Thermal Environment in Residential Areas of Metropolitan Dhaka: Effects of Densification

By

Gouri Shankar Roy

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Department of Architecture
Bangladesh University of Engineering and Technology,
Dhaka-100, Bangladesh

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Ahsanullah University of Science & Technology
Dhaka-1215

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Name: Gouri Shankar Roy

To my beloved parents

Kali Kinkar Roy
and
Aroti Roy

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ABBREVIATIONS

ACC	Active Climatic Control
BCR	Building Construction Rules
BH	Building Height
CBD	Central Business District
DCBCR	Dhaka City Building Construction Rules
DMA	Dhaka Metropolitan Area
DMDP	Dhaka Metropolitan area Development Plan
FAR	Floor Area Ratio
FF	Free Floor
GC	Ground Coverage
GOB	Government of the Peoples' Republic of Bangladesh
HSSR	Hard to Soft Surface Ratio
MC	Mega City
MRT	Mass Rapid Transit
PD	Population Density
PCC	Passive Climatic Control
RajUK	Rajdhani Unnayan Kartripakkha (Capital City Development Authority)
RD	Residential District
TC	Thermal Comfort
TE	Thermal Environment
UHI	Urban Heat Island

ABSTRACT

Rapid urbanization and high population growth rate have made Mega-City Dhaka a container of several millions of citizen. To accommodate influx of huge population within the limited buildable land Residential Districts (RD) are gradually allowing more and more density in terms of physical building mass, energy usage, transportation, etc. Thermal Environment (TE) of these areas is obviously affected by this densification process.

To investigate into the climatic effects of such densification four different types of RD (Sutrapur, Dhanmondi R/A, BUET Teachers' Quarter and Banani R/A) are selected within Dhaka Metropolitan Area (DMA) covering both formal and informal sectors. Existing physical characteristics, which determine the overall settlement pattern, of all four RD are analyzed in terms of Floor Area Ratio (FAR), Ground Coverage (GC), Hard to Soft Surface Ratio (HSSR), Population Density, Sky-Line and Setback Space.

Out door environment is largely dependent on natural climatic pattern, which is almost impossible to control. On the other hand, indoor environment is largely dependent on its internal space layout, enclosure characteristics, use pattern, etc., which are controlled by individual choices. Between indoor and outdoor spaces there is a Transitional Space (TS) (Text 4.2.2) through which a man-made space actually breathes into the natural environment. Thermal environment of TS is modified by the overall settlement pattern. That is why temperature, relative-humidity and wind-gradient data are collected from four TS at four RD. These data are compared among each other and also compared with the data that are collected from Dhaka meteorological station at Agargaon. During April, May and June (summer) people of Dhaka experiences the most hot-discomfort and get heavily dependent on active means of climatic control putting tremendous pressure on scarce energy supply. Therefore the month May is selected for survey and climatic data collection.

Finally, the physical characteristics are correlated with the climatic data of TS of all four RDs and the positive and negative effects of densification pattern on TE are pointed out. The study ended up with some specific recommendations that can be considered in modifying Building Construction Rules (BCR) to facilitate passive climatic control and thereby to create more sustainable residential environment in DMA.

CHAPTER

1

GENERAL BACKGROUND AND PROBLEM IDENTIFICATION

1.1 INTRODUCTION

Certain objective factors related to planning, layout and building design can be instrumental in achieving thermal comfort in the urban residential environment (Ahmed, 1994, p- 161). Higher density living, within a particular range, can be comfortable and controlled in any given climatic situation if the environmental issues are rightly handled. On the other hand lack of awareness, control and sustainable solution could invite irrecoverable damage to a residential quarter. Sustainability initially refers to the ability of the natural environment to sustain given the toll of human activities on the ecological system (Nijkamp and Soeteman, 1988). The long-term stability can be maintained despite the short-term changes and manipulation when the rate of renewable and non-renewable resources use does not exceed the rate of regeneration process (Rahman, *et al*, 2005).

Over 15% of all savings in both developed and developing countries is invested in dwelling construction and the objective of this massive investment is to provide shelter, security and comfortable living conditions for the occupants; and to produce more than 'housing' – to produce homes (Evans, 1980). Tropical urban climatology is a relatively new area of research (Jauregui, 1986). Comfort in urban spaces is becoming an increasingly important issue in the context of sustainability in cities where conventional and passive climatic controls (PCC) are getting important considerations (Ahmed, 1995).

In Bangladesh, with composite monsoon climate, we do not have proper research-based building by-laws to ensure desirable thermal condition in urban residential environment (Akhtari, 2001; Roy, 2002). On the other hand, catering space for the rapid urbanization and fast growing population has become greatly challenging for the city development authorities. These entire shortcomings happened due to improper execution of city master plans and designs, which are now being poorly compensated by ACC, only in cases who can afford, and putting tremendous pressure on scarce national energy supply.

Assessment of impact on ambient (micro-climatic) thermal environment (TE) due to different patterns of physical development in urban residential districts is the primary concern of this thesis. It is targeted to compare the thermal and physical qualities between different fabric patterns in residential developments of metropolitan Dhaka. Attempt is made to identify some guide lines to control the residential densification process, thereby facilitate sustainable thermal environment and reduce dependency on scarce energy.

Climatic data have been collected in the year 2003 and by now the physical density and morphological pattern have changed a lot in the study areas. But the analysis and findings of this study are still be valid for the residential districts presently bearing similar physical densities and morphological patterns to those of four survey areas in 2003.

1.2 BACKGROUND

Dhaka city, the capital of Bangladesh, is experiencing huge influx of rural to urban migration since independence of the country in 1971. With that residential development is taking place at high rate to cater the need of increasing population. To do so new lands at the city fringe areas are being developed both in public and private sectors, large plots are being sub-divided into smaller plots and one-unit houses are being replaced by multi-unit and multi-storied residential buildings. To accommodate ever increasing population all the open areas here and there are being occupied by the new apartment blocks. The morphological structure of Dhaka city has emerged in an organic way. In an organic growth, of course, the development has a continuous fabric rather than a cellular one to provide the possibilities of social interaction and to prevent segregation (Lynch, 1981). The morphology of the city looks like a maze (Nilufar, 2000). In new Dhaka some of the areas are developed in planned way.

Urban micro-climate is getting more and more adverse due to these new physical developments. Along with that tremendous pressure is being exerted to all other urban service facilities and amenities. Dhaka city development authority (RajUK) has so far not shown the capacity to successfully control and maintain a sustainable environmental quality in the city through the implementation of appropriate building by-laws.

Among all amenities in life appropriate thermal environment plays a very significant role for meaningful, pleasing and efficient day to day living. Maintenance of thermal equilibrium between the human body and its environment is one of the primary requirements for health, well-being and comfort (Givoni, 1969, p-19). Prolonged exposure to thermal discomfort situation can cause permanent physical impairment and thus drop of working efficiency. Our daily life cycle comprises states of activity, fatigue and recovery and it is essential that the mind and body recover through recreation, rest and sleep to counter-balance the mental and physical fatigues resulting from activities of the day (Crowden, 1953). For easy recovery, when we come back to our sweet home for rest, we badly need thermally comfortable environment in and around our home. Residential quarters are most important areas of a city compared to other uses like, commercial, industrial, recreational, etc. because, after all, we want to make our home there. No doubt, this thermal comfort is to be ensured as far as possible through PCC, specially where energy or power supply is scarce.

1.2.1 Urbanization in Bangladesh

Like other developing countries Bangladesh has been experiencing high rate of urbanization, specially in the capital city of Dhaka (Roy and Abdullah, 2005). Rapid growth of urban population[1] after independence coupled with shortage of buildable land and lack of proper administrative management made the situation almost out of control. By the end of first decade of the 21st century, majority of the world's population will be living in urban areas and many of the developing countries will be predominantly urban (Islam, *et al,* 1996). A recent prediction by ministry of environment suggests that more than 37% of the total population will be living in urban areas by 2015 instead of 23% in 2001 and we shall have to accommodate about 68 million people in urban areas (Islam, 2002). In line with this, Dhaka is also facing huge burden of population migrating continuously from all over the country. The capital city (Dhaka) development authority RajUK always faces tremendous pressure to keep pace with this ever growing complicated situation. Severe lack of logistics, lack of skilled manpower in RajUK and scarcity of land for new development together made the situation aggravated in Dhaka.

Table 1.1 : Inter-censal growth rate of Urban Population in Bangladesh, (1974-2001)

Census Year	Urban Population		Inter-censal Variation		Annual Growth Rate (Exponential)
	Number	%	Number	%	
1974	6,273,602	8.78	3,632,876	137.57	6.66
1981	13,228,163	15.18	6,954,561	110.85	10.66
1991	20,872,204	19.63	7,644,041	57.79	4.56
2001	28,605,200	23.10	7,732,996	37.05	3.15

Source : Bangladesh Bureau of Statistics (BBS), *Population Census 2001:National Report (provisional)*, 2003, p-28.

[1] A sharp rise of urban population was noticed after independence of the country in 1971 due to rural to urban migration in search of better job, education, business and other opportunity. The high urban growth between 1974 through 1981 was accounted due to extended definition of urban area in 1981. Highest density of population is seen in Dhaka district (5887 per sq. km.) and lowest in Khagrachari district (191 per sq.km.). As much as 91.7% population of Dhaka district is living in urban area. According to adjusted population of census 2001, population of Dhaka mega city (city having population 5.0 million or over) stands 10,712,206.

Developer built multi-storied apartments and mixed-use commercial complexes are slowly cropping up in Dhaka city to cater for the ever increasing needs of residential accommodation. These schemes are designed in such a way that their internal environments are almost impossible to tolerate without extensive mechanical cooling and often air-conditioning (Ahmed, 1994, p-6). These dwelling units, therefore, in their present state can not be accepted as efficient or sustainable solution for urban housing crisis, specially in the context of Dhaka.

1.2.2 Urban Situation in Bangladesh

Unplanned human activity and development process are aggravating the urban climatic conditions within contemporary cities and the planning problem during the past few decades has been responsible for a significant increase in temperature in cities around the world (Ahmed, 1994, p- 5-6). Effects like *urban heat island* can ultimately become driving climatic force in a given city, and is directly attributable to density of built-up area, which causes slower night-time cooling. This effect acts adversely in achieving thermal comfort in the cities of tropical region. Bangladesh is located within the tropical belt and experiences excessive natural heating during day time all over the year except the brief winter. In urban setting proportion of hard surface is comparatively higher than in rural setting, which create increased day time overheating and surface water runoff. Rapidly growing concentration of built-form in Dhaka is experiencing the similar problem in its thermal environment, specially in CBD (Central Business District) areas.

In the study conducted by London Architectural Association School of Architecture (AASA) climatologists have shown that all areas of Dhaka do not get heated in a similar pattern due to differences in the presence of trees, ponds or water bodies in different areas. In peak summer Motijheel or Tejgaon or Karwan Bazar area gets more heated (temperature can rise as high as 42° to 43° Celsius and creates *urban heat island*) than Ramna Park or Dhanmondi residential area. Dr. K. S. Ahmed in his PhD research at AASA (1995) has shown that Motijheel commercial area (old CBD of Dhaka) develops about three (03) degree Celsius higher temperature than in Ramna Park (largest green park located in the central part of Dhaka city) during a typical summer day (during April to July). Md. Nuruzzaman and Ershad Hossain, Department of Environment, Bangladesh, have shown in their study that temperature of Mirpur area remains above average though there is enough green vegetation. They pointed out that high density living and adjacent smoke emitting brick kiln are responsible for this situation. During summer Dhaka city receives solar radiation during day time for about 14 hours, while it reradiates heat during night time for about only 9 hours. A thin layer of cloud and closely built-up buildings also impede nocturnal cooling process and thus cumulative heating goes on. On top of that, artificial heat emitting sources (both indoor and outdoor) aggravate the summer situation and hot discomfort in Dhaka city (Hossain, 2003).

Due to better accessibility and strategic location certain residential districts in Dhaka are getting tremendous concentration of dwelling units. Thus higher density of power usage increases the ambient temperature in those areas and eventually dependence on ACC is increasing. Any uncontrolled activity affects everybody in the community and the environment at large. That's why immediate measures shonld be taken for Dhaka, specially for residential developments, so that the building construction rules and by-laws are properly based on climatic considerations and thus deliberately regulate the PCC.

1.3 STATEMENT OF THE PROBLEM

Heat is the dominant problem in tropical climates and here buildings serve to keep the occupants cool, rather than warm, for greater part of the year (Koenigsberger, *et al*, 1992). The daily, monthly and yearly absorption of heat by the built-environment must be dissipated by the turn of the day, month and year respectively without exposing the inhabitants into severe discomfort. To make a building envelop is to create a system linked to its surrounding environment and subject to a range of interactions affected by seasonal and daily changes in climate and by the requirements of occupants varying in time and in space (Steemers, *et al.* Ed, 1986).

Skin is the outer most envelop of hnman body that interact with its surrounding environment and tries to keep thermal balance by releasing surplus metabolic heat from the body and maintaining deep body temperature at 37°C. And we move to the places where thermal environment is conducive to retain this balance. Our house is a further non-living envelope, which is expected to interact between indoor and outdoor environment and maintains comfortable living environment inside the house. That is why urban dwellings must be designed on the basis of climatic considerations, specially the micro-climate in case of urban dwelling.

In the context of Dhaka there are no such comprehensive rules and control to achieve thermal comfort in urban residential environment. The city of 11 million (2005), the 13th largest populated city and going to be the 4th largest city by 2015 with 21 million population, has Dhaka Metropolitan Development Program (DMDP) where total area, road network, residential areas, lakes and ponds, playing fields, transportation system, etc. have been demarcated. But they are not materialized accordingly and expansion of Dhaka is being made arbitrarily (Karmoker, 2005). Because of that water supply system, sewerage system, waste disposal system, transportation system, etc. are going to be collapsed, which is signaling a very severe environmental degradation waiting to commence. Many residential districts (like Wari, Dahnmondi, Gulshan, etc.) have lost their earlier environmental good qualities and came up with ever-increasing building mass and population densification. Dependence on ACC is therefore rising alarmingly; concentrated consumption of which induce further heat energy in lieu of reducing it as a whole. On the other hand, increasing dependence on ACC is severely taxing on energy sector; production of which always remained lagging behind in Bangladesh. In this situation we urgently and badly need a remedial guide line for sustainable development in our urban residential sector along with other sectors.

1.3.1 Points of Reference

1.3.1.1 Urban Climate and Peoples' Need

We have tropical composite climate in Bangladesh, which changes season from hot-dry summer to warm–humid rainy and then to cool-dry winter. For thermal comfort the built-form need to cut the incoming solar radiation in warm seasons when in winter solar radiation is welcomed. Wind flow through the living spaces is better to be restricted during hot summer day and cold winter night. But it is very much wanted during warm-humid monsoon to facilitate convective and physiological cooling when all other means of surplus body-heat release process fail due to small diurnal range and high humidity. Round the year people here are acclimatized in one season and then exposed to different one with changed or opposite thermal pattern. If this change happens gradually and remain within the tolerable limit, people will have enough time to acclimatize by changing the rate of metabolism in the new set of Thermal Environment (TE) and live with comfort. But the recent researches find that changes in urban climate happened adversely and seasonal differences are getting extreme compare to the earlier decades. Increase of hard built-up mass and reduction of soft natural mass, as mentioned earlier, is identified as one of the major reasons for such extremities. PCC are no longer working and even ACC are not working very well posing threat to sustainability as a whole.

1.3.1.2 Climate – Building Interaction

The variables of TE of an area largely depend on amount of solar radiation received during day-time and released during night-time (Koenigsberger, *et al*, 1975). Low-density developments put less obstruction to airflow and can accelerate the convective cooling process, specially during night time. As soon as density changes, this balance is found to alter. Comparatively cooler temperatures were measured in shaded areas of the planned residential neighbourhoods of Dhaka than in the closely packed unplanned parts of the city (Ahmed, 1994).

Surface quality in terms of hardness and softness is another factor. The amount of solar radiation absorbed or reflected by any surface depends on its *albedo*; indicative of the hardness or softness of a surface. Two buildings of the same volume, built of the same materials, may have quite different surface areas and therefore different rates of fabric heat loss (Evans, 1980; Koenigsberger, *et al*, 1975). Depending on the surface quality, that is softness or hardness, cooling effect can vary largely. We can have this proof if we move from an urban center to a rural countryside, specially during a hot sunny day. Vast expanses of exposed vertical surfaces in high-rise buildings become heat traps for incoming solar radiation (Givoni, 1969; Markus, 1980). Surface characteristics are therefore found to affect the TE directly.

1.3.1.3 Hard and Soft Surface Textures

Cities have produced the most notable man-made changes like, three dimensional urban forms, surface paving, population density, density of activity, etc. that affect the ambient climate (Ahmed, 1995). Due to rapid urbanization and population growth quick densification process is taking place in residential areas of Dhaka (Ahmed, 1994) and is increasing concentration of hard mass or hard surfaces, all of which influence the TE and may result in increased heat absorption and decreased heat emission. On the other hand existing vegetation, water bodies and other natural elements, which constitute soft textures and help increase cooling effect, are destroyed mercilessly in Dhaka city (Mahmud, 2008).

1.3.1.4 Building Construction Act of Dhaka

The recent Building Construction Rules (BCR) for Dhaka that has been activated in 2007 incorporated Floor Area Ratio (FAR) and Ground Coverage (GC) rules for the first time in the history of Bangladesh (GOV, 2007). Before that building setback and height determining rules were the only regulatory mechanism to control physical density of building mass. In these new set of rules small sized plots are allowed more land coverage with lower FAR while the larger sized plots are allowed less land coverage with higher FAR for residential development. Due to weak inspection and loose monitoring of RajUK BCR is violated in most cases, which in turn produces higher density of building mass than the rules allow, posing threat to the TE and public safety (Chowdhury, 2003).

1.3.1.5 Energy Dependency and Crisis

This growing thermal problem increases dependency on ACC, raising demand on valuable conventional energy resources (Ahmed, 1987), (Mowla, 1999). People are largely depending on ACC and consuming more and more energy when failing to depend on PCC. Use of electrical and electronic home appliances has increased manyfold, which also raised the consumption of power supply. Import policy of heavy electrical home appliances like air-cooler (1 ton of refrigeration consume more than 2,500 W), washing machine (80 to 150 W), microwave oven (800 to 1600 W), etc. does not have relationship with the production of electricity within the country. Easy availability of these products now-a-day makes them accessible for the vast middle-income consumers. Unnoticed load shedding in power supply is a very common practice in Bangladesh as power generation always remains less than the actual requirement, which produces intolerable situation during warm seasons. Total requirement during peak hours in 2006 mid-February (end of winter) was more than 4,500 megawatt where production is lacking more than 1,000 megawatt (Prothom Alo, 25 Feb 2006) and the situation deteriorates further during summer when consumption escalates.

At present there are no guidelines to regulate the relationship between TE and development of physical built fabric in residential areas (Ahmed, 1997). To cater to the huge demand of urban dwelling unit both public and private sectors are producing high-rise apartments. These apartments and other multi-storied residential buildings are constructed without keeping enough space between two structures and creating ever increasing density of population and physical mass. Traces of soft and natural textures are being completely withdrawn, which is very much alarming for PCC.

If this process of limitless densification goes on without proper control, TE of urban residential districts in Dhaka will arrive at a point of no return. To ensure the desired comfortable residential environment appropriate rules should be formulated and activated in practice very strictly, so that we can forecast and guide our development. With that we can enjoy better comfort at cheaper cost through PCC and channel our scarce energy supply to other significant development sectors. So, before it is too late scientific investigation should be made to find the comparatively better form of development and go with it in future.

1.3.2 Approaches to the Problem

In this field of study *"Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gain"* has been made by Z. N. Ahmed in her Ph.D. research (1994). The analysis has clearly pointed out the importance of material selection and consideration of U-value as a factor in creating cool interiors. Decreasing U-value of the fabric only helps to trap the internal heat content and average temperature of the interior tend to attain higher than the exterior. However, time-lag of the fabric is an effective restriction to heat influx. But the increase of time-lag by raising thermal capacity of the building fabric is directly proportional to the thickness of the fabric and thus raising cost and dead load of the building. Increased ventilation during the night and limiting the exchange rate during the day has been revealed as a viable passive cooling option available in this climate. This study has been restricted within the formal sector of residential development in Dhaka.

An investigation was made by F. H. Mallick on *"Thermal Comfort for Urban Housing in Bangladesh"* for his Ph.D. research (1994). Here he dealt with the individual building form and its thermal performance. Implication of specific building construction rules in a residential district or a neighbourhood is not assessed in this research.

Another research was conducted by A. S. Akhtari on *"Effects of Building Volume on Urban Morphology: a case study of Dhanmondi residential area, Dhaka, Bangladesh"*, for her M.Sc. thesis at Asian Institute of Technology, Bangkok in 2001. Here she investigated into the morphology of Dhanmondi residential area of Dhaka and tried to identify a set of feasible guidelines to be followed or imposed by the authority to achieve better PCC in formal sector housing development. Her study was focused in monsoon season of Bangladesh when enough air flow through living spaces becomes most essential. To facilitate enough sun light sun angle is to consider as 24°and for air flow enough setback space corresponding to height of the building is suggested. Building orientation is also suggested towards the wind direction keeping ground floor open with perforated boundary walls.

1.4 OBJECTIVE OF THE RESEARCH

Indoor climate is manipulated by many a factors. First by the building envelop itself, its design layout, orientation, exposure, material of construction, colour, texture, depth, height, etc. Secondly, by the occupancy pattern, privacy pattern, security measures, use of power consuming devices, occupants personal choices, etc. Assessment of indoor condition by handling all these variables is beyond the scope of this research. Outdoor natural environment is also beyond our control. So the Transitional Space (TS), through which a man-made indoor space breathes into the outdoor natural space, is taken as the location of investigation. TE of this TS is possible to manipulate or control to some extent through the over all arrangement and design criteria of built-forms in a particular area.

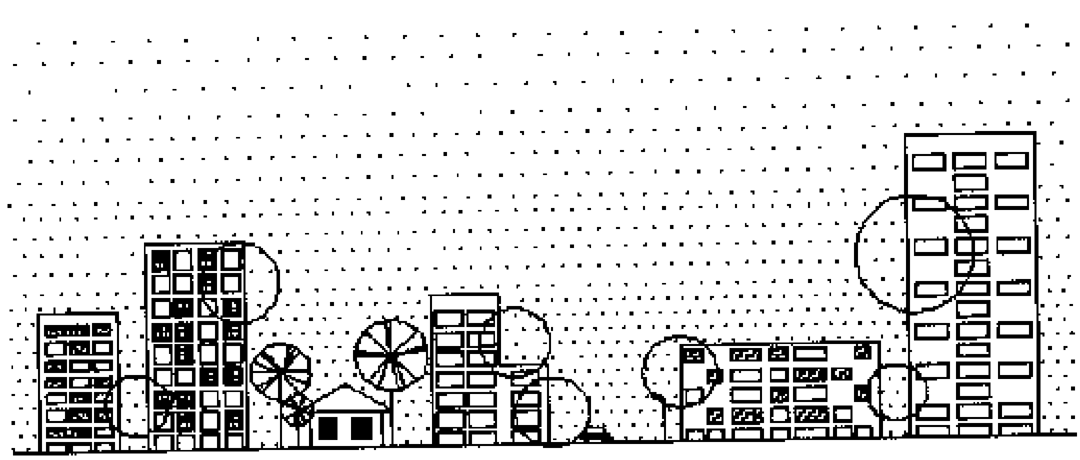

Figure 1.1 Transition point within a settlement marked with circles.

The main objective in this research is to identify the more acceptable fabric pattern and development strategies among existing different fabric patterns in terms of thermal performance and recommending the better one for further residential development. A guide line suggestion can be given to formulate building by-laws which can ensure sustainable comfort situation in the residential districts of Dhaka city relying mainly on PCC and thus reducing dependence on ACC.

Open spaces around a building are those prescribed in building construction rules of RajUK[2] to be kept as mandatory setback space to facilitate free air-circulation, admission of natural light to indoor living spaces and access for service purposes and engineering considerations (Ahmed, 1994). But these rules are changed from time to time to facilitate more and denser accommodation in the same sized plot compared to earlier accommodation. During such changes future impact of climatic factors on changed built-forms is not analyzed, neither is any post occupancy monitoring made to assess their performance. Various setback spaces are compared here from the thermal point of view.

Ratio between soft and hard physical development is analyzed with special care to identify its relationship with TE. The impact of FAR on TE in residential development is analyzed in this study.

1.4.1 Objectives with Specific Aims and Possible Outcome

- To identify relationship between thermal variables and ratios of hard to soft surfaces in residential districts of DMA.
- To determine relationship among physical density, building morphology and wind flow characteristics around residential buildings in Dhaka.
- To suggest a comparatively more acceptable FAR to offset the extreme thermal impacts due to increased densities in residential areas of Dhaka.

1.5 SCOPE AND LIMITATION OF THE STUDY

The study is primarily based on observation, field data measurement, literature survey, discussion with the inhabitants, comparison and analysis of data and then summing up into findings. A number of existing residential districts with different development

[2] *Rajdhani Unnayan Kartripakhya* translated as 'Capital City Development Authority' and who is responsible to introduce construction rules and enforce them in practical development. These rules are Formulated on the basis of 'The Building Construction Act -1952, Bangladesh', and enacted with final amendment through Govt. Gadget 'Building Construction Rules, 1996'.

patterns (both in formal and informal sectors) are selected in metropolitan area of Dhaka city as study areas. This is really a rare opportunity to get different characteristic residential development simultaneously existing from southern old part to the northern new part of Dhaka metropolitan area. Study period is taken in the peak summer (middle of the month May) for investigation as it causes the highest discomfort compared to other periods of a year.

The study has come up with a number of recommendations that can be considered to be included in the existing building construction rules so that it can get a climatic basis. A scientific reference is made to motivate people and convince them to follow healthy building by-laws.

It is not with in the scope of this research to observe and record the gradual development of any residential district and its changing effects on thermal environment for a long period of time. Due to limitation of time and measuring instrument only one spot in every residential district is selected for climatic data collection. It would be better to have more generalized picture if many similar survey spots were used simultaneously for data collection. An appropriate computer simulation study could be done to cross-check the real-life performances.

1.6 METHODOLOGY OF THE RESEARCH

Survey Areas and Strategies

Four residential districts from metropolitan areas of Dhaka city with different densities and level of developments have been identified both from formal and informal sectors. Physical survey in those residential districts is made to determine density of building mass and ratios of open area to built area in a gross calculation. Surface characteristics and vegetal cover is also noted. Different types of building layout, street layout and orientations are recorded to correlate them with measurements of thermal variables and objective comfort factors.

Figure 1.2 Dhaka City map (not to scale) showing four survey areas.

(A-Sutrapur in old city, B-Dhanmondi R/A, C-BUET Teachers' Quarter, D-Banani R/A and E-Meteorological Station of Dhaka)

Survey Spot Selection

To have various fabric pattern and forms of development a reconnaissance survey is made by the author in the metropolitan areas of Dhaka. Within the existing residential districts four different spots are selected. Spot – 01 is in Sutrapur area, located in old part of the city with high-density informal sector development having incremental growth pattern. Spot – 02 is in Dhanmondi residential area, a formal sector planned area where maximum 6-storied residential structures are permitted and population density is also high. Spot – 03 is a planned University Teachers' Quarter with low-density development and having large proporion of soft textures. Spot – 04 is taken in Banani residential area, which is comparatively a new and planned development and population density is comparatively low.

Literature Survey

Thorough literature study is made in the relevant subject. Researches so far made in this broad field by the local researchers were thoroughly studied to have a comprehensive idea about the findings so far made and to understand the processes of investigation in this regard. Several other relevant publications are also reviewed before and during the investigation. Important articles in the relevant field published in widely circulated national dailies are also taken in to account.

Data Collection

Measurement of temperature, humidity and airflow is made simultaneously in all survey areas at a time (during May 2003) with the help of three handheld digital weather meters (Kestrel 3000) procured from United States of America and two data loggers (Hobo H8 Logger) collected from the Department of Architecture, BUET, Dhaka. They were calibrated in the study field situatiou with the prescribed calibration kits. To compare the site climates with the average city climate of the same time temperature, humidity, rainfall and wind speed data from the Dhaka meteorological station have been purchased.

Analysis of Data

A comparative analysis of climatic data collected from different residential areas is made to ideutify variatious in temperature, humidity and air flow pattern among the different residential districts under investigation. Attempts are also made to identify the extents of variations, causes of variations and their qualities of TE. Finally climatic quantities and TE qualities are correlated with densities of building fabric, densities of population, floor area ratios, hard to soft area ratios and building fabric pattern to identify the best performing residential district among all four investigation areas.

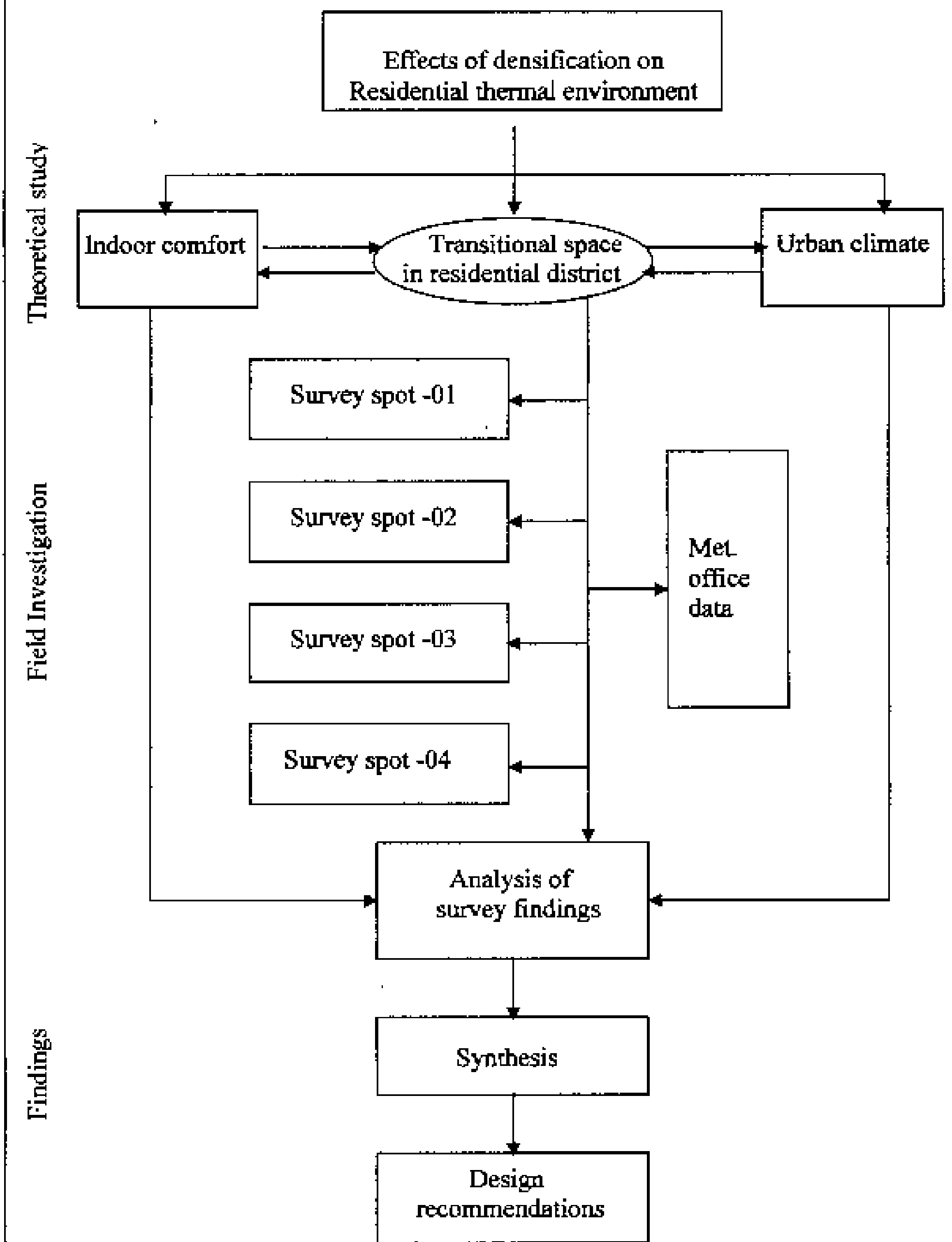

Figure 1.3 Structure of the work.

1.7 STRUCTURE OF THE THESIS

The research is based on primary field survey findings. The surveyed climatic data is juxtaposed with existing factors related to planning and design pattern in four residential development contexts of metropolitan Dhaka. The research is guided by analyzing the comfort criteria, relevant research, existing building regulation, up-coming problems and field data. The broad structure of the thesis is comprised within (06) major chapters.

Chapter – I: Introduction

It is the introductory part of the thesis and it starts by defining aspects relevant to targeted objectives of this investigation. It attempts to indicate the state of the problem underlined by lack of control about the changing surface characteristics in the residential districts (RD) of Dhaka metropolitan city and its adverse impact on micro-climatic situation and overall degradation of thermal environment (TE). This chapter includes statement of the problem, approaches to the problem, objectives of the research, research methodology and structure of the research.

Chapter – II: Macro and Micro Climate of Dhaka

Here discussion is made on regional climatic pattern and various climatic parameters of the investigation areas. Mainly information from secondary sources are used to portray the micro-climate of Dhaka metropolitan area. Expected kind of thermal environment in residential areas of urban life specially in Dhaka, where tropical composite climate is in question are discussed. Factors of urban micro-climatic variations or deviations and their possible eventual impact on TE, especially in the residential districts of metropolitan Dhaka are indicated here.

Chapter – III: Human Comfort and Thermal Environment

Physiological comfort criteria for urban living environment in the socio-cultural and economic context of Dhaka are identified in this chapter. General thermal comfort issues and problems are discussed here. Investigation is made on living pattern and desires of urban dwellers. How hnman comfort in their living environment is related to the thermal parameters of that environment is discussed here.

Residential zones of Dhaka metropolitan areas and their physical changes that have happened over time are analyzed. Their probable future growth is projected to assess the future strategic needs to maintain comfortable thermal environment. Building construction rules and their impact on thermal environment in residential district of Dhaka are discussed here.

Chapter – IV: Field Investigation

Survey areas and strategies:

Strategies for selecting the survey spots in a number of residential areas are mentioned here. Justification of the survey period is also discussed. How the physical survey in those spots were made to determine density of building mass and ratio of open and built areas, surface characteristics and vegetal cover are noted. Different types of building layout, street layout and orientations are recorded to correlate them with measurements of thermal variables.

Data collection:

Primary and secondary climatic data that are collected respectively from field and literature survey are recorded here. Temperature, humidity and airflow data (primary) are measured with instruments simultaneous in different residential spots of Dhaka and furnished them in tabular form. Other socio-physical data (primary and secondary) are also provided to co-relate them with the climatic data that are found in the survey. Climatic data also collected at the same time from meteorological station of the city and furnished to compare them with the survey spot climatic data that are collected from the different residential districts.

Chapter – V: Analysis of Data and Information

Urban or micro climate in and around different residential districts (those which are under investigation) of Dhaka is analyzed and correlated. A comparative analysis is made to identify differences of thermal environment between different study areas with differences in physical pattern. Co-relation between density and TE, co-relation between surface difference and TE, and co-relation between Hard to Soft Surface Ratio (HSSR) and TE of the concerned residential districts are investigated.

In this comparative analyses a number of factors like building height, physical density, layout of building mass, population density, HSSR, GC, energy consumption, etc. are discussed.

Focus is placed in searching building by-laws which can guide and widen the scope of PCC and thus sustainable physical comfort in the RD of Dhaka can be ensured. With this, attempts are made to ascertain ways and means to improve the quality of life.

Chapter – VI: Conclusion and Recommendation

Recommendation for future sustainable physical development of residential districts in Dhaka is given in terms of their TE. Certain guide lines are suggested that can be used by the development authorities of the city in developing rules and regulation for future residential development control and thus reduce dependency on scarce energy resource.

For practicing architects certain design guidelines in terms of building layout, height, ratio between hard to soft surface, etc. are suggested based on the findings and data analysis. Some other general findings are provided in simple specification form so that they can be disseminated through mass media to develop mass awareness about TE issues among the city dwellers. Process of motivation and better participation of all in making better living and sustainable environment in the city are recommended.

1.8 CONCLUSION

Although researeh on climatic issues and thermal environment is vast in nature and needs long observation and laboratory experiments, here it is conducted based on brief observation and thorough literature study and touched specific architectural design and planning aspects due to limitation of this research capacity. A standard and structured investigation is attempted to come up with some fundamental findings. The ultimate achievement may be limited but it will create positive impact to the overall process of residential development in Dhaka city and form the basis of future research in the field.

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CHAPTER

2

MACRO AND MICRO CLIMATE OF DHAKA

2.1 INTRODUCTION

Means and ways of achieving thermal comfort in any living space largely depend on climatic aspects of the concerned region. Proper assessment, analysis and management of climatic parameters can provide us with easy and economic techniques to achieve thermal comfort. Bangladesh has a tropical monsoon climate having a number of seasonal changes through out the year. Changes happen from hot summer through monsoon to cold winter and comfort criteria vary widely from one season to another. Rapid urban development of Dhaka in the present years made huge physical changes and we know urbanization has impacts on urban climates (Oke, 1979). Elements and components that constitute the landscape of a city affect the regional climate through a complex interaction generating distinct microclimates (Ahmed, K. S. 1995, p-14). That is why both the study of macro and micro climate is very important to make an investigation on thermal environment in a heavily built-up city like Dhaka.

2.2 REGIONAL OR MACRO CLIMATE OF BANGLADESH

According to UNESCO description Bangladesh is lying between 20° 34′N to 26° 33′N (tropic of cancer is passing through the middle of the land) and 88° 01′E to 92° 41′ E in the Indo-Malayan realm (Lean, 1990). It is surrounded by land mass on east and west sides. The Himalayan range and Bay of Bengal almost bracket the country respectively from the north and south. Bengal basin, which is situated at the confluence of the Ganges-Brahmaputra-Meghna river system (Datta and Subramanian, 2000), has low elevation (between 5 and 6 meters above sea level; Milliman *et al*, 1989), which suffer frequent flooding (Rasid and Paul, 1987). Regional climatic differences in this flat land are not very significant.

The composite climates are usually occur in large land masses near the tropics and which are sufficiently far from the Equator to experience marked seasonal changes is solar radiation and wind direction (Koenigsberger, *et al*, 1992, p-26). According to the classification given by G.A. Atkinson in 1953 and which is widely accepted and proven useful the composite or monsoon climate has the following temperature pattern through out the various seasons. Approximately two-thirds of the year is hot-dry and the other third is warm-humid (Koenigsberger, *et al*, 1992, p-23; Ahmed Z.N., 1994, p-13). But in Bangladesh the warm-humid season or monsoon prevails for almost half of the year (from

June to October), which is followed by cold-dry winter (from December to February) and then by a short spell of hot-dry summer (from April to May). The summer strikes all of a sudden after a brief comfortable spring in between winter and summer. There is not enough time for acclimatization for summer. That is why it brings unbearable discomfort to the people of this region.

Table-2.1: Air temperature pattern in different seasons of Composite climate

Seasons	Winter or cold-dry	Summer or hot-dry	Rainy or warm-humid
Day time mean max.	up to 27 °C	32-43 °C	27-32 °C
Night time mean min.	4-10 °C	21-27 °C	24-27 °C
Diurnal mean range	11-22 deg C	11-22 deg C	3-6 deg C

Source. (Koenigsberger, *et al*, 1992, p-26)

2.3 URBAN MICRO CLIMATE OF DHAKA

Dhaka, the capital city of Bangladesh, lies just north of the tropic of cancer between north latitude 23° 40′ to 23° 55′ and between east longitude 90° 20′ to 90° 30′ and is far enough inland to be free of coastal effects (Ahmed Z.N., 1994, p-13; Mridha, 2002). The city is surrounded by three rivers and low flood plains of these rivers ou three sides; *Buriganga* river on the south, *Balu* river ou the east and *Turag* river on the west. On the north side there has vast low-lying agrarian land, which is rapidly being raised and transforming into build able land by various real estate companies in the recent years.

Figure 2.1 Map of Dhaka city (not to scale)

The climate of Dhaka is greatly influenced by the presence of Himalayan mountain range and Tibet Plateau in the north and Bay of Bengal in the south. Like other parts of Bangladesh, Dhaka also experience composite monsoon climate. Here four main meteorological seasons, namely Winter (December to February with cool-dry), Pre-monsoon (March to May with hot-dry), Monsoon (June to September with hot-wet) and Post-monsoon (October to November warm-wet) are seen through out the year (Mridha, 2002, p-10). Each time during the transition of seasons from hot to cold and from cold to hot a few weeks appear with comfortable situation.

Table-2.2 : Air temperature pattern in different seasons of Dhaka region.

Seasons	Winter or cold-dry	Summer or hot-dry	Rainy or warm-humid
Day time mean max.	26.6 °C	33.6 °C	31.3 °C
Night time mean min.	14.6 °C	21.7 °C	25.4 °C
Diurnal mean range	12 deg C	11.9 deg C	5.9 deg C

Source: (Ahmed Z.N., *Assessment of Residential Sites in Dhaka with respect to Solar Radiation Gains*, Ph. D. Thesis (unpublished), De Montfort University in collaboration with the University of Sheffield, UK, 1994, p- 13)

Due to the pattern of physical development and geographical location the climatic characteristics of Dhaka city differs from other cities of Bangladesh; it is further modified in different locations within the city depending on difference in surface qualities, density, heights of three dimensional objects and other related factors (Koenigsberger, *et al*, 1992). This fact is more pronounced in developed countries where physical features of urban areas have more difference with surroundings, than tropical environments of developing countries (Jauregui, 1993).

2.3.1 Temperature profile of the last 55 years in Dhaka

Monthly mean maximum temperature in winter is found gradually decreasing and in the end of summer and middle of monsoon it is gradually increasing over the years. In April, which is the hottest month in terms of daytime outdoor air temperature, the mean maximum temperature is found gradually decreasing over the last 55 years (Figure 2.2). Clear sky, dry weather, higher solar altitude angle, higher solar intensity and higher duration of sun-shine have given April the status of hottest month in this region. Among the above mentioned factors only two can be manipulated by the man made situation. By creating more and more pave or hard surfaces we can increase the impermeability and thus increase surface water runoff. This in turn will reduce the moisture in the atmosphere near to the ground and create more dry weather. The second man made environmental manipulation is pollution. The atmospheric depletion of incoming solar radiation is increased by the concentration of more and more pollutants in the air, which in turn will reduce the day time maximum temperature level. Dhaka is experiencing rapid urbanization and air pollution in Dhaka city is the highest compare to other cities of Bangladesh.

With the passage of time we can see that the major man made factor that is responsible for air temperature variation is air pollution, which attenuates the incoming solar radiation during daytime and gradnally reduce the maximum temperature levels over time. On the other hand the monthly mean minimum temperature was found increasing during winter seasons and decreasing during the end of summer and in the monsoon. In the month of April, the mean minimum air temperature was found increasing (Figure 2.3). The same reason of air pollution can be said responsible for night time slow re-radiation and thus increasing the level of minimum temperature near to the earth surface. This indicates the lowering of diurnal range in this month.

The diurnal range was found increasing during the month of May and through out the monsoon period (Figure 2.4). With the advent of rain pollutants in the air are washed out and both incoming and outgoing radiation get comparatively more free passage through the atmosphere. On the other hand gradually increasing hard surfaces in the city creates faster absorption and faster release of heat. With the effect of both these factors diurnal range during the monsoon is increasing.

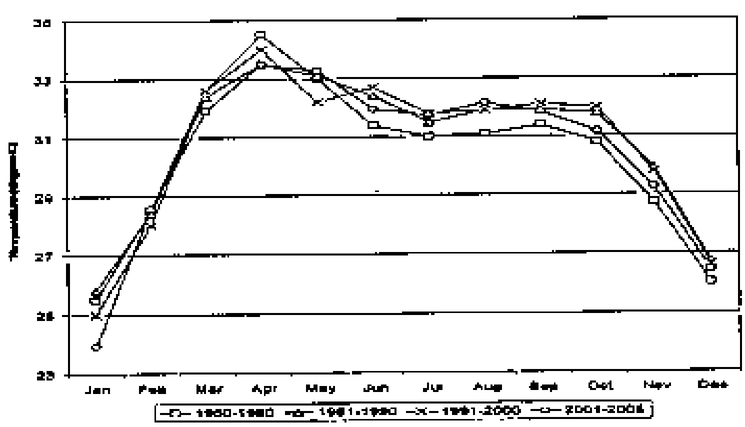

Figure 2.2 Monthly mean maximum air temperatures during 1950-1980, 1981-1990, 1991-2000 and 2001-2005.

Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2007 and Mridha, 2002.

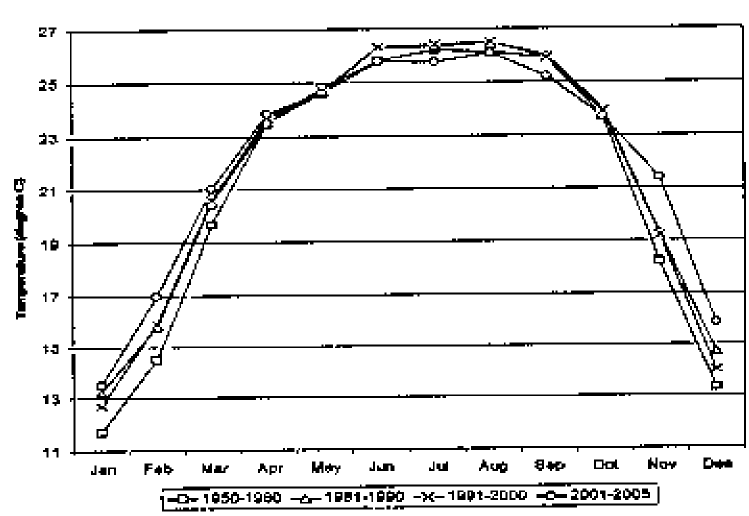

Figure 2.3 Monthly mean minimum air temperatures during 1950-1980, 1981-1990, 1991-2000 and 2001-2005.

Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2007 and Mridha, 2002.

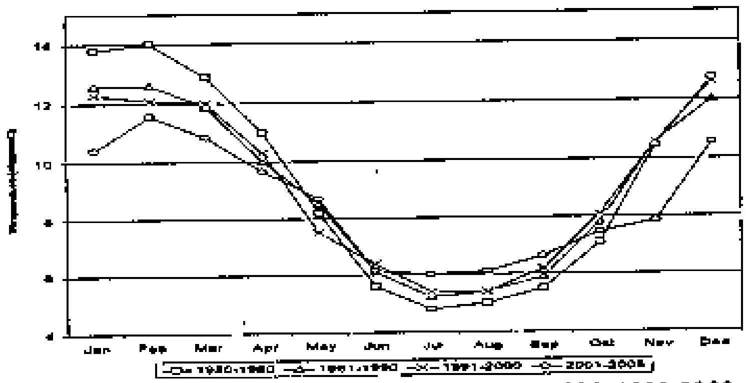

Figure 2.4 Monthly mean diurnal ranges during 1950-1980, 1981-1990, 1991-2000 and 2001-2005.
Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2007 and Mridha, 2002.

2.3.2 Relative Humidity pattern of last 55 years in Dhaka

During the dry period from December through February, that is in winter, an increasing pattern of relative humidity is found over the second half of the 20th century. While during the wet period from June through September, that is in monsoon, an overall decreasing pattern is apparent (Figure 2.5). But the overall level of relative humidity has been found lowest in winter and highest in the monsoon. Relative humidity has been found to be inversely related with the prevailing temperature in Urban Heat Island (UHI) intensity and thus increase of temperature reduces the level of relative humidity in a given situation taking all other conditions remaining same (Mridha, 2002)[1]. The rise of temperature increases the moisture holding capacity of air and thus with the existing level of absolute humidity the measurement of relative humidity will show lower value.

In an investigation Hosssain and Nooruddin (1993) found 2-4% variation in annual average relative humidity between Dhaka and adjacent rural areas. With 50% impervious cover of an area the runoff increases 200% compared with rural conditions and thus urban humidity near the surface decreases due to the rapid run-off (Ahmed Z.N., 1994). Urban, suburban and rural relative humidity exhibits a marked diurnal variation and generally decreases towards city center. During the afternoon in the dry seasons differences may be as high as 12% (Ogunloyinbo, 1984) and nocturnal difference can be as high as 13% in the same seasons (Mridha, 2002).

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[3] Heat island phenomena are the result of urban/rural energy balance and stability differences, which in turn produce different rates of near surface cooling and warming (Lee, 1979)(Oke and Maxwell,1975)(Unwin,1980). The air in the urban canopy is usually warmer than that in the surrounding countryside. This urban heat island effects is probably both the clearest and the best documented example of inadvertent climate modification. The exact form and size of this phenomenon varies in time and space as a result of meteorological, locational and urban characteristics.

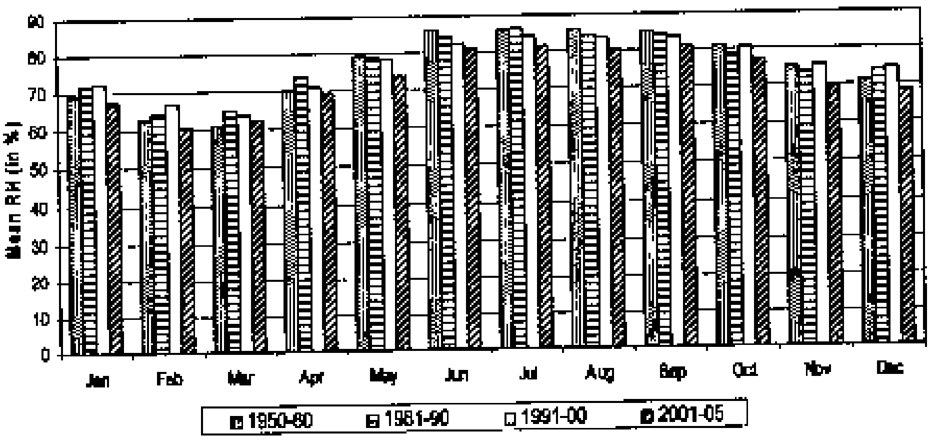

Figure 2.5 Monthly mean Relative Humidity during 1950-1980, 1981-1990, 1991-2000 and 2001-2005.
Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2007 and Mridha, 2002.

In the monsoon the surplus body-heat dissipation depends mainly on evaporative cooling, for which enough air flow at body level in the living spaces is required to propagate the process. If we want to largely depend on natural air flow in this period large gap between adjacent buildings as well as large openings for cross ventilation is necessary. This layout arrangement contradicts with the requirements of dry seasons, when compact form of layout is suitable. To avoid this contradictions a some what medium type of layout is recommended in such composite climate by the experts. Along with this large operable openings are recommended, so that they can be kept open and close as and when required in different seasons.

During the study period here that is in late summer (May, when little rain after a long dry period increases the moisture content in the air, figure 2.5) mean relative humidity in Dhaka city is found between 70-80%, which is moderately high and mean maximum temperature is found more than 33.25°C, which is highest of all seasons (Figure 2.2). If we put this temperature and humidity data in a Bioclimatic chart the situation indicate far away from comfort range and beyond the last limit of achieving comfort by enhancing air movement. The only way to achieve day-time thermal comfort in this period is to preserve the cool environment (achieved through nocturnal cooling) in indoor spaces by avoiding cross-ventilation and cutting all kind of incoming radiation heat. For this we need a very good night-time cooling by ample ventilation through living spaces. Open spaces in between buildings can facilitate this kind of nocturnal ventilation and large canopy of vegetation over these open spaces can cut considerable amount of day-time incoming radiation and thus facilitate passive thermal control in urban situation.

2.3.3 Wind flow pattern of last 55 years in Dhaka

Wind velocity gradient over a city largely depends on its three dimensional development pattern that is on the types of ground cover. Wind speed can be reduced after a long horizontal barrier by 50% at a distance of ten times the height and by 25% at a distance of twenty times the height. In addition to this, air flowing across any surface is subject to frictional effects (Koenigsberger, et al, 1992). The increases in surface roughness within cities cause reduction of wind speeds; mainly during the day (Jauregui, 1984). Near the ground the wind speed is always less than higher up, but with an uneven ground cover the rate of increase in speed with height is much more than with an unbroken smooth surface (Koenigsberger, et al, 1992).

The wind speed is usually measured in flat open location (e.g. airport) at a height of 10 meter above ground level. To convert this to an equivalent wind speed at 3 meter in flat urban or sub-urban locations, the wind speed must be multiplied by a reduction factor as shown in table 2.3. This table illustrates the average reduction factor within dwellings with open windows facing the wind. These reduction factors will only give an approximate indication of the likely variation and will not be applicable in heavily built-up areas, close to high-rise buildings or major obstructions.

Table 2.3 Average reduction factors for wind in different locations

Height	Location	Terrain		
		Open flat unobstructed	Suburban or Wooded	Urban
10 m	In the open	1.0	0.5	0.3
	In building with cross ventilation	0.4	0.2	0.12
	In building with ventilation	0.15	0.07	0.04
3 m	In the open	0.7	0.3	0.15
	In building with cross ventilation	0.3	0.12	0.06
	In building with ventilation	0.1	0.04	0.02

Source: Evans, M., 'Housing Climate and Comfort', The Architectural Press, London, 1980

In Dhaka during monsoon, like other warm humid region, air flow through living spaces with significant speed is very much essential for thermal comfort (by expediting the evaporative cooling process) both in day and night. In summer the outdoor air is hot during day time and it is wise not to allow cross-ventilation through indoor living spaces. But for night time cooling ventilation through living spaces are very much essential and if the air is flowing through a shaded outdoor area before entering the indoor it is allowed even in day. For this situation we need enough open outdoor spaces around our houses and these outdoor areas must have to be covered with soft natural textures.

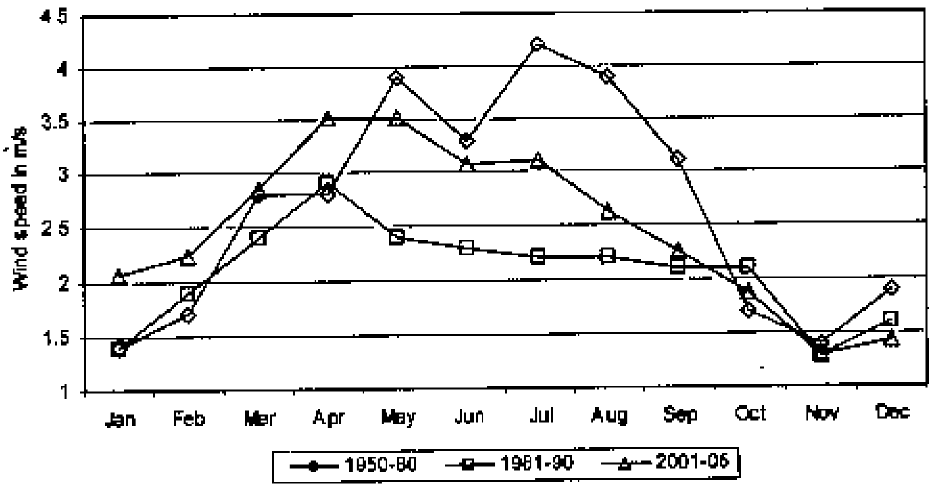

Figure 2.6 Monthly mean wind speeds during 1950-1980, 1981-1990 and 2001-2005.
Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2007 and Mridha, 2002.

Now if we see the figure 2.6 above, we get that usually the wind speed remains higher during summer in Dhaka and lower in winter while the monsoon wind speed remains in-between when it is required higher. The overall magnitude of wind speed in the recent years is showing less than the wind speed during early period (1950-80) and comparatively higher than middle period (1981-90). Due to recent urban densification and replacing the soft textures with hard ones at large scale the city environment is shifting from its early moderate state to a little extreme state. In the urban area the typical building material, building geometry, pollution, lack of vegetated surfaces contribute towards greater heat storage, whilst dense building fabric obstructs re-radiation cooling process (Ahmed K.S., 1995).

2.3.4 Rainfall pattern of last 55 years in Dhaka

The rainfall pattern in any particular month varies over the years keeping within a range. This variation is more pronounced during the monsoon while it is less in winter. If we see in figure 2.7 there is no definite gradual pattern of rainfall variation over the years. Sometimes there the rain was more pronounced during peak monsoon (1950-80) and sometimes it is through pre-monsoon and monsoon (1981-90). But in the recent years (2001-05) starting and ending of monsoon is marked with heavy rainfall. With all this minor monthly variations the annual variation remains within a narrow range and showing gradual decrease over the last 25 years, which indicate increasing drying up of the environment over urban Dhaka. This gradual dearth of precipitation coupled with increasing surface water runoff due to higher percentage of hard surface in urban areas will make the city environment more arid compared to its suburbs.

Table-2.4 : Monthly and Annual mean rainfall in different decayed of Dhaka region.

Time period	Mean rainfall (in mm)												Annual Rainfall
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1950-80	12	20	69	120	258	397	386	326	264	158	26	8	2044
1981-90	6	23	81	199	302	357	377	269	348	159	52	12	2206
1991-00	11	27	69	120	342	267	371	335	293	197	26	13	2093
2001-05	7	15	71	127	289	379	265	247	332	168	12	9	1921

Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2007 and Mridha, 2002.

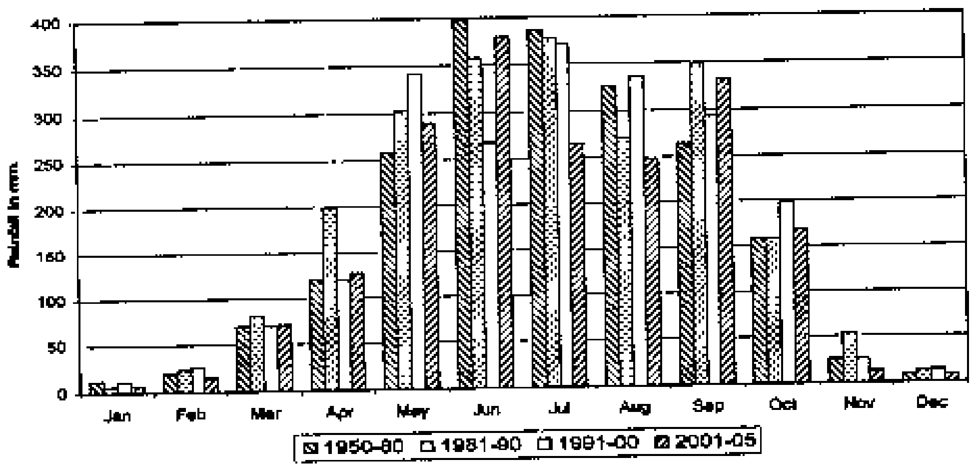

Figure 2.7 Monthly and annual mean Rainfall during 1950-1980, 1981-1990, 1991-2000 and 2001-2005.
Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2007 and Mridha, 2002

2.3.5 Solar radiation pattern over Dhaka

Before 2000, radiation data were not collected regularly by the meteorological department of Dhaka and the raw data are not processed yet (Mridha, 2002). However, radiation data recorded for five (5) years at Joydevpur Agromet Pilot Station and for 7 years at Bangladesh University of Engineering and Technology (BUET), Dhaka, by Mechanical Engineering Department are only available source to evaluate urban effect on incoming solar radiation (Huq and Hassan, 1993).

BUET data were recorded in urban context while meteorological data were collected in rural context. Higher defused radiation usually observed in urban areas due to surrounding built form and hard surface quality. Therefore BUET data represent higher magnitude of global solar radiation. The comparison indicates that the difference between two measured values varies between 13% and 21%, which is in fact very high (Mojumder, 2000).

Table 2.5 Comparison of Monthly Global Solar Radiation between BUET and Meteorological Station of Dhaka

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Global Solar Radiation at BUET (kWh/m^2day)	3.25	4.01	4.66	5.05	4.55	4.01	3.65	3.75	3.75	3.60	3.61	3.15
Global Solar Radiation at Met. office (kWh/m^2day)	2.51	2.61	3.41	3.53	3.04	2.79	2.61	2.56	2.48	2.69	2.49	2.30
Difference (%)	13	21	15	18	20	18	16	19	20	14	18	15

Source: Majumder, A.U., *Thermal Performance of Brick Residential Buildings of Dhaka City,* M. Arch. Thesis (unpublished), BUET, 2000.

Table 2.6 Environmental Matrix of Dhaka

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature			■	■	■	●	●	●	●	○		
Radiation			■	■	■	○	○	○	○	○		
Relative Humidity				●	●	■	■	■	■	●		
Nocturnal cooling prospect	X	X	■	■	■	●	○	○	○	●	X	X

Legend: '■' -very high, '●' -high, '○' -moderate, blank cells indicate low value and 'X' -not required
Source: Mridha, A.M.M.H., *A Study on Thermal Performance of Operable Roof Insulation, with special reference to Dhaka,* M. Arch. Thesis (unpublished), BUET 2002

The amount of solar radiation received on a site largely affected by the physical characteristics of that site and surrounding, which is the major modifier of microclimate or site climate. On a vegetated surface, some of the solar energy is converted into chemical energies and some of the incoming heat is also released by evaporation, but a stone, concrete or especially an asphalt surface cannot do these and can reach a temperature up to 44 degC higher that the surrounding air temperature (Koenigsberger et al, 1975). The actual amount of solar radiation received by the site depends on other factors also like, angle of incidence, atmospheric depletion i.e. the absorption of radiation by ozone, vapours, etc., duration of sunshine i.e. the length of day light period.

2.4 GENERAL COMFORT CRITERIA IN THIS CLIMATE

In different seasons thermal comfort criteria in this region is different. During the cold-dry winter, which is usually not so severe, dissipation of surplus body heat is very easy and one can put on warm clothing to avoid excessive heat dissipation in case of cold wave. North-west direction should be avoided for orientation of house form and window openings. Solar shading devices can be designed in such a way so that in winter, when the sun angle is low, direct sun radiation can enter into the interior living space.

During summer day direct and reflected solar radiation should be avoided in indoor living spaces as the situation gets heated and hinders the surplus body heat dissipation process. Outdoor hot air flowing pre-dominantly from the south and south-east direction should be restricted in the indoor living space at day time. An enclosed type of house form is preferable for day time and there must have ample provisions for night time cooling, so that living spaces become ready for the next day to receive occupants' surplus heat.

The warm-humid climate commence with monsoon and heavy rainfall. Cloudy sky retards both the day time direct incoming sun radiation and night time out going radiation. So diurnal-range is very little and surplus body heat dissipation process through conduction, convection and radiation are not relied for thermal comfort. In such situation evaporative cooling process is the only way to dissipate surplus body heat for which we need ample ventilation at body level and cutting out radiation as mush as possible without sacrificing the airflow. Built forms are thus needed to be loosely spaced and devices to maximize airflow in the living spaces are highly desired for comfort in this season.

2.5 FACTORS AFFECTING CHANGES IN URBAN CLIMATE

High rate of Urbanization deteriorates the atmospheric environment has some implications for the change of climate, especially in many tropical and subtropical cities (Tayseler, 1991). Due to urbanization drastic change in the land use happens, generally transforming agricultural land for residential and commercial usage, which are devoid of vegetation cover and thus increase the albedo. Growth of cities introduces a profound modification of climate by human activities, which is not to be found any place else (Barry and Chorley, 1982). A number of studies show that large cities have experienced significant changes in cloudiness, precipitation, radiation and energy balance, temperature, air quality and visibility (Fortak, 1980; Cleugh and Oke, 1986; Oke, 1982; Nkemdirim, 1988). The pavements, roads, drainage system, built forms, etc. increase radiation heat. Higher concentration of population and the nature of economic activities and generally higher living standards also lead to high energy consumption per capita and unit of land area (Asaduzzaman, 1993). As a result heat island effect develops and in turn leads to higher use of energy to counter its effects. Following table shows the heat-island effects in some cities of the world, where large cities portray stronger effects.

Table 2.7 Heat-Island effects in some cities

City	Increase in temperature	Comments
30 US Cities	1.1 °C	
New York	2.9 °C	
Moscow	3 - 3.5 °C	
Tokyo	3 °C	Increase in minm. Day temperature
Shanghai	6.5 °C	During winter nights

Source. IPCC (Working Group II), *Climate Change; The IPCC Impacts Assessment*, 1990, p.5-3. and Environment Agency (Govt. of Japan), *Quality of the Environment in Japan*, 1989, pp. 19-20. (cited in Asaduzzaman, 1993)

So the major factors that are affecting the urban climate negatively in Dhaka can be summed up as higher percentage of hard surface, dense building fabric, rapid surface water runoff, air pollution, increasing rate of energy usage per capita, increasing rate of energy consumption per unit land area that is higher concentration of energy usage, etc. these are all man made factors, which can be controlled to keep the development process with in the sustainable limit of thermal environment. In a study Hossain and Nuruddin (1993) has shown that air temperature of Dhaka city is 0.5 degC higher on an average in comparison to its rural surrounding (table 2.8). So people should be aware of the changes in urban environment and try to understand the negative effect that is going to be created.

Table 2.8 Comparison of Air Temperature between Dhaka City and its Suburbs (1961-1990)

Location	Mean Minimum Temperature (°C)		Mean Maximum Temperature (°C)		Mean Annual Temperature (°C)	
	Temperature	Difference	Temperature	Difference	Temperature	Difference
Dhaka City (Urban)	21.4	0.5	30.6	0.4	25.8	0.4
Tangail (rural)	20.9		30.2		25.4	

Source. Hossain, M.E and Nooruddin, M., "*Some Aspects of Urban Climates of Dhaka City*", Proc., International Technical Conference on Tropical Urban Climates, Dhaka, 1993.

2.6 CONCLUSION

From the above discussion it is clear that the summer in Dhaka poses the highest temperature profile and also offers the highest potential for nocturnal cooling through clear sky to ameliorate the day time heating and in bringing comfort in comparison to other seasons (table 2.5 and 2.6). UHI effect is also being created and gradually deteriorating the thermal environment with the increase of urbanization and urban density. So rednction of incoming day radiation inside the living spaces, reduction of heat trap in our built forms and provision for ample night time cooling have become paramount important, specially for thermal comfort during summer. In urban situation certain degree concentration of hard mass can not be avoided, which absorbs radiation more compare to a soft natural mass. But we should not cross the limit in formulating the sustainable HSSR around our built environment, as it results in increasing temperature.

The next chapter deals with how humans cope with the thermal environment with particular focus on the tropical conditions found in Dhaka.

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CHAPTER

3

THERMAL ENVIRONMENT AND COMFORT IN DHAKA

3.1 INTRODUCTION

One of the primary purposes of architecture is to reduce extremities of nature. The physical environment of our choice whether man-made or natural acts as modifier and controls sun, wind and rain. Even the most rudimentary shelters are built to protect against the adversities of natural climate and to create environment which is appropriate for all the human activities likely to take place there (Mridha, 2001). Environmental response of people in different cultures and climates thus found expression in their architecture producing a distinctive character. Eskimo's Igloo, Bedonine's Black Tents and Arab's Mashrabias are all indicative of the relative importance placed on the passive control of climate through the design of dwelling units (Imamuddin, et al, 1993). People shape their houses satisfying their functional, cultural, climatic, etc. needs while the houses together produces a changed micro-climatic ambience in a city. Man-made factors like, ground surface quality (reflectance, permeability, soil temperature, etc.), three-dimensional objects (walls and buildings), environmental pollution (in air, water and land), energy use pattern, etc. are responsible for this change (Koenigsberger, et al, 1992).

Buildings occupying formerly open land, pavements on streets, and smoke from factories can alter the climate. Sometimes the unintended change is dramatic. The construction of a simple irrigation canal from the Colorado River to the fertile Imperial Valley of California brought about the formation of Salton Sea in 1905 replacing the desert land after a heavy rain fall in the upper reaches of the river (Eisner, et al, 1993).

3.2 DEFINITIONS AND CONCEPTS

3.2.1 Urban Morphology

Urban morphology is an emerging field of urban study, which mainly deals with the study of cities as human habitat. Morphology is the scientific study of form and structure of animals and plants (Hornby, 2000). Urban morphology is the study of internal organization and land use pattern of a city. It is the foundation for city planning. From morphological point of view, cities are considered as the combination of fundamental physical elements like buildings, plots, lots, blocks, streets, open spaces, greenery, overall landscape, or cityscape. A city cannot grow without people, so people with their social and economic life end uses are also considered in the urban morphology (Akhtari, 2001).

Changes in urban morphology take place due to the changes in government policies, private developers' activities, socio-cultural values, etc. The impacts of these morphological changes are observed in the environmental and social life of the urban dwellers. The geographic study of cities also takes into account of the relationships among people, types of housing, population densities and concentration, rates of growth, and impact of growth on the land and all other resources (Eisner, et al, 1993). Sometimes radical change is made through completely planned redevelopment or urban regeneration.

The morphological structure of Dhaka city has emerged in an organic way. In an organic growth, of course, the development has the continuous fabric rather than a cellular one to provide the possibilities of social interaction and to prevent segregation (Lynch, 1981). But the morphology of Dhaka city looks like a maze (Nilufar, 2000). The area of Dhaka Mega city has expanded 17.88 times while population has increased 25.09 folds during the period 1951 till date. Such expansions have not made in planned way though several plans were prepared to guide and regulate developments of Dhaka (Islam, et al, 2009) except for some areas in the new part of Dhaka.

3.2.2 Urban Climate

Urban climate is a complex combination of man-made and natural climate. Man-made environments can create microclimates of their own, deviating from the macroclimate of the concerned region to a degree depending on the extent and pattern of man's interventions into the natural setting (Text 2.5). Such interventions into the natural environment is greatest in large towns or cities, thus it is justifiable to speak of an 'urban climate'. The factors causing deviations of the urban climate from the regional macroclimate according to Koenigsberger, et. al., are as following:

- a Changed surface qualities (pavements and buildings) –increased absorbance of solar radiation; reduced evaporation.
- b Buildings affecting radiation, re-radiation and wind velocity.
- c Energy seepage by buildings from the consumption of energy, specially by industries and air conditioning plants increase ambient temperature.
- d Atmospheric pollution due to wastes and exhausts from houses, industries and motor-cars creates diffused radiation, re-radiation, fog and induced rainfall.
- e Population density and their socio-cultural aspects affect comfort criteria.

Air temperature in a city can be 8 degC higher than in the surrounding countryside and a difference of 11 degC has been reported. Relative humidity is reduced by 5 to10% due to the quick run-off of rain water from heated paved areas. Wind velocity can be reduced to less than half of that in the adjoining country but the funneling effect through gaps between tall slab blocks can more than double the velocity (Koenigsberger, et al, 1992).

"Although there may still be uncertainties about urban climate, it is believed that there is ample understanding about the causes leading to a deterioration of the urban environment. These causes, it is believed, should be given serious attention as the urban population continues to grow at an almost exponential rate, while facilities is these same urban areas remain far from adequate, especially among developing nations" (Boodhoo, 1993).

3.2.3 Urbanization, Migration and Growth

The simplest definition of *urbanism* or an *urban area* might be the confederation or union of neighbouring clans restoring to a center used as a common meeting place for worship, protection, and the like; hence, the political or sovereign body formed by such a community (Eisner, et al, 1993). "Cities in the developing world has been phenomenal and has been accompanied by all the contradictions and conflicts to be found in a rigidly hierarchical, class-ridden society where new urban immigrants must share the same space" (Taylor, 1992).

Urbanization leads to a very high spatial concentration of energy usage. Urban form constitutes a relationship between the rate of energy consumption and the spatial structure (location, shape, size, density and land use) of the city (Owens, 1986). An analysis using global data showed that a 1% rise in the per capita GNP leads to an almost equal (1.03) percentage increase in the consumption of energy (Barclay G. Jones, 1992). However, if the urban population increases by 1% the growth in the consumption of energy is found to be 2.2%, i.e., the rate of change in energy use is twice the rate of change in urbanization (Asaduzzaman, 1993).

"The population of Dhaka city was reaching one million in the late 1950's. By 1979 the population had grown to 3.5 million, considerably exceeding the capacity of the 1959 master plan, which was designed with 20 year projection of 1.5 million. In spatial terms, the growth of the city did not match such unprecedented population growth, particularly after independence. The trend continues with projections of 13 million by the year 2010 (Figure 3.1). It is evident from the existing pattern of growth and its future trends, that one of the major environmental challenges for the city would be to address the issues of high density living" (Ahmed, 1995).

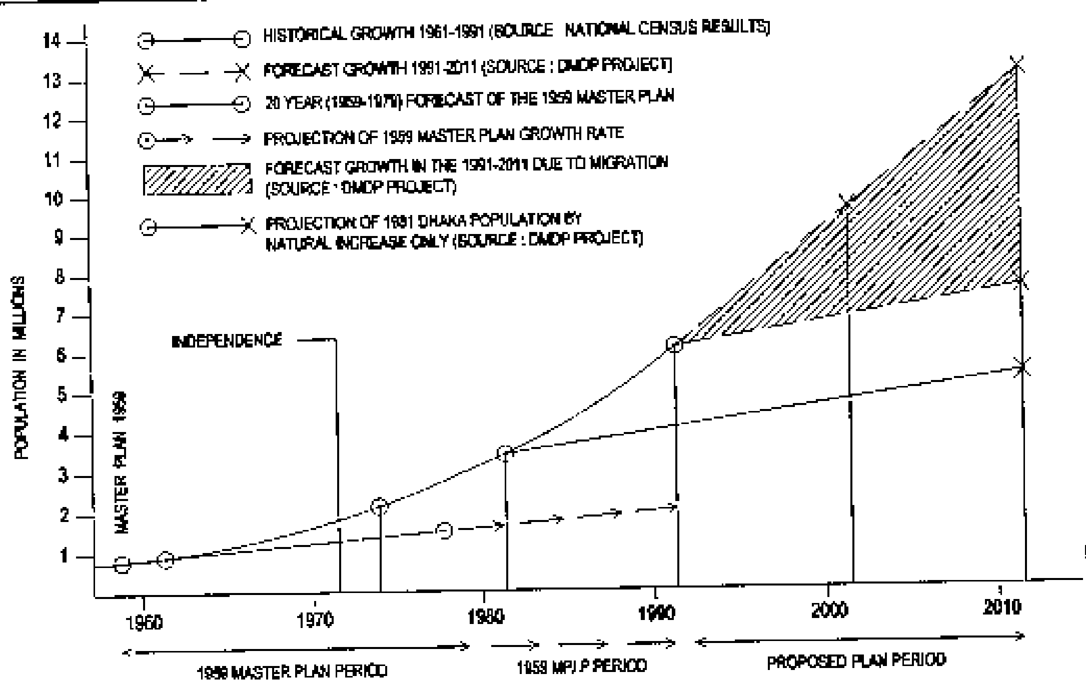

Figure-3.1 Population growth in Dhaka (after Mott Macdonald, 1993), (cited in Ahmed, 1995)

City boundary is extended in course of time due to urbanization of fringe areas and population in those areas is included in the city. That is why growth rate and number of population do not always correspond with the exact situation of a city. There was an adjustment of the total area of Dhaka city in 1981, so that growth rate after 1981 reduced from 9.94% to 5.35% in 1991 (Table -3.1)(Akhtari, 2001).

To accommodate this huge growth of urban population, a new structure plan for the city in 1995 is formulated by RajUK within the package of Dhaka Metropolitan Development Plan (DMDP). This long-term (1995-2015) plan covers about 1528 square-kilometer area including 829 square-kilometers of its earlier size demarcated in Dhaka Master Plan of 1959 (Islam, et al, 2009).

Table 3.1 Population and growth rate of Dhaka city

Year	Population	Growth rate in %
1901	128,857	--
1911	153,609	1.77
1921	168,510	0.93
1931	196,111	1.53
1941	295,735	4.19
1951	335,928	1.28
1961	556,712	5.18
1974	1,772,438	9.32
*	(2,346,489)	(5.62)
1981	3,440,147	9.94
1986	4,464,262	5.35
1991	5,670,575	4.90
1996	7,032,821	4.40
2001**	8,474,543	3.80

* Adjusted for the area of Dhaka city in1981, ** Extended population assuming the same area.
Source: (Population projection of Dhaka city cited in Seraj, 2000)

3.2.4 Density Factor

There is no universal recipe for urban densities in terms of an ideal or most appropriate one particularly for residential development. What is regarded as a high or low density or acceptable density differ between continents, countries and even between cities. However there is evidence that the general process of change is leading to more compact cities (Claudio, 2000).

The new (DMDP) plan is mostly extended in northern side having very limited Mass Rapid Transit (MRT) system and producing huge traffic congestion and mammoth loss of time and energy. This in turn discourages the city dwellers to disperse their habitats. As a result residential densities in those few areas, with easier accessibility and more urban facilities, are increasing in alarming rate, which is manifested in the popularization of high-rise apartment living. The inner core of Dhaka city reveals a tendency towards high density built form, because of close proximity between place of residence and place of work. Transportation sector failed to keep pace with the growth of the cities; there is insufficient provision of appropriate transport modes and inadequate infrastructures (Zaman and Lau, 2000).

Table 3.2 Population density change over time in Dhaka city

Year	Period	Approximate area (sq.m.)	Population	Density per sq.m.
1600	Pre-Mughal	2.6	--	--
1700	Mughal Capital	12.6	90,000	7,149
1800	British Town	20.7	200,000	9,653
1867	British Town	20.7	51,600	2,491
1911	British Town	15.7	125,700	8,012
1947	Provincial Capital	31.1	250,000	8,044
1961	Provincial Capital	72.5	550,100	7,586
1971	National Capital	103.6	1,500,000	14, 479
1991	National Capital	256	3,500,000	13,672
1998	National Capital	300	7,000,000	23,333

Source: Urban growth and the densification of Dhaka 1600-1998 (cited in Zaman, 2000)

3.2.5 Urban Consolidation

'Urban Consolidation' as the process to increase built area and residential population densities; to intensify urban economic, social and cultural activities and to manipulate urban size, form and structure. It has been observed that it is a matter of debate whether the city will be sustainable if it is compacted. City compaction has both its positive and negative consequences in case of cities in developing country. The ultimate aim of consolidation is to reduce development on the fringe areas of a city. It increases the accessibility provision of services and facilities and ensures high quality of life by preserving urban open spaces (Burgess, 2000). High density urban living environments are associated with more traffic congestion and noise, more exposure to toxic releases, more environmental pollution. These negative externalities are further aggravated if infrastructural facilities remain inadequate.

Nevertheless, a common argument is that the cities in developing country are much more sustainable than the cities in developed country as because material consumption per capita levels are much lower in developing one. Lower income urban citizens are models of sustainable consumptions since they can only afford to use very few non-renewable resources and generate very little waste. Considering the negative and positive aspects of consolidation, a careful selection of strategies can ensure positive impacts of consolidation in the cities of developing countries. In case of Dhaka city, consolidation process has been started spontaneously by private sector initiatives about 15 to 20 years back in a most unplanned and sporadic way (Islam, et al, 2009).

3.2.6 Environmental Criteria for Tropical City

The cities are characterized by concentration of various kinds of activities of people and various kinds of physical forms to accommodate those activities. There are two sides which can affect the ambient thermal environment in any land use areas. In one side we get outdoor natural climatic parameters like air-temperature, relative-humidity, rain-fall, solar-radiation, air-flow, etc. On the other side we get indoor sources of heat, humidity, radiation, and flow of air.

Incorporating nature in the cities, in terms of increasing biological diversity (making suitable for wild life) as well by increasing biomass (vegetations) has been identified as being an important criteria for improving the quality of urban life (Blowers, 1993). Environmental problems tend to concentrate in cities with high population density than a geographically dispersed population (Owens, 1986). Among other criteria set by Eisner, et al, for appropriate location of urban settlement following two measures can be related with thermal environment—

- Open areas like parks, agricultural and other spaces where humans are not concentrated should be used as safe havens when required at emergencies.
- Reduction in population densities in areas subject to danger, whether the threat is immediate or at an unknown time in future, should be planned.

In warm-humid tropical regions conventionally dispersed built environments are considered appropriate from the thermal comfort point of view (Koenigsberger et al, 1975; Brown, 1985; Kukreja, 1978). A dispersed arrangement of built fabric results in increased demand in traveling and thus increased transport emission. Even then a dispersed or low density fabric gets more scope for convective diffusion of heat or any kind of concentrated emission. In hot-dry summer compact fabric with thick construction is suitable, as it increases time-lag in thermal transmission and restricts the outdoor heat to reach indoor during day time. But there must have enough openness, either in the form of court or verandah or terrace, to facilitate rapid nocturnal cooling.

The lack of electrification in villages necessitates the use of natural ventilation to its fullest extent and has probably led to bigger sized kitchens and living rooms than needed when mechanical ventilation system could be installed (Ahmed, 1987, p-11).

As the prevailing wind direction during the hot months is principally from the southern side, this side of the house is favoured for the most important rooms; bedrooms, living room, sitting room. Kitchen and toilet are almost never places on this side, a northern location being preferred for the former, while a western one being ideal for the latter. For the same reason, paved areas are avoided if possible from being on the south, preventing overheated surfaces from dissipating their heat into the house with incoming breeze (Ahmed, 1987, p-18).

The width of space that we keep between two structures must be enough to allow natural light and air-flow. Evaporative cooling coupled with shade from plants could be great means of heat reduction during hot summer. We can utilize these means to get reed of hot-discomfort in urban situation. High concentration of human habitation itself is a source of higher rate of heat production. Moreover, with the rise of living standard in an area higher rate of per capita power consumption is seen, which releases higher rate of heat in a small area.

3.2.7 Thermal Comfort Criteria

Our daily life cycle comprises of states of activity, fatigue and recovery (Koenigsberger, et al, 1973). It is essential that the mind and body recovers through recreation, rest and sleep to counter-balance the mental and physical fatigue resulting from activities of the day (Crowden, 1954). This cycle can be and is often impeded by unfavourable climatic conditions and the resulting stress on body and mind causes discomfort, loss of efficiency and may eventually lead to a breakdown of health. The effect of climate on man is, therefore, a factor of considerable importance (Fox, 1965).

People's expectation of comfort increases as the means to achieve comfortable environment gradually come within reach (Mojumder, 2000). But the target of an architect should be to achieve or make provision for standard thermal comfort and ensure efficiency in indoor activity. It is a challenge for the designers to strive towards the optimum of total comfort, which may be defined as the sensation of complete physical and mental well being (Koenigsberger, et al, 1973; Goulding, et al, 1992).

3.2.8 Comfort in Residential Environment

A suitable shelter for human being is perhaps one of the basic and most important necessities of life right after food. Precisely speaking life is not worth having without a shelter and suitable housing facilities. That also form part and parcel of living standard and determine health, efficiency and productivity of the inhabitants and are ultimately linked up with economic development (Hussain, 1977). So, a house must become a home for its dwellers in all respect and special attention in its planning and design is required if we really want to have healthy and prosperous citizens.

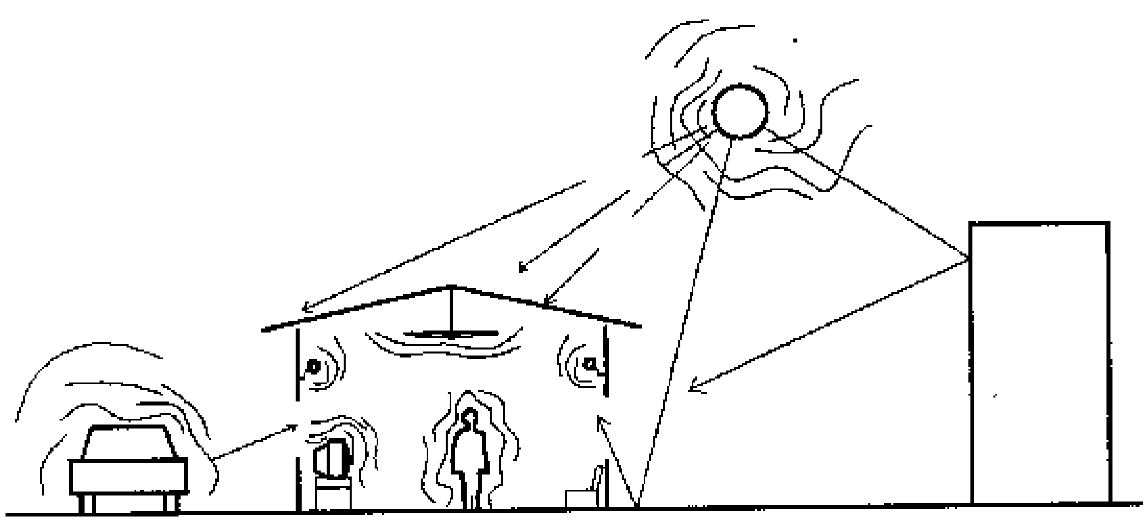

Figure 3.2 Sources of Heat that a Shelter Mediate

Commonly accepted notion is that in warmer ambient conditions people tend to relax more and carry out work at a slower pace (Baker, 1994; Markus & Morris, 1980). So both in summer and monsoon it is imperative to keep arrangement for reducing the penetration of day time solar radiation (both direct and reflected) and increase nocturnal cooling specially from indoor spaces (Text 2.4). There are other indoor heat sources that consume big amount of food and energy supply. Our shelters actually mediate between heat sources that exist on either of its sides during day and on one side during night. So the building and the environment must have provisions to breath and keep thermal comfort situation. For that enough provision of ventilation openings and soft textures around building is required that could enhance convective and evaporative cooling, specially in night. Shorter buildings height can have shades of surrounding trees at day time and can serve better thermal comfort in tropical city.

3.2.9 Interaction Between Body Heat and the Atmospheric Heat

In the tropical climate heat is the main problem in achieving comfort. During the hot-dry and warm-humid seasons, which together last for almost eight (8) months, the atmosphere over Dhaka experiences influx of heat more than the level required to keep thermally comfortable. In this situation, the house-envelop acts as a screen protector for the people living inside that. Whole of the hemisphere is the source of solar radiation and thus raises heat content of the atmosphere over the region. Man as a small entity compared to the whole atmosphere, tends to save him from that hot-discomfort by being inside of a shelter or a membrane or a fabric made of brick, concrete, timber, etc. The design of that shelter is required to keep away the extra heat and preserve thermal comfort inside.

On the other hand, when the winter or the cool season comes, the main objective becomes to preserve heat within the body and the cold atmosphere tends to over-extract heat out of the body and feel us cold-discomfort. The source of heat required to keep comfortable in this ambient cold is the body metabolism, which depends on age, sex, food, clothing, health condition, etc. Although the whole atmosphere is quite mammoth compared to an individual, one can very easily shelter himself within warm clothing and the house envelop acts as further skin to preserve required heat within the body to maintain comfort and also to maintain deep body temperature at 37° C. It is very easy because the heat source is very small and is located within the same body which is needed to keep warm in cold weather.

3.3 DHAKA CITY AND ITS POTENTIALLITY

Dhaka is the largest city of the country and one of the fastest growing metropolises in the world. This Mega-City[1] is stretching over an area of 1528 sq. km. and now accommodating some 9.3 million people growing in an annual rate of 6.0 percent and is generating the demand for 50,000 new houses annually accommodate the demographic momentum (Nabi, et al, 2003, pp53-54).

Distribution of housing facilities for city dwellers exhibits high levels of disparity and segmentation. In Dhaka, 80% of the residential lands have been occupied by only 30% of

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[1] Dhaka entered into the Mega City (MC) list attaining the rank 25th in the year 1980 with a population of 6.6 million. It is predicted by United Nations that Dhaka would be the 6th largest MC by the year 2010 and it would continue to uplift its position to become 2nd largest MC of the world by the year 2015 (Islam, 2005)

the urban population. In the remaining 20% residential area rest 70% city people find their dwelling (WB, 1999; Nabi, et al, 2003, pp53-54).

In this situation a very careful planned development of the residential districts for all class of people is essential. Housing is always a deficit sector for the government and subsidy is required there to uphold both quantitative and qualitative environment. It has to be protected from commercial encroachment by enforcing contextual building regulations.

With the advent of large number of private developers in the housing sector of Dhaka dwelling unit has become a profitable commodity to make brisk business. Many companies have now involved in this business and quickly transforming the low density residential quarters into high density jungles of bricks and concrete. Now it is the high time to control and guide the development process so that Dhaka city does not loss its future scope of becoming healthy and sustainable one.

3.4 SOCIO-CULTURAL ASPECTS AND COMFORT

Mere attempt in the physical ordering can not usher total comfort that includes both physical and psychological comfort. "......physical environment alone, has little effect on human behaviour or welfare. Can we seriously expect that the position of a wall is going to make us happy rather than unhappy" (Alexander, 1971). Open spaces, parks and playgrounds are essential to the life of a community (Rashid and Rashid, 1985). A house plays another vital role. It accommodates a child to grow up there with physical and psychological health. The ingredients that conjure np both physical and psychological environment of a living quarter also constitute the thermal environment of it. So in this study, these elements are addressed here from climatic-comfort point of view.

Higher density areas, in terms of physical built mass, are found to be accommodating more number of people per unit land area and typically coming from low-income or lower-income group who cannot afford to pay more to live in low density areas. Although they are not habituated in snch dense physical environment, as they are typically the first generation migrant from rural to an urban situation, they are mentally prepared to accept a little less comfort in and around their living environment in urbanity.

On the other hand low density areas, which are imbibed with proportionately more open spaces covered with soft-textures, are occupied by higher-income group. These people are involved in more rigid life style and their daily life cycle is framed in a routine work. That is why people living in low density areas need to have ensured thermal comfort in and around their living spaces. But the alarming thing is that low density areas of Dhaka are now being replaced by higher density built-fabric as the buildable open land is almost exhausted. Due to huge demand and rush of consumers in apartment market people are keeping unaware of its eventual socio-cultural effect.

Composite nature of climate in this region naturally produces comfortable thermal condition during considerable proportion of time in a year (February to mid-March and November to early-December). Long monsoon (late May to October) also do not create extreme hot-discomfort. Cold discomfort of winter (December to January) can be taken care of by personal clothing. Only the summer (late March to May) which, appears after nice comfortable spring, poses severe hot discomfort. As the extreme severity of discomfort (which is very difficult to ameliorate without active control) is experienced only for small period of time, people remain unaware about passive means of climatic control in their dwellings and this phenomenon specially seen in the lower-income group.

3.5 ECONOMIC CONSIDERATION

In Dhaka the physical developments are going on with a very high speed specially the residential development. Every year the supply of residential unit is increasing. The multi-storied high rise apartment has now become the only alternative for housing solution among the urban dwellers both in public and private sectors. The major supply is being made by the private developer firms. Thousands of developer firms are competing in the urban housing market of Bangladesh at present. Huge difference between the project brochure and real project, serious lack of standard amenities and facilities, lack of building by-laws for this new building typology, lack of commitment and accountability, etc. are the major drawbacks persisting in this field.

Land price in Dhaka has escalated manifold. In some of the high demanding residential areas one Kattha land (720 square feet) is being sold at, as much as, Taka 10 millions (equivalent to $ 1,42,850), let alone the commercial one, in the recent years due to severe shortage of land. This in tem boosted the apartment price to a formidable height for the vast middle-income and lower-middle income groups of people. To cater to the needs of lower income groups small sized (≤450 sq.ft.) high density high-rise apartment buildings are being constructed in different areas of Dhaka. Profit margin is better in this category and developers are getting more interested to develop these small sized apartments.

3.6 CONCERN FOR THERMAL COMFORT

Undoubtedly in urban situation the most comfortable living environment is always expected in the residential spaces compare to environments like commercial, institutional, recreational, etc. Very subtle change in thermal qualities here may hamper the interests a lot. Thermal comfort in residential units can help us in removing fatigue and tiredness of the day long work and refreshing us for next day's work.

In a developing country like Bangladesh dependence on scarce energy for non-commercial sector, like residential one, should be kept as low as possible without compromising thermal comfort. To do so we must utilize our planning and design tools to their fullest extent in residential districts, thereby facilitate passive thermal control and reduce dependency on power supply. By doing this, we can channelize our limited energy resources to the sectors like agriculture, institution, industry, commerce, etc.

Dhaka is located within the region of 'Composite Monsoon' climate, which represent variable nature of ambient thermal environment throughout the year. As it is a tropical location, dissipation of surplus heat from hnman body becomes major concern during most part of the year. At the same time reduction of solar-radiation in residential quarters also plays important role.

During summer the external environment becomes more hostile. High temperature and very low humidity constitute the situation quite uncomfortable. The hot and dusty air is not suppose to be allowed in indoor environment specially if it is passing over a hard paved surface before entering into the indoor space. Regional wind comes from south and south-east direction in this season, which is similar to rainy season (warm-humid that last for almost six months). In warm-humid period we need more air-flow thuough our living spaces to achieve evaporative cooling. And it is better if this air flows in through cooler or shaded areas. Growth of plants and trees are very easy in this season and they can considerably reduce the ambient temperature. So the combination of soft and hard areas in justified proportion can work satisfactorily that we can find in our traditional rural settlements. Natural green plants can shade us from direct radiation if we keep our shelters in low-rise structures; up to 5 or 6 storied that equals to the maximum height of the common shading trees in our country.

3.7 CONCLUSION

Both land and other resources are limited while urbanization and population growth rates are very high in Dhaka, which gave her the status of Mega City in the recent years. To fulfill the huge demand of housing units earlier small sized personally owned walk-up residences in the existing residential districts are rapidly being replaced by high-rise apartments. Most of these new high-density apartments are constructed, without proper climatic considerations, by the private developer companies whose primary objective is to make brisk business. So the scope is getting narrower to put a good control over the ongoing development process.

For being located in the developing country (where resources are limited) the physical development process of Dhaka city, specially in the residential districts, has to be very judicious and controlled by proper rules and regulation. These rules must be formulated by following the findings of scientific researches on contextual thermal environment. Immediate comprehensive measures in this regards are very much essential. The next chapter discusses the field investigation for this research where the effects of residential building density and their morphology are investigated in terms of the resultant TE.

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CHAPTER

4

FIELD INVESTIGATION

4.1 INTRODUCTION

4.2 OBJECTIVE OF THE FIELD SURVEY

4.3 SURVEY SPOT SELECTION CRITERIA

4.4 DESCRIPTON OF SURVEY SPOTS

4.5 INSTRUMENT USED IN FIELD SURVEY

4.6 COLLECTED FIELD DATA

4.7 SCOPE AND LIMITATION OF THE SURVEY

4.8 CONCLUSION

4.9 REFERENCES

4.1 INTRODUCTION

To make a climatic investigation more successful and authentic long range of data needs to be collected for many years from a large variety of physical developments. The fact is that, it is not always possible to record all these data directly from the field during investigation, nor they are always available as per requirement in meteorological offices. The inherent difficulty in climatic research is that the physical environment in towns and cities are continuously changing to cater to the changing needs of people. Consequently the micro-climate of a city is also being modified continually (Jauregui, 1984; Kirschenmann, 1980). So, to assess the effects on micro-climatic environmeot due to changes in physical development of a particular place, a considerable time length has to be invested for climatic data collection. But this is quite beyond the scope of this research. That is why, field data collection is made within a limited period during extreme discomfort condition of the year. April is the hottest month in terms of mean maximum temperature (Ahmed, 1987, p-64; Mallick, 1994, p-55; Ahmed, 1995, p-24) and the effects of its interaction inside the built forms manifest after few days and thus the data is collected during the middle of May. A number of residential districts have been selected in the urban metropolis of Dhaka to investigate the effects of variable physical development. The districts under investigation have been chosen on the basis of their variable physical properties like, ratio between hard-to-soft textures, physical and population density, open spaces in or around the structures, sky-line, fabric pattern, etc.

4.2 OBJECTIVES OF THE FIELD SURVEY

4.2.1 Type of Field Data Collected

The field survey is conducted to collect climatic field-data simultaneously in different survey spots and to record the respective physical characteristics. Daily maximum and minimum temperature, maximum and minimum relative humidity, and air flow data at different heights are collected. It is considered that the solar radiation data is similar for all sites as they are located within a few kilometers distance from each other. Physical survey is made on the basis of local area plans and visual observation, in all survey sites, to identify notable physical characteristics that have potentiality to influence the thermal environment. Ratio between hard and soft surfaces of each locality on an average is calculated. Physical density of built mass in terms of floor area ratio (FAR), population density, average building size and height and average set-back spaces between two buildings in each locality are recorded during the field survey. The research is targeted to compare the thermal environments and correlate them among the existing different kinds of physical development in residential districts of metropolitan Dhaka. One of the aims of this investigation is to identify, among different patterns of physical development, the comparatively more comfortable residential district among all.

4.2.2 The Need for Transition Space Data

Between indoor and outdoor there is a transitional space through which a man-made space actually breathes into the natural environment. Transitional Space (TS) is the areas between indoor and outdoor or the immediate outside areas of a dwelling unit, which are taken for investigation. The Thermal Environment (TE) in TS is formed primarily due to the introduction of built-forms in the midst of an existing natural setting (Koenigsberger, et al, 1992). Indoor environments make direct interaction with these TS. To assess the effects of various residential development patterns on respective thermal environment climatic data on TS can give us significant pointers.

Thermal transaction from indoor space primarily impacts on this TS and then on the outdoor environment beyond. So the architect's effort in passive climatic control becomes easy and dependency on active control is largely reduced if the environment in TS remains under control. In tropical climate, most of the time naturally shaded environments remain more comfortable than exposed paved or urban built-up environments (Evans, 1980). So, the presence of soft surfaces within and around the built-forms could serve positively and the optimum ratio between soft and hard surfaces in urban residential districts is one of the queries in this research.

4.3 SURVEY SPOT SELECTION CRITERIA

The survey spots in residential areas were chosen from different zones of the metropolitan area of Dhaka city. In the old master plan (valid before 1987) the total area under Metropolitan Planning of Dhaka was 320 sq. miles (Enam K., 2003). In the new master plan 590 sq. miles were taken for development by extending the city towards the north. Study areas were chosen within the old jurisdiction, which are already built-up with varying density. In some areas there have formal planning of plots, streets and community facilities and others have informal planning. Four sites are selected for simultaneous investigation based on variation in their physical growth patterns as given below.

Spot-1: Informal sector residential development is one of the investigation areas, where the growth pattern is incremental and dense and no definite planning control is followed, e.g. Sutrapur in old part of the city.

Spot-2: A formal residential area, e.g. Dhanmondi Residential Area, where many of the original one-bigha plots had been sub-divided into smaller plots, and the remaining original one unit houses per plot are now being replaced by six-storied apartment buildings thus creating higher density of builtding mass.

Spot-3: Institutional housing is another area where the development is completely planned and is far more controlled. Here the density of built mass is least among all four sites and surrounded by lush vegetation. This is located in the teachers' quarter of Bangladesh University of Engineering & Technology (BUET), Dhaka. Other two sites are taken from formal sector where the houses are built on individual large plots.

Spot-4: Formal residential area, Banani Residential Area, has been developed with large plot sizes and most of them are still occupied by single families (sometimes joint or extended family) in one unit houses.

4.4 DESCRIPTION OF SURVEY SPOTS

Each of the four survey spots is taken to represent a typical building typology of the concerned residential area. Ground floor is chosen for climatic data recording point due to ease of accessibility in all selected sites and as it is the bottom or deepest layer in a developed fabric, where interaction between built-form and climatic elements is critical due to reduced wind speed and overshadowing, compared to upper floors (except the top floor), thus affecting thermal comfort situation. In the ground floor south facing semi-outdoor space (transitional space) like veranda was selected to install the data collection instruments. Totally open outdoor spaces were avoided for data collection as they are less influenced by the development pattern. On the other hand enclosed indoor spaces were also avoided for data collection as they develop micro environment largely dependent on use pattern and layout of that space.

4.4.1 Spot – 01 at Sutrapur in Old-Dhaka

Settlement pattern: The old part of present Dhaka, the capital city of Bangladesh, consists of most informal layout of buildings and streets. The study spot no. 01 was selected at *Sutrapur*, a typical old Dhaka residential district. The setting up of this part of the city dates back to *Mughal* times, developed around 1610 A.D. after being declared as a regional capital during the reign of Emperor Jahangir (Karim, 1989). This oldest part is compact and densely built in an organic manner. The houses are inward-looking and built mostly covering the entire plots (Ahmed Z.N., 1994). The streets are narrow (typically 8 to 15 feet wide), meandering in shape and irregularly crisscrossing the settlement (Fig.-4.1). To get accessibility to sub-divided small plots some lanes and by-lanes have been created as dead end. The street network is not suitable for vehicular traffic systems, rather resembles rural village pedestrian path ways. Normally land-holdings by families have been sub-divided over generations and thus have diminished in size (Ahmed Z.N., 1994). Earlier large plots have been sub-divided many times among the successive heirs and now each of them has become very small, sometimes as small as 40 sq. m., ending up with odd shapes (Table 4.1).

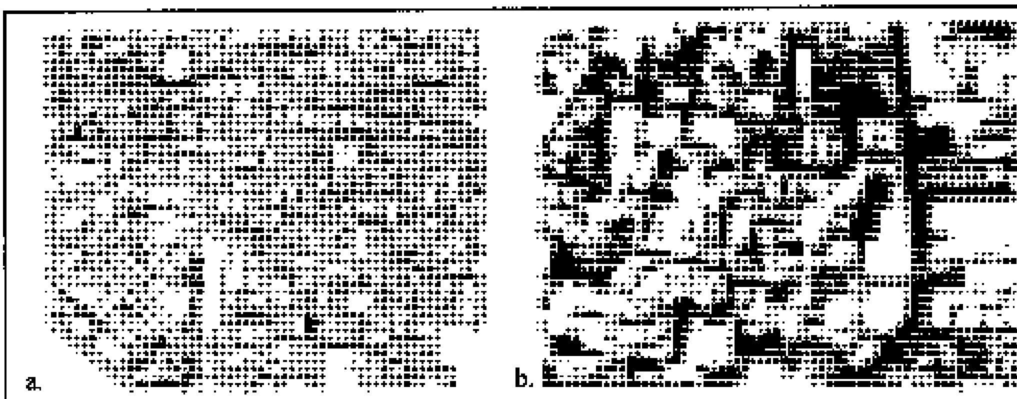


Figure 4.1 A typical settlement pattern and satellite image of old Dhaka Sutrapur area.

(Source: a. Urban Planning Department, Dhaka City Corporation, survey period April to July 2003, b. www.earthgoogle.com, accessed on 24 Dec 2006, not to scale)

Building morphology: Most of the structures in this area are very old, as much as 50 to 100 years old, and are 2 to 5 storied high. These are built incrementally to cater to the subsequent needs with time (Fig.-4.2). The survey revealed that the society is typically composed of low to middle income group and usually having less opportunity to higher education. Many house owners do not have the financial capacity to build a completely new structure by replacing the old one. So they remain satisfied with small extensions on roofs or on the sides, if any open area is still available, to accommodate upcoming crucial needs. Sometimes these extensions within the old buildings are undertaken without proper structural design, risking the occupants' lives.

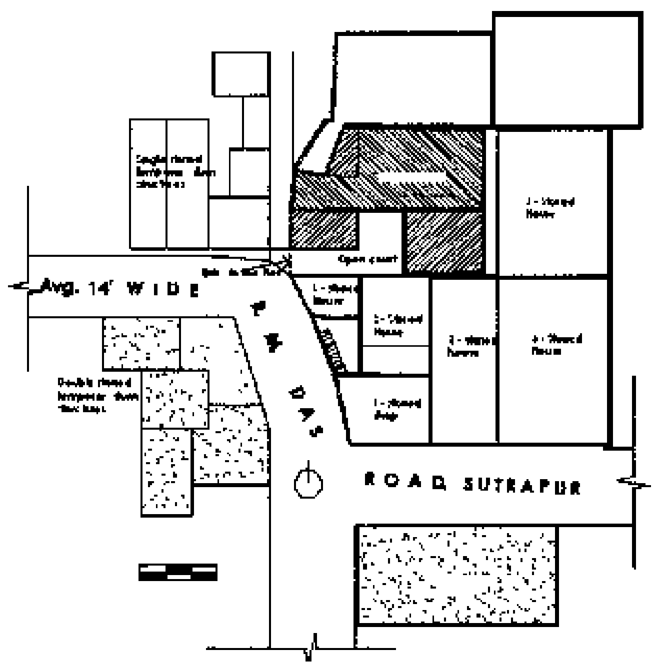


Figure 4.2 Layout plan of survey spot – 01 in Sutrapur, Dhaka.

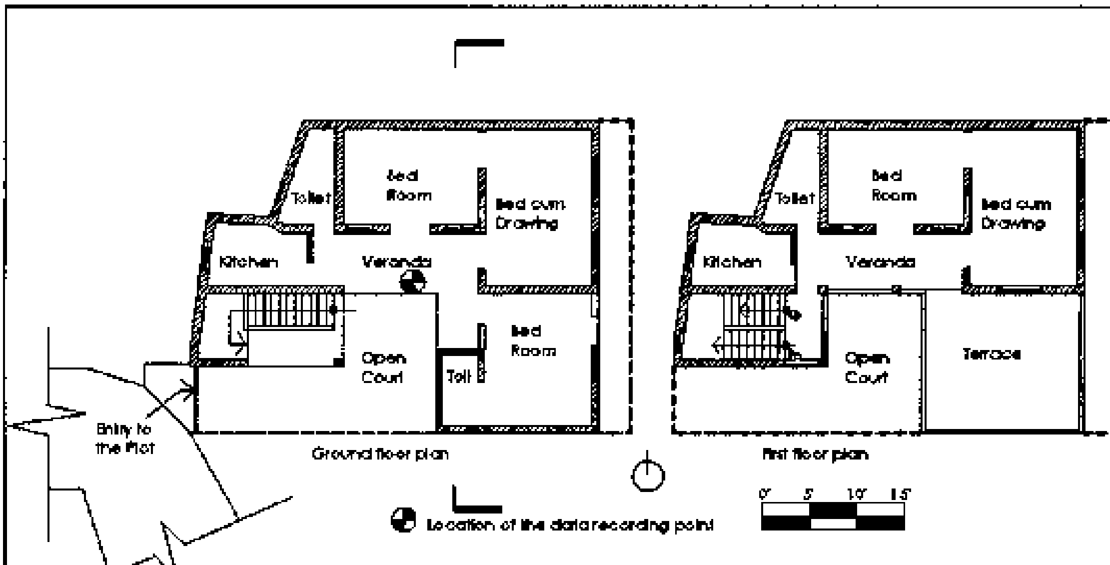


Figure 4.3 Detailed plan of spot –01 at 135/1, R.M. Das Road, Sutrapur.

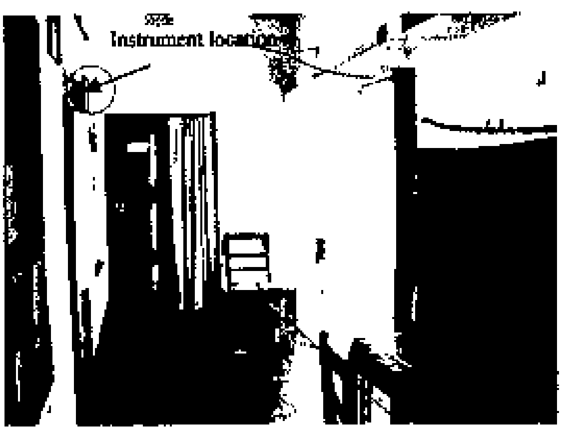


Figure 4.4 Veranda where data was recorded at spot –01 in Sutrapur

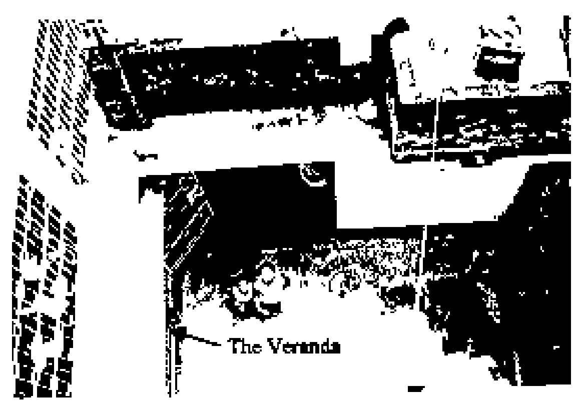


Figure 4.5 Open court in front of veranda of spot –01 in Sutrapur

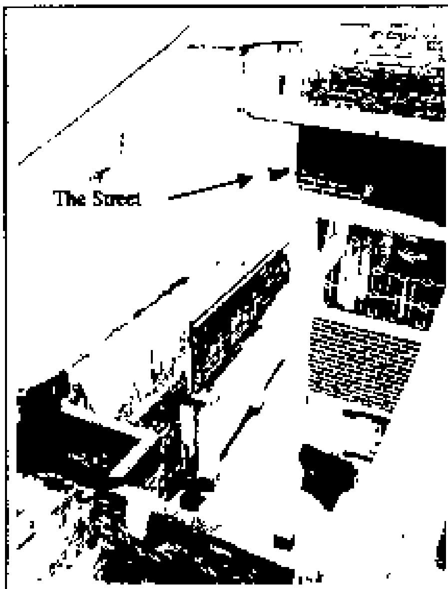


Figure 4.6 Overlooking street from roof of spot –01 in Sutrapur.

Figure 4.7 Survey site within dense fabric of spot –01 in Sutrapur.

Description of the survey spot: The house at 135/1 no. R. M. Das road in Sutrapur area was selected as the survey spot number-01. This is a two-storied residence built on approximately 2.1 katha (140 sq.m.) land. The ground floor is partially (approximately 715 sq.ft. or 66.4 sq.m.) occupied by a three member tenant family and the first floor along with the part of ground floor (approximately 1105 sq.ft. or 102.6 sq.m.) is occupied by five member family of the land lord. About 20% land area on the south-west side of the plot is kept open, through which the main entry approach is made, while the rest is built-up (Table 4.1). The building is physically attached with a three-storied residence on north and another three-storied residence on the south. On the east side it is just 1 meter away from a five-storied residence and on the west side it is separated by a 1.3 meters wide surface drain from a temporary single-storied slum settlement (Fig.-4.7 and 4.8). This plastered brick structure is painted white externally.

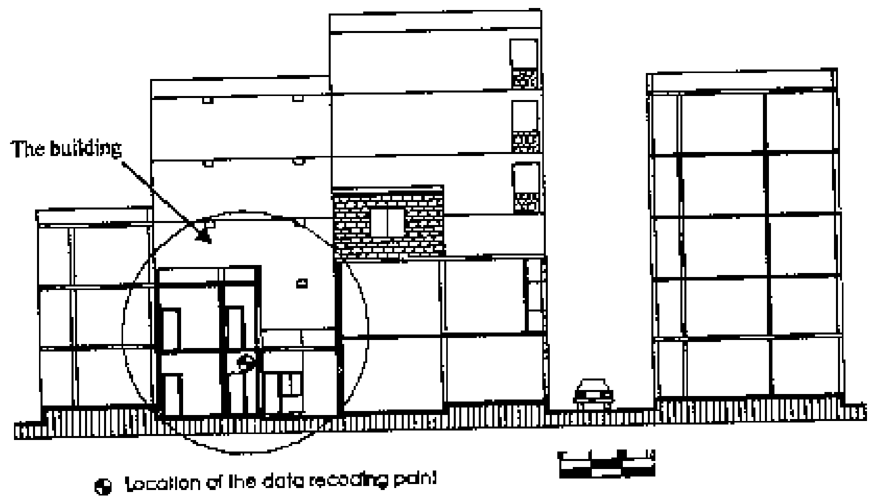
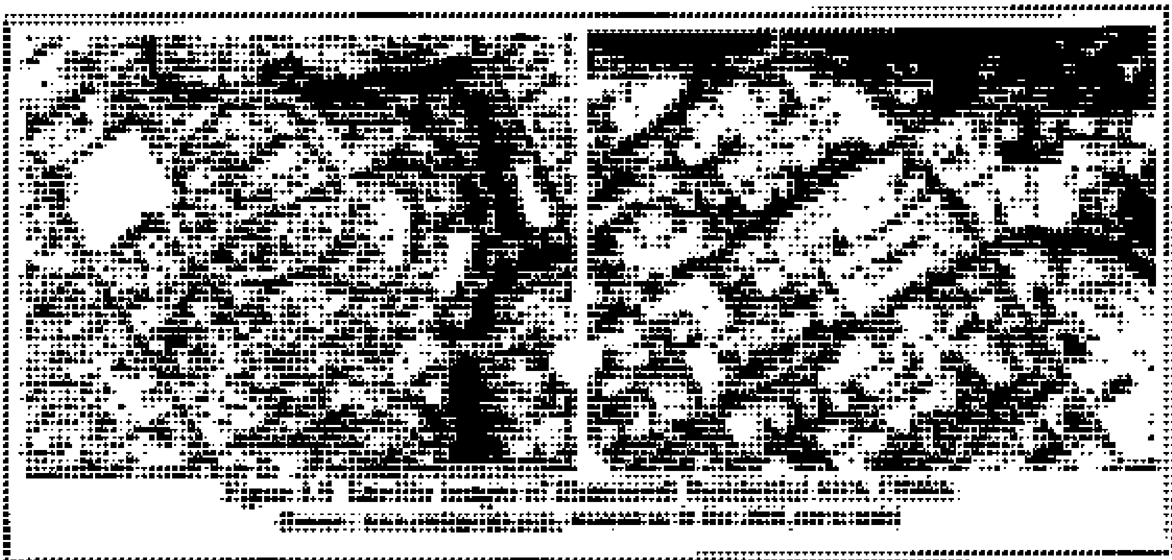


Figure 4.8 Section showing transitional space in spot –01 at 135/1, R.M. Das Road, Sutrapur.

4.4.2 Spot – 02 at Dhanmondi Residential Area

Settlement pattern: During 1950s, the then Dhaka Improvement Trust (DIT, now RajUK; i.e. The Capital City Development Authority) developed a large chunk of land on the north-west side of the old city to cater to the ever-increasing housing needs of the city. Originally the plots were fairly large, usually 1 bigha (1338 m^2) each, and was primarily distributed to government officials (Dani, A.H, 1962). The streets are 9 to 12 meters wide and laid mostly in a grid iron pattern (Fig.-4.9 and 4.11).

Initially large one-unit houses were built in each plot, leaving set-back open spaces on all four sides, more than the minimum required by the building construction rules for Dhanmondi R/A (Table 4.1). These open spaces were covered by lush vegetation and the enviroument was quite soothing. There is a natural lake, extending roughly south to north in Dhanmondi R/A.



Building morphology: Typically the buildings are now six-storied and accommodate upto a maximum of six units per floor. To feed greater number of plots from the east-west oriented streets narrow sides of typically rectangular plots are given road frontage. Keeping the stair and lift in the middle, only one or two units per floor face south and the other faces north. These multi-storied apartment buildings in Dhanmondi R/A are a recent development and are being constructed by replacing the old one-unit houses of 1950s and 60s. At present, only the minimum required setback space is left open on four sides of every building (Fig.-4.10, 4.11 and 4.13). So growth of plant in such deep canyon shaped spaces between two very closely adjacent buildings is very difficult. Sometimes old one-unit houses on adjacent site of these new apartment buildings provide big open spaces, ample light and ventilation. But this advantage is likely to cease very soon as the process of densification is continuing (Table 4.1).

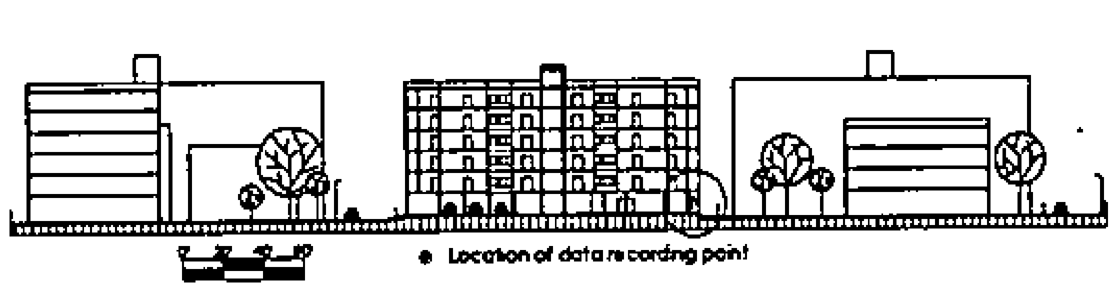


Figure 4.10 Section showing transitional space in spot -02 at Dhanmondi.

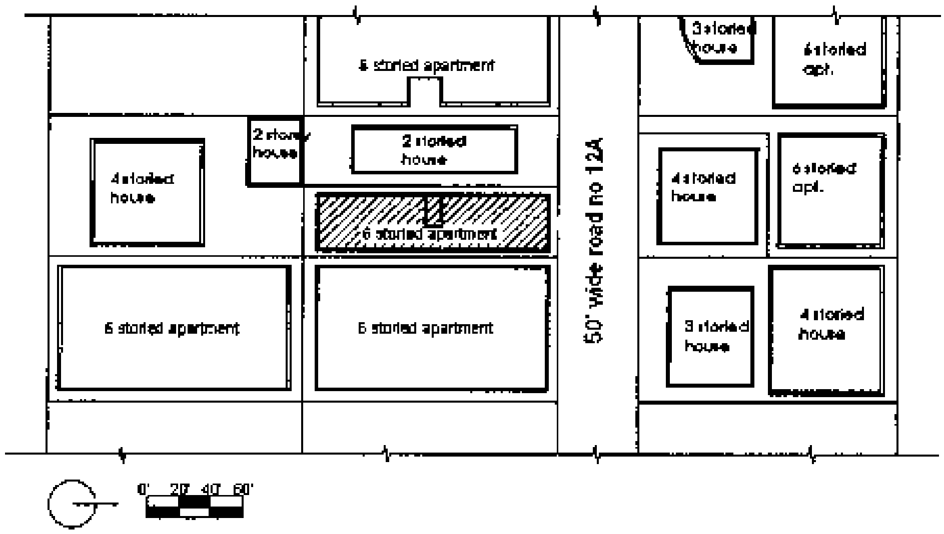


Figure 4.11 Layout plan of survey spot – 02 at Dhanmondi R/A.

Description of the survey spot: The apartment at house-67B, road-12A, Dhanmondi, Dhaka-1209, was selected as the survey spot number-02. This is a new six-storied building built on 10 katha (668.9 sq.m.) land within last 5 years. There are two units per floor (each 2610 sq.ft. or 242.5 sq.m.) except ground floor. The ground floor is occupied by different office uses in southern side and the road side is used as car parking. On the east there is also a 6-storied apartment building and on the west there is an age old 2-storied residential building. On the south there is a big space kept open by the adjacent plot owner and 9 m. access road is on the north. Further north there are 3 and 4 storied houses. Surveyed building is R.C.C frame structure, painted gray and white externally.

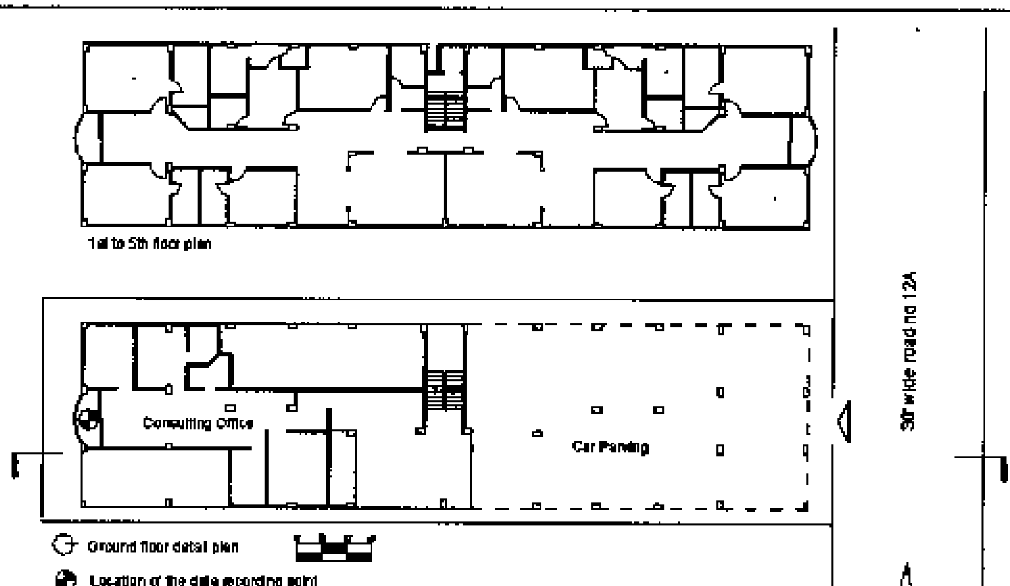


Figure 4.12 Detailed plan of spot –02 at House-67B, Rd-12A, Dhanmondi, Dhaka-1209.
(Source : A & M Architects, Dhaka, Bangladesh)

Figure 4.13 Series of six storied buildings at spot –02 in Dhanmondi

Figure 4.14 Survey building and surroundings at spot –02 in Dhanmondi

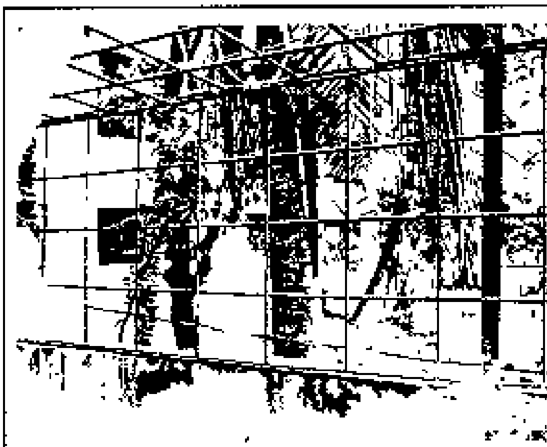


Figure 4.15 Open space in southern plot of spot –02 waiting for new development

Figure 4.16 Free space for parking in ground level of spot –02, Dhanmondi

4.4.3 Spot – 03 at Teachers' Quarter of BUET

Settlement pattern: There are two Teachers' Campuses within the premises of the Bangladesh University of Engineering & Technology (BUET), Dhaka. The survey spot – 03 was selected in one of them. This building is located in the extreme south of the campus and most of the structures are exposed red brick buildings. The four or five-storied structures are all arranged around a vast green open space allowing free air movement for each and every housing unit. Gap between buildings are big compared to all other areas surveyed during this study (Table 4.1). Meandering paved pathways common for pedestrians and private vehicles connect all the 15 structures. Lush vegetation frequented with big trees and their shade make the environment cool and pleasant (Fig.- 4.17, 4.18, 4.20 and 4.21). The ratio between soft and hard textures is quite in favour of soft one. The land is low lying and suffers regularly from water logging during torrential rain in monsoon. As a result surface water run-off is low in this area.

Figure 4.17 Satellite images of BUET teachers' quarter.
(Source : www.earthgoogle.com, accessed on 24 Dec 2006, not to scale)

Building morphology: All of the walk-up building blocks have one or two units per floor except the only 12 storied building on the east. Longer sides of most of the buildings are oriented north and south facilitating south breeze in both units of each block. The five-storied building (marked by rectangle in Fig.-4.17) in which the survey was conducted is atypical for this area, made of concrete frame and brick infill, but externally plastered and painted white.

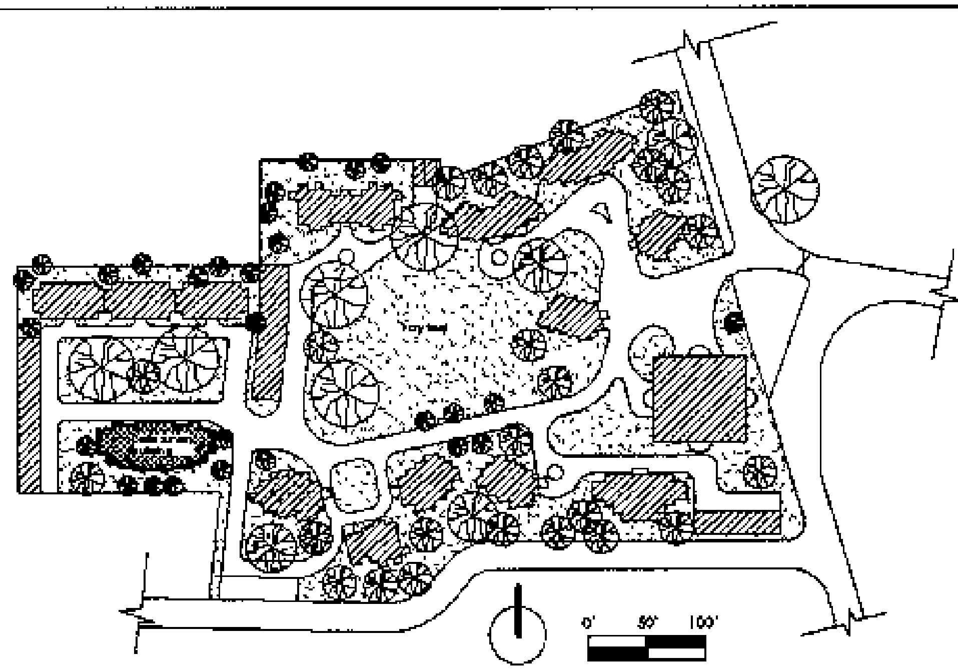


Figure 4.18 Layout plan of survey spot – 03 at BUET teachers' quarter.

The big open space with green between northern and southern layer of building blocks serves as playground for the children of this campus (Table 4.1). Building morphology and land use on the immediate south and south-east of this quarter are different. They are comparatively denser and institutional in nature; drawing large number of people and vehicle during office hours.

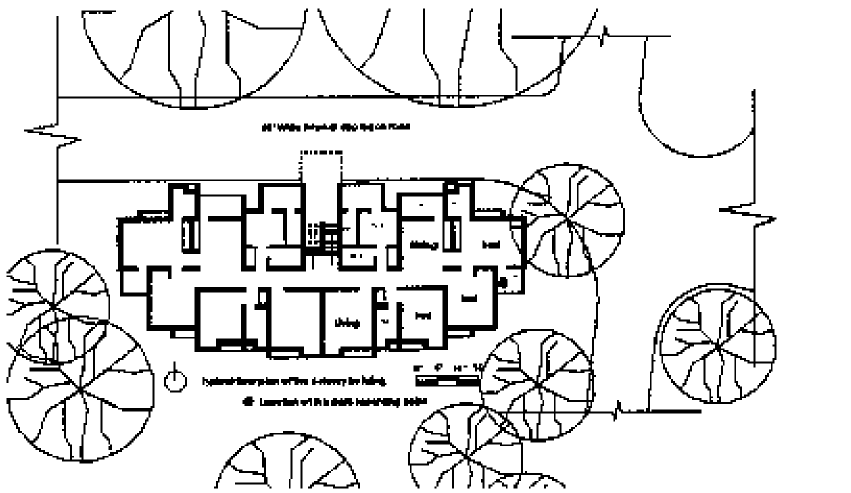


Figure 4.19 Detail plan of spot -03 at BUET teachers' quarter, building no.-46.

Description of the survey spot: The ground floor flat of this five storied building no.- 46 at BUET teachers' quarter is occupied by a teacher of BUET along with his four member family. This 150 sq.m. flat is a three bed room unit located on the east side. There are two opposite and identical units per floor and the stair is located at the middle. The longer facade of this rectangular building is orientated north and south like most of the buildings in this quarter (Fig.-4.19 and Table 4.1)). The data is recorded in a veranda located in south-east corner.

Figure 4.20 Typical open space around every Building in spot -03, BUET teacher quarter

Figure 4.21 Except vehicular road all open spaces are soft textured, spot -03, BUET teacher quarter

Figure 4.22 The central play ground at spot –03, BUET teacher quarter

Figure 4.23 Surrounding cityscape of spot –03, BUET teacher quarter

4.4.4 Spot – 04 at Banani Residential Area

Settlement pattern: Banani , a planned residential area of Dhaka was conceived during the 1970s. This area is located on the north-east side of Dhaka about 10 k.m. away from Dhanmondi. The settlement pattern was almost similar to Dhanmondi R/A at its beginning but with smaller plot sizes, 11/12 katha (7,920/8,640 sq.ft. or 736/803 sq.m.) each and the streets are in grid iron pattern. Both were developed in the formal sector serviced with infrastructure. To feed greater number of plots from differently oriented streets, the narrow sides of typically rectangular plots are given road frontage (Fig.- 4.24, 4.25 and Table 4.1). A natural lake flows along the east and north-east edge of the area. People of high income range reside in this area.

Building morphology: Except for the main commercial street, many of the buildings are still two to four storied high and accommodate the original lessee with family. Plots have not yet been sub-divided into smaller plots and almost all the uses are residential. More than the minimum required setback space is kept open on different sides of every building thus increasing the proportion of soft surfaces compared to the Dhanmondi area. So growth of vegetation here is greater creating a more balanced natural environment. However with time, built mass is increasing in the form of extension with the original house sometimes vertically and sometimes horizontally.

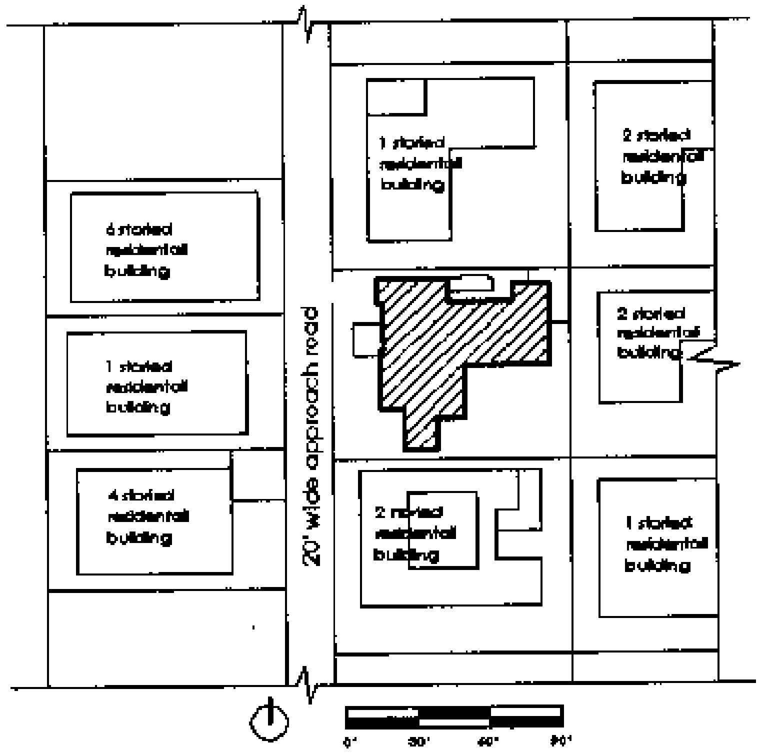


Figure 4.25 Layout plan of survey spot – 04 at Banani R/A.

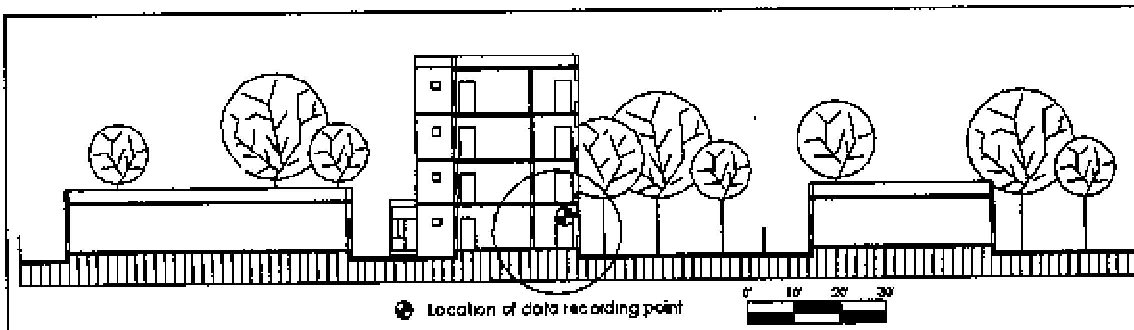


Figure 4.26 Section showing transitional space in spot –04 at Banani R/A.

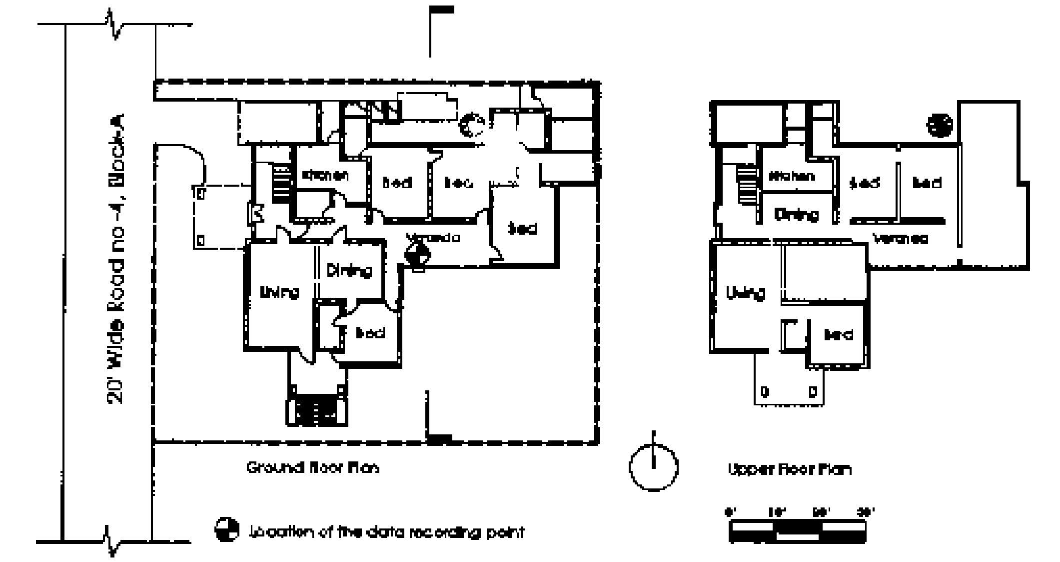


Figure 4.27 Detail plan of spot –04 at House-105, Rd-4, Block-A, Banani, Dhaka-1213.

Description of the survey spot: The four storied house, House no.-105, Road no.-4, Block-A, Banani R/A, Dhaka-1213, is resided by a joint family composed of parents and three sons with their families (Fig. 4.25 and Table 4.1). The building has 3623 sq.ft. or 336.5 sq.m. floor space in ground level and 2650 sq.ft. or 246.2 sq.m. in each of the upper levels. It has 20 ft. or 6.1 meters setback in road side on the west. In the south setback is variable; 16 ft. or 4.9 meters at west-end while 40 ft. or 12.2 meters at east-end. A big open space on the south-east corner of this compound shape building serves as green lawn. The 20 feet or 6.1 meters wide access street is on the west of this 11.14 katha or 745 sq.m. plot. In the west across the street a 2-storied building is serving as eye clinic, a 6-storied apartment building is located on the south-west side and a 4-storied apartment building is standing on the north-west side. There are single storied residences on south and north sides and a 2-storied residence on the east.

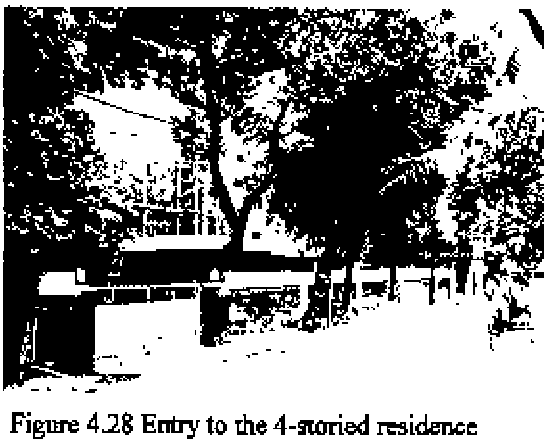


Figure 4.28 Entry to the 4-storied residence spot –04 in Banani

Figure 4.29 Single storied residence on the south of spot –04 in Banani

Figure 4.30 Open space in south-east side of the spot –04 in Banani

Figure 4.31 Single storied residence on the north of spot –04 in Banani

Table 4.1 Calculated physical aspects existing in four residential districts

Aspects/Location	Sutrapur	Dhanmondi	BUET T. Q.	Banani
Existing approximate Floor Area Ratio (FAR)	**between 4 to 5**	**between 3.5 to 4.5**	**between 1.1 to 1.3**	**between 1.5 to 2.5**
Existing Ground Coverage (GC) by structures (approx.)	**between 85 to 95%**	**between 70 to 80%**	**between 25 to 30%**	**between 55 to 65%**
Existing Hard : Soft Surface (HSSR) (approximately excluding road area)	**95 : 05**	**80 : 20**	**30 : 70**	**60 : 40**
Population Density (PD) in persons per acre (approx.)	**300-400**	**250-300**	**150-170**	**150-200**

4.5 INSTRUMENT USED IN FIELD SURVEY

Before final instrumentation for data measurement a pilot survey was conducted in many different residential areas of the city including four selected survey spots. In this pilot survey four similar maxima-minimum thermometers (Appendix-A.2) were used simultaneously. The objective of this pilot survey was to assess the suitability of locating the instruments to avoid effects of direct sun-light, inflated radiation to or from any particular direction, funneling effect of air-flow due to specific channel shape, extraneous humidity due to any excessive water evaporation or dehumidification. In all survey spots, as mentioned earlier, instruments (Appendices-A.2 and A.3) were installed on a south facing veranda wall of ground level at about 2.2 meters height from the floor (Fig.- 4.8, 4.10, 4.19 and 4.26). So the finally recorded data are almost free from localized special influences and can be taken as typical and representative of whole of the concerned districts' transitional spaces.

The instruments used in field study (Appendix A.1, A.2 and A.3 for detail specification) are as follows:

1.	Pocket Weather Meter (KESTREL 3000)	03 Nos.
2.	Programmable Data Logger (HOBO H08-007-02)	02 Nos.
3.	Maxima-Minima Thermometer	04 Nos.

For Air-flow data measurement at three different heights at every survey spot three anemometers (Kestrel 3000 pocket weather meter) (Appendix-A.1) were used simultaneously. Temperature and Relative Humidity data were measured with the help of two data loggers (HOBO H08-007-02) (Appendix-A.3) and with the help of two pocket weather meters (Kestrel 3000). For simultaneous maximum and minimum temperature data four Maxima-Minima thermometers have been used (Appendix-A.2). Prior to the field data collection, necessary field calibration was made by the recommended calibration kit (Appendix-A.1) according to the specification supplied with these instruments.

4.6 COLLECTED FIELD DATA

To get the daily maximum and minimum data of temperature and relative humidity, early in the morning, that is 6.00 a.m., and early in the after noon, that is 2.00 p.m, were selected for data recording. Due to shortage of instruments, wind velocity data were not taken simultaneously in all spots. Wind data were taken simultaneously at three different heights at every spot. Although the surveyors compelled to go on different dates and times at different spots, in every spot similar weather conditions and more or less mid-day situations were chosen for recording wind data. In spot -3 and spot-4 programmable data logger were installed and in other two spots pocket weather meters were used to record temperature and humidity data. For cross checking four maxima-minima (alcohol based) thermometers are also used in all sites during survey.

4.6.1 Micro Climatic Field Data of Four Survey Spots

Following are the data tables for furnishing maximum and minimum temperature, and relative humidity in all four survey spots for the 15 days during May 2003. Wind velocity data at three different heights taken simultaneously to identify the wind gradient. Due to limitation in the quantity of anemometers and other logistics all four survey spots could not be covered in the same time. Different dates are chosen for different sites. But in one spot (Sutrapur) wind data has been taken in several days and found similarity in wind gradient. So one day data (multiple readings used) in other sites gives reasonably correct wind gradient due to the existing fabric pattern.

Spot -1, Sutrapur at Old Dhaka.

Table 4.2 Temperature and Relative Humidity Data at spot-1, Sutrapur.

Date	Temperature °C		Relative Humidity %	
	6.00 AM	2.00 PM	6.00 AM	2.00 PM
12/05/2003	28.8	33.9	89	50
13/05/2003	29.2	32.6	85	60
14/05/2003	29.4	32.2	89	68
15/05/2003	28.3	32.3	81	64
16/05/2003	27.6	32.8	88	63
17/05/2003	29.3	33.8	89	65
18/05/2003	28.5	33.6	78	59
19/05/2003	28.9	33.7	83	61
20/05/2003	27.6	34.7	77	54
21/05/2003	27.5	31.2	73	61
22/05/2003	27.9	31.5	81	67
23/05/2003	30.7	32.1	79	76
24/05/2003	28.8	32.2	84	66
25/05/2003	28.3	31.1	81	74
26/05/2003	29.5	32.8	87	74

Table 4.3 Wind Velocity Data at spot-1, Sutrapur.

Date	Floor level	Max. air speed in m/s.		Avg. air speed in m/s. (10 min. reading)	
		1.00 PM	3.00 PM	1.00 PM	3.00 PM
16/05/2003	Ground fl.	0.5	0.6	<0.3	<0.3
	1st fl.	2.0	2.6	0.6	0.5
	Roof	2.3	3.6	0.8	1.5

Spot -2, Dhanmondi Residential Area

Table 4.4 Temperature and Relative Humidity Data ar spot-2, Dhanmondi R/A.

Date	Temperature °C		Relative Humidity %	
	6.00 AM	2.00 PM	6.00 AM	2.00 PM
12/05/2003	30.3	34.3	84	61
13/05/2003	30.0	33.8	78	59
14/05/2003	29.5	32.5	82	64
15/05/2003	28.8	33.1	77	62
16/05/2003	28.9	34.7	75	60
17/05/2003	27.6	33.5	79	59
18/05/2003	28.5	33.6	74	53
19/05/2003	29.0	34.4	76	47
20/05/2003	28.8	34.8	83	58
21/05/2003	28.6	33.4	80	61
22/05/2003	27.7	31.2	86	65
23/05/2003	29.1	33.8	79	63
24/05/2003	28.7	32.6	81	61
25/05/2003	30.1	33.0	78	57
26/05/2003	31.0	34.1	82	64

Table 4.5 Wind Velocity Data at spot-2, Dhanmondi R/A.

Date	Floor level	Max. air speed in m/s.		Avg. air speed in m/s. (10 min. reading)	
		1.00 PM	2.00 PM	1.00 PM	2.00 PM
19/05/2003	Ground fl.	0.8	0.7	0.3	<0.3
	2nd fl.	0.6	0.5	0.2	0.2
	Roof	2.8	2.1	0.9	0.7

Spot -3, BUET Teachers' Quarter

Table 4.6 Temperature and Relative Humidity Data at spot-3 BUET teachers' quarter

Date	Temperature °C		Relative Humidity %	
	6.00 AM	2.00 PM	6.00 AM	2.00 PM
12/05/2003	28.3	31.5	75	61
13/05/2003	29.1	32.3	76	66
14/05/2003	30.3	31.9	80	63
15/05/2003	29.9	30.7	79	69
16/05/2003	31.1	31.9	88	68
17/05/2003	29.9	31.5	83	70
18/05/2003	28.3	31.9	83	64
19/05/2003	26.7	31.5	68	58
20/05/2003	31.1	32.8	76	60
21/05/2003	26.0	30.3	80	73
22/05/2003	27.5	30.7	81	74
23/05/2003	26.7	30.3	83	71
24/05/2003	30.3	31.1	85	71
25/05/2003	29.2	30.2	86	75
26/05/2003	29.6	30.4	82	68

Table 4.7 Wind Velocity Data at spot-3, BUET teachers' quarter.

Date	Floor level	Max. air speed in m/s.		Avg. air speed in m/s. (10 min. reading)	
		11.00 AM	12.00 Noon	11.00 AM	12.00 Noon
19/05/2003	Ground fl.	0.7	0.9	0.3	0.4
	2nd fl.	1.3	0.7	0.3	0.2
	Roof	2.1	2.7	0.6	0.6

Spot -4, Banani Residential Area

Table 4.8 Temperature and Relative Humidity Data at spot-4, Banani R/A

Date	Temperature 'C		Relative Humidity %	
	6.00 AM	2.00 PM	6.00 AM	2.00 PM
18/05/2003	28.7	32.8	85	61
19/05/2003	25.6	32.8	77	52
20/05/2003	29.1	34.4	87	53
21/05/2003	25.2	30.3	88	75
22/05/2003	26.3	30.7	88	73
23/05/2003	26.0	30.3	87	73
24/05/2003	28.3	31.1	94	75
25/05/2003	26.3	30.7	92	75
26/05/2003	27.5	32.8	94	72

Table 4.9 Wind Velocity Data at spot-4, Banani.

Date	Floor level	Max. air speed in m/s.		Avg. air speed in m/s. (10 min. reading)	
		12.00 Noon	2.00 PM	12.00 Noon	2.00 PM
21/05/2003	Ground fl.	0.8	0.7	0.4	0.3
	2nd fl.	1.9	1.2	0.6	0.5
	Roof	3.1	2.8	0.8	0.7

4.6.2 Macro Climatic Data of Dhaka City

Similar data (temperature, relative humidity and wind speed) during the period of survey at the same time and on same dates were also collected from meteorological station of Agargaon, Dhaka, to get an understanding about the macro-climatic condition and make a comparison with site climates in all four survey spots. This meteorological station is located almost in the middle of the city but far away from CBD (central business district) (Fig. 1.2). These data are recorded in free field conditions and are given in Appendix-B.

Table 4.10 Temperature and Humidity Data recorded at Dhaka Meteorological Station.

Date	Temperature °C		Relative Humidity %	
	Min.	Max.	Max.	Min.
12/05/2003	21.2	34.8	78	45
13/05/2003	25.4	35.0	85	43
14/05/2003	26.7	34.0	92	56
15/05/2003	25.8	32.0	89	55
16/05/2003	25.0	33.8	93	56
17/05/2003	26.8	34.6	93	53
18/05/2003	26.6	34.3	83	52
19/05/2003	21.4	35.5	81	43
20/05/2003	27.8	36.1	94	46
21/05/2003	20.9	31.5	93	65
22/05/2003	23.8	32.1	91	65
23/05/2003	23.0	32.2	91	56
24/05/2003	24.6	32.8	90	61
25/05/2003	23.4	33.6	93	58
26/05/2003	23.8	36.3	90	57

Source. Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2003

Table 4.11 Wind speed data recorded at Dhaka Meteorological Station.

Date	Maximum wind speed		Average wind speed	
	in m/s.	Direction in deg.	in m/s.	Direction in deg.
12/05/2003	3.6	18	3.6	320 (NE)
13/05/2003	5.1	18	3.6	180 (S)
14/05/2003	4.1	13	5.1	180 (S)
15/05/2003	3.1	05	4.1	130 (SW)
16/05/2003	2.6	18	3.1	50 (NW)
17/05/2003	2.1	13	2.6	180 (S)
18/05/2003	2.6	05	2.1	130 (SW)
19/05/2003	12.9	31	2.6	50 (NW)
20/05/2003	3.1	32	12.9	310 (NE)
21/05/2003	3.1	09	3.1	320 (NE)
22/05/2003	5.1	05	3.1	90 (W)
23/05/2003	3.1	36	5.1	50 (NW)
24/05/2003	4.1	18	3.1	360 (N)
25/05/2003	3.1	18	4.1	180 (S)
26/05/2003	6.2	18	3.1	180 (S)

Source: Climate division, Bangladesh Meteorological Department, Agargaon, Dhaka, 2003

The weather condition of Dhaka city on the survey dates were also recorded, based on general observation, so that thermal changes in transitional spaces due to weather change can be identified. This link has been analytically established in the oext chapter.

The following table represents weather report as observed during survey dates.

Table 4.12 Weather conditions of Dhaka city during survey period

Date	*Description of Weather Condition*
12/05/2003	It has rained in early morning and stopped at dawn. After 9.00 AM the sun got brighter with clear sky.
13/05/2003	The sky was gloomy and uniformly clouded and diffused sun-light was coming from all over the sky dome. During late afternoon the sky got cloudier.
14/05/2003	The sky was gloomy and cloudy 20% to 30% all day long. But the sun dominated and the wind had no specific direction.
15/05/2003	The sky remained cloudy both in the morning and after evening. White cotton like cloud was all over the sky with little direct sun. The sun came out at noon.
16/05/2003	There was bright sun and strong wind almost through out the whole day. Glare from sporadic cloud. Duration of sun was short, from late morning to early evening.
17/05/2003	The windy day started with diffused sunlight all over. Bright sun light was during mid day. But cloud was there to cast random shadow.
18/05/2003	The areas are sometimes cloudy and sometimes sunny.
19/05/2003	Cool air flow was during early morning. Gradually the sun got bright. Interplay of sun and cloud started after 11.00 AM.
20/05/2003	The day was a bright sunny and was suffocating. Very low air-speed and randomly from SE and SW direction. At about 9.00 PM there was a brief storm followed by low intensity rain continued till mid-night.
21/05/2003	Morning was bright sunny and afternoon was partially cloudy, air flow was normal. In the late afternoon sky got black and was about to rain. Strong cool wind but no rain. Comfortable weather.
22/05/2003	Very sunny day, but got cloudy in the afternoon and was about to rain. Humidity was high.
23/05/2003	The sky was uniformly cloudy and there was diffused sun-light all over the sky dome. It was raining in night.
24/05/2003	The sky was cloudy about 30% to 40% all day long. But the sun dominated and the air had no specific direction.
25/05/2003	The sky remained gloomy in the morning. Cloud was all over the sky with little direct sun. The sun came out at noon. During afternoon the sky got more cloudy and no direct sun.
26/05/2003	There was cloud cover here and there. Little rain was there. The sky got clear as the day matured.

4.7 SCOPE AND LIMITATION OF THE SURVEY

Exactly similar kind of transitional space in every survey spot is not available in terms of their size, shape, proportion and sequence of outdoor-semi outdoor-indoor. Orientations of all spots are not similar in terms of their accessibility from the street but the data collection points were taken on south side veranda at ground floor level in each and every case. In spot -04, temperature and relative-humidity data could not be recorded from 12 May 2003 as done in other three survey spots due to some unavoidable circumstances. The data logger was installed in the spot-04 a few days later, since 18 May 2003.

Air flow data have been recorded in three heights in each spot. One at ground level, one in roof level and the third one is at mid level of the buildings. As all the buildings are not of equal height the air-flow data are not collected from similar height in all cases. This variation is commensurate with the variation of skylines among different survey areas. Data was recorded only during a short period at the end of summer 2003. If readings could be extended through out the whole summer season and through a number of consecutive years, a wider picture of existing conditions would be available.

4.8 CONCLUSION

Physical density of building mass is found quite variable in different survey areas. Both Dhanmondi and Sutrapur areas are comparatively denser and having less proportion of soft surfaces (Table 4.1). Banani area has a balance situation in its HSSR, while BUET Teachers' Quarter has the highest proportion of soft surfaces. The temperature levels are greater in comparatively higher density areas and greater diurnal range is found in areas with high density building mass and with less soft surfaces (Fig. 5.4, and 5.5). Magnitude of relative humidity data variation is smaller in different areas (Fig. 5.7 and 5.8). As the weather is dry and rain fall is less in the month of May, impact on relative humidity is largely dependent ou local relevant factors. In all die areas under investigation air-flow at ground level was found poor, while at roof level the amount was quite considerable. In higher density areas, like in Dhanmondi, air-velocity at mid-level was found poorer than that at ground level. An elaborate analysis is given in the next chapter using all these data and observation to identify the factors which are directly responsible for degradation of thermal environment in these residential districts of Dhaka.

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CHAPTER

5

ANALYSIS OF FIELD DATA AND OBSERVATION

5.1 INTRODUCTION

Seasonal variation of composite climate in Bangladesh exposes people sometimes to hot-dry summers, sometimes to warm-humid monsoons and some other times to cool-dry winters (Hossain & Nooruddin, 1993). This swinging from hot to cold and from cold to hot poses major difficulty in thermal comfort. The good thing is, usually these changes happen gradually and people get some time for acclimatization. The hot-discomfort during summer and cold-discomfort during winter are not severely extreme, except a short spell in peak summer (when the scorching sun spills intense radiation through the clear sky) and even shorter spells in peak winter (when cold wave comes from northern Himalayas). Rest of the year, the natural environment remains almost comfortable in outdoor shaded areas. During the monsoon high moisture content in the air restricts evaporative cooling process of human body. Relatively higher velocity of airflow at the body level is then essential to enhance evaporative cooling. So it can be said that the macro climate of Bangladesh remains close to comfortable most of the time.

Our built environment must make best utilization of this natural climate, allowing positive aspects into indoor environment and restricting the adversities. Failing to do that in design and planning makes the situation undesirable and uncomfortable. Mass use of electro-mechanical appliances can be the last resort to achieve thermal comfort, which compels higher rate of energy consumption. Higher consumption of energy in a particular place is a further addition of heat, which diffuses within built environment raising the ambient temperature and posing threat to thermal comfort, specially during summer.

Insensitive design and planning of our houses and settlements can cause heat to be trapped within built-mass for long time. Daily thermal balance between day time heating and night time cooling would thus be hampered and thus builds-up compound heat. Cumulative effect of this heat storage may pose a significant disruption to the objectives of a home.

The energy consumption in buildings is related to the energy system, i.e. the climate, in which buildings are located as well as to the properties of shelter itself (Markus & Morris, 1980). With appropriate design, layout and planning we can achieve thermal comfort within and around our built-environment and can pay little for energy consumption.

5.2 URBAN CLIMATE FACTORS

It is generally understood that the climate of urban built up areas vary from that of the surrounding rural areas (Givoni, 1989; Koenigsberger, *et al*, 1992). Due to rapid urbanization and continued densification metropolitan Dhaka is gradually acquiring with the following symptoms that generate threats to its thermal Environment:

- Higher percentage of hard and lesser percentage of soft surface coverage[1].
- Rapid runoff of surface water reducing localized percolation and the ground remains dry almost all the time.
- Less amount of vegetal green mass that fails to provide enough evapotranspirational cooling[2] during summer.
- High density of electrical energy usage per unit area as the density of activity is very high in most of the places.
- High density of population that is also a big source of heat.
- Less scope of heat diffusion due to compact building layout.
- Presence of smog and thus attenuation in long wave re-radiation during night.
- Urban heat island effect in central business districts like, Motijheel C/A, Karwan Bazar C/A, etc.

5.3 DIFFERENCES IN PHYSICAL CHARACTER

Thermal quality of an outdoor space, whether natural or man-made, is actually characterized by their geographic location, surface quality, three-dimensional objects and topography. On the other, hand thermal quality of an indoor space is highly modulated by its use pattern and the ability to interact with the outdoor environment through its

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[1] The stock of public open spaces under Dhaka City Corporation (DCC) control is approximately 190 acres and under Public Works Department (PWD) is 302 acres. These two authorities cover 0.768 sq. miles of open area, which is only 1.4% of Dhaka's land (Nilufar, 1999).

[2] In summer a tree has been found to operate as a "cooler" using up to 100 gallons of water per day and the resultant evapotranspiration rate is equivalent to a cooling potential of 230,000 kcal/day, which depends on a number of factors such as leaf area, moisture presence in soil and ambient energy (Kramer, 1960). Insufficient light, high wind speed or radiation can results in an increased resistance to evapotranspiration (Oke, 1978,)(Lowry, 1991)(cited in Ahmed, 1995)

enclosure. Orientation, building material, building morphology, ventilation system, power consumption, population, activity, etc. of a dwelling unit are the major man-made exponents, which are responsible for indoor thermal environment. Following aspects in different survey areas are compared between each other to determine the overall physical characteristics of the residential districts under this study.

5.3.1 Physical Density

Physical density is defined here as the volume of built area per unit of ground surface area, i.e. by the *floor area ratio* (FAR). This can be calculated by the following equation:

FAR = effective total area in all floors / effective total plot area

There was no FAR control on any kind of development in Bangladesh until 2006. Only recently a new set of building construction rules including FAR control specifications along with Ground Coverage (GC) specifications have been passed solely for Dhaka city and enacted from January 2007 (GOB, 2006). Deviations of those rules during construction of buildings are common due to weak monitoring and control by RajUK (Chowdhury, 2003; Islam, et al, 2009; Reporter, 2010). But we can get hopeful that RajUK has demolished many unauthorized structures from different areas of the city during last two years and many other unauthorized constructioo have been enlisted (about 5000) to be demolished in the very recent time.

In the new Dhaka City Building Construction Rule 2006 (DCBCR-2006) prescribed residential physical density in different scale. FAR starts from -3.00 for smallest plots (up to 150 sq.m. size) to 5.00 for largest plots (above 1300 sq.m. size) and 6.50 for any plot size, specially for high density central areas. Fringe areas can get further considerations. Among the four residential districts under this research in metropolitan Dhaka physical density is found highest in Sutrapur, closely followed by Dhanmondi and lowest in BUET teachers' quarter (Table-5.1). The existing FAR of these areas is far lower than the highest FAR suggested in DCBCR-2006.

A recent amendment (2008) of FAR in fabour of more densification compared to the earlier one has been enacted. Starting FAR-3.15 for smaller plots has been prescribed keeping the highest FAR 6.5 as it is.

Table 5.1 Comparison of physical aspects in four residential districts (2003) with DCBCR

Aspects/Locations	Sutrapur	Dhanmondi	BUET T. Q.	Banani	DCBCR
Floor Area Ratio (FAR)	**between 4 to 5**	**between 3.5 to 4.5**	**between 1.1 to 1.3**	**between 1.5 to 2.5**	**between 3.0 to 6.5**
Ground Coverage (GC)	**between 85 to 95%**	**between 70 to 80%**	**between 25 to 30%**	**between 55 to 65%**	**between 50 to 65%**
Hard : Soft Surface (HSSR)	**95 : 05**	**80 : 20**	**30 : 70**	**60 : 40**	**83.5 : 16.5 75 : 25**
Population Density (PD) per acre	**300-400**	**250-300**	**150-170**	**150-200**	**---**

5.3.2 Ground Coverage

In the "Building Construction Rule 1984 (BCR-1984)" and "Dhaka City Building Construction Rule 2006 (DCBCR-2006)" there are definite rules for Ground Coverage (GC) percentage along with setback rule for all four sides of a building (IAB, 1995; GOB, 2006). For all residential buildings 1/3 or 33.3 % area of a plot was suppose to be kept open and maximum 2/3 or 66.6 % area of a plot could be covered by building construction before 1996. This GC rule was given up in 1996, when the building construction regulation was once reformulated and only setback rule was enacted comparatively in more relaxed form (IAB, 2003). This has encouraged people to build structures more compactly. According to this rule larger plot owners have got chance to cover more proportion of plot area by building structures with more GC compared to the smaller plot owners. Although there were rules to ensure ventilation and lighting in all bed-rooms and mandatory external wall/window for kitchen (practically which are not properly assessed in most of the cases), open spaces have diminished around residential districts. In the new DCBCR-2006 for Dhaka City, GC rule has once again enacted and it prescribes, starting from 65% for smallest plots to 50% for largest plots, for residential landuse to ensure some proportion of open space and soft surface around buildings.

Mass scale violation of building construction rules and frequent unauthorized deviations are found in Sutrapur area and to some extent in Dhanmondi also. The setback spaces around the building are intentionally reduced during construction, to increase interior space, which points towards faulty inspection and/or monitoring by the authority. That is why gap between two adjacent buildings is not keeping sufficient and most of the present day residences in Sutrapur have very poor provisions for natural lighting and ventilation.

Practically only in Banani and in BUET teachers' quarter one-third or more plot areas were found un-built and kept open for vegetation and green development. So the new DCBCR-2008, if implemented properly, will create more open spaces with higher physical density in the residential districts of Dhaka metropolitan area.

5.3.3 Hard to Soft Surface Ratio

Hard surfaces are defined as more solid and less porous and usually having more weight per unit of its volume, that is of higher density. Higher density material often has higher thermal conductivity and this relationship is true for materials of the same kind with varying densities, or for the same material with different densities (Koenigsberger et al, 1992). Pavements, concrete roof, brick wall, etc. are examples of hard surfaces and water bodies, greenery, barren earth, etc. are the examples of soft surfaces.

Large unshaded hard surfaces contribute to the increase of ambient air temperature during sunny days (Ahmed, 1995). Heat gain by convection from such surfaces is substantially increased as turbulent air flow results in a greater convective exchange and rapid mixing of air layers at different densities (Holman, 1989; Duncan, *et al*, 1978). 'Perhaps the most obvious mechanism is the heating of the air near the warm ground on a sunny day, for then a portion of heated air breaking away from the ground will find itself warmer than the cooler air a little way above, and will rise a further distance by buoyancy' (Sutcliffe, 1966).

So in an area, where there is higher percentage of hard surfaces like Sutrapur and Dhanmondi (Table-5.1), the chance of heat transmission during day time is higher through radiation, convection and thence conduction from outdoor to indoor. But in case of comparatively more percentage of soft surfaces, like in BUET Teachers' Quarters and in Banani, the major share of the incoming solar radiation can be released to the sky by the higher rate of evapotranspiration from soft surfaces. Because soft textures like plants, earth surface, water body, etc. contain high amount of moisture.

The simultaneous reflection (r) and emission (e) of radiation during day time depend on surface quality, material and temperature. From Table-5.2 we can find that all the usual building materials except white paint and polished aluminium have high absorbance for solar radiation, which indicate lower percentage of reflectance by those surfaces.

Emittance of those material surfaces are found very high except polished aluminum. These indicate that during day time the usual building roofs and walls with different colours absorb much of the incoming solar radiation and subsequently increase the indoor temperature.

Table 5.2 Absorbance and emittance of different building materials

Surface	absorbance (a) for solar radiation	emittance (e) 10 to 40 °C
Red brick	0.65-0.80	0.85-0.95
Plaster	0.30-0.50	0.40-0.60
White paint	0.10-0.30	0.80-0.90
Window glass	transparent	0.90-0.95
Polished aluminum	0.10-0.40	0.02-0.04

Source: (Koenigsberger et al, 1975, *Appendix 5.6*)

So the increased proportion of hard surface is directly responsible for higher ambient temperature that contributes to the rise of temperature inside the built-form during day time. On the other hand the higher proportion of soft surfaces can dissipate absorbed heat through evapotranspiration of moisture all day long and keep the ambient temperature low, which can contribute to the reduction of temperature from the built form. Moreover, vegetation uses much of the incoming radiation for its biological activities, and it is only the residual energy that goes on to increase the temperature of the receiving surface.

5.3.4 Population Density

Increase of population density is directly related to the increase of heat content in a place as every person dissipate large amount of metabolic heat[3] and indirect heat from anthropogenic activities in his/her living environment (Table-5.3). As the population densities are higher in Sutrapur and in Dhanmondi areas (Table-5.1), day time indoor temperature is seen to rise to higher levels compared to low population density areas like BUET T. Q. and Banani. Although the amount of heat coming from this metabolic source is small compared to the solar radiation (where solar constant is 1350 Watt/m^2), higher density population source can make a considerable impact in the immediate environment before being dissipated to the outer environment.

[3] During day time people remain more active and release more heat, although a house in urban area during day time is not occupied by all the members of a family, as they do during the night. One person working moderately can release as much as four times heat (290 watts) than a sleeping person (70 watts) and a person doing heavy work can release far more heat (700 watts) (Koenigsberger, et al, 1992).

Table 5.3 Heat flow rate by a healthy person during different activity

Activity	Heat flow rate in Watts
Sleeping	min. 70
Sitting, moderate movement, e.g. typing	130-160
Standing, moderate work, some walking	220-290
Walking, moderate lifting or pushing	290-410
Hardest sustained work	580-700
Maximum heavy work for 30 minutes	max. 1100

Source: (Koenigsberger et al, 1975, page-42)

People in the low income areas also perform more work inside their house which the people in higher income areas do not need. Low income people do not merely use their residences for living purpose. In most cases they use their houses for other income generating activities. So this enhanced activity level inside the house generates more metabolic heat and contributes to further rise of temperature. In Sutrapur area many such professional activities are seen in and around the houses.

In Dhanmondi area various commercial activities are encroaching into the residential environment, which has increased the activity density of this area. Along with this, vehicular movement has also increased manifold here. All these must contribute to the rise of temperature during the day in Dhanmondi. In BUET T. Q. non-residential activities are absent and Banani survey area is found relatively free from commercial and other professional encroachment.

5.3.5 Standard of Living

Expectation of comfort increases as the means to achieve comfortable environment gradually come within reach (Mojumder, 2000), in terms of both affordability and availability. For this increased comfort people, of higher income group in Dhaka context, depend on active means instead of relying on passive control of climate. Pattern of Urban-form constitutes the type of link between the rate of energy consumption and the spatial structure (location, shape, size, density and land use) of the city (Owens, 1986).

Maximizing building area for rental purpose without keeping adequate soft areas around the building for passive thermal control and then paying for active means of thermal control is more profitable. House rent in Dhanmondi R/A is about 20.00 Taka per sq.ft. and in Banani R/A it is about 25.00 Taka per sq.ft. at present market price (2010). A family spends an extra Tk. 1,000/= to 1,500/= for active climatic controls[4], which can be recovered by renting out extra 50 sq.ft. of built area.

On the other hand, increased income level, fast life, improved living standard and easy availability of home appliances in urban Dhaka almost compels one to heavily depend on electrical and electronic house appliances like television, refrigerator, sound system, electric oven, blender-mixer, washing machine, electric iron, computer, light, fan, etc. Mass use of these items escalates the energy consumption. This energy comes into a house from the national power grid, transfers into heat after use and then gets trapped inside the house if passive means do not work. Air-coolers or air-conditioners become the final resort to get rid of this unbearable situation, especially during summer, thus putting tremendous pressure on the scarce energy reserves of the country. Finally this extra energy usage contributes heat to the ambient environment due to ill planning and design of buildings.

5.3.6 Setback Space of Buildings

In building construction rules for Dhaka (one that enacted in 2006 and previous ones enacted in 1984, 1996) provisions for setback spaces in all four sides of a residential plot are recommended to facilitate light and ventilation inside the buildings. For different plot sizes different widths of spaces are recommended, which are not based on climatic comfort requirements (Table-5.4, Table-5.5 and Table-5.6). Recommended setback space in front of a plot remained same in all three changes of rules. But in the sides and back of a plot it is reduced in new rules compare to the 1984 rules for the same sized plot. This will lessen provision for soft surfaces around buildings. And if proper inspection and monitoring remain faulty during construction, people will be interested to further reduce those setback spaces around their buildings as usual practice.

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[4] The amount is found by comparing the electricity bill during the peak summer between two similar families; one from a compact multi-storied apartment and other from a house with enough setback space for lighting, ventilation and plantation in the same residential district.

Figure 5.1 Typical old Dhaka streets with no set back space in front of buildings.

The low income group has more tendencies to violate the rules at highest magnitude in case of building construction. This is evident in old part of Dhaka where lower and middle income group people are living. Figure 5.1 shows the building on both sides of a typical old Dhaka street constructed without leaving any space in road front side.

Table 5.4 Recommended minimum setback around residential buildings in Building Construction Rules of 1984.

Plot area in m^2	Setback space width in front (in m.)	Setback space width in sides (in m.)	Setback space width in back (in m.)
Up to 134	Minimum 1.5	Not mandatory	1.5
Up to 200	Minimum 1.5	1.25	1.5
Up to 268	Minimum 1.5	1.25	1.75
Up to 335	Minimum 1.5	1.25	2.5
Above 335	Minimum 1.5	1.25	3.0

Source: *Directory 1995*, Institute of Architects Bangladesh (IAB).

Table : 5.5 Recommended minimum setback around residential buildings in Building Construction Rules of 1996.

Plot area in m^2	Setback space width in front (in m.)	Setback space width in sides (in m.)	Setback space width in back (in m.)
Up to 134	Minimum 1.5	0.8	1.0
134 to 200	Minimum 1.5	1.0	1.0
200 to 268	Minimum 1.5	1.0	1.5
Above 268	Minimum 1.5	1.25	2.0

Source: *Directory 2003*, Institute of Architects Bangladesh (IAB).

Table : 5.6 Recommended minimum setback around residential buildings in Dhaka City Building Construction Rules of 2007.

Plot area in m^2	Setback space width in front (in m.)	Setback space width in sides (in m.)	Setback space width in back (in m.)
Up to 201	Minimum 1.5	1.0	1.0
201+ to 275	Minimum 1.5	1.0	1.5
275+ to 1300	Minimum 1.5	1.25	2.0
Above 1300	Minimum 1.5	1.5	2.0

Source: *Dhaka City Building Construction Rules*, GOB Gadget 2007.

In the study area of Sutrapur, residential buildings were 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 is possible (Figure-5.1). External window openings were found normally on road side walls, and seldom on other sides. Other side walls had window in upper floors only when adjoining buildings on those sides are below that level. These upper storied openings are liable to remain closed permanently, once surrounding adjacent structures are extended vertically in favour of privacy and security. So the provision for natural light and ventilation in the living spaces in this residential area is extremely restricted, risking thermal comfort.

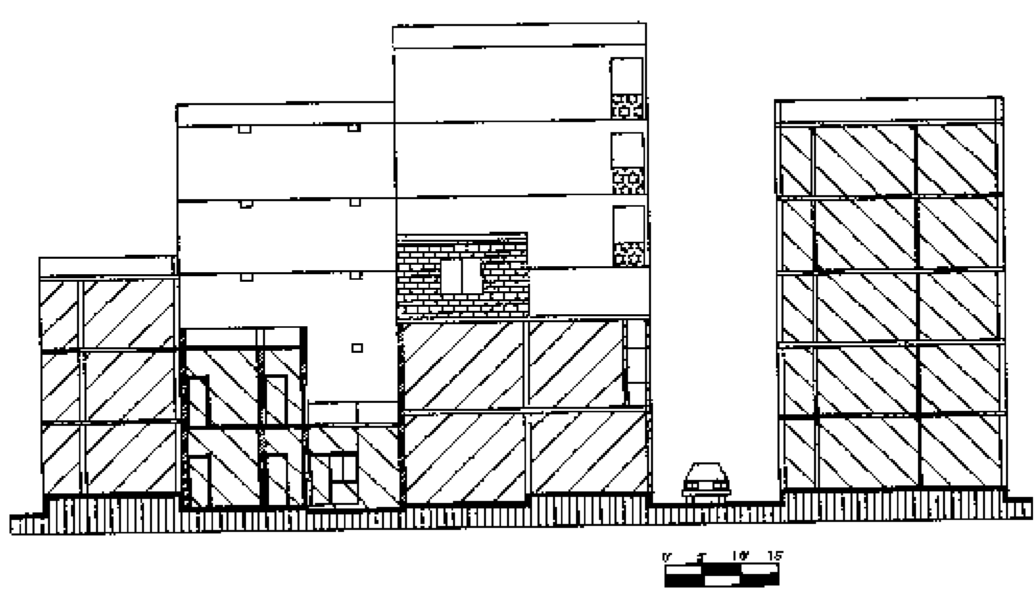

Figure 5.2 Section showing lack of setback spaces around the buildings at Sutrapur. Adjacent buildings in section are shown with hatch at different angles.

This compact situation acts like a big porous insulative layer between the sky and the earth. Unlike built-form in arid region the roofs of all structures are in different levels, indoor-outdoor air exchange is allowed in day time and walls are not enough thick to make 9 to 12 hours time-lag in heat transmission. The summer radiant heat that penetrates inside the buildings during day time can not be easily released after sunset due to lack of ventilation and compact nature of development. As summer matures the cumulative effect can raise the overall indoor temperature posing serious threat to thermal comfort.

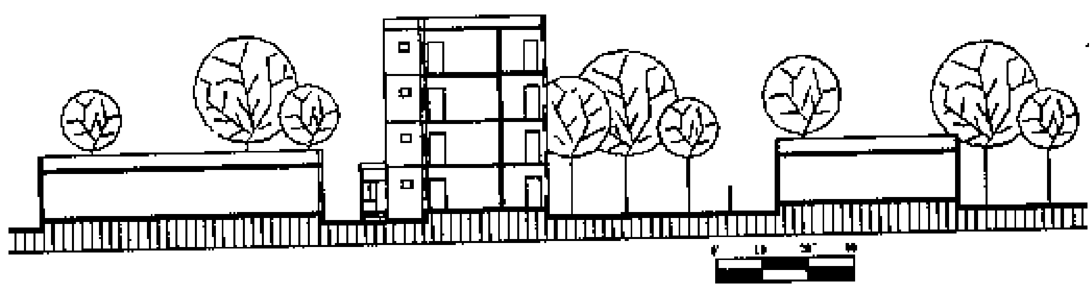

Figure 5.3 Section showing enough setback space in between adjacent buildings at Banani.

Banani and BUET Teachers' Quarter show a different pattern. Here the gap between two buildings is found big enough to facilitate ample light and ventilation through the different vertical layers of the buildings (Figure 5.2) and this air flows in through softer and cooler outdoor environment. In summer nocturnal cooling is expedited by this ventilation (Mridha 2002) and by avoiding cross-ventilation during day time comfortable situation can be retained for long time in the indoor environment.

5.3.7 Building Height

In all the study areas residential buildings were found up to a maximum of six storied height. The construction rules permit this maximum height only when the ground floor is kept free for car parking. In Sutrapur area, structures are found with a good mixture of variable heights, which created a more or less uneven or bumpy building skyline (Figure-5.2). This unevenness can increase the turbulence effect in the natural air flow (Figure-5.10). As a result, better air flow can be ensured at different layers of all buildings in residential district (Givoni, 1998; Akhtari, 2001).

In Dhanmondi area wind flow is deteriorated by the increase in building volumes at same height with narrow interval spaces (Akhtari, 2001). Almost all of the new buildings are six storied with almost similar in height. This similarity combinedly creates a large horizontal plane above the structures (Figure-4.10). Small width of setback spaces between adjacent buildings remains in wind shadow. As a result higher velocity of air flow is experienced above roof level, which drastically cut off in the bottom layers (Figure-5.11). But in the ground level a little higher velocity of air-flow compared to middle layers is experienced. This happens due the openness in the ground floor level, which is kept free for car parking. Free floor at ground levels prescribed for parking use with more perforated boundary controls between buildings can create continuous openness and thus ensures better air flow (Akhtari, 2001).

BUET teachers' quarter does not have notable variation in height among the buildings, neither do they have ground floor free. But there are big open spaces enriched with lush vegetation between the buildings along north-south direction. Due to these spaces comparatively better air flow at different height is found (Figure-5.12).

Banani area is also found with variable height of the buildings and large open spaces in between buildings with soft surfaces (Figure-5.3). So far best distribution of air flow at different height is found (Figure-5.13). It can be assumed that if ground floor could be kept free, like that of Dhanmondi R/A, a far better distribution of air flow could be ensured here in Banani R/A.

In view of all these practical observations it can be inferred that, to ensure higher velocity of cool air through transitional spaces, the most effective fabric pattern or building morphology shonld be of variable height with large open spaces in between structures (enriched with soft surfaces) similar to Banani R/A. Free ground levels in all buildings similar to Dhanmondi R/A can accentuate air-velocity and better distribution of cool air flow. A combination of these two physical characteristics will be most affective for desirable cooler air-flow through the transitional spaces in a residential settlement specially during summer. Openness has got a direct relationship with the availability of higher air-velocity at all height and thus better scope of ventilation.

5.4 TEMPERATURE DATA ANALYSIS

Usually the outdoor air-temperature attains its maximum level between 1.00p.m. to 3.00 p.m., which we can find in the hourly data table that are recorded by data loggers (Appendix B). That is why temperature at 2.00 p.m. was taken for fifteen consecutive days at all four survey spots (except in Banani R/A due to survey limitations). The graph in figure-5.4 shows that, in most of the survey dates, Dhanmondi R/A area attains highest maximum and Banani R/A area attains lowest maximum temperature compared to other two areas.

The second highest 2.00 p.m. temperatures are found at Sutrapur. Average (average of 15 survey days' data) 2.00 p.m. temperatures of Dhanmondi and Sutrapur are approximately 33°C. While the average 2.00 p.m. temperatures of BUET Teachers' Quarter and Banani residential area are approximately 31°C. On an average, about a 2degC higher in 2.00 p.m. average maximum temperature is found in higher density areas (Sutrapur and Dhanmondi) than that of lower density areas (BUET Teachers' Quarter and Banani).

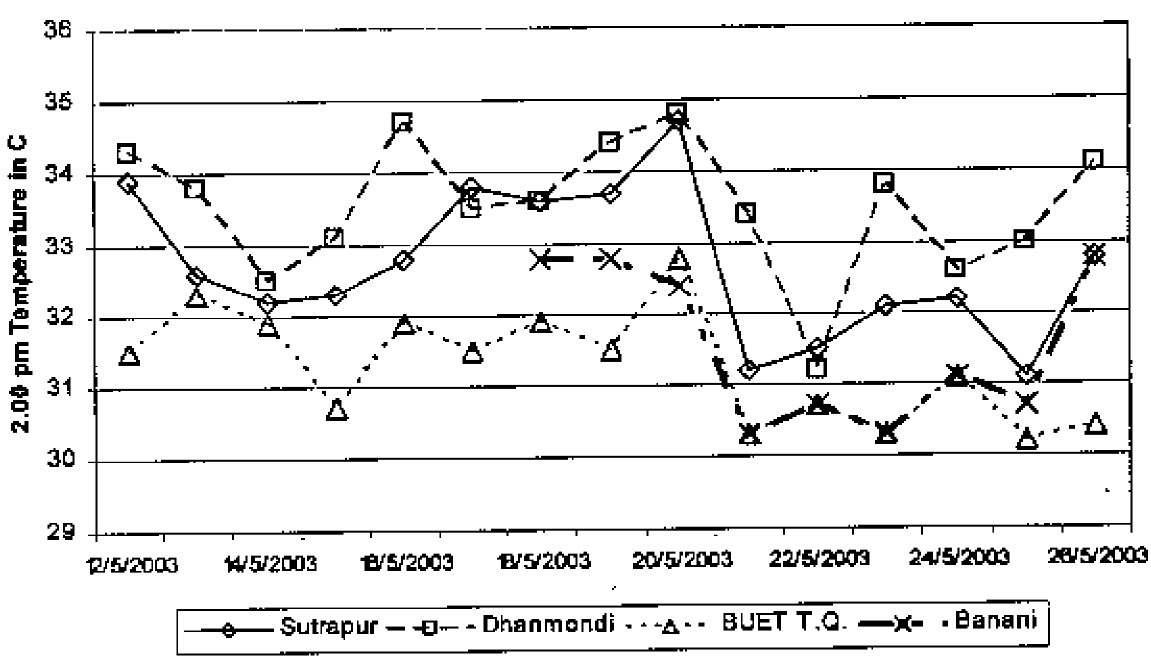

Figure 5.4 Comparative graph of 2.00 pm temperature in the four surveyed spots.
(Data used from Table 4.2, 4.4, 4.6 and 4.8)

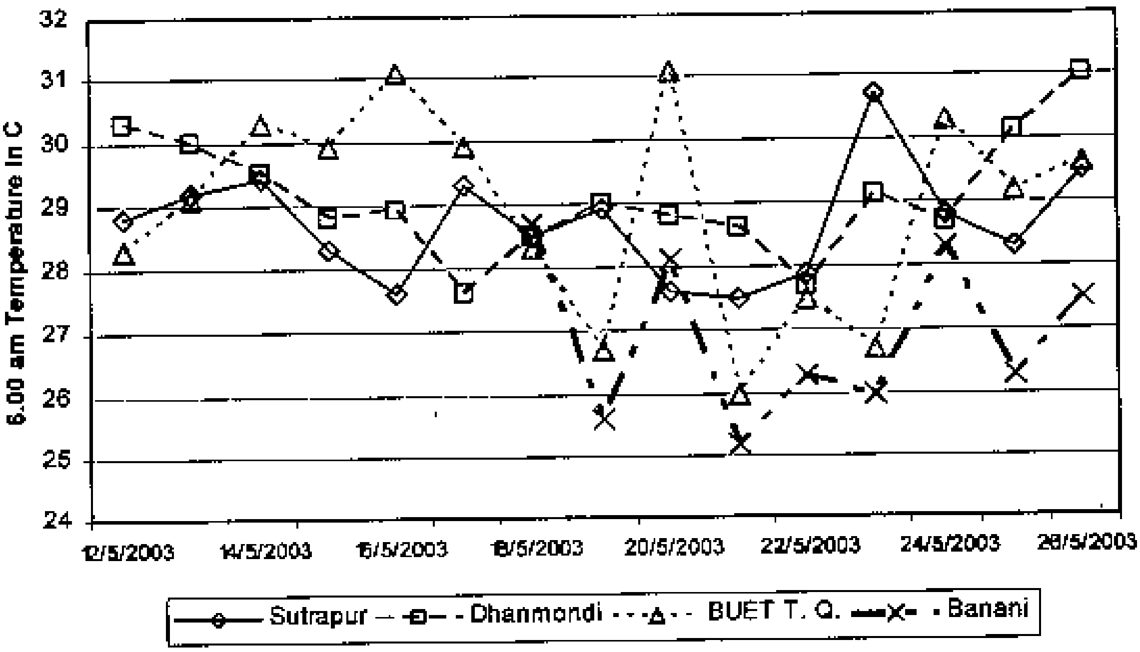

Figure 5.5 Comparative graph of 6.00 am temperature in the four surveyed spots.
(Data used from Table 4.2, 4.4, 4.6 and 4.8)

Both Sutrapur and Dhanmondi areas have higher existing FAR value and proportions of hard surfaces are very high. On the other hand BUET Teachers' Quarter and Banani areas are found having less FAR value and proportion of hard surfaces are comparatively less while green plants with soft surfaces are more here (Table 5.1 and table 5.2).

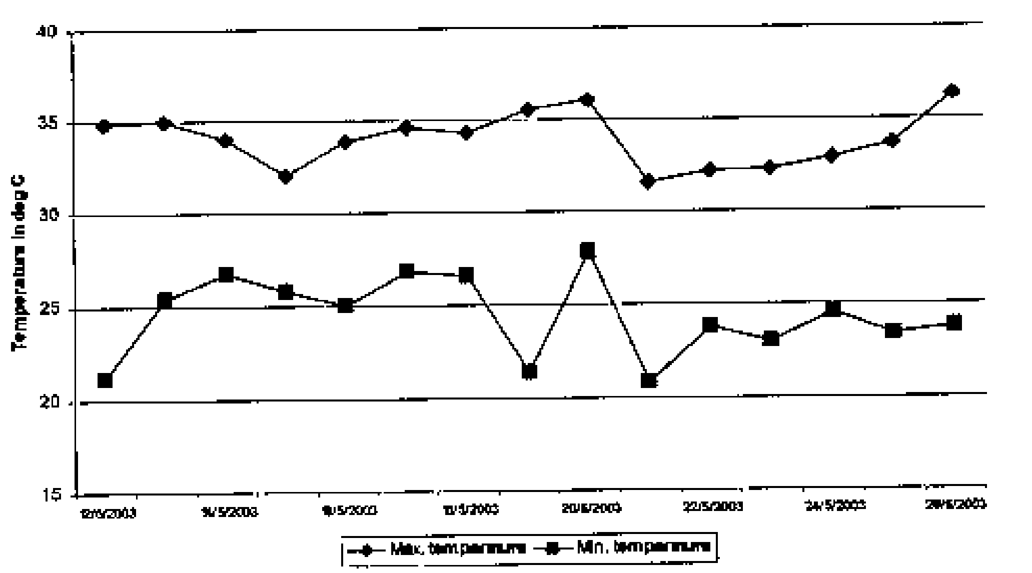

Figure 5.6 Daily max. and min. temperature graph of Dhaka during the survey period.
(Data used from Table 4.9)

If we see the graph of 6.00 a.m. temperatures in figure-5.5, we find that both Sutrapur and Dhanmondi areas have similar moderate kind of temperature range and average minimum temperature is found within 28°C to 29°C. Both BUET Teachers' Quarter and Banani areas show 2 to 5degC fluctuation in consecutive days. Compared to all four spots Banani is showing lowest average minimum 6.00 a.m. temperature while BUET Teachers' Quarter shows ups and downs on different days. Scope of long wave re-radiation through open spaces and evapotranspirational cooling by the soft surfaces are greater in both Banani area and in BUET Teachers' Quarter, while this nocturnal cooling process is hampered in Sutrapur and Dhanmondi areas. The small difference, in this regard, between Banani and BUET Teachers' Quarter could have caused due to other local variable factors, like airflow pattern, convective cooling, presence of moisture in the air, cloud cover right above the spot, etc. Although there is highest quantity of open space and soft surface in BUET Teachers' Quarter compared to other survey spots, lack of nocturnal cooling may be the major reason of not getting lowest 6.00 a.m. temperature here. But some days show that the 6.00 a.m. temperature became much lower in BUET Teachers' Quarter. Relative humidity and airflow analysis could reveal more logical explanations.

5.5 RELATIVE HUMIDITY DATA ANALYSIS

On an average the 2.00 p.m. data of Relative Humidity (RH) is found higher in BUET Teachers' Quarter and in Banani spot, while Dhanmondi spot shows least average RH values followed by Sutrapur spot RH values as second lowest. This RH pattern in all four areas logically corresponds with the pattern of surface water runoff and situation of SS found in different survey spots. Sutrapur and Dhanmondi areas have more percentage of HS coverage compared to BUET and Banani areas (Table-5.3). That's why surface water runoff in the latter two areas is less and presence of green vegetation is more, creating more evaporation, thus raising the RH level locally.

So in hot and dry summer, during the hottest hours at about 2.00 p.m., this comparatively more moist air[5], along with lower temperature, provides better thermal comfort situation in BUET T.Q. and in Banani residential area. On the other hand lower RH level in Sutrapur and Dhanmondi areas are further aggravated by the higher temperature.

[5] Temperature and Relative Humidity data of Banani and Sutrapur in the same dates have been put in Psychometric chart and read the Absolute Humidity data, on an average it is more in Banani than Sutrapur.

Although the higher ambient temperature impedes the heat dissipation process from the body, lower RH here allows faster evaporative cooling if the ventilation is good. Analysis of the air flow situation in the different areas follows.

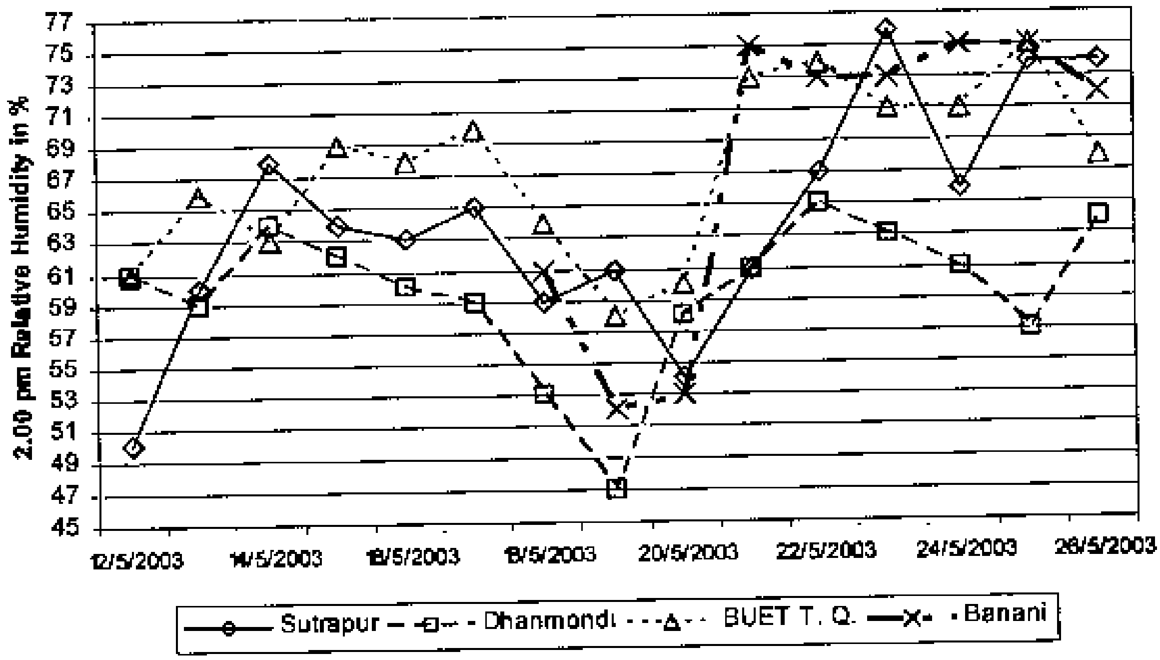

Figure 5.7 Comparative graph of 2.00 pm Relative Humidity in all four spots.
(Data used from Table 4.2, 4.4, 4.6 and 4.8)

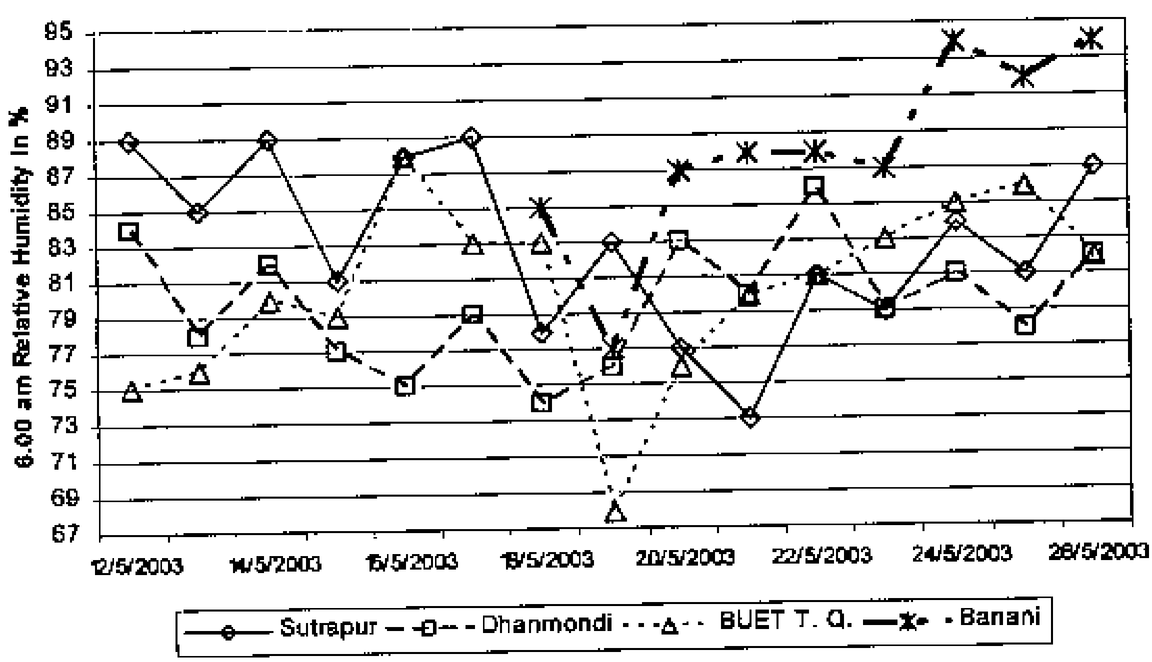

Figure 5.8 Comparative graph of 6.00 am Relative Humidity in all four spots.
(Data used from Table 4.2, 4.4, 4.6 and 4.8)

5.6 WIND VELOCITY DATA ANALYSIS

During survey period the maximum wind speed measured in Dhaka meteorological station shows (Figure-5.9) a moderate range within 2 to 6m/s except 13m/s on 19th May.

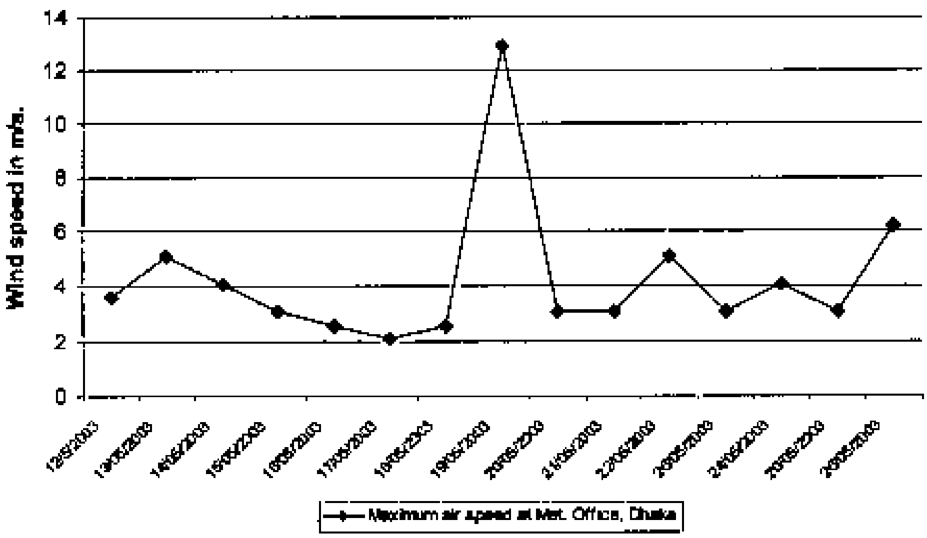

Figure 5.9 Maximum wind speed graph of Dhaka meteorological station, data in May 2003

5.6.1 2-storied residence, Spot-01, Sutrapur

The wind velocity (WV) both maximum and average values (of the measurement period) are found largely attenuated at ground level in Sutrapur. While the mid level is enjoying only a little less WV compared to the roof level values. This indicates that the WV at top layer happens to make turbulence due to the variable height of the building fabric and thus the upper floors get more WV than bottom floors.

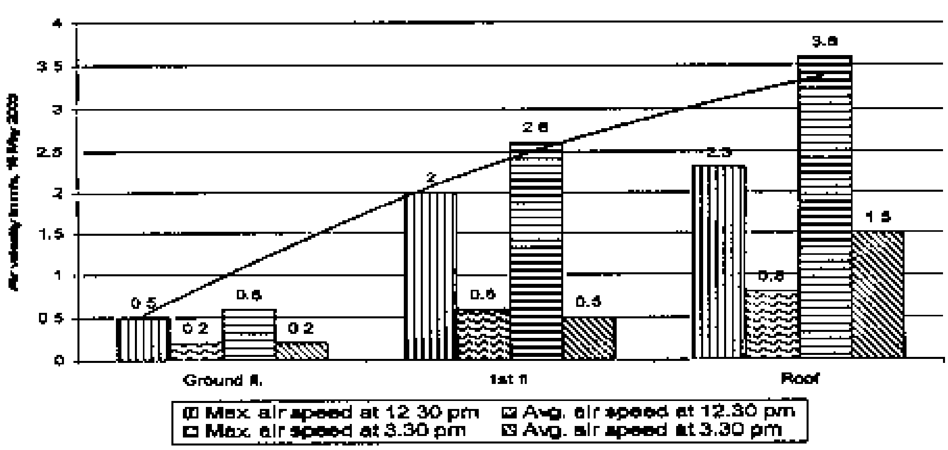

Figure 5.10 Wind speed graph of Spot-01, Sutrapur on 16 May 2003

5.6.2 5-storied residence, Spot-2, Dhanmondi

Here the higher WV at roof level, both maximum and average values, is drastically reduced in the mid level floors and this reduction is comparatively less in bottom floors. The almost equal roof height of the buildings and dense fabric pattern, which are encouraged by the previous (1997) building construction rules, are actually the main causes of this wind pattern at different heights here. On the other hand at ground level free car parking spaces enhance WV and get better compare to mid level (Akhtari, 2001).

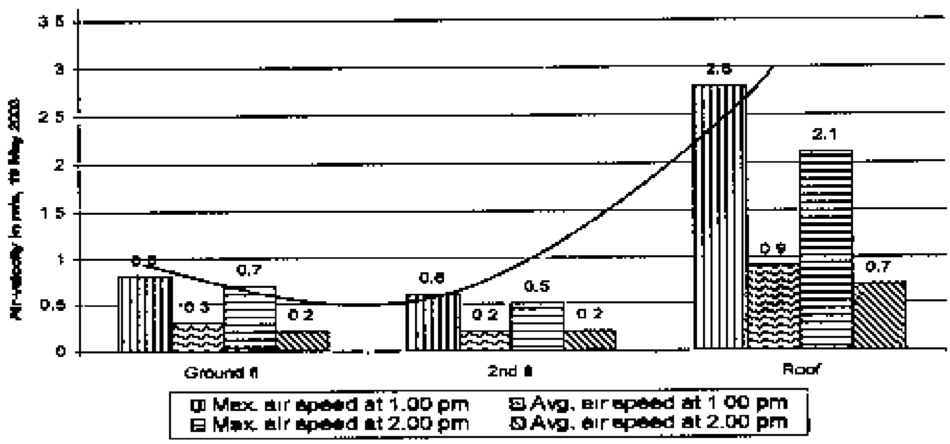

Figure 5.11 Wind speed graph of Spot-02, Dhanmondi R/A, on 19 May 2003

5.6.3 5-storied residence, Spot-3, BUET

The WV both maximum and average values (of the measurement period) are found decreasing from roof layer to bottom layers. Roof level gets relatively much high WV. Difference between mid-level and ground-level is not so big. This indicates that the WV at top layer is unable to make turbulence like in Dhanmondi. A probable cause may be almost similar height of the buildings (all are 4/5 storied) and tree canopy existing here.

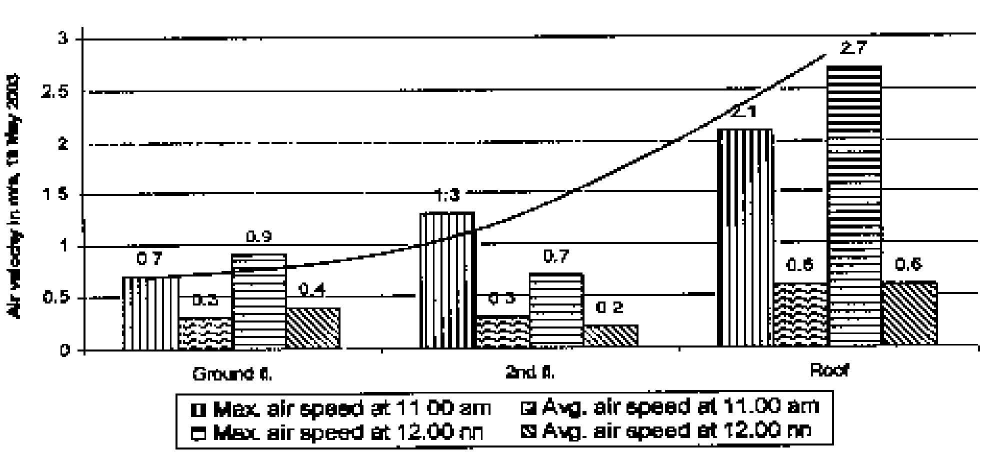

Figure 5.12 Wind speed graph of Spot-03, BUET T. Q., on 19 May 2003

5.6.4 4-storied residence, Spot-4, Banani

Both maximum and average WV values (of the measurement period) are found uniformly decreasing from top to bottom here. The mid-level is enjoying only a little less WV compared to the roof level while ground level gets a further little less compare to the mid-level. This indicates that variable height of the building fabric is making turbulence in air flow pattern and the positive effect of this reaches up to the ground level to some extent. A much better distribution could be possible if ground layer was free for air flow in all buildings.

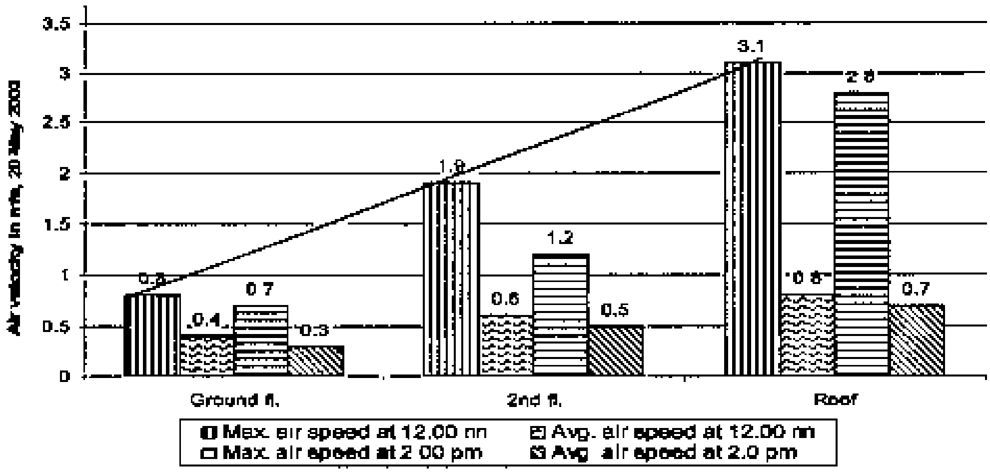

Figure 5.13 Wind speed graph of Spot-04, Banani R/A, on 20 May 2003

5.7 COMPARATIVE ANALYSIS OF DIFFERENT SITES

For summer situation, Banani R/A and BUET T. Q. are serving much better thermal comfort with average maximum temperature about 2degC lower and RH significantly (10 to 15%) higher than that of Sutrapur and Dhanmondi R/A. The WV distribution at different height is comparatively better in Banani than that of BUET T.Q. even though the hard to soft surface ratio is much better in BUET T.Q. than that of Banani. Variation in height of building and other physical objects plays a vital role in the distribution of WV at different height. So in overall judgment Banani R/A offers the best thermal environment during extreme hot discomfort situation compared to all other study areas with the existing density and fabric pattern. Free or open floors at bottom layers also serve better for more WV and thus can provide enhanced nocturnal cooling in this season in Dhaka.

Smaller plot size of Banani and Sutrapur areas compared to Dhanmondi area helps to produce more fragmentation in building mass. Prevalence of private plot ownership is found in these two areas. That is why construction of building mass varies with the owners' variable affordability and naturally produces a variable fabric pattern appearing in an incremental growth. On the other hand, developer-built or institutional apartment building comes with final uniform shape, uniform height and uniform size (Figure 4.10 and 4.13) that discourages variable building mass and thus causes less turbulence in air flow and produces comparatively poorer WV pattern. On top of that developers try to combine more than one adjacent plot together and construct massive buildings with more GC, maximizing profit and minimizing fragmentation both horizontally and vertically, making the development monotonous. So, to ensure fragmentation and varying height of buildings in a residential district special policy measures have to be adopted by RajUK.

5.9 CONCLUSION

In conclusion of this chapter it can be said very clearly that the analysis with temperature, RH, WV and physical property data that are collected simultaneously from different selected residential areas shows significant relationship to development patterns. These can come to a very good use for the policy makers to guide and control the developments towards better future. As the approach to development by institutions and developer companies differ from that by individual private owners, further study can be made to identify ways and means to guide the overall development in this regard. During analysis it is also felt that the study and findings would be more refined if much more survey spots in all four residential districts could be investigated simultaneously for a long period of time with enough instrumentation. Within the limited scope of this research, the methodology adopted here is found quite workable, and can be replicated for greater validation.

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CHAPTER

6

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

From the analysis of field data certain specific correlations between density of building mass, physical fabric pattern (morphology) and their thermal environments in all the residential districts under investigation have been found. These findings can provide important guidelines and directions to facilitate passive climatic control by ameliorating the man made problems, which are amounting to unbearable condition in some of the urban residential environments of Dhaka. The survey has been conducted in 2003 in the then existing four residential districts to collect primary climatic and physical data. Analysis and synthesis are made on the basis of those data. The physical characteristics of those areas have undoubtedly changed by this time. But findings of this study are true for residential districts that are developing and attain similar characteristics over time. The conclusions from this investigation can be used to formulate future settlement patterns regarding densification so that the problems identified in these studies are not repeated.

Pragmatic ideas and feasible solutions in the present context are given priority in searching possibilities. General people are highly interested to build more areas within their personal jurisdiction and authorities are concerned to look after the common interests. Unfortunately, these two interest groups do not seem to be committed to the same goal of controlling environmental implications. Active initiatives are being taken now to update the Building Construction Rules (BCR) for Dhaka city. It is important to give it a scientific basis and ensure that the rules alleviate present environmental situation.

This research aimed to investigate the effect of physical densification on thermal environment (TE) in residential districts of Dhaka. In doing so, Building Height (BH), Floor Area Ratio (FAR), Ground Coverage (GC), Hard to Soft Surface Ratio (HSSR), Free Floor Arrangement (FFA) and Population Density (PD) are found to be related to the corresponding TE. Certain practically feasible solutions in the context of Dhaka are indicated here encompassing the examined physical aspects that may likely be found in future development projects, thus enhancing scope for passive climatic control. Both short term (in the form of motivation, incentives and tax) and long term (in the form of building by-laws) possibilities are taken into consideration. From the study and analysis of previous chapters the following findings and recommendations have been drawn.

6.2 FINDINGS SUMMERY

Density variation in four urban residential districts has been evaluated in terms of a number of socio-physical factors, which characterize different morphological parterns of residential districts. At the same time, various combinations among the four objective thermal comfort factors, i.e. temperature, humidity, wind and radiation (Koenigsberger, et al, 1992), found in these areas have also been evaluated. Relationship between socio-physical factors and objective thermal comfort factors are co-related to identify logical relationships between causes and effects. These variable relationships of causes and effects are summarized here.

6.2.1 Effect of Physical Density on TE

Floor area ratio (FAR) is one of the indicators of physical density or building mass density in any urban area. Among the four study locations the higher FAR (3.5 to 5) value areas, such as Sutrapur in old Dhaka (spot-1) and Dhanmondi residential area in new Dhaka (spot-2), are found developing higher mean maximum temperature (measured during 2.00 p.m.) compared to the areas with lower FAR (1.1 to 2.5) value, such as BUET teachers' quarter (spot-3) and Banani residential area (spot-4), (Table-5.1).

Sutrapur, populated by lower middle and middle income group, is found with highest FAR level between 4 and 5, closely followed by Dhanmondi area where FAR is found between 3.5 and 4.5. On the other hand BUET teachers' quarter (spot-3) and Banani (spot-4) areas have far less FAR level, between 1.1 and 2.5. Correspondingly the mean maximum temperature profile shows the highest in Dhanmondi area, closely followed by Sutrapur area (roughly between 32°C and 34.5°C), while BUET teachers' quarter and Banani areas shows 1.5degC to 2.5degC less value (roughly between 30.5°C and 32°C).

> *So it can be said that a higher density residential development builds up higher day time maximum temperature during summer in the context af Dhaka. On an average, the FAR increase of 2.5 corresponds with the mean maximum temperature rise up ta 2degC.*

If we compare between Dhanmondi and Sutrapur area we get a little higher FAR, ground coverage (GC) and Hard to Soft Surface Ratio (HSSR) in Sutrapur. But, on an average, the mean maximum temperature profile is found a little higher in Dhanmondi area. Varying building heights in Sutrapur area produces a bumpy skyline, while uniform building heights in Dhanmondi area produces a flat skyline. The bumpy-skyline of a settlement produces greater surface area exposure towards open sky than a uniform-skyline, which creates better provision for heat release. Better scope of heat dissipation (convective and radiative) accentuated by varying heights of buildings (Text 5.3.7) are assumed to be the main reasons of lower day time maximum temperature in Sutrapur.

On the other hand, between BUET and Banani areas a little higher FAR, GC and HSSR are found in Banani, while the mean maximum temperature is found little higher in BUET teachers' quarter. Differences in skyline that is varying heights of buildings in Banani allows more scope for heat dissipation compared to the flat skyline of BUET teachers' quarter. Almost similar kinds of building materials are used in all the areas.

So it can be said that during summer, heat dissipation potential in residential districts with higher FAR, GC and HSSR can be increased by varying building heights in the context of Dhaka.

Mean minimum temperature profile is found moderate in Dhanmondi and Sutrapur areas (with high FAR values), while the area of BUET teachers' quarters shows highest mean minimum temperature (where FAR is the lowest among all four areas) and Banani area shows least value in this regard. This indicates that FAR levels are not directly related to the mean minimum temperature profile of a residential area.

So it can be said that control of physicol densification through FAR control can not alone ensure desirable TE for the residential development in metropolitan Dhaka.

6.2.2 Effect of Hard to Soft Surface Ratio on TE

Both Sutrapur and Dhanmondi areas are found with higher proportion of hard surfaces compared to that of BUET and Banani areas. Consequently absorbance of solar radiation and rate of surface water runoff are likely to be higher in the former two areas (Spot-1 and 2) than the latter two areas (Spot-3 and 4). Both Sutrapur and Dhanmondi areas develop increased mean maximum temperature (about 2°C greater) and decreased (about 10% to 15% lower) mean maximum relative humidity (RH) compared to BUET and Banani areas. Higher temperature aggravates the summer discomfort. While sustained lower relative humidity will have environmental implications, leading to loss of vegetal life and depletion of the ground water table, – resulting in ecological imbalance.

From the readings, it can be said that areas with HSSR 60:40 develops about 2°C lower mean minimum temperature and about 10% to 15% higher RH compared to that of areas with 80:20 HSSR.

6.2.3 Effect of Ground Coverage on TE

Ground Coverage (GC) in Sutrapur and Dhanmondi residential districts are extremely high (80% to 95%) and the mean maximum temperatures recorded in these areas are also relatively high, which are critical for thermal comfort. The greater the GC the less is the space in between two buildings and thereby narrower the provisions for ventilation potential. As the urban buildings are made of permanent materials, they produce surface water runoff. These readings show that greater GC in an urban area creates more surface water runoff, which results in a reduction of the RH level and should thus be kept below the GC level of Sutrapur or Dhanmondi, i.e. less than 80%.

Ground Cover (GC) in the residential districts of Dhaka should be less than 80% in order to reduce surface water run-off and to control the RH and generate potential for wind movement. For identification of optimum GC proportion further specialized research is needed.

6.2.4 Effect of Building Skyline on Wind Pattern

Wind velocity usually increases with the increase of height from the ground-level in free field condition. But in this study increase of wind velocity (WV) with height is not direct for all the sites. This effect on wind gradient seems to be related to the building skyline of the respective sites. In Sutrapur and Banani areas (where building skyline is uneven) the increase of wind velocity is found more or less gradual with the increase of height. In Dhanmondi and BUET teachers' quarter (where building skyline is uniform) it is not gradual; rather wind velocity dips at the mid-level before increasing again at roof level.

These readings point to the possibility that uneven skylines with variable building heights both in Sutrapur and Banani create more friction and thereby more turbulence in the natural flow of air. This is helping to distribute the wind velocity in a more gradual pattern at different heights creating better ventilation potential in the vertical layers.

> *So it can be said that uneven building skyline in residential districts can produce better distribution of wind velocity at all the vertical layers, demonstrating improved ventilation potential compared to that of uniform building skyline.*

6.2.5 Effect of Free Floor Arrangement on Wind Pattern

During the survey period, in Dhanmondi most of the buildings are found 6-storied with free floors (FF) at ground level for parking as prescribed by Building Construction Rules (BCR). Measured wind velocity at ground level is found higher than that of mid-level (Figure 5.11) unlike other three study areas. The other three residential districts do not have FFs at ground levels. The results clearly demonstrate that free floors directly influence and cause this increased wind velocity, displaying distinct ventilation potential of the immediate surrounding TE.

> *So it can be said that a Free Floor (FF) between ground and roof level of a multi-storied building can increase wind velocity to its immediate surrounding TE.*

6.2.6 Effect of Population Density on TE

Population density in Sutrapur and Dhanmondi area are found almost double the density of Banani and BUET teachers' quarter areas. More population density in urban situation means more concentrated consumption of energy (many heat producing sources like, electrical appliances, many cooking burners, many auto-mobiles, and much surplus metabolic heat) (Figure 3.2), a major portion of which ultimately converts into heat energy and contributes to the rise of temperature (2 to 3 degeeC higher temperature is found in Dhanmondi and Sutrapur areas than that of Banani and BUET areas during survey periods) in the concerned TE.

> *Higher population density is directly related with higher mean maximum and mean minimum temperature.*

6.3 APPLICABILITY IN BUILDING CONSTRUCTION RULES

From the findings of this research we can say that present rules and regulations to control Floor Area Ratio (FAR) based on front road width, Ground Coverage (GC) and Setback Open Space can not ensure enough provisions for Passive Climatic Control in residential districts of Dhaka Metropolitan Area (DMA). Prescribed specifications on the above mentioned factors are also needed to be modified. On top of that, certain new clauses can be introduced in the existing set of rules to ensure 'Uneven or Bumpy Skyline', Free Floors' and control of population density. These can facilitate Passive Climatic Control and thereby reduce dependency on Active Climatic Control.

To ensure uneven residential skyline and to encourage lower density energy usage BCR can adopt policies whereby even and odd numbered plots in a row (along a road) can have same FAR but different ground coverage specifications. To ensure higher ventilation potential in all vertical layers of a multi-storied building 'Free Floors' (FF) can be prescribed at certain intervals. These FFs at different heights can satisfy both the purposes of community activity for the inhabitants of the plot, as well as wind-channels for surrounding buildings (Figure-6.1). Further investigation will no doubt be needed for detailing out the appropriate distribution of these free floors, relating them to heights and distances of concerned bnildings in a settlement.

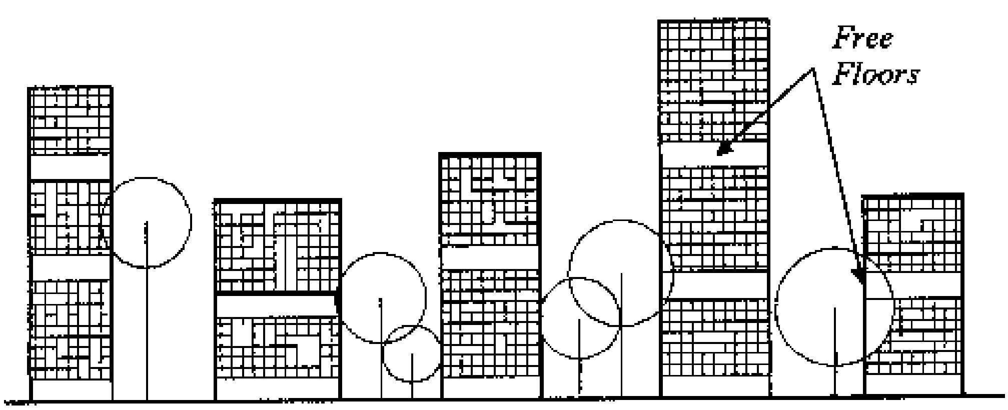

Figure 6.1 Schematic sketch of proposed Residential Development Pattern with Higher FAR and staggered arrangement of free-floors

The rules can also include provisions for increased FAR permission in any plot (beyond its prescribed limit). To enjoy that privilege one can be asked to insert more FFs in the building. Vertically staggered placement of these FFs located in all buildings in a residential district can create a very good flow of air, thereby accentuating the ventilation potential through out the whole area, also ensuring better air flow along the whole height.

Table 6.1 Proposed FAR, GC and Energy Consumption Rate

Road width in front of the plot	Ground coverage for (*even* holding no.)	Ground coverage for (*odd* holding no.)	Highest limit of energy use at normal rate (kWh/month/family)
More than 18m.	x%	x - y%	200
Minimum 12m.	x%	x - y %	150
Minimum 9m.	x + 5%	x - 5%	150
Minimum 9m.	x + 10%	x%	150
Minimum 6m.	x + 20%	x + 10%	125

Where 'x' may be a value as affixed after further investigation and wind tunnel experimentation to ensure increased ventilation potential under Dhaka's urban context.

Judicious consumption of power can be encouraged by putting hierarchical usage limit (monthly kWh per family to be purchased at normal rate) corresponding with a hierarchy of the plot sizes. Energy usage beyond these limits can be allowed at significantly higher rates than the regular unit price to discourage excessive consumption and limit wastage.

A new set of BCR (2008) has been recently introduced in Dhaka, which is not formulated on the basis of proper climatic research. Moreover, its effects will not be experienced until a number of constructions are made following these rules. This set of rules permits FAR from 3.0 (for plots below 150 sq. m. size with front road width minimum 6 m.) to FAR 6.5 (for plots of any size with front road width minimum 24 m.) for residential development in Dhaka. Ground coverage has been allowed from maximum 65% for smaller plots to maximum 50% for larger plots or for plots which have wide roads (≥18 m.) in front.

The development pattern that is allowed in the new rules (2008) of Dhaka is exemplified with a calculated below. If we take a plot of 1337.76 sq. m. size in Dhanmondi residential area (original allotment of 20 Kathas equivalent to 14400 sq. ft.) with front road width 12 m, the new rule will allow maximum 50% ground coverage and FAR 6.5. So the building with full 50% GC can go up to 13 storied high. By the previous (1996) setback rules, without FAR restriction, one could build a maximum of 6-storied (height was restricted) building in Dhanmondi residential area producing a FAR of 5.0 and GC of 84%. In new rules (2008) higher FAR is allowed with lower ground coverage. So the new rule will create more open areas and provision for higher proportion of soft surfaces compared to the earlier rules. Scope of ventilation can be made better with this. But physical as well as population density will be increased with the practice of new rules.

6.4 RECOMMENDATIONS

Based on the findings in this research which are summarized in the previous sections it can be said that physical densification in the residential districts of metropolitan Dhaka has a direct relationship with the rise of temperature during summer time and attenuation of the convective cooling process. Physical densification is also reducing the proportion of natural green (soft surfaces) in the environment, and increasing the proportion of hard surfaces, posing threat to the thermal environment in residential districts. This continued densification is also gradually narrowing down the prospects of passive climatic control and putting alarmingly increasing pressure on limited available energy supply. Under these circumstances, following recommendations can be drawn based on this research.

6.4.1 As unlimited physical densification in residential districts of metropolitan Dhaka shows definite rise in temperature, this densification process needs to be controlled. Because this retards cooling process, especially nocturnal, and compels higher consumption of energy, which eventually raises the temperature in a cumulative process (from findings no. 6.2.1, 6.2.2 and 6.2.6).

6.4.2 As Banani residential area is found with best thermal condition among the four study areas, its (i) FAR - 2.5 (ii) ground coverage (55% to 65%) and (iii) Hard to soft surface ratio (60:40) can be followed to develop existing residential areas as well as new residential areas (from findings no. 6.2.1, 6.2.2 and 6.2.3).

6.4.3 FAR control specifications alone can not ensure desirable thermal environment for residential districts in metropolitan Dhaka. It must be linked with other physical variables like, Ground Coverage, Hard to Soft Surface Ratio, Population Density, Energy Usage, etc. and needs further specialized research to identify the appropriate combinations of all these factors for each of the residential areas. (from findings no. 6.2.1, 6.2.2 and 6.2.6).

6.4.4 Varying heights of buildings in residential area creates better convective and radiative cooling provisions and thus decreases the mean maximum and minimum temperatures. So the building rules (by manipulating FAR and Ground Coverage specifications) can be modified to ensure varying heights of buildings in any given area (from findings no. 6.2.4).

6.4.5 For multi-storied residential buildings staggered arrangement of Free-Floors (FF) at different vertical layers can be prescribed in BCR (by determining necessary intervals between FFs through further specialized research), which can provide both community space and better ventilation potential throughout the whole area (from findings no. 6.2.5).

6.4.6 A set of primary limits in power consumption per dwelling-unit can be prescribed in BCR (to be sold at normal price). However, consumption beyond those limits can be allowed at much higher price. Limits and prices of different slabs can be determined through further research (from discussion at 6.2.5).

6.5 SCOPE OF FURTHER RESEARCH

Within the limited scope of this research the relationship between physical density and thermal environment of only four urban residential districts in the context of Dhaka are investigated. If the scope is widened further new research can be carried out to achieve a more comprehensive scientific set of Building construction rules and thereby ensure more sustainable residential thermal environment. So, following further researches can be conducted in future.

6.5.1 To assess the thermal behaviour of residential districts more specifically further research could be conducted by setting more survey stations at different vertical levels in a greater number of buildings. So that comparison and relationship between different residential areas on many other detailed aspects can be made.

6.5.2 Significant researches could be conducted to identify the effects of various ratios between open area (including areas allocated for road network, parks, etc.) and built area on residential thermal environment in different urban contexts.

6.5.3 A thorough research can be conducted to develop effective combinations of FAR, GC, HSSR and Population Density on the basis of thermal environment considerations for different sizes of plots with different road widths.

6.5.4 Research can be conducted to determine feasible specifications of Free-Floors (FF) for multi-storied residential buildings to be prescribed in the BCR of Bangladesh.

6.5.5 Similar research to assess the effect of densificarion on the thermal environment in urban residential districts can be carried out in different seasons like, monsoon, winter, etc. With the findings of all these researches a more comprehensive set of building construction rules can be formulated and enacted to attain comfortable thermal environment all round the year.

6.5.6 Effect of power consumption pattern on die thermal environment of urban residential districts can be determined through a research. Findings of this study could be utilized to specify general power usage limits per dwelling and different price limits to ensure judicious power consumptions.

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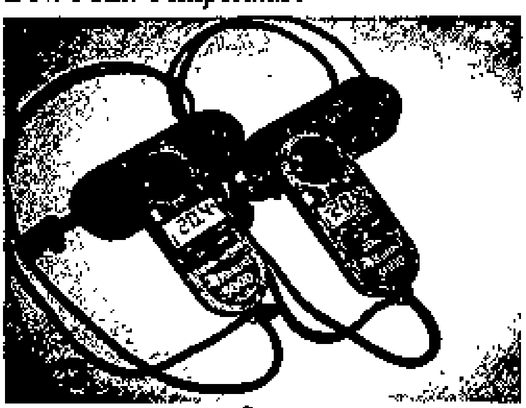
APPINDIX

APPENDIX
EQUIPMENT DETAIL

1.
Kestrel® 3000 Pocket Weather™ Meter
NIELSEN-KELLERMAN, USA.

MEASURES:
Wind Speed
Temperature
Wind Chill
Relative Humidity
Heat Index
Dew Point Temperature



Two of the Kestrel® 3000 Pocket Weather™ Meters

FEATURE AND SPECIFICATIONS:

Wind Speed Functions
Operating Modes: Moving 3-second average (   ), maximum 3-second gust since power on (MAX) and average since power on (AVG).
Scales: Knots, M/s, Km/h, M/h, F/m, Beaufort.
On-axis Accuracy: Greater of ±3% or ±least significant digit.
Off-axis Accuracy:-1%@5°,-2%@10°,-3%@15°.
Calibration Drift: <2% after 100hrs use at 6M/s.
Minimum Speed: 0.3M/s.
Maximum Speed: 40M/s.

Temperature and Humidity Functions
Operating Modes: Temperature, Wind Chill Relative Humidity, Heat Index, Dewpoint Temperature.
Scales: Centigrade (°C), Fahrenheit (°F), Percent (%).
Accuracy: Temperature and Wind Chill ±1.0 °C, Relative Humidity ±3%, Dewpoint Temperature ±2°C and Heat Index ±3°C, (between 5% and 95% RH).
Minimum Temperature: -29 °C (-20 °F).
Maximum Temperature: 70 °C (158 °F).
Humidity Sensor Response Time: 1 Minute.
Humidity Sensor Calibration: May be field or Factory calibrated.

Display
Type: Reflective $3^1/_2$ digit LCD.
Digit Height: 9 mm.
Update: 1 second.
Range and Resolution: Depends on measurement scale selected.
Temperature Limitations: Normal operation from -15°C to 60°C. Below -15°C, accurate readings may be taken by keeping the unit warmer than -15°C and exposing it for the minimum time necessary to take a reading (less than one minute).
Auto Shutdown: After 30 minutes of no button presses.

Environmental
Sealing: Electronics enclosure IP67 – water resistant to 1m. (3ft.). Floats.
Shock: Drop tested to 2m. (6ft.).
Storage Tempearture: -40°C to 60°C (-40°F to 140°F).

Physical
Buttons: Two sealed tactile rubber buttons control all functions.
Battery: User-replaceable CR2032 coin cell. Typical life, 250hrs (25,000+ readings).
Impeller: 25mm. (1in.) diameter, sapphire bearings, light weight. User-replaceable impeller/housing assembly.
Temperature Sensor: Hermetically sealed precision thermistor.
Humidity Sensor: Solid state silicone capacitance sensor.
Case: Slip-on case prevents damage to display and moving parts.
Dimensions: 122x42x14mm.; case, 117x46x19mm.
Weight: Unit, 43g,; case, 23g.

Kestrel® Pocket Weather™ Meters Relative Humidity Calibration Kit

NIELSEN-KELLERMAN, USA.
0824 CALIBRATION KIT.

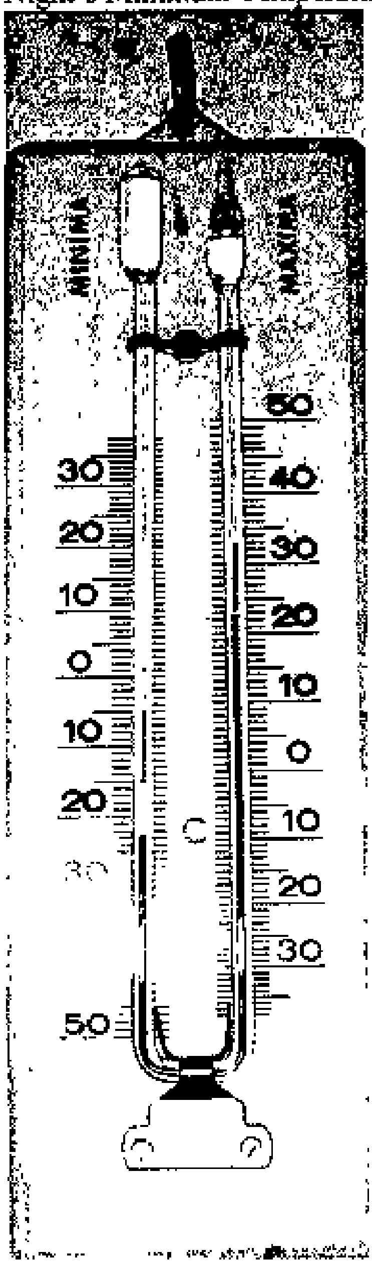
Relative Humidity Calibration Kit with a Kestrel® 3000

FEATURE AND SPECIFICATIONS:

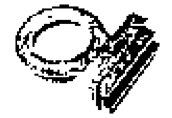
Calibration Salt
Sodium Chloride: 75.30%
Magnesium Chloride: 32.80%

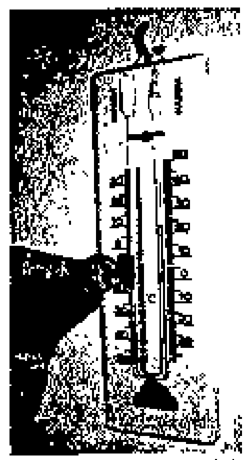
2.
Maxima Minima Thermometer

MEASURES:
Day's Maximum Temperature
Night's Minimum Temperature



A Maxima-Minima Thermometer


A Magnetic Slider


Blue Signal Positioning Action in a Maxima-Minima Thermometer tube

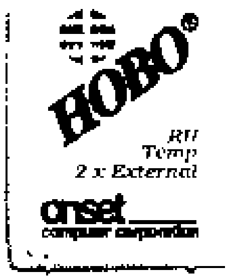
FEATURE AND SPECIFICATIONS:

Functions
The day's maximum and the night's minimum temperature can be determined on these instruments at every time or be read afterwards as conveniently as one read every raise and fall of temperature indicated on it.

How They Work
First one has to pull with the magnet (magnetic slider) and replace the blue signals (magnet sensitive) in the tube down to the mercury column in either tube arm. When temperature raises or falls, the signals will be pushed upwards and will rest in the capillary in a free position, so that even at some later time one may easily read from the basis of the signals the maximum and minimum temperatures of the last period.

Country of Origin: Germany.

3.
HOBO H08-007-02
Data Logger for measures: Temperature/RH/2 x External



Temperature, RH Data Logger w/ 2 External Inputs Specifications

Data Storage Capacity	7,943 8-bit Samples/Readings
Sampling Rate	0.5 Second to 9 Hours (User Selectable)
Operating Range	Temperature: -20°C to 70°C (-4°F to 158°F) Humidity: 0 to 95% RH non-condensing, non-fogging
Operating Modes	Stop When Full Wrap-Around When Full
Temperature Sensor	Range: -4°F to 158°F (-20°C to 70°C) Range Outside Case: -40°F to 248°F (-40°C to 120°C) Accuracy: ±1.27°F (±0.7°C) at +70°F Resolution: 0.7°F (0.4°C) at +70°F Response Time (Sensor Inside Case): 15 min. Response Time (Sensor Outside Case): 1 min.
Humidity Sensor	Range: 25% to 95% RH at 80°F for Intervals < 10 Sec, Non-Condensing and Non-Fogging Accuracy: ±5% Response Time (In Air): 10 min. Sensor Operating Environment: 5°C to 50°C (41°F to 122°F), Non-Condensing and Non-Fogging
Compatible External Input Types	Temperature Sensors (#TMCx-Hx) Split Core CTs for AC Current (#CTV-X) Voltage Transmitters (#T-CON-ACT-X) 4-20mA Input Cable (#CABLE-4-20mA) 0 to 2.5 Volt DC Input Cable (#CABLE-2-5-STEREO) Carbon Dioxide for Telaire Monitor (#CABLE-CO2)
External 2.5V Input	2.5 mm Jack: External Input Ground, Input, Switched 2.5 Volt Output; External Input Ground Connection is not the Same as PC Interface Connection Ground and Not Be Connected to Any External Ground Input Range: 0 to 2.5 Volts DC Accuracy: ±10 mV ±1% of Reading Resolution: 10mV (8-bit) Out Power: 2.5 Volts DC @ 2mA, Active Only During Measurements
Drop Proof	Up to 5 ft.
Time Accuracy	±1 Minute per Week at 20°C (68°F)

Storage Range	Temperature: -40°C to 75°C (-40°F to 167°F)
Battery Life	Typically 1 Year
Battery	3-Volt CR-2032 Lithium Battery (User Replaceable)
Standards Compliance	CE
Weight	29 grams (1 oz)