Analysis of Wind Flow in Residential Areas of Johor Bahru City

Tetsu Kubota*[1] and Supian Ahmad[2]

[1] JSPS Postdoctoral Fellow / Researcher, Faculty of Built Environment, Universiti Teknologi Malaysia, Malaysia
[2] Professor and Dean, Faculty of Built Environment, Universiti Teknologi Malaysia, Malaysia

Abstract

Most cities in Malaysia experience hot and humid climate during most part of the year. In large metropolitan cities such as Johor Bahru, the use of air conditioners to cool dwelling units has been increasing sharply partly due to continuing rise in disposable income brought about by recent high economic growth. This has resulted to significant rise in non-renewable energy consumption, thus does not contribute toward sustainability. Natural wind flow is one of the most effective energy-saving methods to improve the thermal environment at the neighborhood level. This paper presents the results of several wind tunnel tests on selected residential areas in Johor Bahru Metropolitan City. By comparing the average of wind velocity of each case studies, the paper discusses the planning methods at the residential neighborhood level area in order to create sufficient wind flow and help achieve energy saving and sustainability objectives in Malaysia.

Keywords: wind flow; wind tunnel tests; residential neighborhood; energy saving city; sustainability

1. Introduction

In Malaysia, the population has almost doubled in past 30 years. It was 11 million in 1970 and 23 million in 2000. One of the major causes for this rapid increase was the effect of accelerated urbanization. The percentage of the urban population was only 27% in 1970, but it has risen to 62% in 2000. This rapid population increase and recent high economic growth have resulted in the tremendous increase of the demand for energy consumption. The present final energy demand is almost 5 times larger than that of 1980's (Malaysia, 2002).

The aim of this study is to discuss the various planning guidelines at the neighborhood residential areas toward the attainment of an energy saving city in Malaysia. Several approaches may be adopted in order to achieve the energy saving objectives. However, this study focuses the discussion on wind flow effects of the neighborhood residential areas. Most cities in Malaysia experience hot and humid climate during most part of the year. Thus, it is very important to consider the planning methods to minimize the use of air conditioners in the cities by using the natural energy. Natural wind flow is one of the most effective methods to help achieve the energy saving objectives in the cities in particular under the tropical climate like Malaysia.

Many studies of wind velocity distribution around buildings have been carried out (e.g., Murakami and Mochida, 1988; Hagishima et al., 2000). However, most of those studies have been focused on surrounding or some blocks of buildings. Thus, it is important to notice that there are relatively few studies of wind flow in larger areas such as residential areas, particularly at the neighborhood level.

The present authors have conducted several researches in order to examine the planning methods of residential areas in consideration of wind flow in Japan (Kubota and Miura et al., 2000, 2002). The above study presented the results of the wind tunnel tests on selected residential areas and examined the relationship between the housing patterns and the mean value of wind velocity at the neighborhood level.

The present study is based on the above research. The idea is to apply those developed methods in Japan into Malaysian planning contexts. This paper presents the results of several wind tunnel tests on selected residential areas in Johor Bahru Metropolitan City. The main purpose of the wind tunnel tests is to examine the planning methods to create sufficient wind flow and help achieve energy saving and sustainability at the neighborhood level in Malaysia.

2. Outline of Case Study Areas

Johor Bahru Metropolitan City is located in the southernmost part of the Peninsula Malaysia. It is the second largest city after Kuala Lumpur and the population size is approximately 1 million in 2000. Since the majority of housing patterns of Johor Bahru Metropolitan City are low-rise terraced houses, this case study mainly concentrate on these housing patterns (Fig.1). The selection of the three neighborhood residential areas was based on the housing density and five areas among them were chosen for the wind tunnel

*Contact Author: Tetsu Kubota, JSPS Postdoctoral Fellow
Faculty of Built Environment, *Universiti Teknologi Malaysia*
81310 UTM, Skudai, Johor, Malaysia
Tel&Fax: +6-07-5537305
e-mail: tetsukubota@hotmail.com
(Received May 10, 2004 ; accepted March 22, 2005)

Table 1. Brief Outline of Case Study Areas for Wind Tunnel Tests

Case	Gross buildings coverage ratio(%)	Gross floor area ratio (%)	Ratio of buildings coverage of each stories(%)	
			1-2	more than 2
1	21.9	43.8	100	-
2	24.5	31.0	93	7
3	28.9	48.9	100	-
4	30.6	55.3	100	-
5	32.5	44.8	100	-


Fig.1. Terraced Houses Residential Area

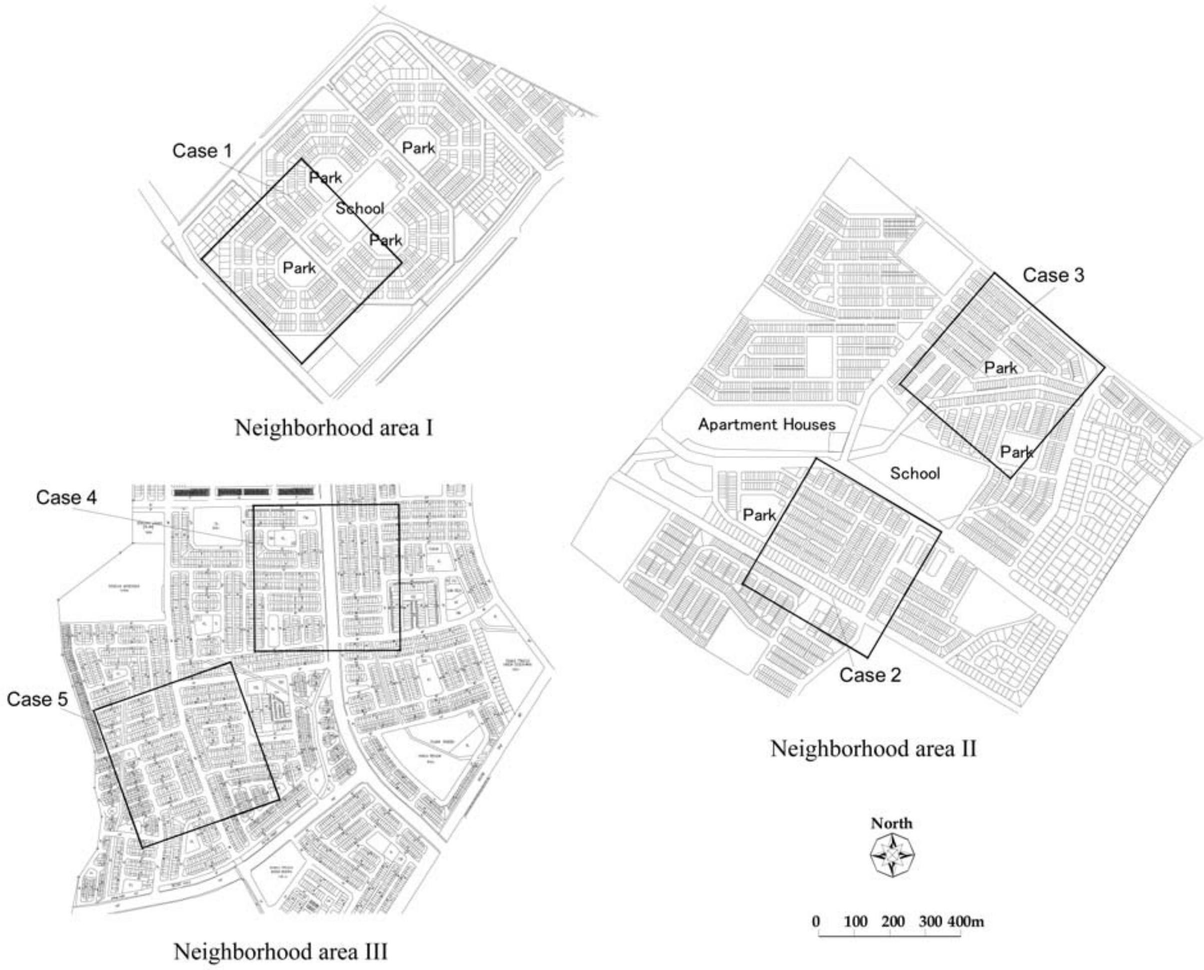


Fig.2. Site Plan of Case Study Areas

tests (Fig.2). A brief outline of these five case study areas is shown in Table 1.

Case1 is in a new residential area located in the outskirt of Johor Bahru City. The main features of this residential area are unique housing patterns and large area of open spaces (Fig.2-I).

Both Case2 and Case3 are middle class neighborhood residential areas located approximately 6km from the center of the city (Fig.2-II). It was developed in the late 1970's. This residential area is composed of some housing patterns along with the development units.

Both Case4 and Case5 are situated in north of the city center; there are parts of the expanded residential areas of Johor Bahru City (Fig.2-III). The development of this area has started in early 1990's. In Case4, a wide road is located in center of the area. However, since the housing density of the whole area is relatively high, the gross buildings coverage ratio is higher than the former cases.

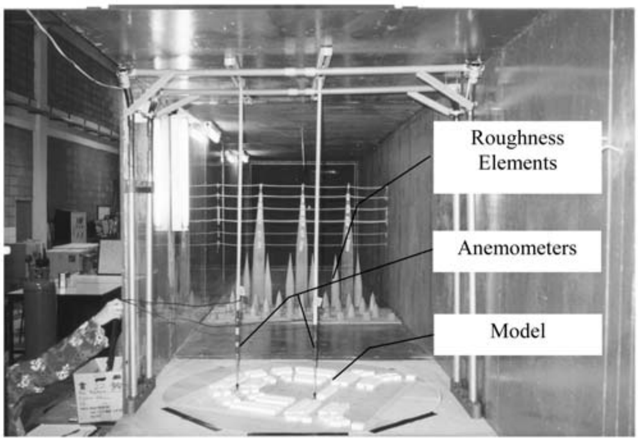


Fig.3. Wind Tunnel Tests Facilities

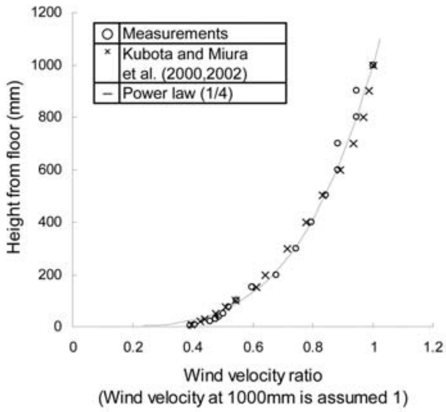


Fig.4. Vertical Profile of Mean Wind Velocity

3. Methods of Wind Tunnel Tests

The boundary layer wind tunnel at *Universiti Teknologi Malaysia* was used for the tests (Fig.3). The cross-section of the wind tunnel is 1.4m x 1.4m, with a test length of 9m. The vertical profile of mean wind velocity in the tests was prepared to obey a 1/4 power law by using roughness elements (Fig.4).

The models for the tests are scaled in 1/500. The real scale of each area is 410m x 410m, thus the scale of models becomes 820mm x 820mm. Since the main purpose of the present study is to assess the effects of housing patterns on the wind flow, the models did not take into account the existing trees, setbacks and roof shape of buildings. To cover the whole area, 49 measuring points were placed equally in outside of buildings in each area as Fig.5 and 6. Both wind direction and wind velocity at 1.5m height of each 49 measuring point were measured in each 16 wind directions, such as the north, north-northeast etc, through the wind tunnel tests.

4. Results of Wind Tunnel Tests

Fig.5 shows some examples of the results on analysis of wind flow in each case. In each figure, the wind direction is arranged to agree with a direction towards bottom to top. Thus, the geographical orientation of the sites changes in line with the above arrangement. Each of the wind velocity ratios indicated in the figure were computed by dividing wind velocity at 1.5m height with buildings to wind velocity at the same height measured without buildings. When a measuring wind velocity is the same as the wind velocity without buildings, the wind velocity ratio is “1”. The wind velocity ratio “over 1” means that a measuring wind velocity was increased by the effects of the surrounding buildings.

All data that was measured at 49 measuring points in 16 wind directions are summarized in Fig.6. The second column in Fig.6 indicates the mean wind velocity ratio of all measuring points in each 16 wind direction. In order to consider the relationship between housing patterns and each mean values of wind velocity ratio, the site plans and those charts of mean wind velocity ratio are oriented to the same direction. The third column in Fig.6 shows the frequency of all data of wind velocity ratio, which are total data of the measuring points of all wind directions.

In Fig.5, arrows and circles are added in order to illustrate the areas in which the wind velocity ratios indicate either relatively high or low values. The mean values of wind velocity ratio were obtained in around 0.6-0.7 throughout the five cases as in Fig.6. Thus, in Fig.5, the areas where the wind velocity ratios are more than 0.7, they are recognized as a main wind flow area in the present study and indicated in arrows in consideration of the measurement of wind direction; thin arrows indicate around 0.8, thick arrows indicate more than around 0.8. On the other hand, the areas where the wind velocity ratios are less than 0.5, they are recognized as a weak wind flow area and marked with circles in Fig.5.

The points in each case from the figures are summarized as follows.

(1) Case1

In Case1, the highest value of mean wind velocity ratio is obtained when the wind direction is north (Fig.6-1). Although there are a few weak wind flow areas, a wind is blown through the central park (Fig.5(1)-N). However, when the wind direction is northeast, wind velocity ratios in the central park indicate still high values but low values are given between the buildings placed at an obtuse angle to the wind direction (Fig.5(1)-NE).

When rows of terraced houses are almost parallel to the wind direction, wind velocity ratios between the buildings tend to indicate higher values. This is due to the channel effect (Gandemer, 1975). On the other hand, when the angle of rows of terraced houses to the wind direction becomes close to 90 degrees, wind velocity ratios between buildings tend to drop. When the wind direction is northeast in Case1, this tendency is seen (Fig.5(1)-NE).

(2) Case2

In Case2, one of major parts of terraced houses is placed at perpendicular arrangement like Case1 and a row of semi-detached houses is also situated in the southeast direction of the area (Fig.5(2), Fig.6-2). The effects of the semi-detached houses on the wind flow are clearly seen when the wind direction is northeast. At the northeast wind direction, the leeward side of the row of semi-detached houses has similar wind velocity ratios as that on the windward side. That is, a wind is blown through the spaces between semi-detached houses from windward side to leeward side (Fig.5(2)-NE).

It is evident that if the row of semi-detached houses were a long row of terraced houses like that of Case3, the wind flow will not be able to reach the upper part. Therefore, in order to avoid the increase of weak wind flow areas, semi-detached houses would be effective as an alternative housing patterns.

The difference of the mean values of wind velocity ratio in each wind direction is not large. The mean value of all data of wind velocity ratio is 0.72; this is higher than that of Case1 and Case3 (Fig.6-2).

(3) Case3

In Case3, two long rows of terraced houses lie diagonally from west to east in the middle (Fig.5(3), Fig.6-3). These rows have much influence on the whole wind flow. For example, when the wind direction is north, since the angle of rows to the wind direction is around 90 degrees, the values of wind velocity ratio around the two long rows of terraced houses significantly drop (Fig.5(3)-N). This is due to the interruption on the wind flow by the two long rows. The lowest value of mean wind velocity ratio is obtained at the north wind direction (Fig.6-3).

When the wind direction is northeast, the values of wind velocity ratio at leeward side of the two long rows increase. However, the wind velocity ratios around the terraced houses arranged perpendicular to the northeast wind direction indicate low values at the same time (Fig.5(3)-NE).

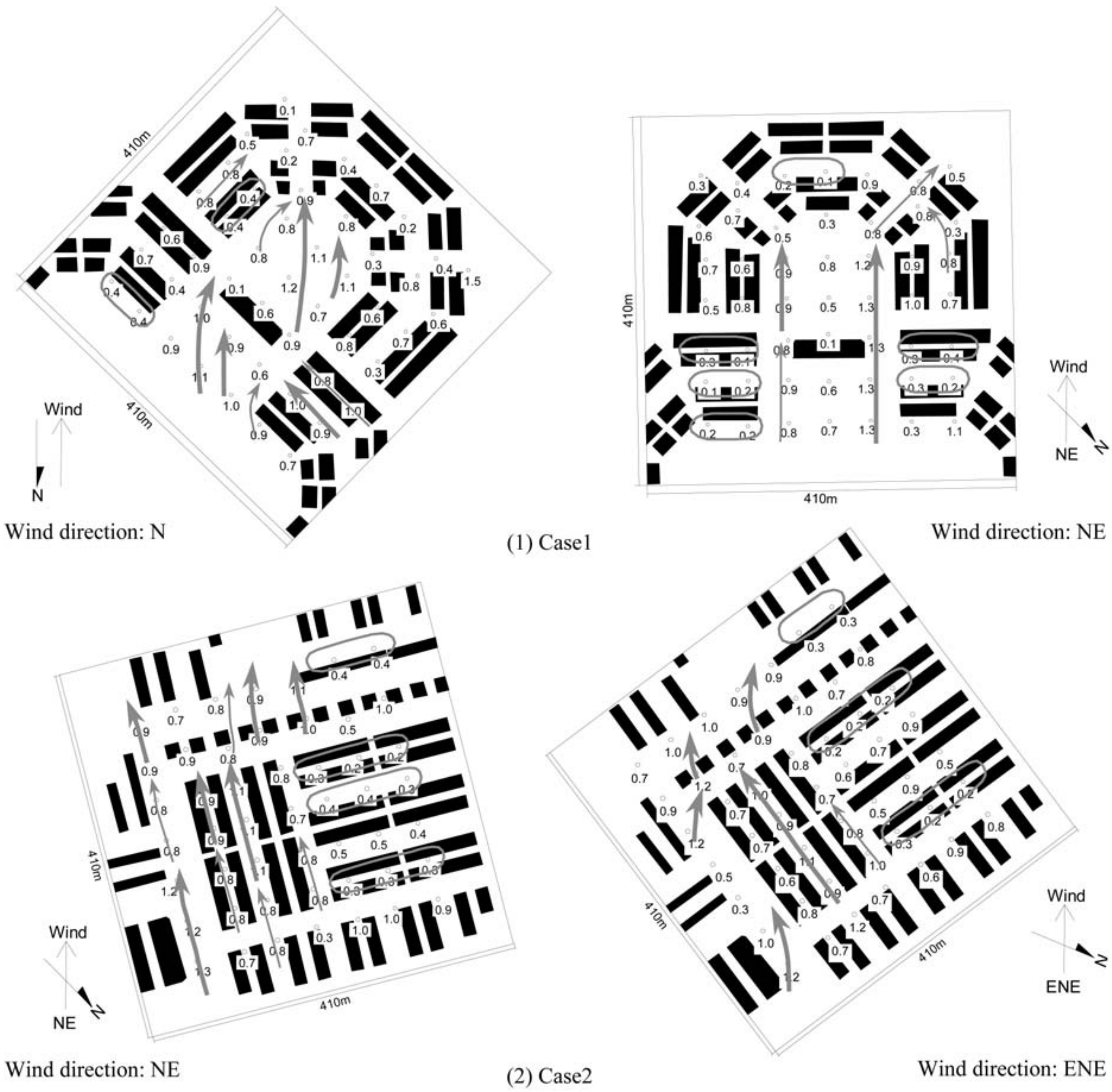
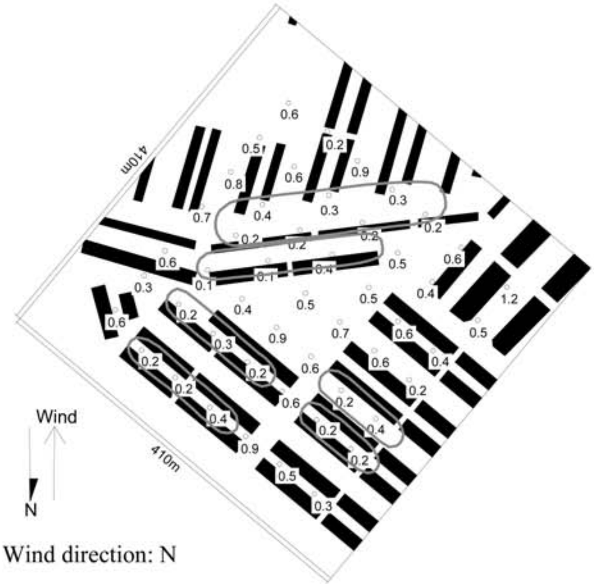
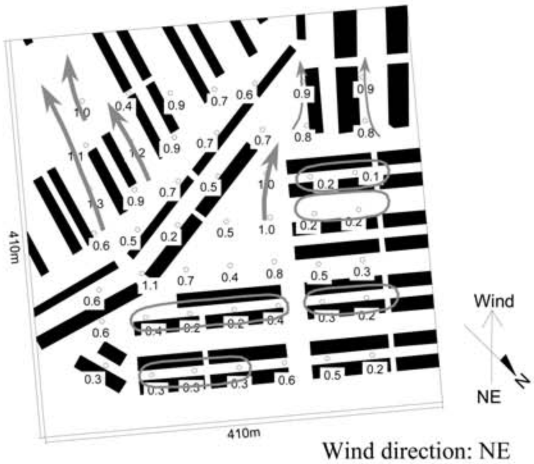


Fig.5. Examples of Results on Analysis of Wind Flow in each Case

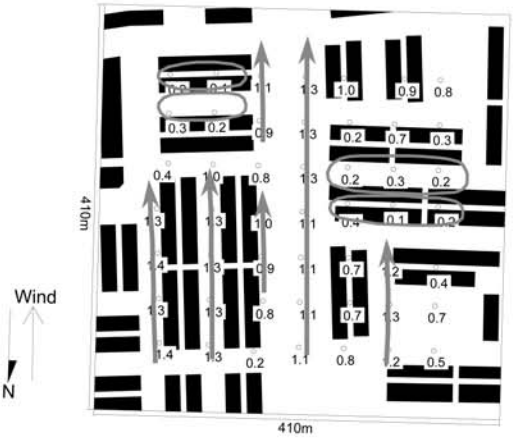


Wind direction: N

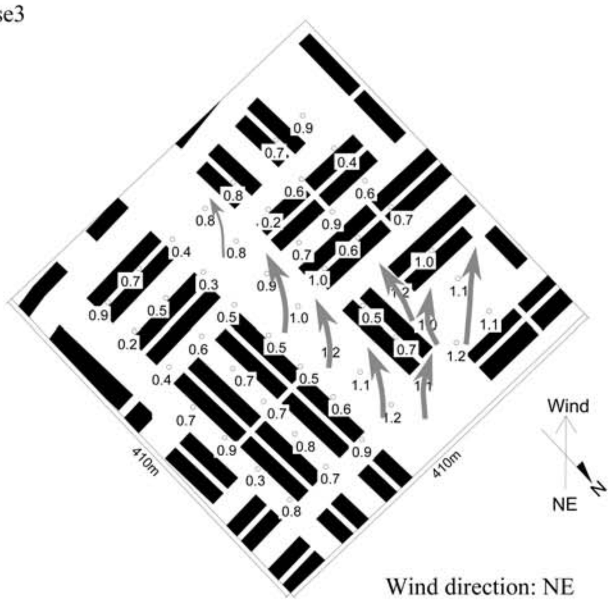


Wind direction: NE

(3) Case3

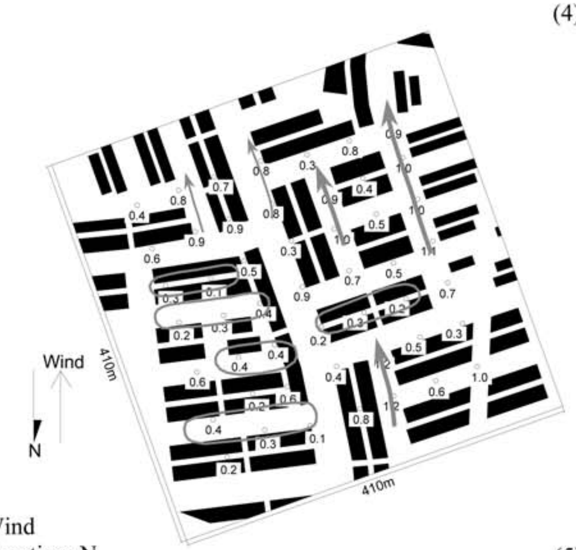


Wind direction: N

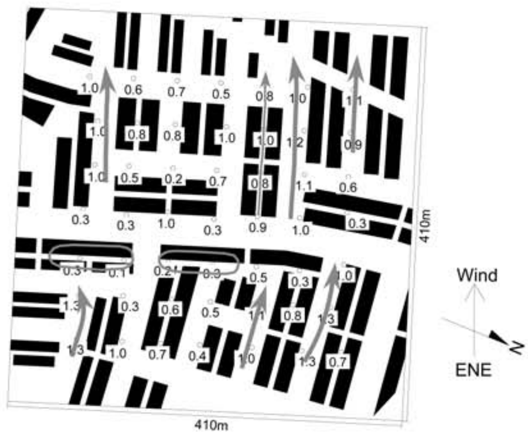


Wind direction: NE

(4) Case4



Wind direction: N



Wind direction: ENE

(5) Case5

Fig.5. Examples of Results on Analysis of Wind Flow in each Case (Continued)

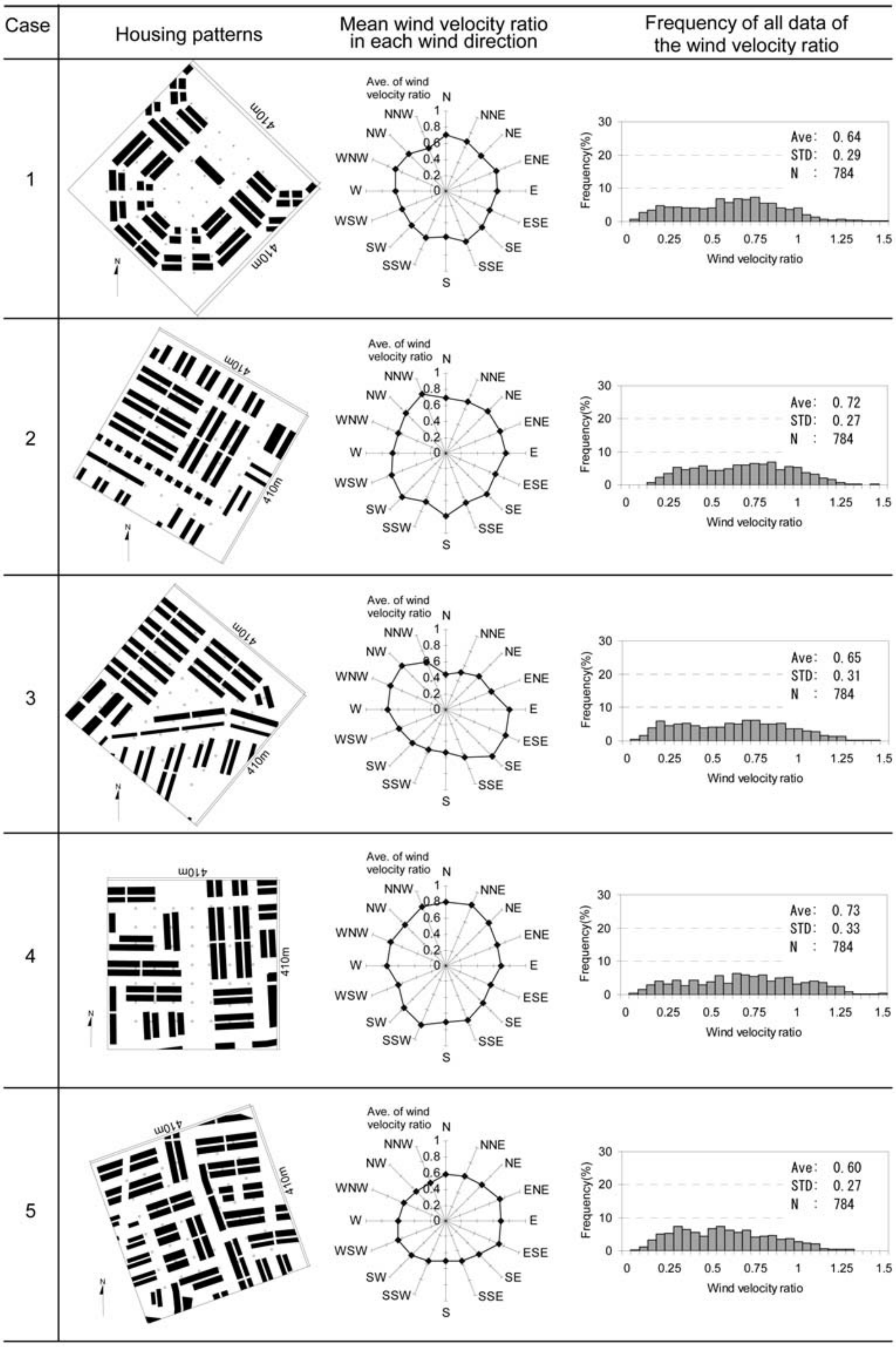


Fig.6. Frequency of Wind Velocity Ratio of all Points in 16 Wind Directions in each Case

The mean value of all data of wind velocity ratio in Case3 is 0.65; this is almost same as that of Case1 (Fig.6-3). In Case3, it was found that the two long rows of terraced houses had much influence on the whole wind flow. These influences are also seen in the distribution of the mean values of wind velocity ratio in each wind direction (Fig.6-3). This is mainly caused by the length of the rows of terraced houses and the orientation of the buildings.

(4) Case4

In Case4, a wide road is located in middle of the area in the north-south axis (Fig.5(4), Fig.6-4). When the wind direction is north, high values of wind velocity ratio are obtained and many points indicate the values of over 1 within the wide road (Fig.5(4)-N). Even when the wind direction is northeast, the wind velocity ratios in the wide road still indicate high values (Fig.5(4)-NE). This is

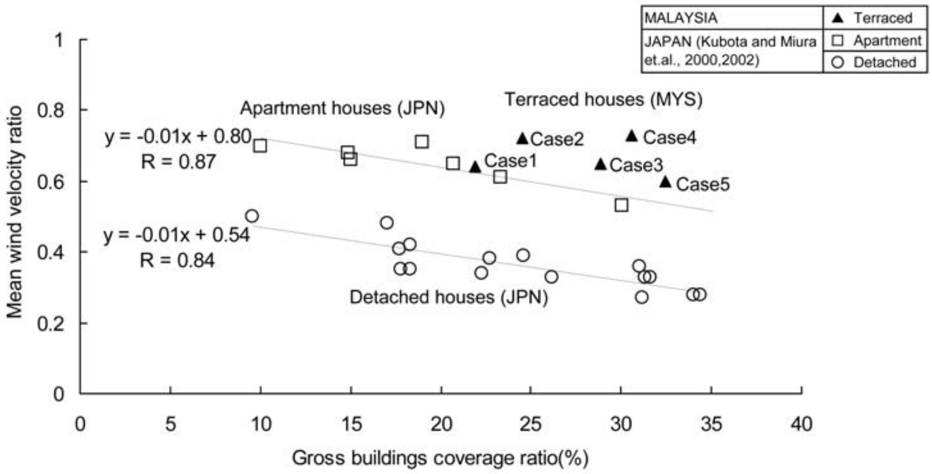


Fig.7. Relationship between Gross Buildings Coverage Ratio and Mean Wind Velocity Ratio of Cases
Source: Japanese Cases Quoted from Kubota and Miura et al.(2000,2002)

mainly due to the wide width of the road. The mean value of wind velocity ratio of all data is 0.73; this is the highest value among the cases.

(5) Case5

The gross buildings coverage ratio of Case5 is 2% higher than that of Case4, and the highest of all cases. In Case5, there is neither large open spaces like Case1 nor wide roads like Case4 (Fig.5(5), Fig.6-5). The highest value of mean wind velocity ratio is given when the wind direction is east-northeast. This is because the orientation of many terraced houses are almost parallel to the wind direction (Fig.5(5)-ENE). The mean value of all data of wind velocity ratio in Case5 is 0.60; this is the lowest value of all cases.

Each five cases in the present study mostly consist of long rows of low-rise terraced houses. The perpendicular arrangements are seen in all cases and this seems to be one of the typical housing patterns of terraced houses in Malaysia. Throughout all cases, it is found that wind velocity ratio between the buildings tend to indicate higher values when rows of terraced houses are almost parallel to the wind direction. However, because of the perpendicular arrangements of terraced houses, some other rows of terraced houses are placed at an angle of almost 90 degrees to the wind direction at the same time and wind velocity ratios between the buildings drop. Therefore, it can be considered that the perpendicular arrangements of terraced houses are not so suitable from a viewpoint of the average wind flow.

5. Discussions

Fig.7 shows the relationship between the gross buildings coverage ratio and the mean value of all data of wind velocity ratio of the cases.

In Fig.7, the results of the Japanese cases (Kubota and Miura el al., 2000, 2002) are also indicated as white marks. According to the above study, both in the areas of detached houses and in the areas of apartment houses of Japan, increase of the gross buildings coverage ratio tended to decrease the mean value of wind velocity ratio (Fig.7). Further, this figure indicates that the mean value of wind velocity ratio in the areas of Japanese apartment houses is higher than that in the areas of Japanese detached houses.

At the beginning of the present study, it was predicted that since the plans of housing patterns of Malaysian terraced houses a little resembled that of the Japanese apartment houses, the mean value of wind velocity ratio also must be similar to that of the area of the Japanese apartment houses. However, as in Fig.7, the mean values of wind velocity ratio of the Malaysian cases are slightly higher than the trend line of Japanese apartment houses as a whole. It is considered that since the housing patterns of these Malaysian terraced houses are more straight and much longer than that of the Japanese apartment houses, the factors of increases, such as the channel effect, occurred more frequently in the Malaysian cases. Thus, as a result, the mean values of wind velocity ratio become higher. However, whether or not this explanation is true would not be known until further study is carried out.

6. Conclusion

This paper presented the results of several wind tunnel tests on selected residential areas in Johor Bahru Metropolitan City. The summary of the results is as follows.

Throughout all cases, it was found that wind velocity ratios between the buildings tended to indicate higher values when rows of terraced houses were almost parallel to the wind direction. However, because of the perpendicular arrangements of terraced houses, some other rows of terraced houses were placed at an angle of around 90 degrees to the wind direction at the same time and wind velocity ratios between the buildings dropped. Therefore, it could be considered that the perpendicular arrangements of terraced houses were not so suitable from a viewpoint of the average wind flow.

At some wind directions of Case2, it was seen that a wind was blown through the spaces between semi-detached houses from windward side to leeward side. Accordingly, it was stated that in order to avoid the increase of weak wind flow areas, semi-detached houses would be effective as an alternative housing patterns.

The relationship between the gross buildings coverage ratio and the mean value of all data of wind velocity ratio of the cases was shown. Also, results of the previous Japanese cases were compared with them. The mean values of wind velocity ratio of the Malaysian cases were slightly higher than the trend line of the Japanese apartment houses as a whole. It was considered that since housing patterns of these Malaysian terraced houses were more straight and much longer than that of the Japanese apartment houses, the factors of increases, such as the channel effect, occurred more frequently in Malaysian cases. Thus, as a result, the mean values of wind velocity ratio became higher. However, whether or not this explanation is true would not be known until further study is carried out.

Some findings of the wind tunnel tests are summarized above and it is evident that further research is required. In particular, it is necessary to clarify both the usage of energy and the resident's consciousness to energy saving in residential areas through social surveys. This kind of survey would be useful not only for collecting the required data but also for enhancing the resident's awareness toward energy saving.

Acknowledgements

We would like to express our sincere gratitude to Mr. Abdul Jalil Talisman, an Assistant Director of Planning of Johor Bahru City Council, and his staffs that have provided useful information for this study. Also, we would like to thank Assoc. Prof. Dr. Ho Chin Siong for his comments and advice at the early stage of this project.

We are particularly grateful to the Aero Laboratory of UTM for lending us the wind tunnel experiments. We are also grateful to Prof. Dr. Masao Miura, Assoc. Prof. Dr. Akashi Mochida and Prof. Dr. Yoshihide Tominaga for their useful suggestions. Also, our thanks are due to our research assistants who have helped to conduct the surveys and the wind tunnel tests, and thanks to Mr. Dilshan Remaz Ossen.

This research was supported in part by the Short Term Research Project Grant from Research Management Center, Universiti Teknologi Malaysia. Further, one of the authors, Tetsu Kubota, was supported under the UTM Post Doctoral Fellow scheme by the Ministry of Science, Technology and the Environment of Malaysia in 2003-2004 and the JSPS Postdoctoral Fellowships for Research Abroad by the Japan Society for the Promotion of Science in 2004-present.

References

1) Economic Planning Unit, Malaysia (1966-2001) Malaysia Plan 1st-8th
2) Gandemer, J. (1975) Wind environment around buildings: aerodynamics concept, Proceedings of 4th International Conference on Wind Effect on Buildings and Structures, London, 423-432
3) Hagishima, A., Katayama, T., Tanimoto, J., Moritake, T. and Ezoe, N. (2000) Wind tunnel experiments on airflow characteristics around the buildings of rectangular blocks with two different height, J. Archit. Plann. Environ. Eng., AIJ, No.538, 15-21 (in Japanese).
4) Kubota, T., Miura, M., Tominaga, Y. and Mochida, A. (2000) Wind tunnel tests on the nature of wind flow in the 270 square meters residential area, using the real model, Effects of arrangement and structural patterns of buildings on the nature of regional wind flow part 1, J. Archit. Plann. Environ. Eng., AIJ, No.529, 109-116 (in Japanese).
5) Kubota, T., Miura, M., Tominaga, Y. and Mochida, A. (2002) Standards of gross buildings coverage ratio in major cities for the planning of residential area in consideration of wind flow, Effects of arrangement and structural patterns of buildings on the nature of regional wind flow part2, J. Archit. Plann. Environ. Eng., AIJ, No.556, 107-114 (in Japanese).
6) Malaysia (2002) Ministry of Energy, Communications and Multimedia- National Energy Balance Malaysia 2002
7) Murakami, S. and Mochida, A. (1988) 3D numerical simulation of airflow around a cubic model by means of the k-model, J. Wind Eng. Ind. Aerodyn. 31, 283-303