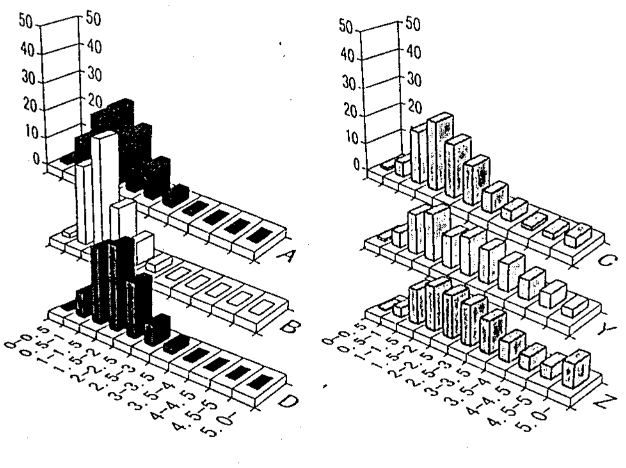

Fig.9 Frequency of wind velocity in August (daytime)

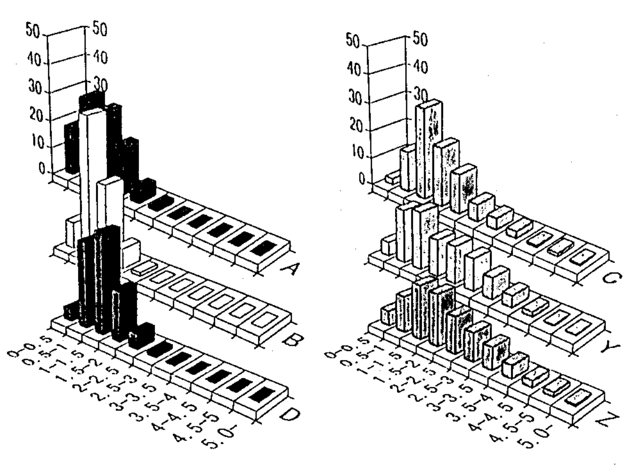

Fig.10 Frequency of wind velocity in August (nighttime)

matic measurements.

Fig.8 and 9 show wind velocity frequency distributions from the results of long-term measurements in August. Fig.8 shows the results for daytime and Fig.9 shows the nighttime results. The point of maximum wind velocity was point Y, and point B had the minimum. In general, wind tends to abate at night, and this tendency was most apparent at points A, B and D. During the day the maximum peak wind speed was 1.0-1.5 m/s at points A, B and D; 1.5-2.0 m/s at points C, Y and Z. At nighttime the peak wind speeds were 0.5-1.0 m/s at points A, B and D, and 1.0-1.5 m/s at points C, Y and Z. At points A, B and D we suppose that the wind was affected by microclimatic effects. In point C, Y and Z the wind seemed to be more affected by local topographic and climatic influences.

3.3 Implications for Urban Planning

We propose the following issues be carefully considered in the planning of residential zones in the research area.

Ambient temperatures: In the research area, the main topographical features are hillsides, which tend to cause spreading of cool masses of air away from the mountain by advection. This feature should be taken into careful account in the planning of infrastructure such as roads and residential estate layouts and buildings. Our results confirmed the rise in air temperature in cleared and built-up areas, even in areas directly neighboring mountains. Therefore, in any new developments we should arrange suitable cool spots by leaving as many green areas as possible, constructing water bodies, and so on.

Wind velocity distribution: According to our results, it was confirmed that the wind velocity was very low in areas not influeced by general wind patterns. Thus, in such areas we should take care to create passages for cooling breezes through our design and layout of residential buildings. In this case, if we recognized Zone C as a point of entry for the wind during the day, we could aim to direct this flow of air to zones B and A from this zone.

In such a small area, our results confirmed the distribution of outdoor thermal environment. Therefore, we should use the land fitted the thermal environment of the area.

4.Conclusion

In this paper, we reported on the results of measuring air temperature and wind velocity distributions on hillsides neighboring a densely populated area. From our results, we briefly considered how the local topographical and microclimatic characteristics of the studied area can be used effectively in the planning and design of residential estates. At present these proposals are based largely on qualitative analysis and not through any solid quantitative analysis, but in future we intend to carry out further experiments as follows. Our air temperature distribution work will be expanded to find a widely applicable method for estimating temperature changes through development of model to predict air temperatures in hillside areas. As far as wind field distribution goes, we will try to find ways to better understand the interactions of different wind patterns and local topographies on the layout of roads and buildings, through wind tunnel experiments.

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