

Ventilation Potential: Examining the Effects of Growing Densification in the Tropics

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SUMMARY

The density of Dhaka is increasing exponentially, and with it the demand for residential accommodation. Rapid densification is increasing hard surfaces and changing the urban texture, thereby escalating heat absorption. This intensifies dependency on valuable conventional energy resources, for thermal comfort.

Research shows that regional climatic data differs markedly from localised microclimatic effects within the built environment. In built-up residential areas of the city there is the lack of natural wind flow, one of the most important ingredients for comfort during the warm monsoons. Electricity is growing costlier day by day and its supply is erratic, while load shedding to balance the supply and demand, is very common.

This paper presents the findings of an ongoing research, to investigate the effects of growing densification in the city on the potential for natural ventilation. The work is based on the premise that the effect of variation in density will be reflected in the comparative differences in qualities of the thermal environment (indicated by the temperature and wind speed measurements) in the different residential areas of Dhaka. Higher temperatures in the denser parts of the city may be attributed to larger daytime absorptions and slower night-time cooling, and lack of breeze to distribute the unevenness. In conclusion some passive measures are suggested to rectify the negative aspects of the environment.

Keywords: thermal environment, natural ventilation, urban density

INTRODUCTION

Dhaka is a tropical city lying on the edge of the Tropic of Cancer, with a composite monsoon climate having a rather long warm-humid season [1]. In the past four decades since it became the capital of independent Bangladesh, the city has grown exponentially and is projected to become the second largest city in the World with respect to population growth by the year 2015 [2]. The influx of population increases demand for residential accommodation, which raises the density of the built environment.

Research shows that the main ingredients for comfort [3] during the warm monsoons is the presence of air movement. The built environment modifies values of solar radiation, wind flow and with it, the temperature, humidity, and related climate data [4]. Rapid densification, increases obstacles to wind flow, and also increases hard mass or hard surfaces, affecting the thermal environment by changing the urban texture and escalating heat absorption. There is therefore a wide difference in regional wind availability and microclimate found on urban sites and in the respective temperature data. Previous research also shows that air velocities within building interiors falls dramatically from outdoor regional averages, further lowering the ventilation potential of available wind in typical residential areas of Dhaka [5].
In the absence of naturally induced air movement within building interiors, residents of Dhaka resort to the use of electricity, to accelerate evaporative cooling, allowing a semblance of thermal comfort, despite the high humidity. But active energy is growing costlier day by day, with the latest price hike scheduled for March 2007 [6], while its supply is very erratic with load shedding a common phenomenon [7]. These black-outs are employed by the authorities, to keep equity between the supply and demand of electricity.

Addressing these issues, this paper presents the findings of an ongoing research [8] conducted by the authors, where the potential for natural ventilation is examined from an investigation into the effects of growing densification in the city.

The basic hypothesis of the work is that the effect of density variation will be reflected in the comparative differences in the temperature and wind speed measurements of the different fabric patterns in the formal and informal residential areas of the city. Higher temperatures found in the denser parts of the city may be directly attributed to larger absorptions during the day and slower night-time cooling due to changed wind speeds and convection patterns.

One of the main objectives of this work was to increase awareness of the wind regime in different residential areas of the city and to suggest passive measures to rectify the negative aspects of the environment.

THE INVESTIGATION

Setting the Context

The study was conducted on the residential areas listed below, representative of differing levels of development and density in Dhaka metropolitan area, including formal and informal sectors (indicated in Map by numbers in Fig.1).

- Informal sector residential development where growth pattern is incremental and dense, and no definitive planning control is followed, e.g. Sutrapur (1) in old part of the city.
- Institutional housing where the development is far more controlled, eg Teachers’ Quarters of BUET (2).
- Formal high-density residential area, e.g. Dhanmondi Residential Area (3), where many of the original one-bigha plots (generally in grid-iron layout) have been subdivided into smaller plots for descendents, and the remaining original one unit houses per plot are now being replaced by six-storied apartment buildings.
- Formal medium-density residential area, e.g. Banani Residential Area (4), with large plot sizes, most still occupied by single families (sometimes joint or extended family) in one unit houses.

Physical survey of these residential districts revealed density of building mass and ratio of open and built areas along with surface characteristics and vegetal cover. These data were then correlated with measured thermal variables of temperature, humidity and airflow using portable instrumentation.
Data collection at survey spots and analysis

Suitable buildings were selected in each of these spots for data collection. For actual data collection, transition points were identified within the buildings, defined as transitional areas either between indoor and outdoor, or the immediate outdoors of dwelling units. These points form the boundary conditions for the building fabric. Recognising that transitional areas form buffers between the external and internal environments, understanding of the thermal environment in these spaces can make passive climatic control easier. Moreover, dependency on active control is largely reduced if the transitional point environment does not get extreme.

Table 1  Comparing the Density and physical qualities of the four residential districts

<table>
<thead>
<tr>
<th>Location</th>
<th>Sutrapur</th>
<th>Dhanmondi</th>
<th>BUET T. Q.</th>
<th>Banani</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing avg. Floor Area Ratio (FAR)</td>
<td>4 to 5</td>
<td>3.5 to 4.5</td>
<td>1.1 to 1.3</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>Existing avg. land coverage by building structures on plots</td>
<td>85 to 95%</td>
<td>70 to 80%</td>
<td>25 to 30%</td>
<td>55 to 65%</td>
</tr>
<tr>
<td>Existing avg. ratio of hard : soft surface (exc. road area approx.)</td>
<td>95 : 05</td>
<td>80 : 20</td>
<td>30 : 70</td>
<td>60 : 40</td>
</tr>
<tr>
<td>Population density in persons per acre approx.</td>
<td>357</td>
<td>310</td>
<td>162</td>
<td>180</td>
</tr>
</tbody>
</table>

For Air-flow data, measurements were taken at three different heights at every survey spot using three weather meters simultaneously. Temperature and Relative Humidity data were measured with the help of two additional data loggers, while two maxima-minima thermometers were used for simultaneous maximum and minimum temperature data. Prior to the field data collection, necessary field calibration was made by the recommended calibration kit according to the specification supplied with these instruments. The regional averages were also noted from weather stations and published sources for the survey days to note micro-climatic deviation at surveyed spots. For solar radiation data it was assumed that the values would be similar for all sites as they are located within a few kilometres of each other and there is no noticeable difference in air quality/atmospheric condition.

Field data was collected within a limited time, during May, when conditions are representative of high thermal discomfort. April is the hottest month in terms of mean maximum temperature [9] [10], and the effects of its interaction with built form is expected to set in after a few days, i.e. by the middle of May.

A comparative analysis of climatic data collected from the different residential areas was then made to identify variations in thermal environments and to ascertain the extent and causes of variations. This analysis is expected to help formulate correlations between the thermal environment, climate and density of building fabric.

RESULTS AND ANALYSIS

The Context

Physical survey of the four residential districts revealed characteristics given in Table 1. The first row gives the existing floor area ratio (FAR) of each of the survey areas, calculated from the volume of built spaces per unit of ground surface area. This ratio is directly proportional to density of development and is found highest in Sutrapur, closely followed by Dhanmondi.

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* Kestrel 3000 Pocket Weather Meter; Nielson-Kellerman; USA
† Programmable data logger HOBO H08-007-02. Logger is initiated by software BoxCar Pro 4 (BCP4.0-ON) supplied with the logger. Measure:RH/Temp/2x External.
A new set of construction rules has just been implemented in Dhaka [11], but its effects will not be felt until construction in accordance with it has taken place. Therefore the following discussion is based on the previous Building Construction Act of 1996 [12]. With only 1.25m side setback and 1.5m front setback, residential districts therefore are very compact and dense. Where plots are small, setbacks are further reduced. Owners therefore tend to build up to the limit, leaving almost no open spaces, e.g. in the

Sutrapur area. There is also mass scale violation of building construction rules and unauthorized changes in design after formal approval. All this leads to high land coverage and very high density, as seen in the second row of Table 1, resulting in reduced gap between adjacent buildings, poor provision for natural lighting and ventilation.

In the Sutrapur area, a good mixture of buildings of variable heights were found, which created a rough urban texture. In Dhanmondi, most buildings tend to be six storied, and in BUET the norm is five storey walk-ups, with only one eleven storey tower building. The Banani area also has a mix of building heights, many only two storeys high.

Only in Banani and BUET (Fig. 2a) one-third or more of the plot areas were kept open for vegetation and green development. In areas where the hard to soft ratio is low, evaporation potential increases, while solar absorption is also much reduced.

Population density was found highest in Sutrapur (Figs 3a, 3b), while many professional activities were discovered going on in and around the residences. In Dhanmondi (Figs 4a, 4b) also various commercial activities are encroaching onto the residential environment, which
has increased the activity level of this area. Such activities and densities are bound to contribute to higher temperatures.

Building spacing is seen to vary despite the same setback rules being applicable in all the settings. In Sutrapur, the buildings are constructed very compactly without leaving setback spaces on all four sides. In most cases, buildings in adjacent plots were built without keeping any space in between and no window opening on that side was possible (Fig. 3a). Window openings in the ground floor were only found possible on the road side. Windows on sides are only possible on upper floors, where the adjacent building is lower. These upper storied openings are liable to remain closed permanently, once surrounding adjacent structures are extended vertically. So the provision for natural light and ventilation in the living spaces in this residential area is extremely restricted.

This compact situation acts like a big porous insulating layer between the sky and the earth. The heat that penetrates inside the buildings during day time can not be easily released after sunset. As summer goes on, the cumulative effect could raise the overall indoor temperature posing threat to thermal comfort.

Because the gap between two buildings was found big enough to facilitate ample light and ventilation through the different vertical layers of the buildings, Banani and BUET area show a different pattern (Fig 2a). During summer, nocturnal cooling can be expedited by this ventilation and by avoiding daytime ventilation, comfortable situations can be retained for a long time.
Temperature and Wind Velocity Data Comparison

Preliminary readings revealed that maximum outdoor air-temperature is found between 1.00 to 3.00 pm. For this reason, temperature at 2.00 pm. taken for fifteen consecutive days at transition points in the four survey spots (Fig 5) shows that generally, Dhanmondi attained highest and Banani the lowest temperatures compared to the other areas.

The results also show that the temperature figures are closely related in the Sutrapur and Dhanmondi region (both high density areas) on the one hand, and in the BUET and Banani region (both of lower densities) on the other. Mostly variations between spots were significant, being on an average, about 2°C, reaching a maximum of 4°C. A relationship between the temperature readings and surface quality can also be established from these results. Thus, where the FAR value and proportion of hard surfaces is higher, higher temperature values were obtained.

Air velocity readings were also taken at all the survey spots. Fig 6 gives readings for the average and maximum air speeds in high density Dhanmondi and low density BUET. The readings show how the velocity rises with building height for both the low density and high density situations. It is also clear from the readings that there is very little dependence on density when ground level and top level flows are concerned, i.e. almost the same velocity is measured in high and low density areas at these levels. However, at mid-levels, the high density area (Dhanmondi) displays a fall in the wind gradient in comparison with the ground level flow. For the low density area (BUET) on the other hand it is seen that there is a steady increase in wind gradient with height. This is expected because in the former case there is a lot of obstruction at lower levels which results in turbulent and inconsistent wind patterns,
while in the case of BUET the wind hits the buildings without its laminar flow being disturbed, as building to building distance is considerable. Therefore there is a steady increase in wind flow with height. This supports research findings that wind velocity reductions at lower levels are more pronounced with increased urban roughness [13] due to turbulence. In the Dhanmondi area, the reason for the air speed at ground level being higher compared to mid levels, could be because the ground floor is kept free for car parking.

DISCUSSION

The following points emerge from an examination of the data:

- Temperature is higher in denser areas. These areas also have a higher percentage of hard surfaces, which may be a contributing factor.

- Wind speed was not found to be directly affected by density of built form, either at ground levels, where there is maximum interruption to airflow, or at roof top levels, where the flow is uninterrupted. But at mid levels, density plays a significant role, possibly due to the higher turbulence in dense spaces, where building heights are also variable.

- It is possible that the higher temperatures measured in denser areas may be caused due to lower wind speeds in these spaces. Therefore the accumulated hot air does not find easy escape and the heat remains trapped.

- As the global horizontal solar radiation data is unlikely to vary in spaces so close to each other, it is possible that the radiation is absorbed by the greater percentage of hard surfaces in the denser setting. This may cause the elevated temperature in the denser regions.

The hypothesis, that a dense area can create a situation similar to a big porous insulating layer between the sky and the earth, trapping heat, seems to be justified from the findings. The effect of density variation is therefore reflected in the comparative differences in the temperature and wind speed measurements.

Recommendations

One of the objectives of the study was to be able to suggest ways in which the situation can be made more comfortable, i.e. where wind speeds can be increased at the lower levels and temperature levels can be kept down. Whereas it is understood that any recommendations should be tested before being considered as having a strong basis, nevertheless, some pointers towards improving the situation, have been tentatively presented below.

1. More openings and height variations at mid levels would undoubtedly increase wind flow at those levels, thus increasing comfort under warm humid conditions. This could be done by introducing terraces interspersed within the built fabric, bringing variation in the building volume.

2. Increasing soft surfaces could bring temperatures down, thus reducing dependency on wind flow to impart thermal comfort. To achieve this, vegetation can be introduced at different levels, cutting down on solar radiation gains.

3. Creating some open areas within an otherwise dense situation would undoubtedly alleviate a lot of the wind and temperature stagnation. Such an open area could draw winds out from the surrounding dense areas, thus improving the overall situation.
Building activity is a continuing activity in Bangladesh, as in much of the developing World. It is imperative to be conscious of the effects of urbanisation and building activity on comfort potential and energy consumption, both of which can be brought to acceptable levels if adequate ventilation can be targeted. This paper is an attempt to make concerned professionals aware of these facets of Architecture and the environment.

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