An investigation into parameters affecting an optimum ventilation design of high density cities

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ABSTRACT

For a high density city, given the need to accommodate a fix amount of building volume, what can one do to optimise the benefits of the natural (air) environment? It is hypothesised that in densely built cities, the amount of gaps, permeability and porosity of the cityscape will affect the ventilation / wind environment. Using wind tunnel, experiments are conducted with different amount and positions of gaps of a simplified city layout. The Air change potentials of buildings, an indicator of the air ventilation potential of the urban environment, as well as the air speed at pedestrian level are calculated. It can be established that a cityscape with more gaps will perform better. But it is noted that the characteristics instead of the amount of gaps are more important parameters. Based on the investigation, a number of guidelines have been established.

1. INTROUCTION

The study of the city cannot be merely morphological, historical or geometrical. A topical issue of city nowadays is the environment. Another issue is the rapid urbanisation process of human settlements and the growth of mega-cities and high density cities. When the two are put together, the question becomes: how to design a high density city environmentally?

City design is about providing an environmental infrastructure for the enjoyment and benefits of its inhabitants. An important consideration is to provide natural outdoor conditions that are pleasant to human activities. A well-designed outdoor urban environment will also make the design of individual buildings easier.

Hong Kong has limited land resources with a growing and demanding population. Planning the city to cope with her needs is a difficult task for its planners and architects.

2. REVIEW

2.1 Approach

Many authors have studied the relationship between built forms and their environmental performances. Attempts have been made to isolate a particular issue and study it in detail. The advantage of an atomic approach is that the study is focused and the causal relationship could be detected easily. It is a robust methodology. It is most useful for obtaining initial information for a possible direction, as well as for indicating the likely sensitivity of the parameter.

2.2 Literature

Many scholars worldwide have conducted researches on parametric studies that led to simple design guidelines. Many design understandings and guidelines started with the use of results of parametric studies. For example, Givoni (1969) studied the use of wing walls for room air ventilation. This is now adopted by the HK Government for its new generation of performance based regulation. Hawkes studied the relationship between block spacing and daylight performance which later led in a site planning guide in the UK (Hawkes 1970). Ng studied the amount of space fronting the window and the vertical daylight factor of the window. (Ng 2003, 2004) Ng and Wong also studied wind environment based on skylight, gaps and density. (Ng and Wong 2004a, 2004b) Chan (2001, 2003) studied the effects of building block spacing and air pollution dispersion. His results indicate preliminarily that there is an optimum gap designers should attempt to aim for. Cheng et al (Cheng 2003) studied parametrically the effects of envelop colour, thermal mass and window features. The study concludes that optimisation of indoor thermal comfort could be achieved by carefully design the windows of different orientations.

The above parametric studies are useful to designers, as the results give them hints and quantities to begin their designs.

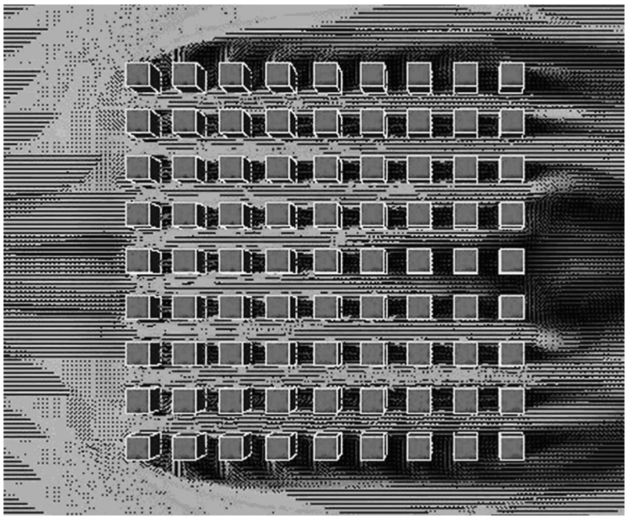

Figure 1: The base 5x5 array with 2 additional layers surrounding the four sides making it a 9x9 array for testing in the wind tunnel.

3. METHODOLOGY

3.1 The model

For this study, to mimic the conditions of an urban neighbourhood, a 5x5 base array was used. The base array had 25 buildings sites. The building sites were 1 unit x 1 unit on plan, and the spaces between sites were 1 unit. On each of the building sites, blocks of 1x1x1 unit were stacked. There were altogether 100 blocks. The number of blocks of all scenarios tested was the same. This controls the "volume density" of the tests. Surrounding the base array, two further rows of buildings sites were placed (Figure 1). This gave a reasonable context to the base array. Pressure sensors were placed at the centre of the 4 surfaces of the blocks.

3.2 Measurement

Air Change per Hour (ACH) is used as a criterion for wind and ventilation studies (Awbi 1991). The indicator gives an idea of the ventilation potentials of buildings with different outdoor environment, hence allows one to evaluate the environmental effectiveness of the outdoor design. For this study, ACH is calculated using Contam96. ACH, which is the reciprocal of age of air (ASHRAE 1997), determines the ventilation performance of an indoor space.

Simulation of ACH values using Contam96 requires the input of Wind pressure (P_w), which can be calculated by using equation (1). C_p values can empirically be obtained either by field measurements or wind tunnel tests. In this study, C_p values are obtained via wind tunnel test.

$$p_w = (\rho * C_p * v^2)/2 \tag{1}$$

P_w: wind pressure (Pa)

C_p: pressure coefficient

ρ: density of air (= 1.20kg/m^3)

υ: wind speed at reference point in wind tunnel (m/s)

Wind tunnel was used (Plate 1982) (ASCE1999). A physical scale model of the test area and its surroundings were constructed and placed in the open circuit boundary layer wind tunnel at National University of Singapore. The wind tunnel dimension is 17m length x 3.75m width x 1.75m height.

The pressure reading at each pre-installed sensor tap, corresponding to the ventilation opening on building envelop, was recorded by the scanivalve with a sample size of 25, and then converted to electrical signal by the pressure transducer. Through the data acquisition system, electrical signal were acquired into Cp.

Specifying the reference level for wind velocity is essential for wind pressure calculation, sine the surface roughness and height above the ground can influence the strength of wind (BS5925 1991). The wind velocity (Uz) at the reference height in the wind tunnel is computed with equation (2). Equation (2) provides an approximation to account for height difference and intervening terrain between 'on-site' wind data and reference point in wind tunnel.

$$U_z = U_m * k * z^a \tag{2}$$

U_m: 2.5m/s (at a standard height of 10m)

z: 90m (height of reference point in wind tunnel)

k, a: 0.35 and 0.25 respectively in urban context

The layout of typical level was required for Contam96 simulation. (Figure 2) The building was modelled as a number of zones depend on the layout of the building and zoning of the ventilation system. Assuming each level was divided into 4 equally-spaced unit, the mean C_p value at each unit was converted to P_w. Contam96 was used to simulate age of air in each zone by using P_w obtained from the external envelop of building. The same P_w was used for the 2 fenestrations on the particular facade. The overall mean ACH (Z1 to Z4) was noted.

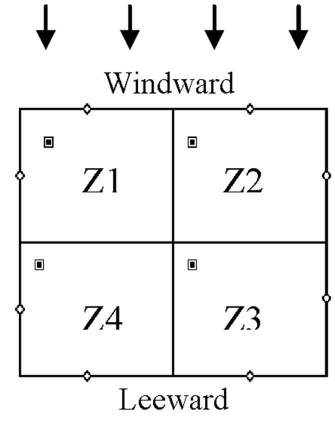

Figure 2: Zone layout for Contam96.

The following properties are input into the indoor zone, airflow path and airflow element:

<u>*Zone data*</u>

- Temperature at 23°C
- Variable pressure
- Volume of 147m^3 or floor area of 49m^2
- Variable contaminant concentrations

<u>*Airflow path*</u>

- Relative elevation of 1m
- Multiplier of 1
- Constant wind pressure (Pa) – input of P_w data

<u>*Airflow element*</u>

- 1.8 m^2 cross sectional area (Fenestration is assumed to be 1.5 x 1.2m)
- 0.5 flow exponent
- 0.6 discharge coefficient
- Hydraulic diameter of 1.34164m
- Transition Reynolds number of 30

3.3 Measuring wind speed

As the strength of the wind is influenced by surface roughness and the height above the ground, a reference level for wind velocity must be specified for use in the wind pressure calculation (BS 5925, 1991). The wind velocity (U_z) or (v) at the reference height in the wind tunnel is computed by formula (2).

The above equation is an approximate correction to account for height difference and intervening terrain between 'on site' wind data and reference point in wind tunnel. Dantec air flow system was used to measure the wind speed at different locations. It consists of probes with wire-wound sensors protected by thin walled nickel tubes, which are mounted on 2-mm thick plates equipped with two-pole connector. The probes are also equipped with temperature compensation sensors which reduce the temperature sensitivity from 10% to 0.2%. Also they are calibrated with displacement correction. The probes are connected to a data logger, which records the probe signal in terms of volts. This probe signal is converted into wind speeds using conversion software which runs in Microsoft Excel.

With the conversion of voltage to wind speed, the turbulence intensity is then calculated using the following formula (3) (Awbi 1991):

$$TI = (\upsilon/V)*100 \qquad (3)$$

TI: turbulence intensity (%)

υ: root mean square of the fluctuating velocity, which is also the standard deviation

V: time-mean velocity (average velocity of the flow over a time interval)

4. RESULTS

4.1 Gap difference

4 cases were studied to determine if there is a difference between the amount of gaps in the city. (Table 1) All gaps are positioned in block level 2 in line with common design practice in Hong Kong that a void be created between the bottom podium and the upper towers. (Figure 3)

Table 1: Settings of cases studied

	A1	A2	A3	A4
Density	100	100	100	100
Bldg to Street ratio	1:1	1:1	1:1	1:1
Height Profile	P	P	R	R
Gaps	F	H	F	H

P =same building heights
R = Random building heights
F = 25 full gaps
H = 25 half gaps

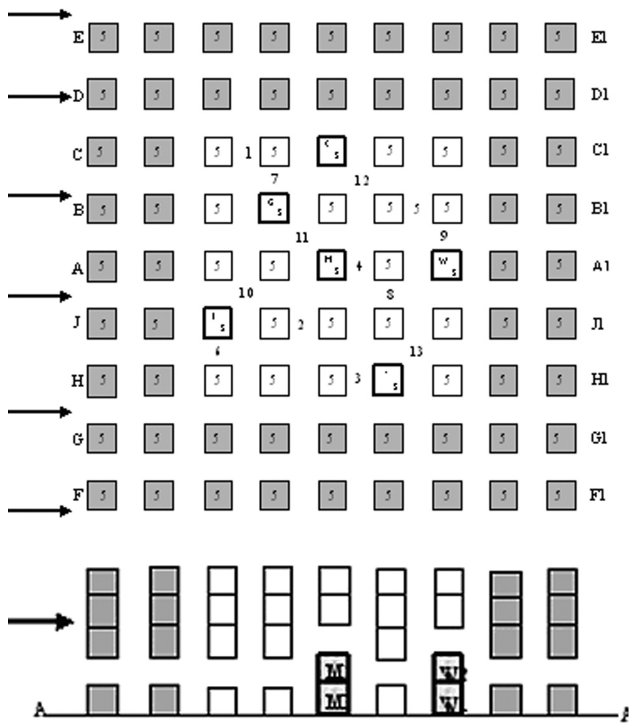

Figure 3: One example of the cases. In this case 25 Full gaps are inserted at level 2 blocks with the exception of the 2 sensor positions. Thick blocks indicate positions of the ACH sensors. Numbers on ground denote air speed sensor positions.

Refer to Table 2, it can be noted that the amount of gaps will generally improve the air ventilation potentials of units at the bottom levels. This may be due to the larger pressure differences that bigger gaps could generate. But it helps very little the air movement on ground. As has been noted in an earlier study (Ng 2005), small height differences at the top helps little the air movement performance at the bottom. On the whole, it can

be concluded that the “size” and “amount” of gaps may not provide significant advantages.
From a design point of view, this is important to note, as doubling the gaps on the one hand has a lot of financial implications, but on the other hand provide little benefits.

Table 2: Results

	A1	A2	A3	A4
Density	100	100	100	100
ACH	10.9	15.6	16.3	14.2
VR on ground	**.29**	**.32**	**.29**	**.29**
TI	8.4	8.3	7.6	7.1

ACH = average ACH of 46 zones measured
VR = Wind velocity ratio near ground
TI = Turbulence Intensity on ground

4.2 Number of gaps

4 cases were parametrically studied in terms of the gaps in between building blocks.

Table 3: Settings of cases studied

	B1	B2	B3	B4
Density	100	100	100	100
Bldg to Street ratio	1:1	1:1	1:1	1:1
Height Profile	P	P	P	P
Gaps	H	H	F	F
No. of Gaps on ground	5	10	5	10
ACH	15	16.6	20.7	19.7
VR on ground	**.26**	**.23**	**.24**	**.24**
TI	8.9	9.6	8.4	8.9

A key difference in this study is the amount of gaps at the ground levels, Cases B1 and B3 have 5 gaps (open voids) on ground, and cases B2 and B4 have 10 gaps on ground. It is note that the differences are minor. It is concluded that shifting some gaps to the ground levels may not yield good benefits.

4.3 Configuration of gaps

Since 4.1 and 4.2 above indicate that the amount and the number of gaps are not important factors, the study proceed with a third study to investigate if the “arrangements” of gaps have any useful effects.

Table 4: Configurations and air paths

	C1	C2	C3	C4
Density	100	100	100	100
Bldg to Street ratio	1:1	1:1	1:1	1:1
Height Profile	P	P	P	P
No. of Open space	6	6	6	6
No. of Air paths	0	1	2	3
ACH	15.3	17.5	23.8	19.6
VR on ground	**.28**	**.31**	**.34**	**.33**
TI	8.2	8.1	8.4	7.9

The opening of air path(s) into the city produces useful gains. Some 15% to 20% could be expected. (Figure 4)

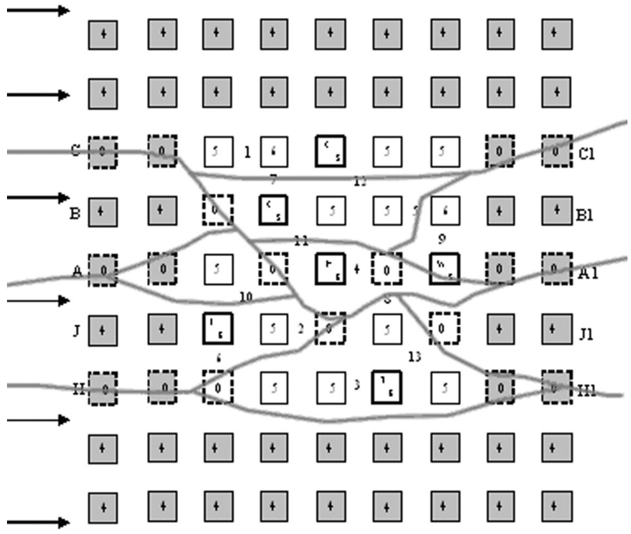

Figure 4: Possible air paths through the city.

5. CONCLUSIONS

Many researches focus on “strong” wind problems of cities and building layouts, the “weak wind” problem is largely ignored or forgotten. In tropical high density city, most of the time and especially in summer, it is the design of better “weak” wind that should be the focus.
The study demonstrates that for air ventilation, better overall performance could be obtained by building into the city planning suitable air paths. In general, this can be more effective than closing the city off with surrounding obstructions, and then trying to design internally – with gaps, spaces, voids and so on.
City planning is complicated. Most of the time, one has to seek for effective, or more precisely cost effective measures to optimise the design. Since 2002, the research team at CUHK has conducted a number of parametric studies to have identified that varying building heights and forming air paths through the cities are effective measures. Planners should note and design them into their design guidelines. (Ng et al 2004)
In Hong Kong, the recommendation of air paths through the city will soon be incorporated into Hong Kong Urban Design Standard and Guidelines. (Figure 5 and 6) (HKSAR 2002) It is possible to examine our city more strategically and incorporate wider air paths through the portion of the city that needs it most. At the moment of this paper writing, the Hong Kong Government has commissioned a studied to generate an Urban Climatic Map for Hong Kong. Hopefully, the map could better identified areas in our city that require most attention and intervention.

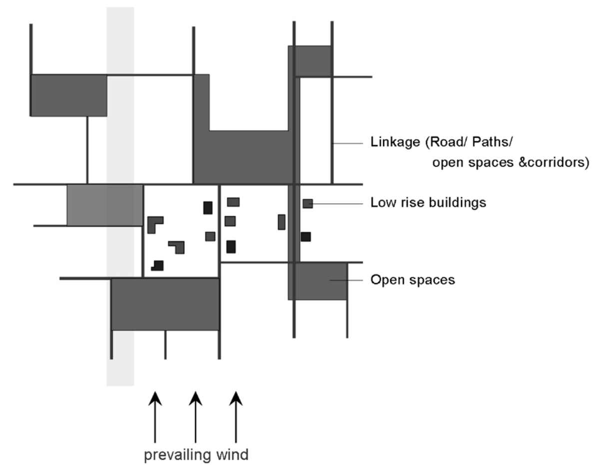

Figure 5: An example in Hong Kong's Guidelines – Linkage of Open Spaces.

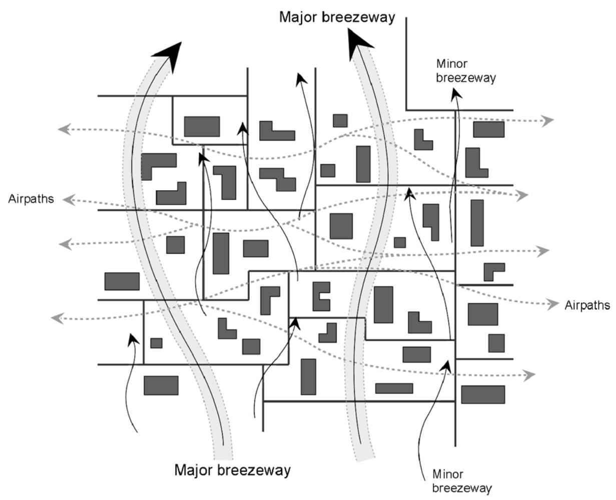

Figure 6: An example in Hong Kong's Guidelines – network of air paths and open spaces along the direction of the prevailing wind is desirable.

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