PERMEABILITY MAP OF RESIDENTIAL SETTLEMENTS IN THE TROPICS

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ABSTRACT

Source of information for ventilation design of residential settlement is generally derived from wind tunnel or, recently, CFD studies, which involves both modeling and simulation of wind flow pattern and speed. Yet this is not readily accessible to most architects. In order to gain similar objectives but without involving detailed studies, the present study introduces a graphical method of gathering information about permeability of residential. It describes how the way wind reaches and flows through built spaces and forms (streets, park/garden, buildings), and makes use of access graphs and numerical measures to indicate permeability of a given residential settlement. Since the method is still in the initial development, further study will be required for refinement and validation. Nevertheless, the method can be employed to provide information for ventilation design of low-rise residential settlements, particularly at the schematic level.

Key words: settlement morphology, architectural science, natural ventilation, tropics.

ABSTRAK

Informasi untuk perancangan ventilasi alam pada permukiman selama ini sangat bergantung dari hasil-hasil yang diperoleh dari studi terowongan angin ataupun studi simulasi komputer dengan menggunakan CFD. Namun demikian ketersediaan informasi tersebut sangatlah terbatas bagi arsitek. Studi yang dilakukan penulis berusaha untuk mengisi kesenjangan yang ada dengan menyediakan tampilan grafis untuk menunjukkan permiabilitas sebuah permukiman. Perilaku angin di dalam dan permiablitas permukiman dijabarkan dengan menggunakan grafik akses dan pengukuran-pengukuran numerik. Oleh karena pengembangan metoda ini berada pada tahap awal, beberapa studi lanjutan sangatlah diperlukan.

***Kata kunci**: morfologi permukiman, sains arsitektur, ventilasi alam, iklim tropis.*

INTRODUCTION

Ventilation and air movement have long been known as an important means of restoring comfort in the tropics, especially in warm humid areas. High solar radiation and temperature, which are then aggravated by high humidity, are the main thermal problem in this type of climate. This is further worsened by the fact that air movement is frequently at a low speed. Availability of adequate wind speed, therefore, becomes a center of interest in the studies and design of ventilation of building in these areas.

Some of the important factors governing availability of wind in a given area or settlement are characteristics of terrain of the area, density or ground coverage, and street layout of the settlement (Santamouris & Asimakopoulos, 1996). The characteristics of terrain of an area determine surface roughness of the area. This in turn will affect wind gradient/velocity profile, and extent of the boundary layer in that area. In open country, this is found to be at the lowest. By contrast the condition is at the highest in urban areas. This follows that attenuation of free wind will be greatly articulated in urban area than in open country. As indicated by Allard (1998), in a condition of moderate to strong wind, and for a height of 20 m above the ground, there will be a reduction of 20% to 30% in the average wind speed when moving from the countryside into an urban area. Down to the site and buildings, the reduction will be often greater due to the high ground coverage and low permeability of urban structures.

At the settlement level, ground coverage has an important role in determining whether or not a complete dynamic process of wind (i.e. spacing required to allow wind to return to the ground after being deflected upward by building) can occur. From the study conducted by Lee et al (1980), it was found that the process can be satisfied if the ground coverage is around 8.5% and 17% respectively for the normal and staggered arrangements. In a building, it is the level of its permeability that partly determines internal wind environment of the building.

Ground coverage of a planned settlement in urban areas commonly takes values of above 20% (Urhahn and Bobic, 1994; Antaryama, 1999). It follows that the dynamic process of wind can rarely be attained in such settlement. However, if the incoming wind moves toward streets of the settlement, the flow may still be continually distributed over the street's branches before finally reaches buildings. The latter condition relates chiefly to the street layout of the settlement, which also will determine permeability of that settlement.

It is the factor relating to the street layout of a settlement that concerns the present study. It will develop method of exploring airflow distribution in a settlement using access graph. The aim is to provide graphical information about permeability of the settlement. For architects, especially those who want to integrate environmental aspects (i.e. natural ventilation and air movement) into their design, provision of such information can be beneficial.

SOURCE OF INFORMATION FOR VENTILATION DESIGN OF BUILDING

Methods available to device prediction of wind environment in and around buildings are commonly based on calculations and laboratory works using wind tunnel. Recently, the prediction can be made by means of computer simulation, i.e. computational fluid dynamic (CFD). It is from these methods, information for ventilation design of buildings is obtained.

Performing calculation is usually laborious and time consuming. If one makes use of wind tunnel to simulate wind environment in and around buildings, the same situation might also occur. Computer, on the other hand, can make prediction much easier to do. By using CFD for instance, the simulation can be done faster and more efficient (Satwiko, 2000). The use of the program, however, is limited because it requires well-trained operator, and the capital and running cost are high. As a consequence neither calculations, laboratory works nor computer simulation are readily accessible to most architects.

Information regarding ventilation design usually comes in the form of design guidelines. This could be presented in a numerical measure or a chart. Some of the common measures are ratio of building height to spacing between buildings, ground coverage, ratio of opening to wall, and shape ratio. Properties of wind being considered are speed, flow pattern and distribution, pressure, and ventilation rate. Works of Brown (1985), Liddament (1996), Santamouris and Asimakopoulos (1996), Givoni (1998), Allard (1998), and many others are intended not only to inform academics/ researchers but also assist architects.

As mentioned above the present study attempts to develop method of exploring airflow distribution in a settlement. Unlike the available methods described previously, it employs access graph to represent permeability of a settlement. Access graph itself has been used in many architectural studies (Steadman, 1983), such as to describe circulation system/pattern in flats or office buildings and to reveal social significance of a building and settlement. In the latter study, the use of access graph has been elaborated as can be found in the works of Hillier and Hanson (1993) and Hillier (1996).

The underlying idea of the method being developed in this study is that the extent of distribution of airflow in a settlement is dependent on the configuration of spaces of the settlement. The closer and the more accessible the spaces in the settlement from the root of the incoming wind, the shallower the configuration will be. The opposite is true when only single access is available to many spaces and the spaces themselves are at some distance away from the root (i.e. the area outside of the settlement). The same method was applied in the study of climatic aspects of buildings (Antaryama, 1999), and the results showed an agreement with the internal ventilation conditions of the building.

DEVELOPING PERMEABILITY MAP

The following paragraph describes the procedure for constructing permeability map of a settlement and calculating level of its permeability. The flow of wind through spaces in a settlement is assumed to be laminar, and that which spans only up to building height (i.e. 1-2 stories) is considered.

1. Permeability Map of the Settlement

- Consider the settlement as a group of spaces, each of which represents its content, such as streets, plots, open spaces.
- Convert the space into convex space, i.e. a space where every straight line drawn in

the space from any point can reach another point without being obstructed by the space boundaries.

- Construct level of the space's depth, which is determined according to the distance of the space from the area outside of the settlement.

Establish permeability map of the settlement by denoting each of the space with a point/circle, and any connections between spaces a line.

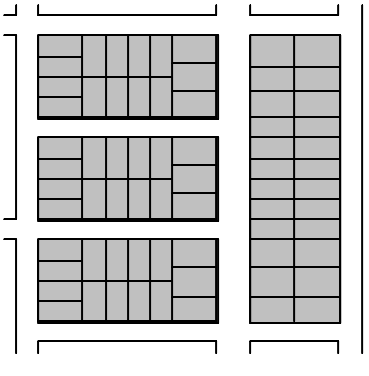
2. Degree of Permeability of the Settlement

To obtain an idea of how the way wind may reach spaces or distribute in a settlement, the depth of each space from outside is established as explained above. The depth of the settlement is then described by means of a justified access graph, which is extracted from the permeability map. In this graph format, spaces are so arranged that those which have a direct access to the outside are represented by circles at one level higher than the outside. Those spaces that can be accessed only by passing through another at level 1 are place at level 2, and so on. Based on this graph measure of degree of permeability (DP) of the settlement is calculated. The formula is given as follows:

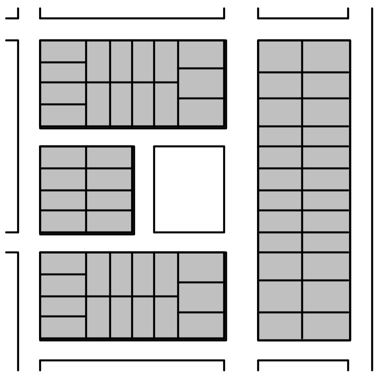
$$DP = \frac{2(MD-1)}{v-1}$$ (after Hillier and Hanson, 1993)

where, MD: mean depth and v: number of total spaces (includes the outside space)

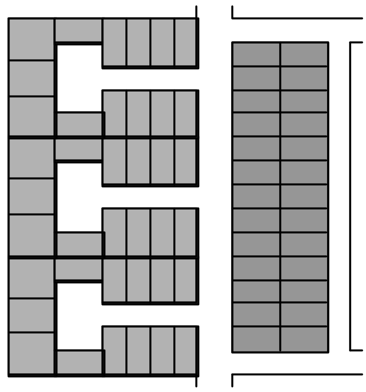
To enable the study to demonstrate the application of the method, three models representing three types of settlement are taken as examples. The models are distinguished according to road patterns, namely grid [labeled A], loop (with green/open space) [B], and cul-de-sac [C]. These three road patterns are chosen because they are likely to be employed in residential settlements developed by housing estate in Indonesia (Kwanda, 2000). For the exercise, however, only part of the three types of settlement is considered (Figure 1).



(A) grid pattern



(B) loop (with green)



(C) cul-de-sac

Figure 1. Part of the three types of settlements considered in the study

Permeability maps and justified access graphs of the settlement are shown in Figure 2, 3 and 4. Degree of permeability (DP) of the settlement is given in Table 1. In order to allow comparison to be made between settlements with different number of spaces, DP is modified by dividing the value by D-value (Hillier and Hanson, 1993). This then gives a value of Real Degree of Permeability (RDP) of the settlement that spans between 0 indicating a shallow configuration and values above 1 representing deeper configurations. From the ventilation design point of view, the former configuration clearly describes how easy wind may reach and penetrate plots and buildings, while in the latter the opposite conditions may be found.

PERMEABILITY MAP OF THE SETTLEMENT

This section discusses the application of the method on the three models of settlements described above, and presents as well as discusses results of the analysis. Parameter used to examine whether or not the method is applicable is the agreement between the access graph representation and the possible airflow distribution occurring in each settlement.

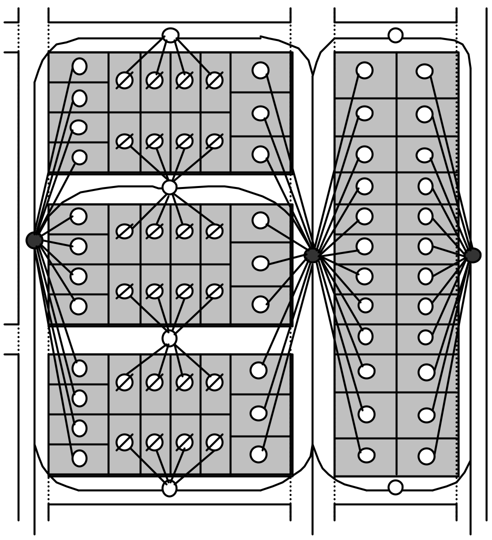


Figure 2. Permeability map of the settlement: an example (A1)

Obviously the greater the conformity of the representation with the possible air distribution the more applicable the method is.

Theoretically, the more accesses available inside and toward a settlement, and the more open spaces are also provided in a settlement, the easier for the wind to reach every part of the settlement. Results of the analysis (see Table 1 and Figure 4), as one may expect, shows that in the settlement with loop pattern (B) there is a greater scope for providing adequate ventilation. In the settlement with grid pattern (A), the availability of wind decreases slightly. In the last pattern (C), i.e. cul-de-sac, the condition is significantly deteriorated.

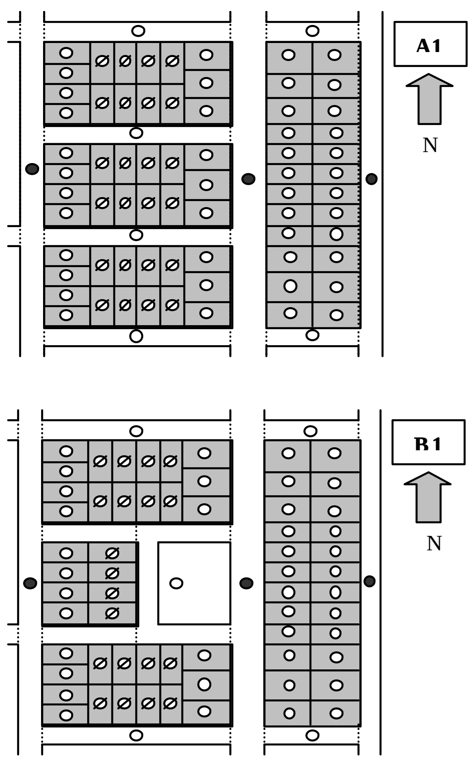
Looking at the results of analysis more closely, settlement with cul-de-sac pattern in particular has the deepest space configuration from outside, when the wind blows both from North and West (see permeability maps and justified access graphs of the settlement in Figure 3 and 4). The same conditions also appear on the results of numerical calculations: RDP for C1 is 0.5 and C2 is 0.7 (Table 1). Configuration of spaces in the settlement becomes shallower (lower RDP) when many accesses are available in the settlement such as that with grid pattern (RDP = 0.3 and 0.5). Similar configuration is also found when open space is integrated in the settlement, as can be seen in the settlement with loop pattern (RDP = 0.29 and 0.48).

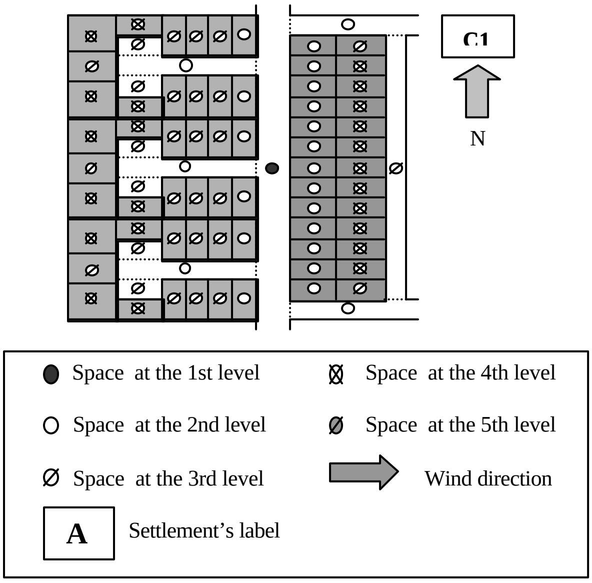
Table 1. Degree of Permeability (DP) of the Settlement

Settlement	Wind Direction	Element	No. of space at level					Total	Mean Depth	DP	RDP
			1	2	3	4	5				
A1	North (N)	Building	0	45	24			69	2.3	0.03	**0.30**
		Street, etc	3	6	0			9			
GC	**32%**	**Total**	3	51	24			**78**	D-value		0.100
A2	West (W)	Building	0	21	36	12		69	2.8	0.05	**0.50**
		Street, etc	2	5	3	0		10			
GC	**32%**	**Total**	2	26	39	12		**79**	D-value		0.099
B1	North (N)	Building	0	42	20			62	2.2	0.03	**0.29**
		Street, etc	3	7	0			10			
GC	**28%**	**Total**	3	49	20			**72**	D-value		0.105
B2	West (W)	Building	0	17	39	6		62	2.7	0.05	**0.48**
		Street, etc	2	6	3	0		11			
GC	**28%**	**Total**	2	23	42	6		**73**	D-value		0.104
C1	North (N)	Building	0	19	23	23		65	2.9	0.05	**0.50**
		Street, etc	1	5	7	29		13			
GC	**27%**	**Total**	1	24	30	23		**78**	D-value		0.100
C2	East (E)	Building	0	6	26	21	12	65	3.5	0.07	**0.70**
		Street, etc	2	2	3	6	0	13			
GC	**27%**	**Total**	2	8	29	27	12	**78**	D-value		0.100

(DP = degree of permeability; RDP = real degree of permeability; GC = ground coverage)

It is clear from the above description that availability of wind increases when many accesses as well as open spaces are implicated in the design of a settlement. They allow the wind to flow freely toward and through spaces in the settlement from whatever directions (Figure 3). In this regard if the frequent wind direction is taken into account, it is likely that the advantage of such a design can be greatly benefited.

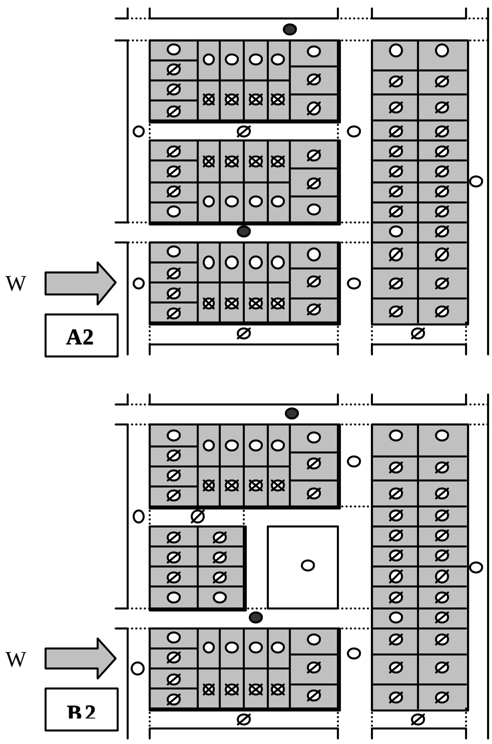


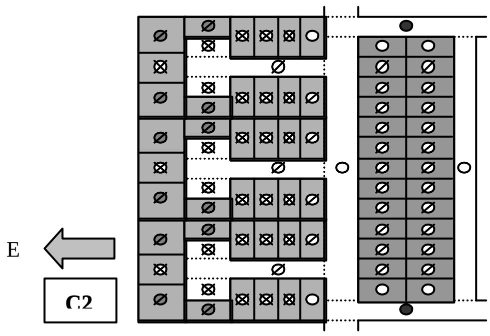


a. Wind direction: North

Figure 3. Permeability map of the settlement *(access connecting spaces is not shown)*

The foregoing shows that the method proposed in this study is relatively sufficient to describe permeability of a settlement. An indication that different patterns of settlement display different kind of permeability also supports the statement. However, it should bare in mind that due to the nature of the graph representation, the method does not take into account dimensional properties of the settlement





b. Wind direction: East and West

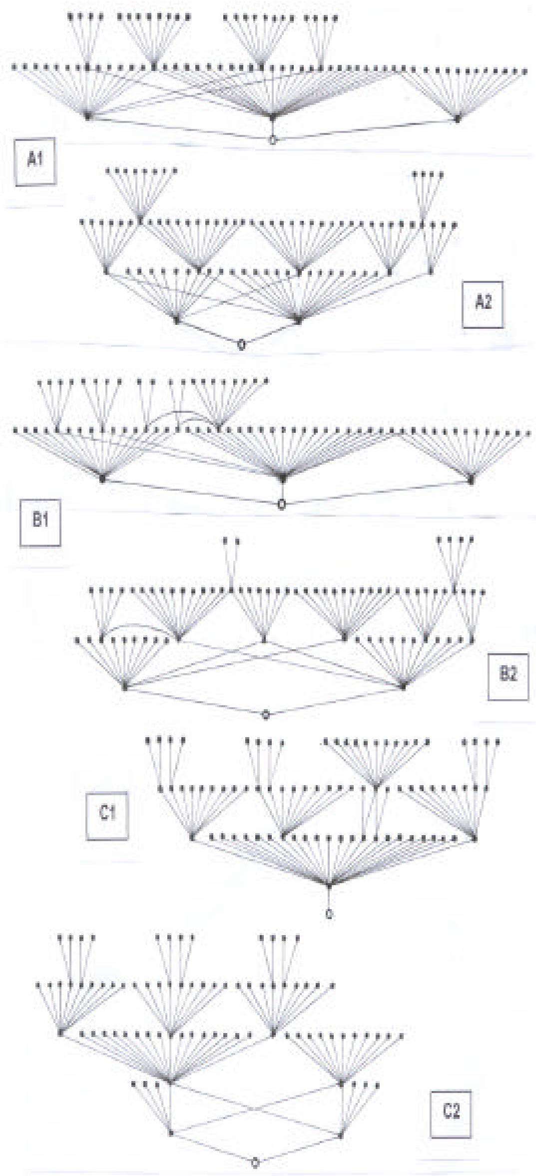
Figure 4. Permeability map of the settlement (continued)

(i.e. width and length of the streets, area of plots and open spaces, height of buildings), which is of important if prediction of wind speed and flow is to be made. In order to produce more accurate information, it is recommended to combine the permeability map and measure with results obtained from either laboratory works or computer simulations.

To overcome such a handicap as well as provide architects with handy information regarding ventilation design, a chart containing information about permeability (i.e. RDP) and ground coverage (GC) of a settlement, which is later called PGC chart, is proposed (Figure 5).

Figure 4. Justified access graph of the settlement Areas indicating highly permeable settlement (0-0.6; Hiller and Hanson, 1984) and recommended ground coverage (0-17%; after Lee et al, 1980) are attached on the chart. Intersection of these two areas is the recommended permeability and coverage for a given settlement. After analysing permeability of a given settlement, an architect through this chart can determine whether or not his/her design might be able to provide adequate ventilation. At the initial stage of design, this information is particularly beneficial because at this stage scope for design modification is greater.

As an example, results from the permeability analysis (RDP) are plotted on the chart against the associated ground coverage of the settlement. The ground coverage of each settlement is calculated on the basis of assumed plot coverage, i.e. 50%. This gives GC for settlement with grid pattern 32%, loop pattern 28%, and cul-de-sac pattern 27%. It can be seen from Figure 5 that none of the settlement is within the area of the recommended permeability and ground coverage. Yet they scatter somewhat above the area.



(A) = grid pattern; (B) = loop; (C) = cul-de-sac

Figure 5. Justified access graph of the settlement

CONCLUSION

The above exercises demonstrated that permeability map coupled with RDP value could give rough information about airflow distribution in a settlement. A combination of the RDP and ground coverage can produce the same information but with greater accuracy. Since the method is still in the initial development, validation will, of course, be required. Nonetheless, at the schematic level, the map can serve as a source of information for ventilation design of low-rise residential settlements.

Aside from validating the method, further study can be designed to record permeability maps and measures of some existing settlements in order to complete the Permeability and Ground Coverage/PGC chart shown in Figure 5. Evaluation of permeability of a given settlement, therefore, can be made on the basis of visual examination only.

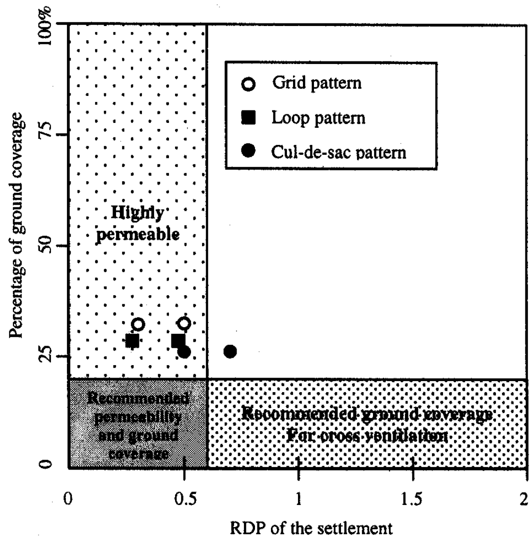


Figure 6. Permeability and ground coverage of the settlement

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