Natural ventilation in dense residential areas: studying alternatives

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ABSTRACT

The provision of adequate naturally generated airflow is a vital component of energy-efficient healthy buildings. Increasing densification in cities of today acts as a dominant influence on the wind regime, diverting and obstructing natural wind flow to unpredictable levels. Localized air movement is often inadequate and vastly different from regional magnitudes and directions and cannot be used as the basis of design. The pressures of population are expected to continue unabated and timely interventions to offset the negative effects of proximity must be examined before development proceeds beyond redemption.

This paper examines the role and adequacy of natural airflow in urban Dhaka and discusses alternatives at planning and detailed levels through examples. For healthy buildings, perceptible air movement is a pre-requisite for comfort in warm–hot–humid situations. Existing bye-laws govern development trends, and modifications are investigated to find solutions to insufficient air movement. Lack of wind due to density is offset by design features using stack pressures for generating air exchange.

INDEX TERMS

Climate–building interactions; Natural ventilation; Stack effect

INTRODUCTION

In Bangladesh, high humidity throughout most of the year necessitates the provision of air movement on to living zones; therefore, buildings should have adequate openings. With large enough openings, interior and exterior climatic conditions tend to equalize differences. When outdoor temperatures are high, this tendency is not desirable. With high enough humidity levels, however, the cooling potential of wind cannot be denied, as evaporative cooling is enhanced by increased air movement. This paper examines the state of natural ventilation within residences in Dhaka and finds alternatives to the present day conventional practices. Residences being 24-h-use buildings are particularly sensitive structures, as they have to present satisfactory conditions under widely varying circumstances for various use patterns.

Increased Densities Leading to Changing Microclimate

Densities in Dhaka have always been high. One famous area in old Dhaka housed as many as 300 000 people in one square mile of land in the 1980s (Bangaladesh Bureau of Statistics, 1983). But such densities in the past were restricted to landless urban migrants from the surrounding countryside, seeking the opportunities of the city.

However, now densities even in planned neighbourhoods are growing alarmingly, with little or no increase in the proportion of common open spaces or road/paved surfaces. For example, a typical plot of 1338 m^2 of land in Dhanmondi in the 1970s used to house one family of six to eight persons. This same land now in the hands of developers is accommodating twenty-five to thirty families on the average. But the surrounding infrastructure remains unchanged. Illegal encroachment also contributes to over-densification and consequent deterioration of the environment. Naturally, greenery has dwindled in these residential areas to accommodate this stupendous increase in density.

This change is responsible to a large extent for a slow change in the local weather conditions of the city. More paved areas and hard surfaces, being less permeable to water penetration, are responsible for water retention after rains, making flash floods a common problem after even short-span heavy rain bursts. Hard surfaces presented by building facades also add to the heat retention during hot sunny days, release of which during the nights adds to night-time temperature levels. The increased amount of cars, and greater mix of slow and fast moving traffic, contributing to inefficient utilization of fuel and greater vehicular exhaust emissions, adds to the pollution of the city. This affects sunlight penetration and the eventual dispersion of heat from warm surfaces. Thus, the air temperature and relative humidity are affected. With increased air temperatures, more convection eddies are formed changing the course of the natural wind pattern beyond predictability. For outdoor air speeds below 2.5 m/s, ventilation created by wind effects may not be effective in providing thermal comfort as stack pressures can negate wind effects (MaCarthy, 1999) requiring consideration of the latter alternative. The overall deterioration of the air quality also affects the health of the inhabitants and of the wild life around. The discussion below attempts to analyse the reasons for this amplified densification.

Set-Back Regulations for Residential Sites in Dhaka

The *Rajdhani Unnayan Kartripakhya* (RAJUK), which is the planning authority of the capital city, divides plots into rectangles, characterized by their drawing-board divisions of straight edges bordering roads elongated on the main cardinal axes. Therefore, aside from a handful of sites with irregular edges bordering the lakes, which form an intrinsic part of these areas, the sites are geometric and regular. RAJUK's Planning regulations, set out in the *Imarat Nirman Bidhimala* (RAJUK, 1996), which mainly deals with set-back rules, are responsible for shaping the residential area and are presented in Table 1.

Table 1 Set-back regulations for residential sites in Dhaka

Site area	Rear set-back	Side set-back
Sites of up to 134 m^2	1.00 m	0.80 m
Sites between 134 and 200 m^2	1.00 m	1.00 m
Sites between 200 and 268 m^2	1.50 m	1.00 m
Sites greater than 268 m^2	2.00 m	1.25 m

These codes are not designed with climatic considerations in mind. If passage for proper natural light, air and possibly privacy, achieved through physical distance, are the criteria for set-back requirements from property line, then the minimum distance prescribed in the bye-law is clearly inadequate for this purpose. Apart from the above regulations, there is no existing national building code that can be legally implemented.

To overcome this vacuum, from a government initiative, professionals of the country prepared a proposed set of codes called the Bangladesh National Building Code (BNBC, 1993). The BNBC proposes a minimum plot size of 65 m^2, though RAJUK does not specify any minimum. There is no fixed width to depth ratio for RAJUK plots, and BNBC proposes minimum frontages for plots of specific size. According to the code, plots can be considerably elongated, with depth 3.2 times the width in most extreme cases of row-type housing. For detached houses, the width of the plot may be as much as 3.25 its depth. The set-back limitations on the various sides of the plot, however, varied only negligibly to the RAJUK stipulations and seem to be based on such codes for neighbouring countries, without any background contextual climatic basis.

Trend of Development in Residential Areas

The RAJUK setbacks mentioned above ensure that there is a monotonous height and density situation (Figure 1).

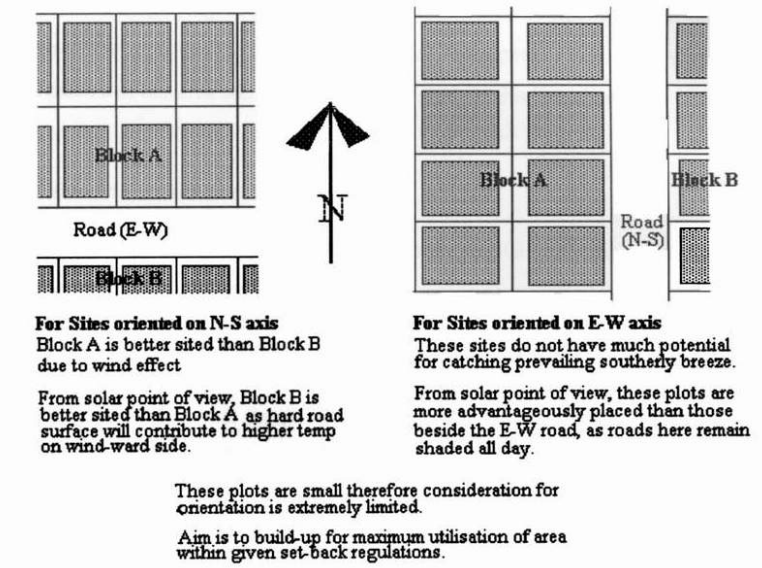


Figure 1 Densely built-up area in grid-iron pattern, maximum utilization of area with minimum set-backs.

Building spacing is presumably related to final heights that are to be achieved. The 2.5 m spacing between the sides of six-storey blocks is extremely inadequate for naturally ventilated interiors, if established research (Koenigsberger *et al.*, 1978) spacing of $2H$ is taken into consideration. (Here H is the height of the windward building and research point to a $6H$ distance for the normal unobstructed wind to resume its natural flow. However, $2H$ has also been recommended as a compromise.) The back-to-back spacing of 4 m is also not likely to produce adequate conditions. It is only the site frontage with the openness of the access road that may allow some natural air movement into the site, provided the natural breeze is available from this side. Moreover, the master-plans of residential areas in no way try to minimize the percentages of plots elongated on the east–west axis, despite the fact that from the climatic perspective, exposure to east–west is likely to adversely affect interiors.

BACKGROUND STUDIES

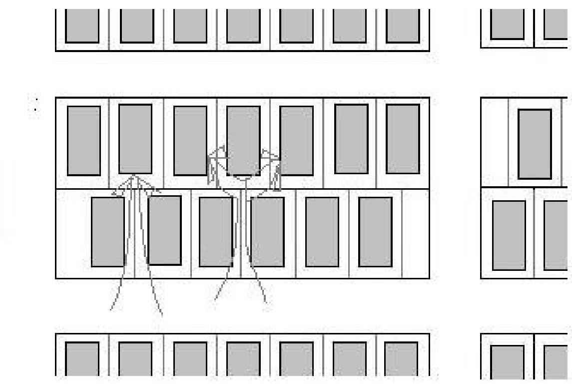
In the past, studies to determine the thermal situation within buildings in Bangladesh have been undertaken by researchers. In warm–humid conditions, like that found for two-thirds of the year in Bangladesh, settlement patterns usually demonstrate plenty of open spaces for the free movement of air to provide thermal comfort. But in the dry season, when solar radiation is more direct, shading becomes one of the priorities for good thermal conditions within buildings. The two conditions are self-contradictory and only one of the options or strategies can be adopted at the planning level. Limited urban space, high land prices and other social and microclimatic issues all contribute to increased densities in urban Dhaka. The adequacy of the natural wind flow in Dhaka in providing indoor thermal comfort ventilation has been investigated through experiments and found inadequate (Ahmed, 2002). Solar data are much more predictable and reliable for providing design information in the urban context. As the sun position is geometrically fixed for a set time of year and day, and solar gains are predictable to a reasonable degree of accuracy, microclimatic changes due to the presence of neighbouring structures and changed surface characteristics can be predicted from shading patterns. In an attempt to determine the overheating caused by solar radiation in residential sites in Dhaka (Ahmed, 1994) it was found that window sizes need to be very limited, as direct and reflected radiation through glazed and unglazed openings raises internal temperatures to a high degree. As windows let in the natural breeze, limiting its size hampers air movement due to wind effects. The following section examines how the above problems of ventilation can be alleviated through planning decisions and building design.

EXAMINING ALTERNATIVES

The discussions above reveal that, though air movement is necessary for thermal comfort in Dhaka's climate, the outdoor wind flow is not reliable enough to ensure adequate natural ventilation in building interiors. Therefore, designers need to explore alternatives to the conventional cross-ventilation pattern. The issue of ventilation can be examined from two points of view; the macro- or planning level and the more detailed architectural level.

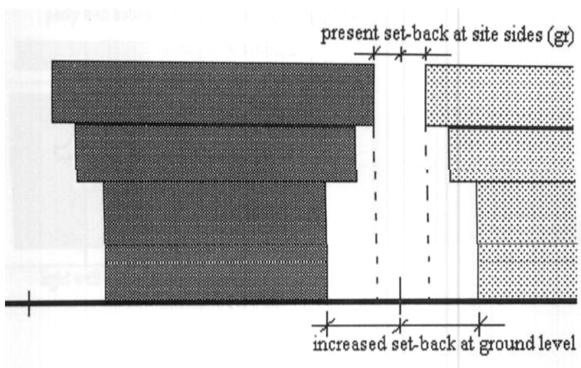
Ventilation related to Macro-level

If natural ventilation were to be emphasized at a planning level, a few obvious errors could be avoided. First, plots would not be placed back to back. The gridiron pattern of plot layout seems to be preferred, though staggering the same would allow the buildings to be located with greater opportunities to catch available prevailing breeze. Staggering plots back to back would result in some reduction in plot numbers every alternate row, thus reducing returns from land sale, but, on the other hand, it would serve to improve the overall wind flow in these developments, which is much needed for high-density settlements. With proper landscaping the corner leftover areas could enhance the value of the location. The social impacts of such landscaped pockets are also likely to be an added bonus for these neighbourhoods (Figure 2).

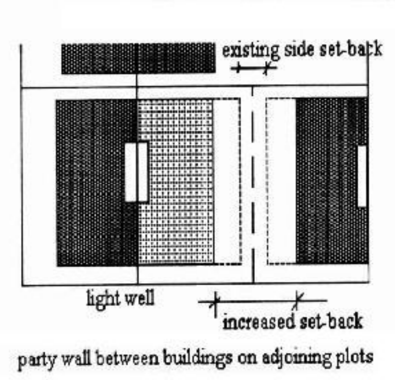


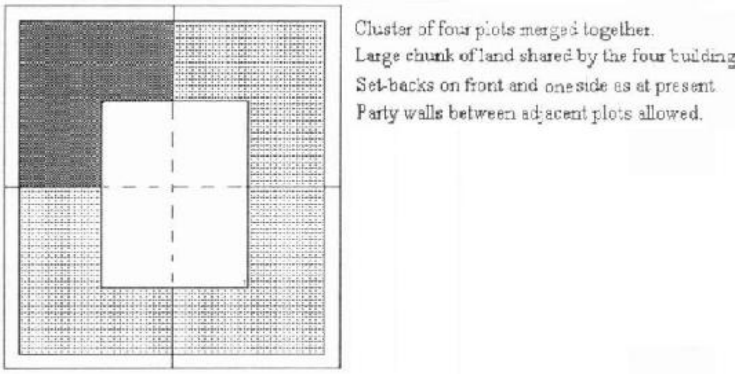
Wind Access improved by staggering rows.
Corner plots provide option for corner gardens/social mingling.

Existing set-back regulations are rigid and inappropriate for adequate natural ventilation. Spacing between buildings, both on sides and back-to-back should generate from climatic considerations of wind and solar exposure. In such cases, set-back variability for different heights can also be considered, i.e., progressive reduction of set-back for higher floors may be a viable alternative for reaping benefits of increased floor areas at higher levels, without seriously hampering the environment (Figure 3).



Moreover, incentives could be created to encourage individual plot owners to build using party walls so that open areas of the plot could be more meaningfully designed. This would allow larger consolidated and functional spaces between buildings, thus providing potential for greater wind generation. The negative effects of added solar exposure, due to less mutual shading, could be overcome by more vegetation and more effective shading devices. Modified rules allowing one or two party walls in clusters of two to four neighbouring plots are therefore recommended (Figures 4 and 5).





Ventilation Related to Detailed or Architectural Level

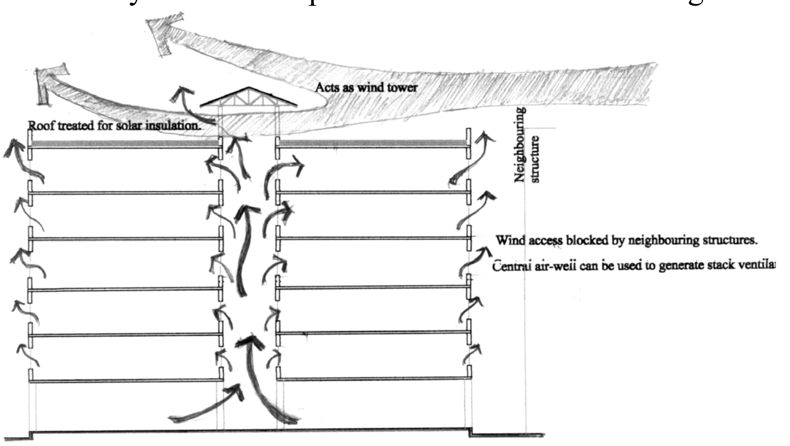
While density of buildings was low, natural wind pattern could be used to generate internal air movement. But with increasing density, especially around urban Dhaka, the natural wind is slowly losing its potential to provide thermal comfort ventilation. However, with the energy issue at such a critical point globally, it is imperative to make built areas energy-efficient. In order to generate some natural ventilation, therefore, the alternative of using stack pressure for air movement is therefore being considered here.

There is a growing trend for residential buildings to be constructed as high-rise with lifts for vertical transportation. This makes the issue of using thermal forces for generating airflow a viable alternative to the lack of wind force in urban Dhaka. Internal courts can serve as light/ air wells. Stack pressure is directly proportional to the cross-sectional area available for the flow, the temperature difference between the lower inlet and the upper outlet, and the height. Extensive experimentation (Givoni, 1976) shows that the volumetric airflow Q for standard openings in $m^3/min/m^2$ of free opening area can be calculated by

$$Q = 7A(h\Delta t)^{1/2}$$

where Δt is the indoor–outdoor temperature difference in °C, h the vertical distance between inlet and outlet in m and A the area of outlet in m^2.

In a study on thermal performance of brick buildings in urban Dhaka (Mojumder, 2000), conducted under the supervision of the author, temperature differences of as much as 7°C were measured between interior and exterior temperatures in the hottest month of April. Such differences are not uncommon for top floors as solar radiation on the roof contributes significantly towards raising indoor temperature. The case for using thermal forces to generate significant air change under such conditions is reasonably strong. For the standard six-storey building in Dhaka with average openings of 1.5 m × 1.5 m, such temperature differences can generate air movement of about 2.9 $m^3/s/m^2$ on the top floor where the height difference between the centre of opening and ground entry point is about 17.5 m (Figure 6). Lower floors with lower indoor–outdoor temperature difference and lower values of h will have lower air speeds.



The use of wind towers and scoops can also be considered in such buildings to make use of the wind force along with any thermal force generated within the building itself. In such cases, the total wind speed will be enhanced by suction forces caused due to the negative pressure created at the top of the wind tower. The simplest design of a wind tower involves the use of a cover on top of an open chimney for rain protection. To enable free flow of wind between the tower top and the cover, the gap area in windward elevation should be greater than 40% of the tower cross-section (McCarthy, 1999, p. 32).

Adaptation of the tower principle in the design of a residential complex in Dhanmondi (Ahmed, 1999–2001) by the author shows the court serving both as light well, as well as rain protected wind tower with stack height of six stories (Figure 6). Here, though there is no extra tower rising above the general height of the surrounding structures, yet the top of the well will generate negative pressure similar in principle to that found over towers. The gap between the tower top and cover is 2 m × 7.5 m, while the cross-section of the well is 3.75 × 7.5 m, i.e. a gap of 53% of the cross-sectional area. Thus, the stack effect ventilation of approximately 2.9 $m^3/s/m^2$ is supplemented by wind-driven ventilation through the tower top and such mixed modes can be utilised to create healthy exchange of air between interior and exterior despite the growing densification.

CONCLUDING REMARKS

It is obvious that traditional practices of using the prevailing wind as a means of providing thermal comfort within buildings is unlikely to work for urban Dhaka due mainly to the growing proximity of buildings and therefore stack force needs further investigation. This paper has attempted to address the issue and suggest ways both at the planning level as well as at the detailed architectural level to overcome the situation. Further validation and field testing will reveal more possibilities, all of which will reduce the demand on active energy which is not only a global issue but a very acute one in the energy situation of Bangladesh.

REFERENCES

Ahmed, Z.N. (1994). Assessment of Residential sites in Dhaka with respect to solar radiation gains. Unpublished Ph..D. thesis, De Montfort University; Leicester.

Ahmed, Z.N. (2002). The effects of room orientation on indoor air movement in the warm–humid tropics: scope for energy savings. *Journal of Energy and Environment*; Centre for Energy Studies, BUET, Dhaka, September.

Ahmed, Z.N (1999-2001). Niraloy Apartments (Prova); Six storey residential complex; Plot #75, Rd #8A. Dhanmondi R/A; Dhaka.

Bangladesh Bureau of Statistics (1983). Dhaka District Statistics, BBS. Govt of the People's Republic of Dhaka: Bangladesh, p. 4.

BNBC (1993). Bangladesh National Building Code; Seminar organized by Housing and Building Research Institute and Development Design Consultants; IEB; Dhaka, May 1993.

Givoni, B. (1976). *Man Climate and Architecture*, pp. 281–2. London: Applied Science Publishers Ltd.

Koenigsberger, O.H., Ingersoll, T.G., Mayhew, A. and Szokolay, S.Z. (1978). *Manual of Tropical Housing and Building; Part One; Climatic Design*. London: Longman.

McCarthy, B. (1999). *Wind Towers, Detail in Buildings*; .Academy Editions: Great Britain; p. 18.

Mojumder, S.A. (2000). Thermal performance of brick residential buildings in Dhaka City. Unpublished M.Arch thesis, Department of Architecture, BUET; Dhaka; 2000; p .162.

RAJUK (1996). Rajdhani Unnayan Kartripakhya (Capital Development Authority); *Imarat Nirman Bidhimala*; Article 18. Dhaka: Government of the People's Republic of Bangladesh