THERMAL COMFORT FOR URBAN HOUSING IN BANGLADESH

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ABSTRACT

The existence of a thermally comfortable domestic living environment is important for a healthy and productive life. In Bangladesh, the use of artificial means of environmental control to achieve indoor comfort is not viable for reasons of increased energy costs vis a vis national economy. The problem has to be addressed through appropriate design of buildings that promote thermal comfort through its natural interaction with the outdoor environment.

This thesis focuses on indoor comfort in urban housing, present day trends in the design of which often result in indoor conditions which are overheated for a major part of the year. This is through two main areas of concern. Firstly, the determination of environmental conditions that are percieved as comfortable by the occupants of such housing, secondly the ability of different kinds of urban houses to meet these conditions.

The inquiry on thermal comfort draws from the results of a field survey carried out with occupants of urban housing where the environmental variables that correspond to different thermal sensations were recorded over a period of time. The analysis identifies the range of conditions that are percieved as comfortable by most of the people. These conditions are then compared with thermal data from different types of urban houses recorded in them for short periods in the three different seasons and also with the occupants general opinions on comfort in their own houses. Comparisons between different houses are made to identify design features that influence thermal behaviour and contribute to comfort. These features are used as a basis for computer based parametric studies using the thermal simulation programme SPIEL to evaluate the isolated effects of each.

The conclusions are concerned with design features in urban houses which promote indoor comfort. The results of the analysis identifies considerations pertaining to choice of site, building construction, orientation, and exposure of surfaces as the primary material. The resulting recommendations that are a function of design tasks also include means that may be adopted to promote passive cooling.

For my parents.

Azizur Rahman Mallick
Rahamat-un-Nessa Mallick

FIGURES

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7:

TABLES

CHAPTER 3

CHAPTER 4

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DECLARATION

An experiment on roof insulation methods was carried out as a subject of interest related to the concern of this thesis. The results of this experiment was published as a conference paper.

Some of the results of the analysis on thermal comfort included in chapter three have been presented in a conference paper. The thermal data from the case studies have been also used as a basis for a conference paper.

These papers are included in appendix 8.

CHAPTER ONE

Introduction, Definition of the Problem and Approach to Investigation

1. INTRODUCTION, DEFINITION OF THE PROBLEM AND APPROACH TO INVESTIGATION

1.1 Introduction: Design, Climate and Comfort.

A building is the three dimensional manifestation of a logical and rational thought process supported by adequate technical knowledge and familiarity with the context. In the words of the Indian architect Charles Correa, the architecture of a place is shaped by influences of technology, aspirations, culture and climate. Relative to all others climate is a constant and unchanging factor (1).

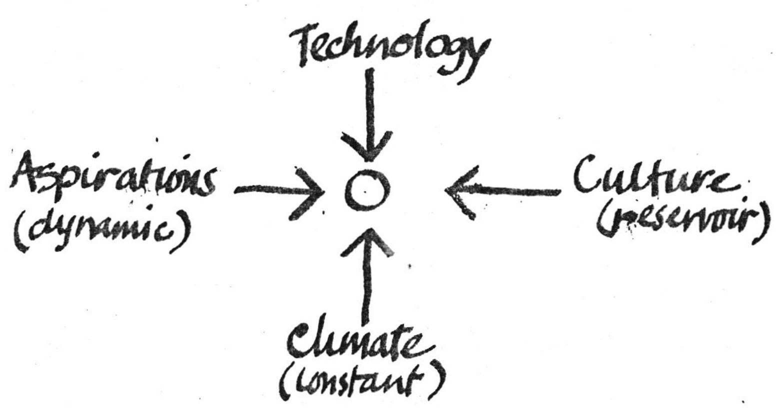

Fig 1.1. Influences in Architecture (after Charles Correa)

To provide a comfortable living environment is an important purpose of architecture. Comfort, like architecture is influenced by the same forces. There are the aspirations of comfort often different from the achievable. Technical intervention provides the means to achieve comfort, often with the use of energy consuming devices and at a price (at times to the environment) which raises aspirations. Cultural conditioning and social attitude influence notions of comfort. Acclimatisation to the climate of a place influences comfort and differences in climate result in different adaptations to it (2)(3)(4).

The search for and the attainment of comfort has been the driving force for man, the builder throughout history. The igloo, the Mongol yurt, the sun break of the Kalahari tribesmen all recognise the effect of the outdoor on comfort (and survival) and seek to modify it. Traditional structures all over the world demonstrate attempts at modifying the natural environment (5). Classical treatises on building design such as by Vitruvius, Alberti and

Palladio all refer to the importance of environmental consideration and describe methods in fair detail. (6)(7)(8). The *vedas* and *shastras* of the Indian Sub Continent have references to designing buildings for health and comfort as early as 8000 BC with specific guidelines (9).

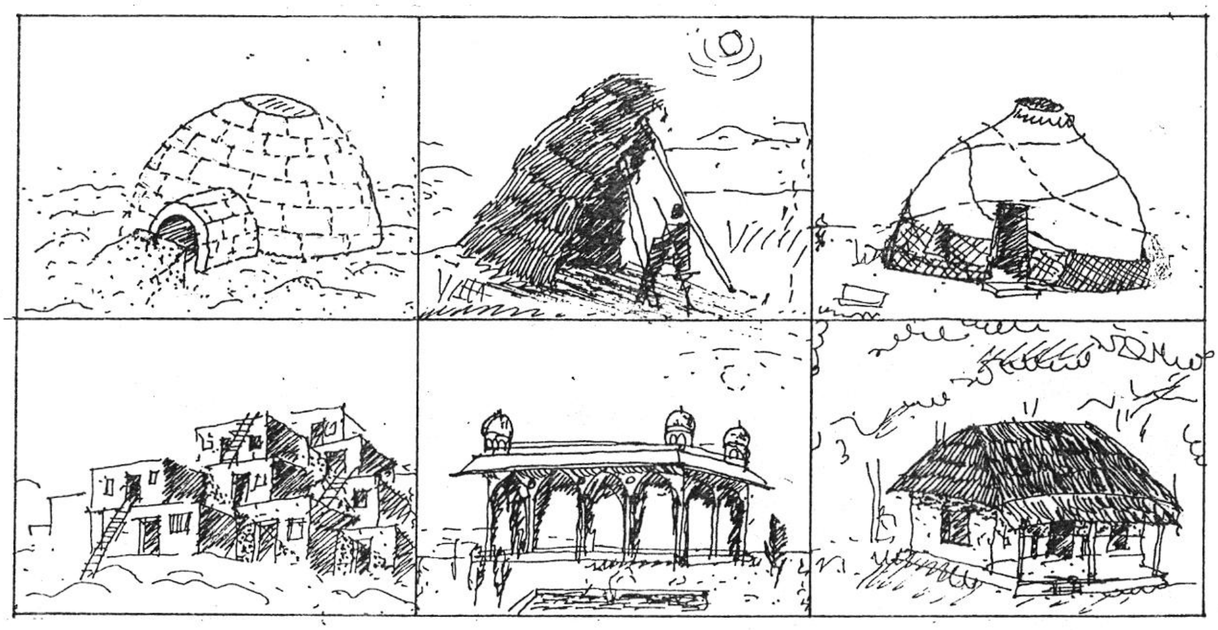

Fig 1.2. Traditional responses to climate

Building design methods in the modern world have innumerable references to texts describing methods and means to achieve desirable indoor environmental qualities. The developments in technology have made it possible to quantify both the problem and the solutions. Comfort can be defined in terms of desirable figures of the physiological, personal and environmental variables and means are available to achieve the same inside buildings. The involvement of designers with these issues often ignore the individual occupant and the practicalities of building design in favour of accounting for numbers (10). The deterministic nature of the technicalities separates mainstream architecture from environmental issues whereas they are one and the same (11)(12).

In developing societies the problem of indoor comfort is still very much a problem of design. Economic considerations do not allow the use of mechanical means to control indoor environments and the creation of liveable indoor environments is the task of the designer and requires considerations of the building's response to the natural climate besides structural and service requirements (13). Although comfort requirements for people in such societies like any other can be defined within fixed values of environmental variables, indoor conditions are less accommodating. Because free running buildings interact with variations in outdoor conditions the indoors are often often warmer or cooler than the thresholds of comfort.

Comfort requirements of people in warmer environments such as in most developing countries show a tolerance for higher temperatures (14)(15). Buildings in Bangladesh, however, do not always meet comfort requirements and given the climate of the country, indoor conditions are usually warmer than comfortable.

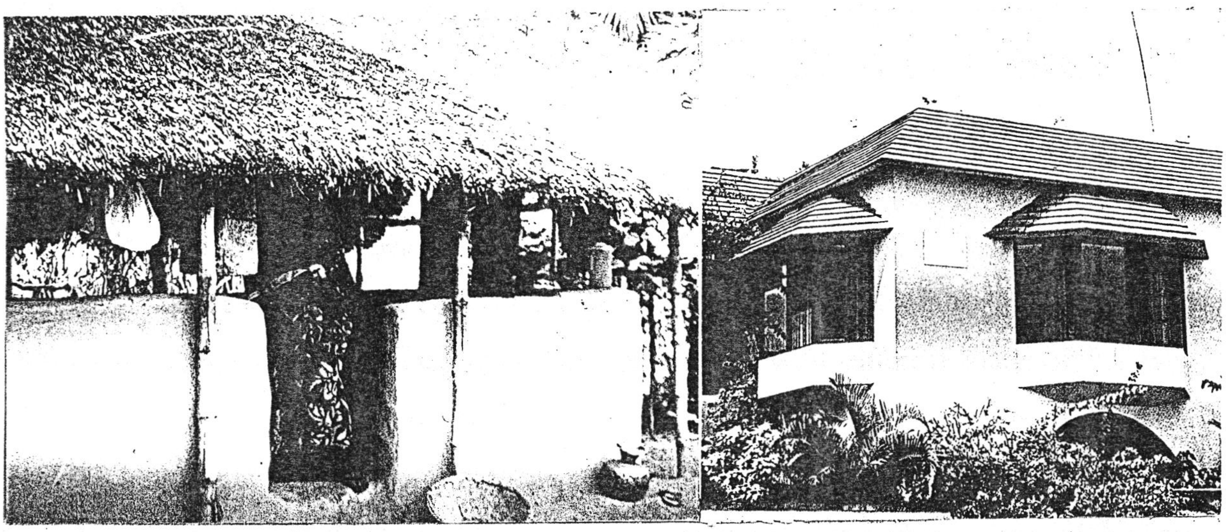

Fig 1.3. Traditional and modern houses in Bangladesh

The building design and construction process in Bangladesh is still very much informal as compared to developed as well as other developing countries. The building codes are in the process of incorporating specific environmental requirements (16). Designers rely on knowledge gained from experience and on speculation. Where the designer is a formally trained architect (of which there are about 400 in a country of 110 million) the input is supplemented by qualified knowledge. The knowledge of experience on the part of the architect is more of cause and effect. The effect is apparent in existing situations but the causes can be many.

Simple understandings of what is happening, and why is it so, offers the potential of more educated choices. Indoor environments in buildings with different design characteristics are different, the urban context add a further dimension to the problem of comfort through its microclimate. Given the scope of manipulation of design elements, choices that will result in indoor conditions that are closer to comfort preferences determine the habitability of houses. The final verdict is of course, with the occupants themselves.

1.2. Definition of the problem: Comfort in urban housing

In a country where the ordinary population have always accepted the often disastrous effects of nature as inevitable the question *why is it hot in the summer?* is a question which does not necessarily require an answer. What is important is the modification of the indoor environment to achieve a situation as close as possible to comfort. Certain principles are followed without questioning their basis. Shading from the sun, orientation to the wind etc. What results such actions provide are also accepted in the same spirit of inevitability.

There is little in the way of published knowledge about the environmental characteristics of urban housing in Bangladesh, but it is common knowledge that in summer indoor temperatures are often above comfort levels. It is also obvious to those who have some knowledge about building construction and are familiar with different kinds of buildings, that some houses are more comfortable than others. The results of the occupant survey regarding the state of comfort in their own homes at the beginning of chapter 5 identifies aspects of house design that have a bearing on indoor comfort at different times of the year.

Climate and design strategy for comfort.

Considering the overall climate of the country i.e. the range of temperatures and relative humidities and its relationship to established comfort criteria the emphasis is on cooling for most of the year. Daytime conditions for the cool period are within the comfort zone and in both the hot dry and hot humid periods the outdoors are warmer. The response of the occupants in this regard show that there are more incidences of comfortable occupancy in the hot humid periods than the hot dry. The temperatures in the humid periods are slightly lower and although humidities are higher the state of comfort seems to be unaffected by it.

Comfort responses of the people.

Acclimatisation to a climate where there is exposure to high temperatures and very high humidities for most of the year support the notion that the comfort responses of the people are adjusted to such conditions (2)(3)(4)(13)(14). This is further reinforced by the responses of the occupant survey where the people reported more instances of comfortable occupancy than suggested by a straightforward comparison of the climate with generalised comfort criteria (fig 1.4). Comfortable occupancy of the houses are also affected by air flow and radiation, the exposure to which vary under different conditions.

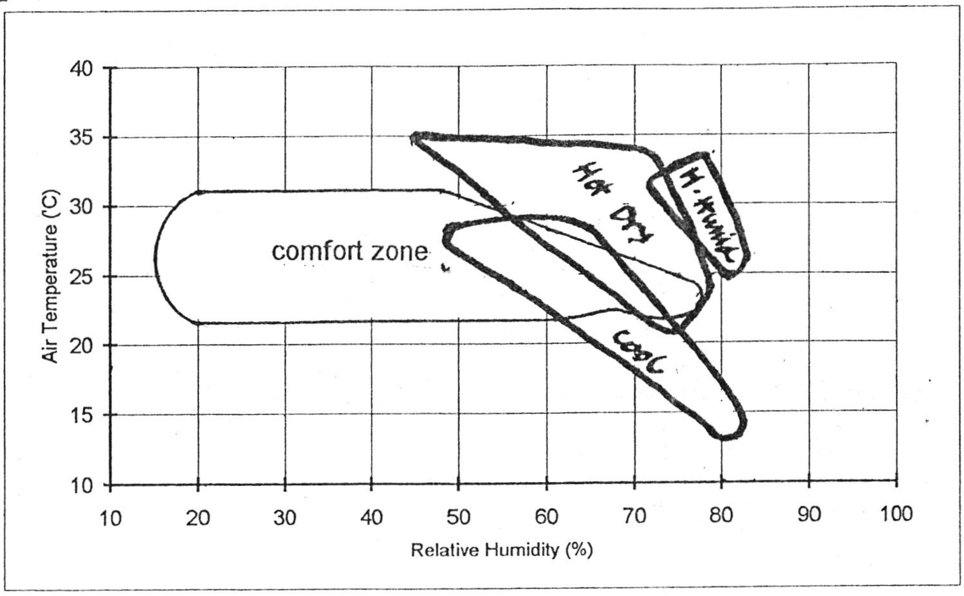

Fig 1.4. The comfort zone for warm climates (after Olgyay and Koenigsberger and adjusted for sedentary work and summer clothing) and local climate

Housing design and comfort

The building is a moderator of the outdoor environment and varying design features contribute to different indoor environments. Of the types of houses that exist in the urban areas some are more comfortable than others because of such variations in design and also because of the context of the site.

The occupant survey provides clues as to the design features that may add to comfortable occupancy. Structures with higher thermal mass by way of wall thickness seem to be more comfortable. Conditions of exposure to the exteriors also seem to influence indoor comfort. Houses on ground and intermediate floors are cooler than corresponding top floors where the roof is exposed to solar radiation. Orientation by way of exposure to radiation and air flow influences indoor comfort. The occupants identify openness of the site as a contributor to comfort.

Internal arrangements of houses contribute to the problem of warmer interiors, particularly because of heat gain from the kitchen. Whereas the outdoor temperatures in the cool period are conducive to comfortable occupancy, the occupants, have felt cold on occasion.

Comfort is related to occupancy patterns of the households and the times and location of people within the house are important considerations.

1.2.1. Issues arising

Thermal comfort in Bangladesh

In order to assess comfort in urban houses, it is important first, to evaluate the conditions that are perceived as comfortable by the people. The occupant responses to comfort in their own homes suggest that the comfort responses are indeed influenced by the local climate. Studies on comfort in different climates and in climates similar to Bangladesh suggest tolerance of higher temperatures and high relative humidities for comfort (4)(13)(14) than cooler climates and provides the basis for a comfort evaluation of local people.

Design and Comfort.

It is evident that certain features of housing design contribute to indoor comfort while other aggravate them. No single feature acts in isolation as a determinant of indoor conditions, they are a result of combinations where some may have more influence than others. The issue of designing for comfort needs to identify the features that have positive effects and optimise their application.

1.3. Approach to the investigation

Aim.

The investigation has two main aims:

1. To identify the environmental conditions that are perceived as comfortable by people
2. To identify elements of housing design that promote comfort indoors.

Setting the context

The general background of housing in Bangladesh is the preamble to the study on thermal behaviour and comfort conditions. The emphasis is on urban housing, its typology in terms of architectural vocabulary and form.. Materials and construction methods with regard to influence on environmental behaviour. Current design trends and their environment modifying features are source material for detailed investigation. Traditional housing and living patterns provide references of natural adaptation to the environment.

The climate provides the environmental context for building design. The focus is on urban climate in different parts of the country. The analysis is based on the individual characteristics of the different regions, each represented by the climate of a major city. The analysis of the climate in relation to comfort criteria is the basis for determining an environmental strategy for building design. Its realisation is through the application of techniques in the design process. The comfort potential of a building may be supplemented by the adaptation of design strategies that promote cooling as a natural process. A review of passive cooling techniques applied in warm climates, with particular reference to their applicability for the design of buildings in Bangladesh is the context for a climate conscious design process.

Comfort Evaluation (field investigation)

The most credible approach to identifying comfort conditions is the actual measurement of it. Investigation of comfort for local subjects is through the analysis of field data collected through recorded comfort observations from people living in urban housing. The analysis has reference to other studies on thermal comfort in warm climates as well as the background of definitions and measures of comfort.

Thermal and Comfort evaluation of Urban Housing (field investigations)

With the background of comfort evaluation for the region, the actual thermal conditions in urban housing examples form the basis for an understanding of their thermal performance and its relationship to comfort. From the typologies described in the review of urban housing, examples that describe the basic variations are identified and selected for detailed observations. The study of thermal conditions and comfort are preceded by the analysis of the survey of occupant's responses to comfort in the same houses. This offers the potential for comparison between reported and measured conditions.

The temperatures in different houses are measured for a twenty four hour cycle each in the three main seasons for an understanding of their year round performance. The observations are simultaneous for all houses to provide an accurate basis for comparison. The measurements include simultaneously occurring outdoor conditions which when compared are indicative of the environment modifying characteristics of each example. Conditions of air flow and humidity as influences on comfort are measured and noted along with observations on behaviour and occupancy.

Conditions observed are then evaluated for their comfort performance with cross reference between the different cases. The results compared with the attributes of each example provide explanations as to reasons for their thermal behaviour. Within the variations in design of the different examples, the analysis focuses on four particular aspects. (i). site conditions (ii). construction (iii). orientation and (iv) exposure of the building surfaces.

Two aspects pertaining to thermal behaviour of buildings are investigated as issues which have a bearing on design.

The aspect of internal gains with reference to the kitchen as a source of internal gain. In three examples temperatures of the various rooms are recorded over a twenty four hour period in along with kitchen temperatures. The result have a direct bearing on internal layout and planning of spaces in the house.

The site conditions are also evaluated separately using the common reference of data for the same period from the meteorological office, the objective is to identify the moderating effect of local conditions and their potential contribution (or otherwise) to comfort indoors.

Supporting studies (computer simulations)

Computer simulations of thermal behaviour act as a complementary source to the measurements made on site. Whereas the indoor conditions in the houses are a result of a number of factors acting simultaneously, the simulations are able to study the isolated effects of a changing parameter. Where certain situations could not be evaluated, they act as supplementary data to the field measurements and investigate means of optimising comfort potentials.

Conclusions

The conclusions aim to identify considerations in the design of urban housing that promote indoor comfort. The inferences are based on the results of analysis of thermal behaviour and simulation studies with respect to the established comfort criteria and are supplemented by design methods for passive cooling.

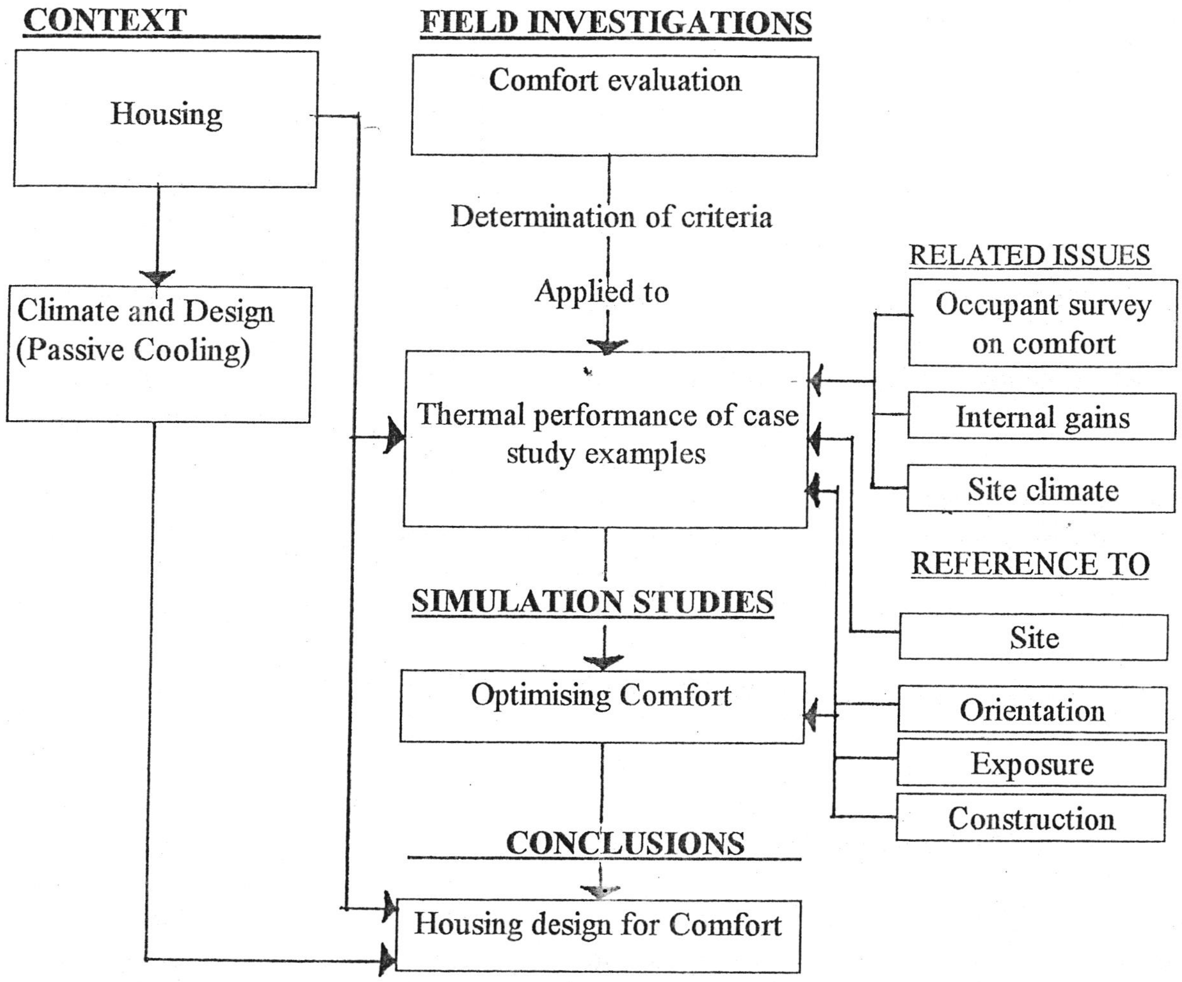

Fig 1.5: Structure of investigation

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CHAPTER TWO

Housing in Bangladesh

2. HOUSING IN BANGLADESH

2.1. Background

The rapid growth of population is the major problem of housing in Bangladesh today. The total population of the country according to the census of 1991 was 110 million people with a growth rate of 2.03% (1). The projected population for the year 2000 stands at more than 139 million people. It is the eighth most populous country in the world with around 770 persons per square kilometre (2). There are about 18 million households in the whole country and potentially the same number of housing units. According to the classification of the house types about 80% of the houses are semi permanent i.e. they use components that are not fit for long term use, the rest are called permanent by virtue of using materials such as brick wood or cement (3).

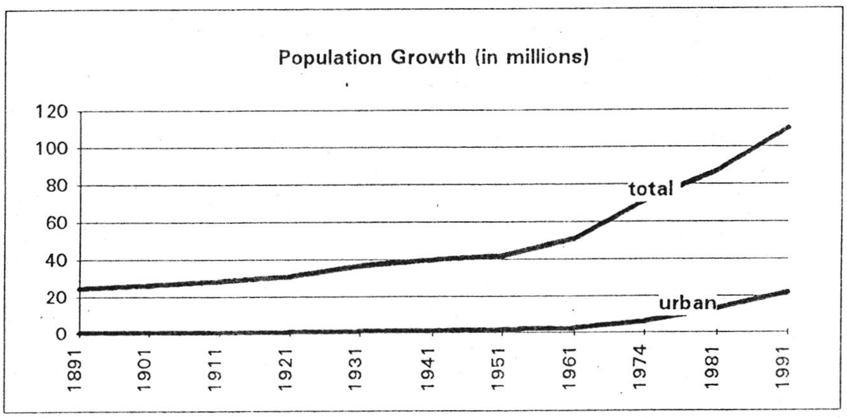

Fig 2.1. Population growth *(source: Statistical Yearbook of Bangladesh)*

Very low income levels add a further dimension to the housing problem. The lack of access to adequate housing is primarily due to the lack of resources. The government is able to provide housing to a very small percentage of the people, mainly in the urban areas. Recent programmes, mostly by non government organisations have made it possible for economically weaker sections to have access to better housing. It is interesting to note that the poorer sections of the rural population do not perceive housing as their immediate pressing problem, more than half consider shelter as their third major problem after food and clothing (4).

Construction of houses in most cases is the responsibility of the homeowner. Individuals have to arrange for the building of their own houses. In the rural areas construction techniques are still rudimentary and methods practised are based on tradition carried on from the past using local materials. The level of skill required to construct a rural house is well known and most of the work involved is very basic, within the scope of local people and takes only a few days. Recently there have been some new approaches to housing construction in the rural areas. Precast and prestressed concrete structural members and ferrocement technology amongst others, have been used in some projects but are yet to be replicated in large scale (5).

In the urban areas construction technology is relatively developed and accessible. Brick walls with cement mortar and reinforced concrete slabs are common, in some cases using high strength steel. A major portion of the steel, cement and bricks consumed by the building industry is for construction in the urban areas (6). The number of new housing units built per year is not able to meet the requirements that is a result of population growth, there in a constant backlog which according to some estimates stand at nearly 50,000 units per year for Dhaka city alone (7).

Utilities such as piped running water, electricity, sewerage, gas etc. are available in the urban areas though not always accessible. In the rural areas, with the exception of electricity in some areas, other utilities are virtually unknown. The same is true for other municipal services such as roads, shops, garbage and refuse collection etc. Communication as a whole is underdeveloped especially in the northern part of the country. Riverways connect the whole country but makes transportation slow and difficult.

The problem of shelter is somewhat made easier by the climate of the country. The weather is not extreme and people can survive in the most basic of shelters. Winters are relatively mild and the houses do not need to be overly protected from the cold. The summers are only hot enough to require shading. The need for air flow is facilitated by the openness of the houses, more so in the rural areas. In its simplest form, a building need only meet the basic requirements of privacy and shelter. The house for a family has to meet the requirements of security and has to provide a stronger image of permanency and therefore needs to be something beyond this simplified idea.

Although the weather is conducive to simple houses, the effect of natural calamities from time to time cause mass scale destruction of the housing stock in the country. Almost every year there are floods, cyclones or tidal surges and along with loss of life they are responsible for the destruction of a large number of houses. Since 1950 there have been 27 different incidence of natural calamities which have caused destruction of houses in the country (8). In the floods of 1988 alone, 13 million houses were partially or fully damaged (9).

The building regulations for new construction are for the urban areas only and are in the process of being upgraded to address issues relating to materials, construction and detailed environmental considerations (10). The rules relating to housing construction in the cities are at present concerned mainly with setbacks from plot boundaries and proportions of built up areas (11).

There are five main government organisations concerned with housing along with the planning authorities of the four main cities. The area of concern of each of these are not clearly spelled out and their responsibilities often overlap. The situation is even more confusing given the lack of any definite policy statement from the government regarding housing. The housing issue is often the subject of political rhetoric without a specific agenda.

The situation so described and the lack of a disciplined attitude to housing design and construction has a positive aspect. The architects and professionals related to housing have the scope to incorporate new ideas and concepts without beauracratic opposition.

2.2. Traditional Housing

80% of the country's population live in the rural areas in traditional houses. The rural house is the physical manifestation of the traditional way of life of the people as well as an example of optimisation of local resources and means. Its climate modifying characteristics are natural responses to the outdoor environment. The traditional house and its design provides the source and basis for an understanding of present day urban housing.

2.2.1. Form

The traditional rural homestead is a collection of single celled, single storied units called "ghors" arranged around a courtyard. Together they form the house or "bari". On average a bari covers about .6 acres of land (4). The courtyard is the centre of all domestic activity and is not totally enclosed but has "leaks". Each unit has a different function and in extended families, houses each immediate family. The notions of front and back formal and informal areas of the urban houses originate here. Another factor which influences the form and organisation of the house and is not very apparent in the urban house is that of male and female separation (23).

2.2.2. Materials and Construction

Materials for construction are all local, except for corrugated iron sheets which relies on the import of raw material. Walls are made of mud or bamboo or sun dried reeds. The use of mud depends on the suitability of local soil. Earthen construction uses stabilisers such as rice husk, lime or cement. Blocks of earth are laid on shallow foundations to form walls with mud mortar the joints are later fused by dampening the surfaces. Bamboo walls are made of mats fixed on a bamboo frame. Openings are smaller in earthen construction. The roof is pitched and is on a frame of timber or in smaller houses, bamboo. Corrugated iron sheets are fixed to this or if thatch is used, it is placed in layers. Some houses have no permanent fixtures on openings except for a piece of unattached bamboo mat shifted over the doorway when needed. Door and windows are usually made of wood. All houses are on earthen plinths.

2.2.3. Environmental Functions.

Each homestead is set in its own microclimatic context. Where the area is prone to flooding the whole homestead sits on a raised plot of land. Trees which are in abundance offer the first line of defence against the elements. They provide shade to the whole site. Evapotranspiration of the leaves lowers the air temperature. There is a traditional of planting in the north to protect from cold winds in the winter (13).

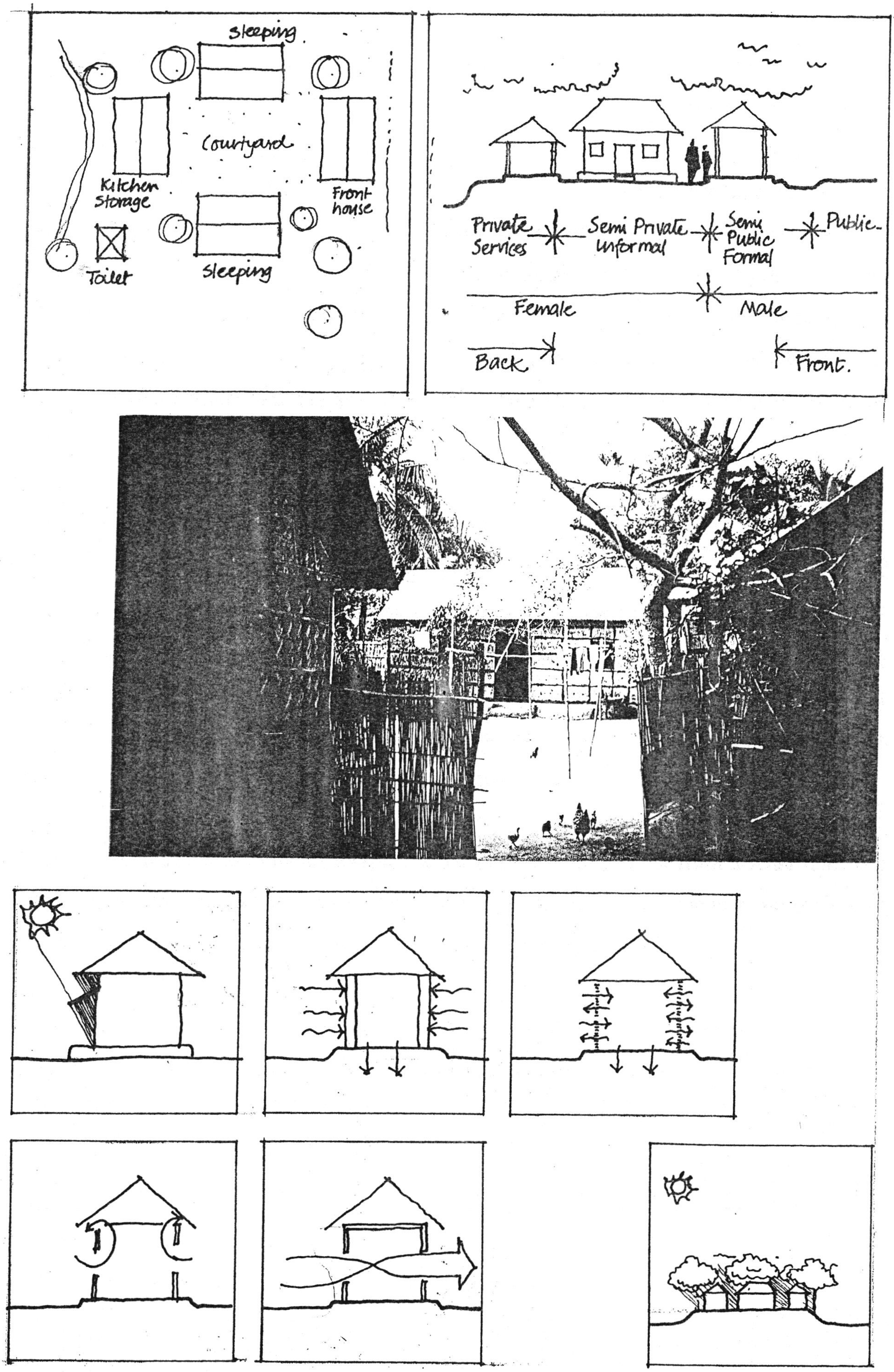

Fig 2.2. Traditional rural house, space arrangements, environmental functions.

The two types of walls work differently to promote indoor comfort. The thick mud walls because of its thermal inertia keep the indoors cool. Light bamboo walls allow a constant convective exchange with the outside. The choice of wall type is more a function of availability rather than response to changes in regional climates. Roofs have overhangs to shade parts of the wall surfaces. Verandas, used as intermediate spaces also shade surfaces. The space between roof and ceiling is effective as insulation from heat. Thatch is a more thermally appropriate than corrugated iron but needs replacement and maintenance. Thatched roofs absorb water during rainfall which evaporates and cools interior surface. There is direct contact with the ground via the earthen floor which promotes lower radiant temperatures.

The design of the house reflects the importance of air flow for comfort. The arrangement of the rooms around the courtyard allows air flow to the different units although it is argued that the courtyard is there primarily for social rather than environmental reasons (14)(15). The single cell units allow direct air flow through spaces. The orientation of the sleeping units is with the breeze direction. In bamboo walled structures openings are large and the porosity of the wall itself allows air flow. In some structures there is a gap where the wall meets the roof which allows a circulation of air in the room.

Rain protection is offered by the overhangs but does little to protect from driving rain. The roof shapes allow run off. The rainy season can cause problems of dampness and growth of moss on surfaces as well as degradation of bamboo and timber.

Given these conditions the indoor temperature may still rise above comfort levels in hot days, it is important to note that people in the rural areas spend most of then day outdoors and use the rooms for sleeping at night.

2.3. Urban Housing

2.3.1. Historical Background.

Bangladesh is essentially a rural based country. About 15% of its population live in the urban areas of which 41% live in the four main cities (2). 50% of the projected population increase of the country in the next 30 years is expected to be in the cities. This would rank Dhaka, the capital, as a populous city in the world order.

Although large scale urbanisation is a recent phenomenon for the whole country, Dhaka has had an urban history which date back to the 8th century (16). Precolonial urban centres were dependent on rural economy and rural traditions strongly dominated the scene. As a result lifestyles of the people in the villages and cities tended to be similar in nature (17). With colonisation the commercial and administrative potential of the cities increased, new occupations were created resulting in migration of the rural population to the cities. Cultural attitudes remaining the same, the city now offered a new environmental context.

The early houses were just denser versions of the rural house, the basic arrangement being a number of rooms around a courtyard. The concept of separating home and workplace brought about some of the spatial changes as did the building style of the colonial rulers. The traditional house form derived from rural areas underwent several stages of development before arriving at its present state.

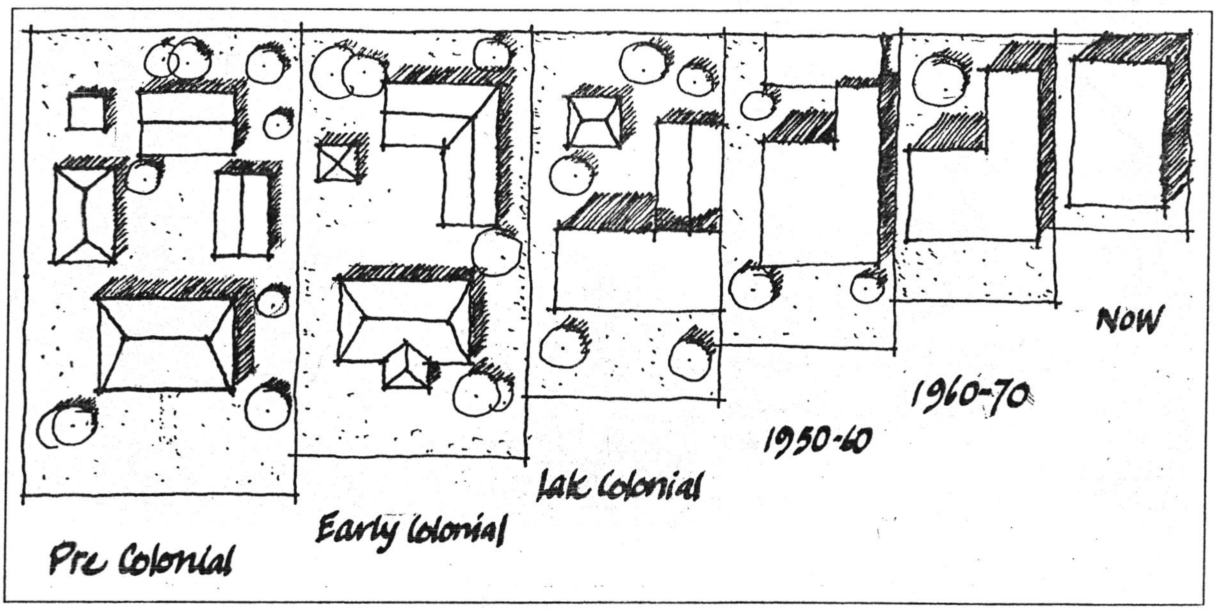

Fig 2.3. Historical development of the urban house form.(after Mallick)

Initially, the urban house was in part a representation of the colonial house with elements borrowed from it but retaining the rural character of the house form as being a number of loosely arranged units. Later, the urban house was a consolidation of its earlier stage. The relative location of the functions remained the same but in more compact form and with a smaller, usually paved courtyard. This was mainly due to lack of space and improvement in service facilities. The stage of development that followed was a result of the shrinking plot size and the increased influence of new styles of urban living where the main house became a single building and the courtyard disappeared (18).

In the overall urban context, with increasing population pressure older housing areas became more dense and newer areas had to be developed. Some areas in the old city continued the densification process and very dense settlements developed in the middle of the last century. Taylor describes houses in mid eighteenth century Dhaka up to four stories in height with frontages as little as eight of ten feet having no windows at the sides and a small court at the centre (19). The congestion of such areas were so high that it lead to unhealthy sanitary conditions and the Civil Surgeon of Dhaka in 1868 showed his concern by insisting that some spaces should be left unbuilt (20). It was this sort of concern that lead to the first planned layouts of the colonial era, where considerations for light and ventilation were given due regard.

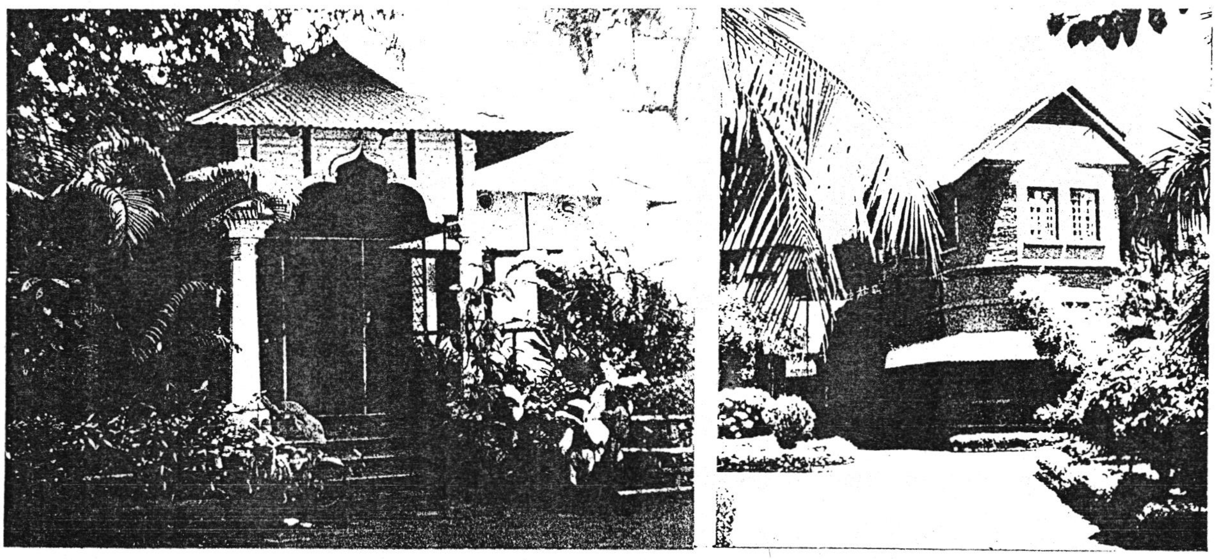

Fig 2.4. Early urban houses (circa 1925)

After the partition of India the new government of Pakistan decided to develop its cities further into the new era and called for a master plan for the new capital of East Pakistan. The plan developed by the firm of Minropio, Spenceley and Macfarlane of the UK in 1958 called for the development of blocks of flats to replace the congested old city (21). There had been flats built in Dhaka prior to this but it was ideas like this that gave it a stamp of approval and brought about a new typology of housing.

The government is responsible for providing housing to its employees and it adopted the flat typology very easily. It was common for the government to build estates containing such flats laid out in rigid geometrical fashion. It was convenient from two points of view (a) it cost less than individual houses and (b) it provided the opportunity to make vertical extensions, which is now commonplace. Other semi government agencies followed suit and flat buildings up to six storied high became an acceptable form of housing for the urban population. Flat buildings rarely went above that height as that would need lifts and increase costs substantially.

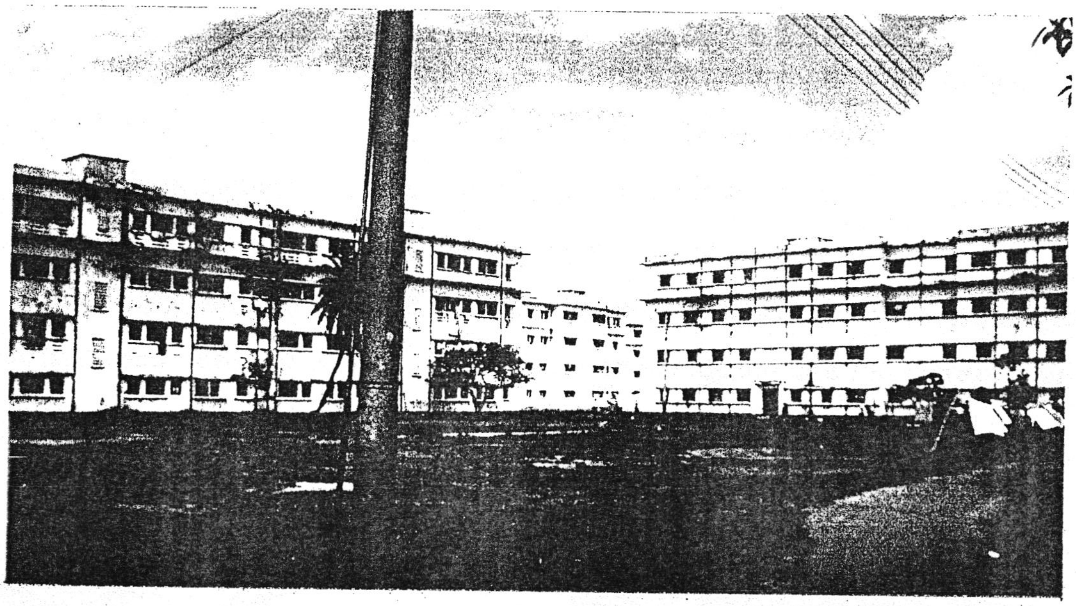

Fig 2.5. Early flat buildings in Dhaka (circa 1958)

In an effort to encourage flat building construction the House Building Finance Corporation offers soft loans to private builders of flats. Sub division of land over the generations at some stage makes further divisions meaningless and the construction of flats is a better way of sharing property. Most new construction of housing in the cities consist of flat buildings and this is evident from the developments in the new site and services schemes. It is also a popular type of construction with developers and the construction of multistoried apartment complexes now dominate a significant part of the urban skyline.

2.3.2. Typologies and Current Trends

Flats are the most common type of housing in the urban areas today. While there are other types it is now uneconomic to build single or two family houses. A broad classification of the types, not including slum or informal housing, would include the following categories.

Single family houses

Popular in the years after the partition of India, when land was easily available such houses are not common nowadays except for the villas of the very rich. Some of these are taken down later in favour of flat buildings. In the smaller towns they still continue to be built wherever land is available and cheap. The older single family houses are in the process of being converted to accommodate more people either by subdivisions or through vertical extensions. Wherever they exist they usually tend to be lavish in their design with wide verandas and large number of rooms. They either belong to the extremely well off or are the older accommodation quarters built for senior government officials, a type no longer built. Two reasons can be ascribed to its demise, the urban family nowadays is more of the nuclear type and does not require such lavish accommodation and the increased price of land does not make it economically viable.

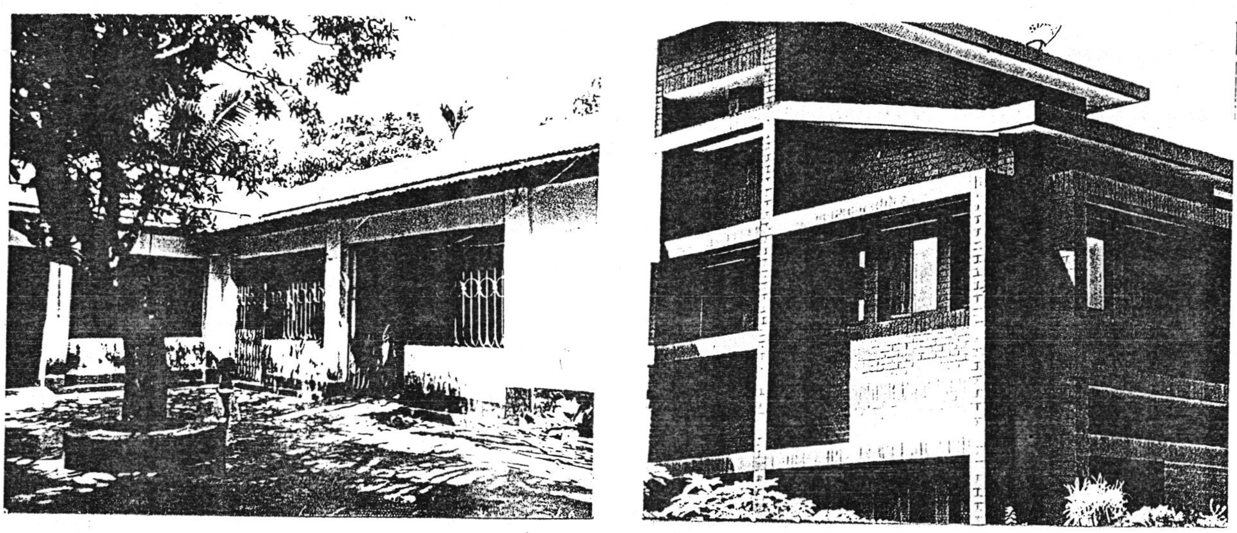

Fig 2.6. Types of single family houses

Two to four family houses

A popular type of the late fifties and sixties when the pressure on land had just begun, such type are also diminishing. A popular style then, such houses would also be large with units placed on top of each other served by a single staircase. They are usually found in the early site and services schemes of the late fifties and sixties. In the mid sixties the first developer built schemes were of this type.

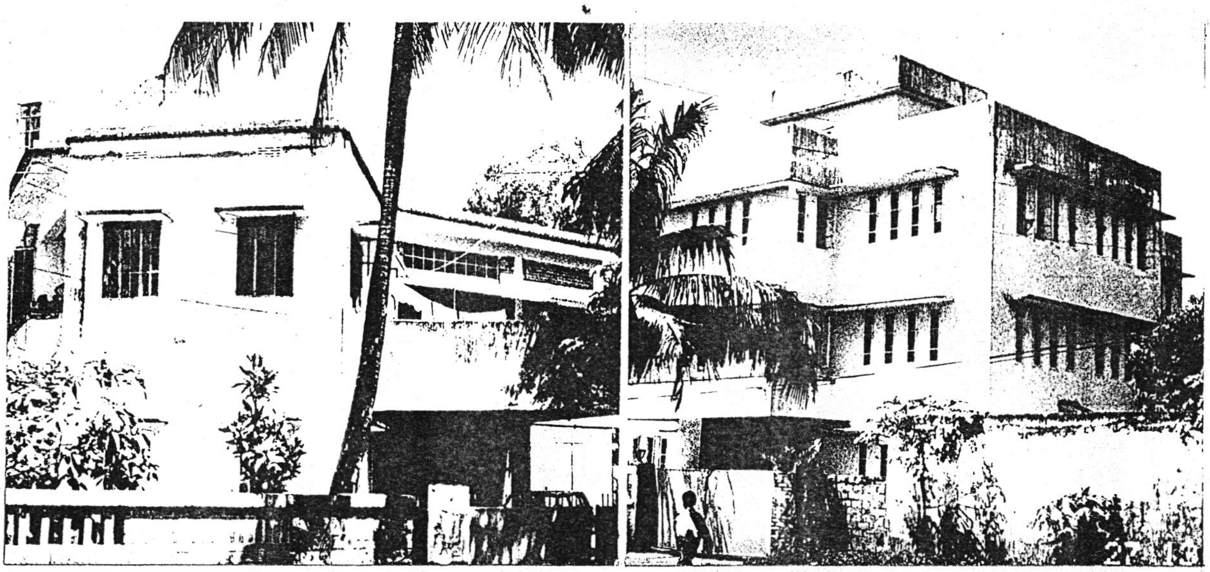

Fig 2.7. Two to four family houses of the early 1960's

Multi unit flat buildings

This is perhaps the most common type of housing found in the city today. The pressure on land as well as economic return through rental made it a popular alternative to other types. When first built it was a marked change to the bengali style of living for early dwellers of such buildings could no longer enjoy the privilege of kitchen gardening or keeping animals as practised in traditional houses.

The most common type are buildings with four of five flats on top of each other served by single staircase, this can go up to six stories but rarely beyond without a lift. Most of the plot sizes today allow one flat of reasonable size per floor. Some houses may have two smaller flats if the plot were bigger. With the existing setback regulations these buildings are usually very close to each other without adequate space for lighting or air flow.

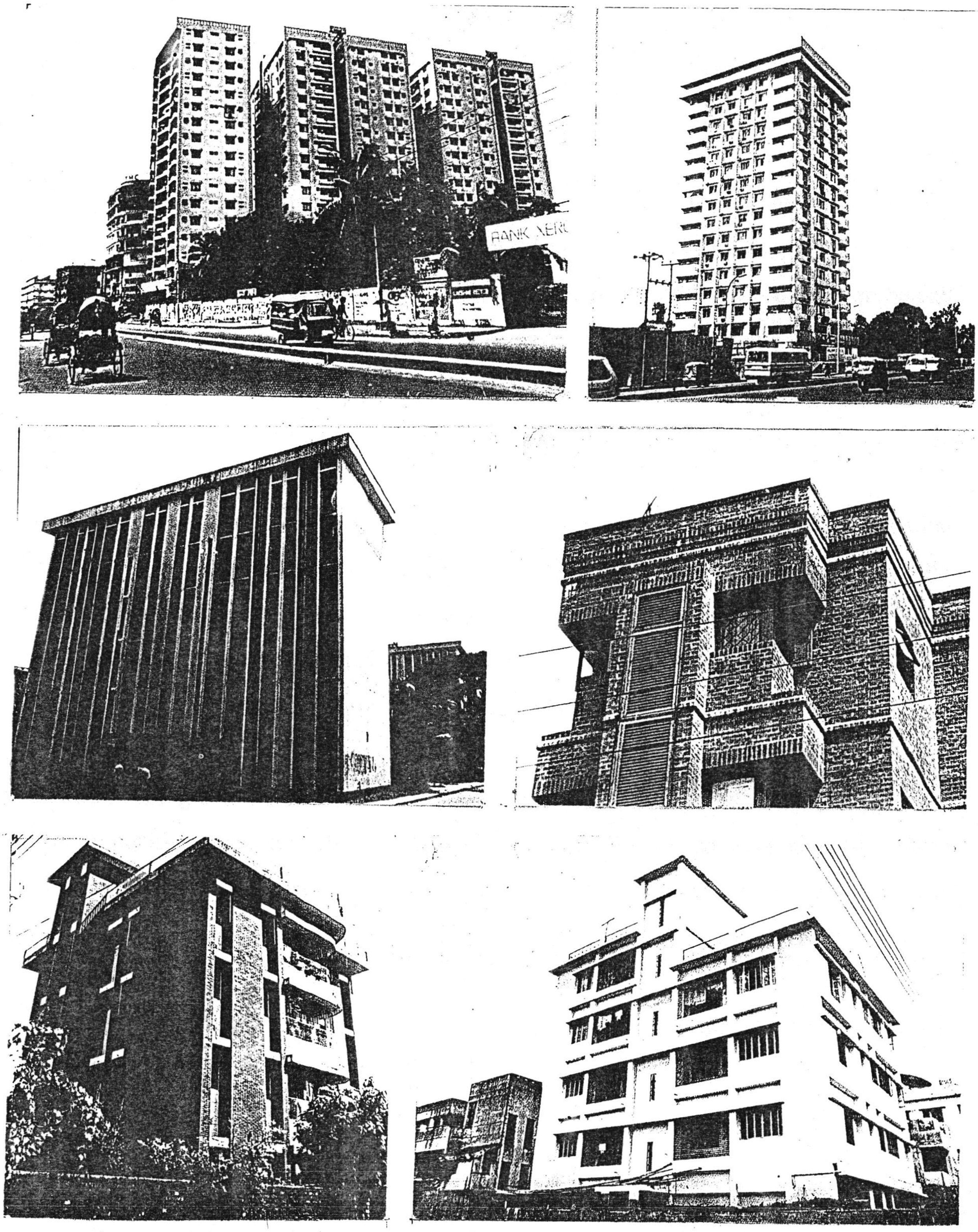

Fig 2.8. Multi unit buildings.

This type is also a common occurrence in government housing estates where large lots of land are dotted with such buildings arranged in geometrical order. Following the example of the government other semi government and private organisations find it convenient to copy this style. The present standards of residential accommodation for government employees are all flat buildings, without exception (22). Lower government housing structures are required to have a foundation capacity for up to six stories of construction to allow future extensions (23).

Developer built housing have almost exclusively adopted the flat typology as a standard. They often have to build on small plots of land. Where the main motivation is profit they provide the best alternative. Such is the demand for such flats that they continue to be built with a host of design and planning problems some of which pose serious health and safety risks (24). The construction of such flats by developers now include high rise blocks.

Other types:

There are some scattered examples of some other types of housing structures in the urban areas. There are some examples of row houses single and double storied. In the smaller towns single storey row houses are still found specially in the housing colonies of railway employees. They are rows of single family accommodation attached to each other usually with small courtyards at the back with separate kitchen and toilets. Such housing is common is settlements areas for relocated squatter population of the cities. There are some examples tenement housing in the old parts of the cities. These examples are few and far between and does not justify a separate category. There are a large number squatter housing built at various locations in the cities but the nature of their construction is temporary and constantly under threat of demolition.

Given the current trends in housing construction it quite evident that the future of urban housing is in flat buildings.

2.3.3. Design Features

Amos Rappaport in House Form and Culture emphasises the influence of socio cultural factors as a generator of house form:

> "........ the house form is not simply the result of physical forces or any single casual factor, but is the consequence of a whole range of socio cultural factors seen in their broadest term. Form is in turn modified by climatic factors..... "(25)

The concept of space division within the urban house has its origin in the traditional homestead patterns of the villages. The allocation of spaces within the house is based on the concept of zones . The three zones within the house are the formal, informal or family and the service zones (18). The formal zone is the container of all functions related to the outside and activities associated with visitors to the house. It is also the limit beyond which outsiders are not expected to enter. The informal zone contains the functions for the family, mainly the bedrooms and other family spaces such as the dining area. The service zone has storage, kitchen and the toilets.

This concept of zones is associated with the notion of front and back of the house. In the case of the older houses the front is the side towards the street, in the flats this is usually towards the front entrance. The formal zone is towards the front and the service zone at the back. This is a fairly strong notion and often takes precedence over environmental factors such as ventilation or light. The kitchen usually suffers the worst location in the service zone. It is only used by one or two members of the household. The veranda is a common element for all the zones in the house and is used as a connection between the zones as well as a functional space.

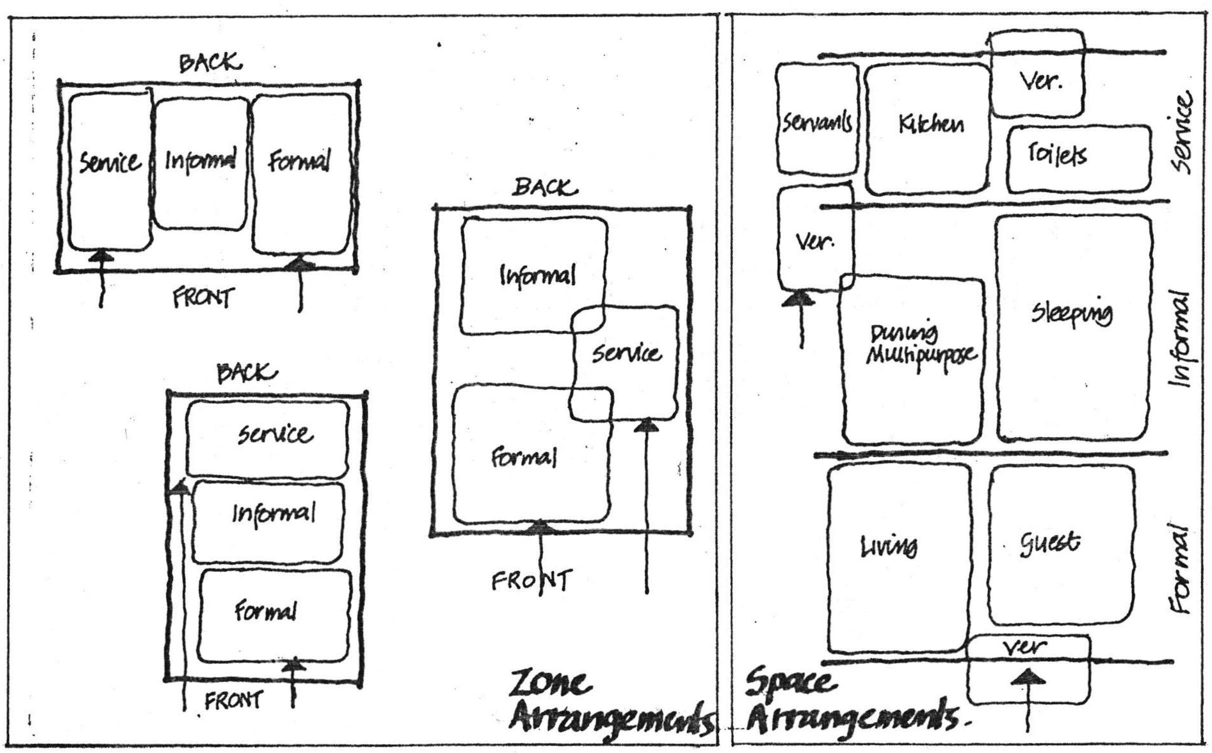

Fig 2.9. Zones in the house, front and back., space arrangements (after Mallick)

The general shape of the house depends on the plot shape. In the older urban houses with large plots the plan configuration would be with offsets or staggering of a basic rectangular shape. This would allow parts of the house to have an orientation towards the dominant southern breeze direction as well the creation of open spaces within the plot perimeter. In recent years with shrinking plot sizes mostly rectangular shaped, the urban house has a compact form also rectangular.

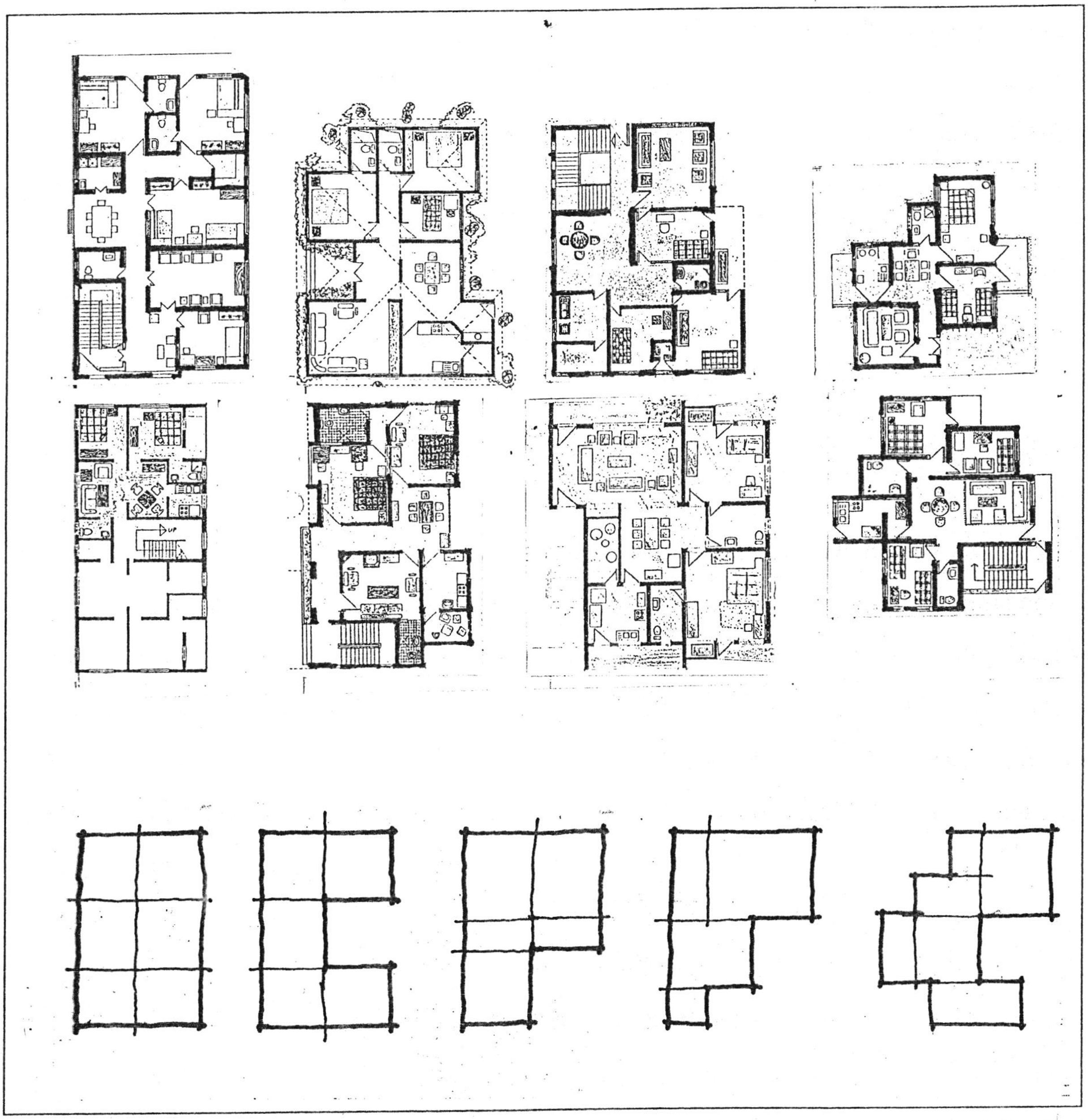

Fig 2.10. House shapes and division geometry

Most modern houses are now rectangular blocks with a multi room arrangement in at least one direction. In the other direction, usually along the width the arrangement is two room deep for considerations of light. Verandas and balconies are common elements and do well in shading some of the external walls and windows.

Given the layout of plots it is not always possible to have the preferred south orientation for urban houses. Because of the density of houses in urban areas air flow is blocked or changed at site level. The shadows of surrounding buildings in localities with many such buildings deny ground floors adequate light and sunshine. In an attempt to allow some more spacing between buildings at the upper levels recent modifications of the building codes in the cities require the floors beyond the third to be staggered progressively from front (11). This creates more gap between upper floors of adjacent buildings where because of height above the ground there is scope for more air flow anyway. The problem of the ground floor remains.

2.3.4. Materials and Construction

Classification of buildings by type of construction is officially divided into three categories they are;
Pucca construction, which refers to construction which is permanent in nature. **Semi Pucca** is construction where part of the construction is permanent and some of the components may be temporary such as a corrugated iron roof of dry jointed brick walls. **Kutcha** construction is temporary construction usually referring to buildings which are not to remain in that state or is not fit for long term occupancy. In the 1981 census report on urban areas 22.9% of urban housing were found to belong to the first and 43.1% and 34% in the second and third categories respectively (26).

Walls
Brick is manufactured locally in gas, oil or coal fired furnaces and is the most common walling material . Cement mortar is used for bonding and walls of various thickness are constructed depending on the structural needs. Thicknesses of 75mm and 125mm are used for non structural walls. For structural walls the thickness is 250mm. Brick walls can be kept exposed or they may be rendered with cement plaster. Exposed brick surfaces are a popular means of architectural expression. High quality finish "ceramic bricks" are common for facing work. Corrugated iron sheets are also used as a cheaper walling material.

Roofs

The type of roof determines the nature of a structure. Concrete if used makes the structure a permanent or pucca structure. Concrete is possibly the only roofing material for buildings above one storey height. Roofs in urban houses are almost always flat unlike rural houses.. Flat concrete roofs are sometimes topped off with a layer of lime concrete to serve both as insulation and to create a slope for water run off. Corrugated iron sheets is used as a material for roofs of one storey houses. This is laid on framework of wooden or steel trusses and purlins. Buildings with corrugated iron roofs are not classified as permanent structures although a lot of them have been there for more than three decades. Over time this material requires to be replaced .Tiled roofs are common only in the western parts of the country. Clay tiles are used as a cladding material over concrete roofs in the more fashionable villas.

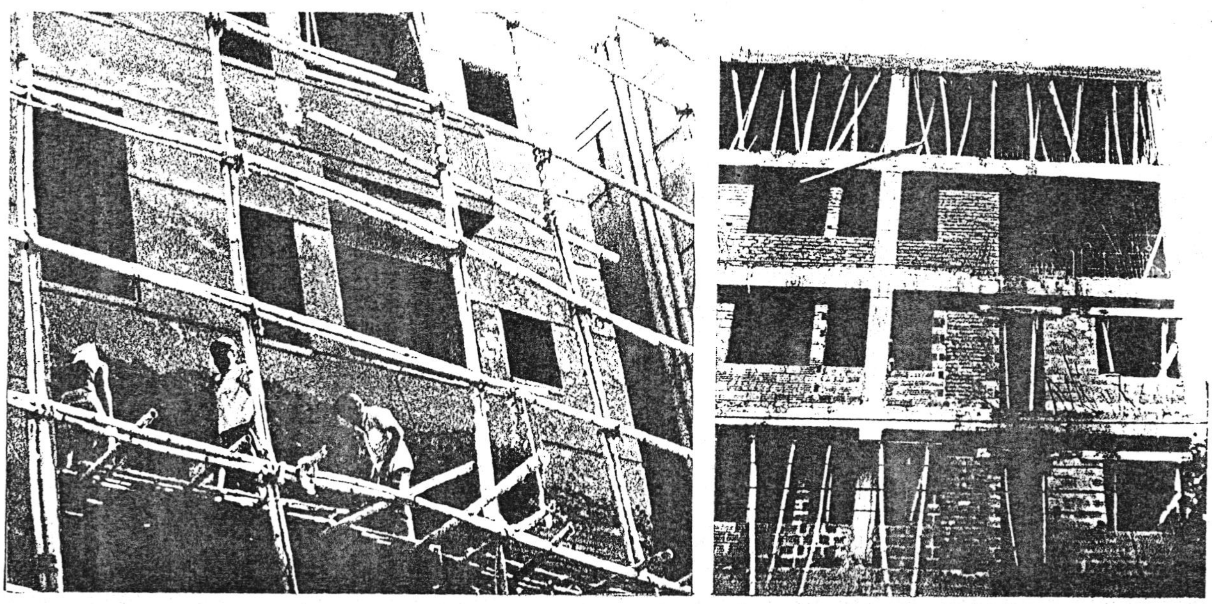

Fig 2.11. Construction of urban houses.

Structural Elements

All steel or all timber construction is rare for housing in Bangladesh and only large buildings such as factories and warehouses use steel as a component for the roof trusses. Steel used in reinforced concrete is imported in billet form and made into rods in local re-rolling factories. Timber is expensive, quality control difficult and is susceptible to decay. Wood is used for doors and windows. Good quality wood is expensive and particle boards are a common alternative for doors. Steel framed windows are used to keep costs down. Aluminium frames are also available but beyond the reach of most people. PVC window frames are very recent and yet to be common.

Construction Systems

The two most commonly used construction systems used for housing are the load bearing wall type and post and lintel construction. In the former the walls take the load of the roof in which case they are 250mm or thicker The basic design restriction is that the alignment of major structural walls have to be maintained on subsequent floors thus reducing the flexibility in design. In the post and lintel type the load is distributed through concrete columns and beams and the walls can be arranged freely. This system is more expensive and common only for buildings more then two storey height or when soil conditions are bad. This allows the walls to be thinner than 250mm. Combinations of both systems are used.

Construction methods in Bangladesh are labour intensive specially in the case of private housing. Almost all structural components are cast or fabricated on the site. Shuttering for concrete in residential structures are of bamboo and wood. Steel rods are bent and cut on site manually. Concrete is mixed in small machines and cast on site.

2.3.5. Environmental consciousness in design.

Indoor conditions in buildings are determined by the moderation of the exterior environment as brought about by its design features. Artificial control of indoor environments is not common in Bangladesh, the only widely used device is the ceiling fan. Given the climate of Bangladesh the emphasis is on cooling for most of the year which is through promotion of air flow and control of heat gain of the building fabric. Building practices do not use any calculation methods for building element design, they are mostly based on experience.

Air flow is through openings by orienting them to the direction of air flow. Natural air flow is from the south in the warm seasons. Traditional building design have always emphasised this orientation as preferable. The roots of this practice is in the rural areas where, because of the openness of the surroundings the direction of air flow is reliable. In the urban areas this is not always so, even then a south oriented house is popularly understood as a good house. Windows in the urban houses always have security grills, at times coupled with insect netting. This leads to a reduction of outdoor air velocity, wherever available. The notion of cross ventilation is also strong and practised in the traditional houses. In the urban areas, because of compactness of plan this is not always achievable.

Shading of openings and walls is a widely practised means of solar control, although the practices are more intuitive than informed. Windows have overhangs for protection usually in the form an extension of the concrete lintel above it or by recessing the window at a depth. Architectural variations occur in the form of different shapes, sizes and design of protection elements. Sometimes projections are also made from the sides. Orientation and solar angles should ideally determine the geometry of the protection elements but this seems to have no bearings on reality. Some consciously designed buildings have angled louvers to which respond to orientation (Fig 2.12).

Shading of walls is with the projection of roofs and floor slabs. It was common to project slabs at all levels and all along the building perimeter. Some recent trends prefer straight profiles of elevations where this in no longer possible. Verandas are a common element in most houses they serve a useful secondary purpose by shading walls and openings. Shading of roof slabs is important to protect it from direct gains. This is not a common practice mainly for costs involved.

By virtue of using brick masonry the effect of heat gains of the building fabric is moderated by thermal inertia of the walls. This a function of wall thicknesses which vary in multiples of the standard brick dimension of 125mm, it is commonly 250mm for load bearing construction and rarely more than 500mm.

Protection from rain is an important consideration. Shading devices, projections and verandas serve this purpose in moderate rains, in driving rains, they are not always adequate.

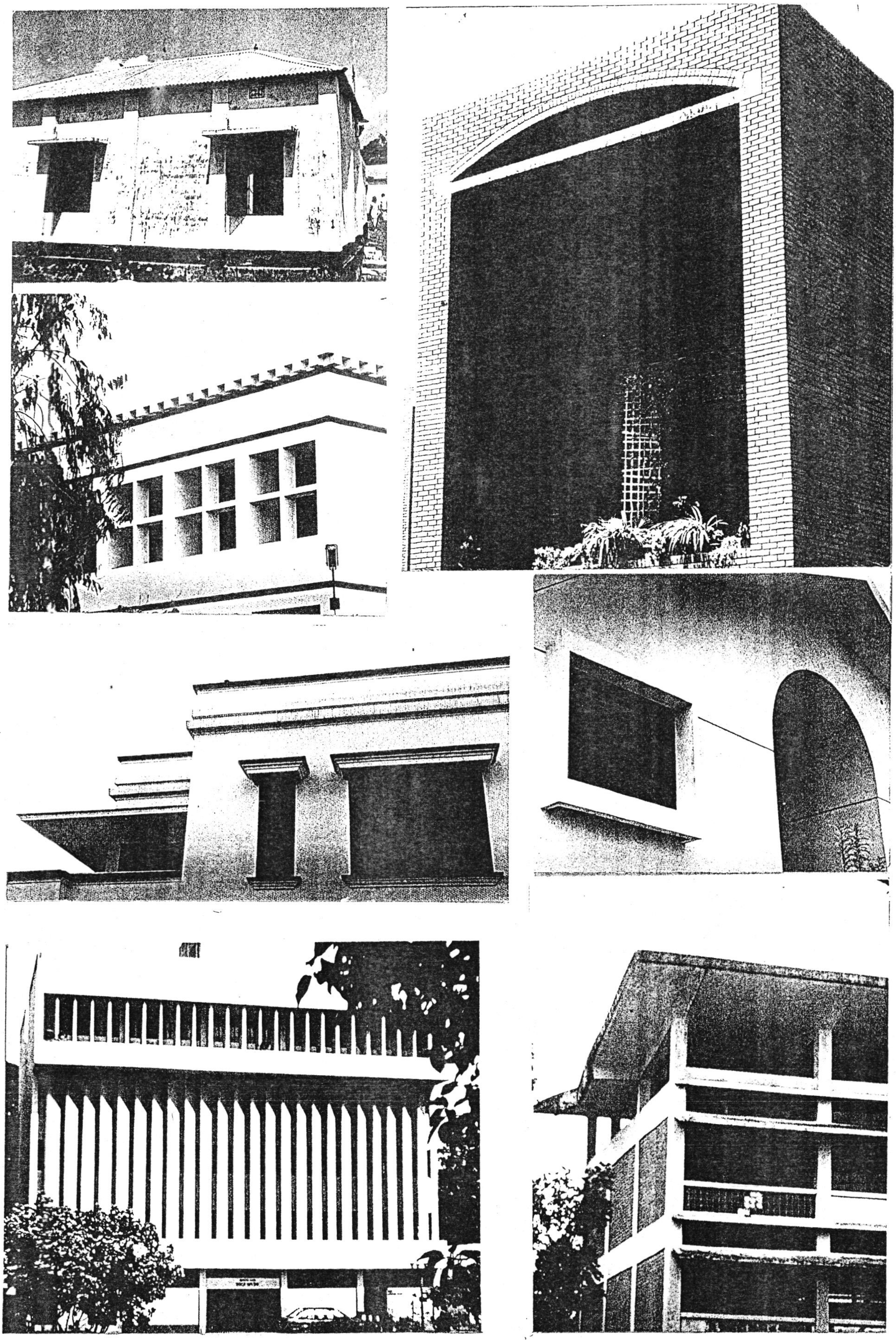

Fig 2.12. Shading practices

2.4. Future needs

While the design of traditional houses is the optimum utilisation of resources in its response to socio economic and environmental needs, prerequisites for future development are mainly and primarily infrastructural. Urban houses in a rapidly changing context needs the development of an attitude towards design which addresses changes in lifestyle while being conscious of environmental needs. The active involvement of an increasing number of qualified professionals is encouraging in its potential for a more informed approach.

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CHAPTER THREE

Climate and Design

3. CLIMATE AND DESIGN

3.1. Introduction.

The climate of the country is the environmental context for building design. In tropical climates such as in Bangladesh where the outdoors are usually warmer than comfort building interiors require to be cooler. The building fabric and its design is the interface between indoors and outdoors, the manipulation of the elements of which result in the creation of a desirable indoor environment. The following sections are concerned with the evaluation of the climate of the country to determine design requirements for comfort and the passive cooling strategies that may be used or adapted for buildings in Bangladesh.

3.2. Climate: General Overview and Classification

Bangladesh lies between 20°34' N and 26°33' N and 88°01' E and 92°41'E. On three sides it is bounded by land mass and on the south by the Bay of Bengal. The climate of the country is hot and humid for a major part of the year and is generally representative of what is understood as tropical.

According to Atkinson's classification of tropical climates, Bangladesh lies in the composite or monsoon climatic zone (1), which is located on land masses near the tropics of Cancer and Capricorn. The characteristics that define this type of climate are in close agreement to that of the country. This zone has three distinctive seasons, the **hot humid**, the **hot dry** and a third **cool dry** season. The difference with other locations in the same zone (New Delhi, Kano, Lahore etc.) is that the hot humid period is longer and has heavier rainfall. It is also referred to as the Wet Tropics (2). Interestingly, local traditions divide the year into six seasons, spring, summer, rains, autumn, late autumn and winter. This division, however, has more to do with cycle of flora and fauna and with harvest times than with marked changes in meteorological factors.

The hot dry period[1] is between March and May when the average maximum temperature is 34°C. With the rains and the beginning of the hot humid period this drops to around 31°C. Throughout this period from June to September temperatures are more or less constant and

1. Hot dry in the context of Bangladesh is used in a relative sense with respect to temperatures and humidities in the other seasons.

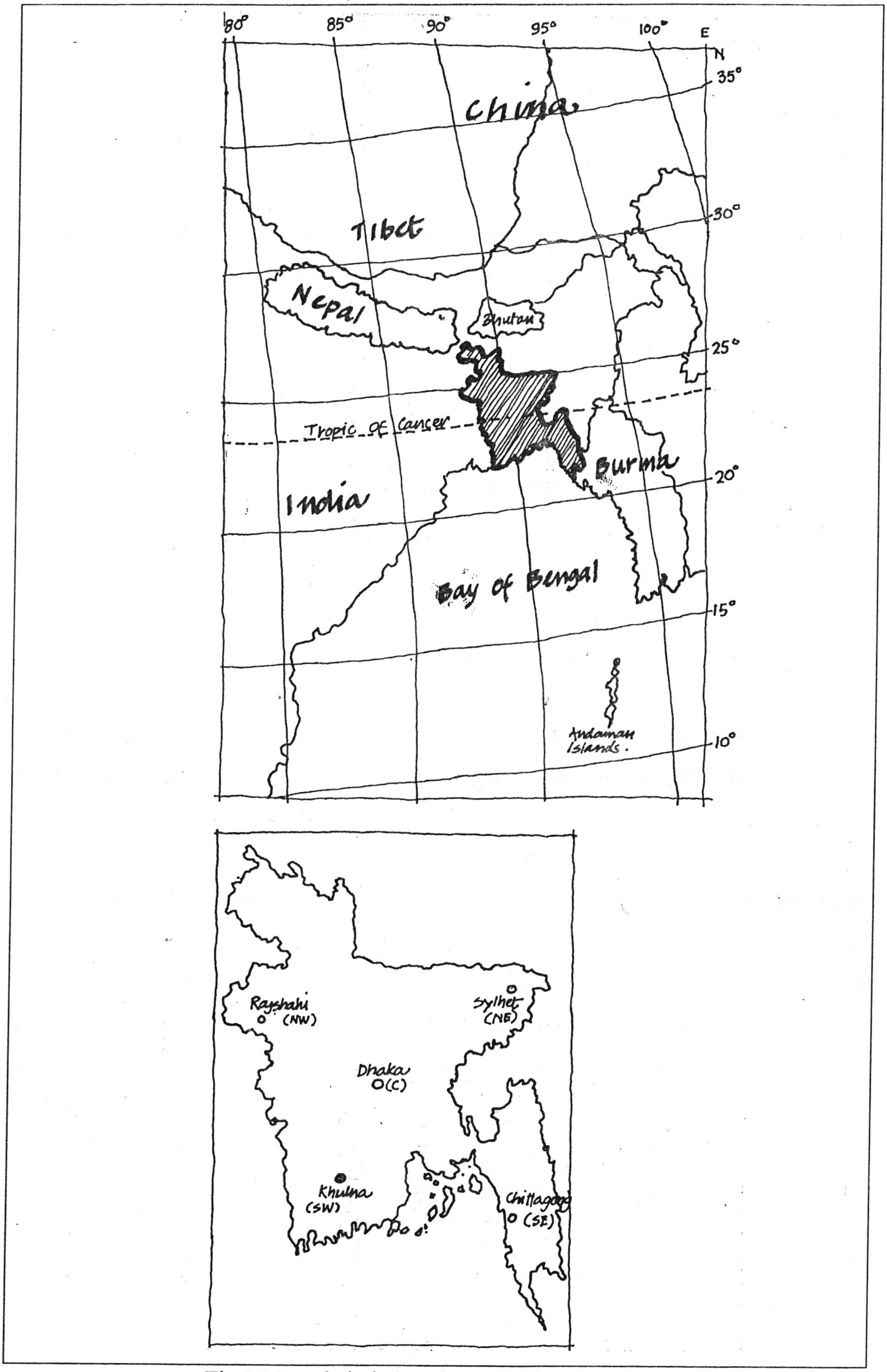

Fig 3.1 Bangladesh, location and climatic regions

the average relative humidity is above 85% and rainfall in high (above 800mm in the north-eastern part of the country).

The cool season starts around mid October when the drop in temperature becomes noticeable and lasts till about February. The average temperature during this period is about 19°C with the mean minimum temperature going down to 11.7°C in parts of the country. Temperatures in parts of the far north are known to go down up to 3°C in January, the coldest month.

3.3. Climatic Regions and Urban Climate

There are some differences within the patterns of climatic factors in various parts of the country. The north western part is drier and hotter whereas the north eastern part is wetter. The areas near the coast have relatively moderate climates.

The weather data of the five main cities loçated in different parts of the country offer a basis for identifying the different climatic zones. Dhaka (C), the capital located *centrally*, Chittagong (SE), the main sea port located in the *south eastern* part, Khulna (SW), the second port city in the *south western* part, Rajshahi (NW), in the *north western* part and Sylhet (NE) in the *north eastern* part of the country.

It is generally understood that the climate of urban built up areas vary from that of the surrounding rural areas (3)(4)(5). At the same time differences occur within areas of the city as a result of differences in surface quality and heights (6)(7)(8)(9). This may seems to be particularly true for the developed nations where the physical features of the urban areas have more differences with surroundings, than in tropical environments which are mostly in developing countries (10)(11)(12).

It is argued that in Bangladesh urbanisation is yet to make a significant impact on climate of the cities (13)(14)(15) for urbanisation is more of a demographic rather than physical change. Published accounts of recorded observations in Dhaka show a maximum heat island intensity of 2.5°C during early evenings in the hot dry periods, at other times the effect is negligible. Incoming solar radiation is 12% less than surrounding rural areas (16). However, some unofficial observations in the central commercial area of Dhaka in the hot dry period have shown temperatures 6-8°C higher than the maximum recorded by the meteorological office for the day (17).

3.4. Temperature

The hottest period is between the months of March and May, the highest temperatures are reached around late March and early April. During this period there are significant differences in temperature between the regions. The hottest part of the country is the north west with maximum temperatures reaching 36.4°C in April with a swing of 12.9°C. The coolest is the north eastern with maximum temperatures of 31.3°C and a swing of 10°C. The coastal areas have lower temperatures.

Table 3.1. Average temperatures of the major cities during March, April and May.

	Dhaka (C)	Chittagong(SE)	Khulna (SW)	Rajshahi(NW)	Sylhet (NE)
Maximum	33.3	31.7	34.5	35.1	30.9
Mean	28.1	27.4	29.2	28.6	25.7
Minimum	22.6	23	23.9	22.1	20.6

In the hot and humid period between parts of June and October the temperature swing is lower although the mean temperatures remain more or less the same as in the hot dry period. Unlike the hot dry period regional differences are lower. The north western part is the warmest with maximum temperatures in June of 33.2°C and a swing of 7.3°C, the north eastern part is less warm with a maximum temperature of 31.1°C and a swing of 5.9°C. This part of the country also has the highest rainfall.

Table 3.2. Average temperatures of the major cities during June, July, August, September and October.

	Dhaka (C)	Chittagong (SE)	Khulna (SW)	Rajshahi (NW)	Sylhet (NE)
Maximum	31.1	30.9	31.8	32.1	30.6
Mean	28.3	27.9	28.7	28.8	27.3
Minimum	25.5	24.9	25.9	25.6	24.2

In the cool period the average maximum temperature is more or less the same for all locations. January is the coldest month with mean minimum temperature between 11 and 15°C. The north western and eastern parts are the cooler in terms of swing which is about

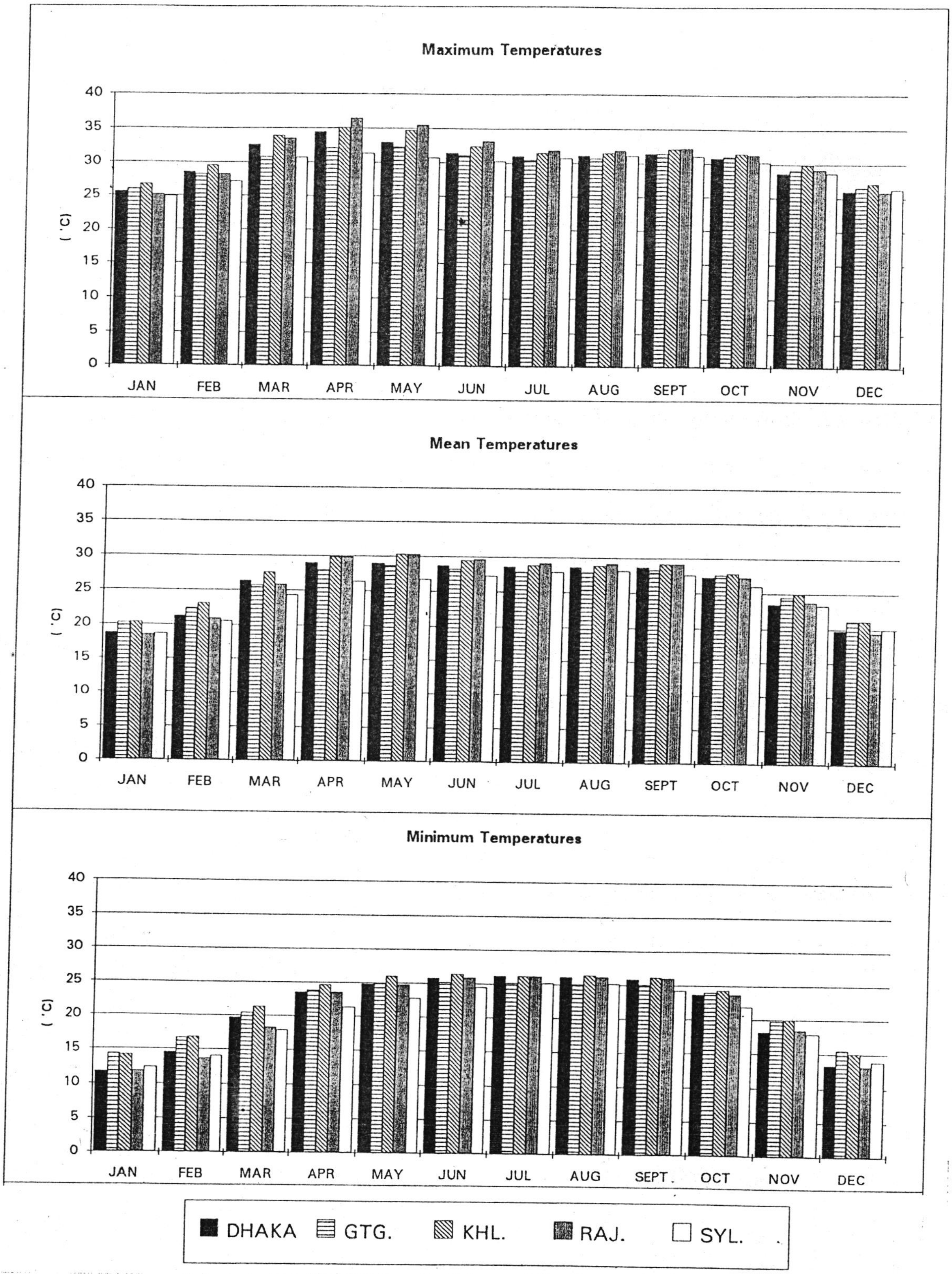

Fig 3.2 Maximum, mean and minimum temperatures of the major cities.

13°C and also in terms of incidence of lower temperatures. The north western part has the lowest absolute temperatures. The central part is cooler than the coastal cities

Table 3.3. Average temperatures of the major cities during November, December, January and February.

	Dhaka (C)	Chittagong (SE)	Khulna (SW)	Rajshahi (NW)	Sylhet (NE)
Maximum	27.1	27.4	28.2	27	26.7
Mean	20.7	22	22.3	20.6	20.6
Minimum	14.4	16.5	16.5	14.2	14.5

3.5. Relative Humidity

Relative humidity is high throughout the year for the whole country combined with high moisture content of the air. It is only comparatively low in the hot dry period when it is mostly between 60 and 65%. During the rainy season, June, July, August, September and part of October it is between 80 and 90% for all locations. Regional variations occur in the months of February, March and April when the north western part of the country has lower relative humidities averaging around 59% as compared to the south eastern part where it averages around 75%. In comparison the average for the rest of the country in the same period is between 65 and 70%. In the cool period the humidity values for all location are around the 70%.

Relative humidity data is compiled from meteorological sources where it is measured twice daily, at 0600hrs and at 1800hrs. Spot measurements of humidity by the author at intermediate periods have shown variations in the cool and hot dry seasons when at around mid day and early afternoons it was found to be as low as between 40 and 50%. (see chapter 5)

Table 3.4. Humidity ranges for the major cities in the three seasons

	Dhaka (C)	Chittagong(SE)	Khulna (SW)	Rajshahi(NW)	Sylhet (NE)
Mar Apr, May	60-70%	70-80%	65-75%	55-65%	65-75%
Jun, Jul, Aug, Sep, Oct	80-90%	80-90%	75-90%	70-85%	80-90%
Nov, Dec, Jan, Feb	70-75%	70-75%	70-75%	70-75%	70-80%

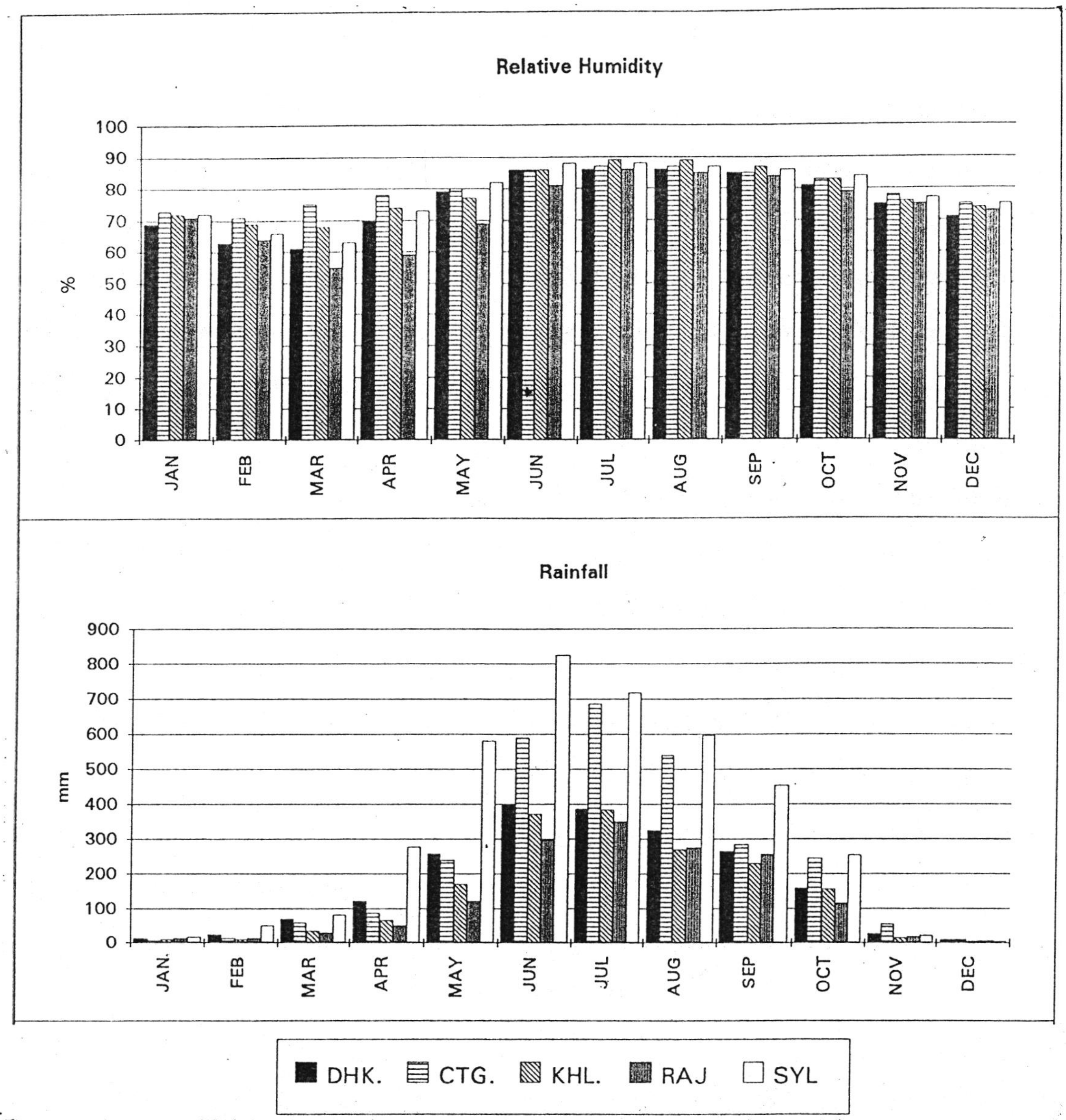

Fig 3.3. Rainfall and Humidity

3.6. Rainfall

Rainfall is high in the monsoon months specially in the eastern part of the country. The north eastern part has the highest rainfall. From May to September there is around 400mm of rainfall per month in all locations the wettest months (June and July) except Chittagong and Sylhet. Sylhet in the north eastern part which has nearly 900mm in the month of June. Rajshahi in the north western part has the lowest rainfall reaching only about 300mm in the wettest months. There is little rainfall anywhere in the cool period

3.7. Solar radiation and sunshine

Solar radiation and sunshine data is not available for all locations. The meteorological office monitors sunshine hours data only for Dhaka (C) and Chittagong (SE) and does not measure solar radiation at all. Solar radiation for Dhaka has been measured by some organisations for their own purposes. The Mechanical Engineering department of the Bangladesh University of Engineering and Technology has some published accounts of Solar Radiation, which is the only reliable source (17).

In the cool period, hours of sunshine per day for both Dhaka and Chittagong are more than 8. During the Monsoon months it is low due to the cloud cover and is about 4 hours per day during the months of June and July after which it increases steadily.

Solar radiation data for Dhaka shows maximum intensity in the hot dry period (5 kWh/m^2/day in April).. During the humid monsoons the radiation is mostly diffused due to cloud cover and is constant around 4kWh/m^2/day. In December and January it goes down to slightly above 3kWh/m^2/day.

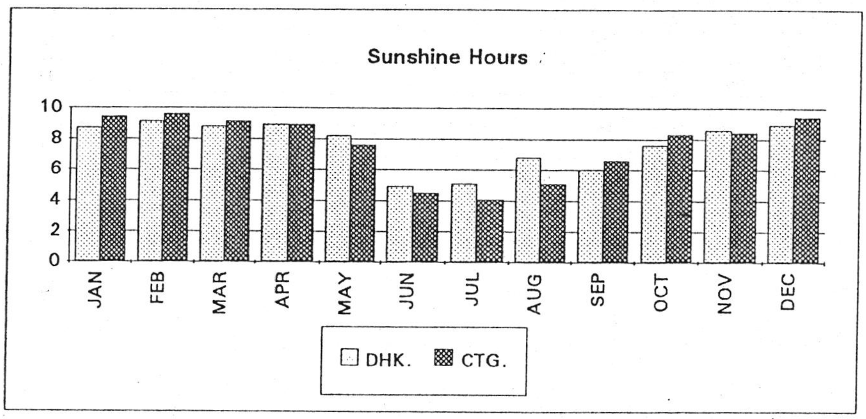

Fig 3.4. Sunshine hours for Dhaka and Chittagong

For other location the conditions can be approximated based on general conditions. The drier and hotter north western part is likely to have more radiation for the whole year whereas the wetter north eastern parts lesser with a relatively larger diffused component.

3.8. Air Movement

Air flow is an important consideration for comfort. Meteorological data are based on conditions measured in open locations (and are valid as general conditions for the city as a whole). In the hot periods, the direction, is from the south and mostly from the south east for all locations. Wind speeds are higher in the hot dry period than the hot humid period, particularly in the coastal city of Chittagong (SE).

In the urban areas it is important to consider that both wind speeds and directions are moderated by physical characteristics e.g. buildings, surfaces, vegetation and local conditions can be quite different than regional values (18)(6)(9)(3). The actual air flow conditions at the level of buildings is different from that of the city.

Table 3.5. Wind speeds (m/s) and direction

		J	F	M	A	M	J	J	A	S	O	N	D
Dhaka	vel.	1.5	1.6	2.9	2.6	3.9	3.3	4.1	3.8	3	1.7	1.5	1.8
(C)	dir.	NW	N	SW	SW	S	SE	SE	SE	SE	N	NW	NW
Chittagong	vel.	1.7	2.1	5.2	5.7	3.9	2.3	2.1	2.6	3.4	3.3	1.9	1.7
(SE)	dir.	NE	NE	S	S	SE	SE	SE	SE	SE	SE	NE	NE
Khulna	vel.	1.6	1.3	2.4	2.2	1.7	1.8	1.6	1.8	1.7	1.9	1.3	1.9
(SE)	dir.	N	SW	S	S	S	SE	SE	SE	SE	NE	NE	N
Rajshahi	vel.	1.3	1.3	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.5	1.2	1.2
(NW)	dir.	N	NW	W	SE	SE	SE	SE	SE	SE	N	N	NW
Sylhet	vel.	2	2	2.2	2.2	2.3	2.1	2.1	2	1.7	1.9	2	1.9
(NE)	dir.	E	E	SSE	SSE	SSE	SSE	SE	SE	E	E	NE	E

3.9. Strategy for building design.

The conditions of temperature and humidity for the country can be compared with comfort requirements as presented in the Bioclimatic chart (fig 3.5) adjusted for local needs (see Chapter 3). The emphasis for the hot dry and humid periods which together constitute more than nine months of the year is to for cooler indoors. In the cool period there is the need at times for warmer interiors, particularly at night.

From the point of view of average temperatures the whole year can be said to have only two periods, the hot and the cool period, for the mean temperatures of the hot dry and the hot humid periods are nearly the same. The difference in diurnal swing between these two seasons needs effective consideration in building design.

The north western parts have slightly higher temperatures and cooling is particularly important in the hot dry period.. For the rest of the year the temperature differences between regions are not sufficient to require separate design considerations. In the north eastern part the main problem is excessive rainfall during the rainy season and the resultant humidities.

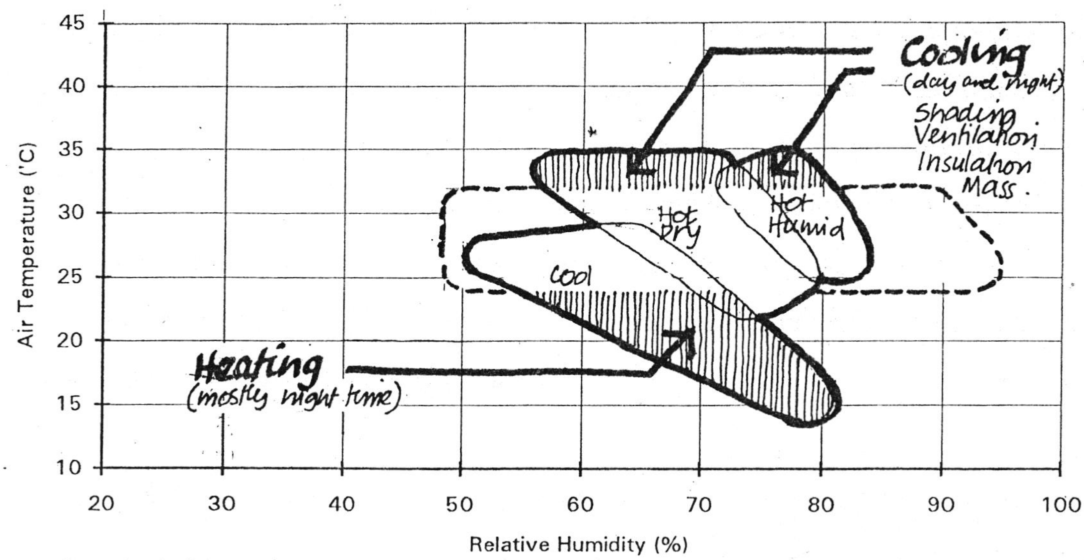

Fig 3.5. The Bioclimatic chart and design requirements

Data for wind speed as available from meteorological sources is of little use for consideration in building design for urban areas since they are measured under open conditions. They can only offer guidelines as to the general direction of air flow.

Houses in Bangladesh do not use active means for environmental control and the cooling requirements have to be met by passive means. In design terms this implies manipulation of solar radiation, temperature,humidity and air flow by the design features, through shading, adequate scope for ventilation, control of heat flow, promotion of heat loss etc. which are discussed in the following sections.

3.10. Design with Climate: Passive Cooling

An ideal house should provide its occupants with a feeling of well being where the senses are in agreement with the environment in activity and at rest (19) and perceived as thermally unstressful (20). A building may do so through passive means i.e. by virtue of its design alone (21)(22)(23) or employ active energy utilising means. Traditional building practices in many cultures have inherently used passive methods to achieve indoor comfort (24)(25)(26)(27)(28)(29) and some modern building solutions continue to use such techniques with remarkable success (30). Modern day technology makes use of the development in materials such as low emmisivity glass, phase changing materials, etc. to achieve passive design solutions (31)(32).

In warm climates, such as in Bangladesh the environmental objective of building design is to create conditions indoors which are cooler than the outdoors for more than three quarters of the year. Like most developing countries the use of passive cooling methods is particularly important for reasons of national economy (33). Once the comfort objective is identified in terms of target indoor conditions the designer may opt for a passive cooling strategy that best adapts to the climate and design requirements.

3.11. Heat exchange of buildings

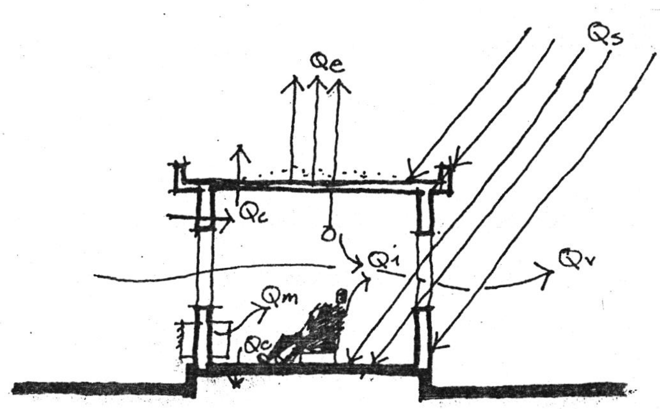

Fig 3.6 Heat exchanges of a building (after Koenigsberger et al.)
(Q_i- internal heat gains Q_s- radiation Q_c -convection Q_v -ventilation Q_m -mechanical equipment Q_e - evaporation)

The house is a defined unit which interacts with the environment in the exchange of heat through various processes simultaneously (34). The resultant heat balance of the house determines the cooling requirement of the house.

Heat flow through the building fabric takes place through conduction (Q_c) and depends on the thermophysical properties of the building materials. Conduction takes place through all surfaces of the building in physical contact with the exterior including the ground. The heat flow by conduction is determined by (a) its surface area in contact (b) the transmittance or U value of the material and (c) the temperature difference between the surfaces.

$$Q_c = A \times U \times \Delta T$$

Where Q_c in the heat flow rate, A is the surface area in contact, U is the transmittance or the U value of the material in contact and ΔT is the temperature difference between the two surfaces.

Convective heat exchanges (Q_v) are a result of heat brought in or carried out by air flow, through intended ventilation or unintended infiltration. Where windows are left open the air flow through them is the main determinant of convective heat exchanges. The ceiling fan, often used in warm humid climates, contribute to the convective gains or losses.

Heat gain from solar radiation (Q_s) coming into a room is the product of the intensity of the incident radiation and the area of the aperture in question. This is relevant for open windows or any other opening. Heat gained by walls and other building elements are also transmitted through building materials through conduction.

Internal heat gain (Q_i) is from the occupants. This depends on the number of people in the room and their activity. Other sources of internal heat gain are equipment, such as electric lights or operating equipment that give out heat.

Heat may be added or removed (Q_m) if there are any heating or cooling equipment in the room. For passive buildings there are ideally be no such equipment however, supplementary cooling may be required in some cases.

Evaporative cooling (Q_e) is brought about by the evaporation of moisture from the space itself or from the building surfaces. The process requires latent heat which decreases the sensible heat content of the building. If the location is subject to rainfall the evaporation of accumulated water on building surfaces contribute to the cooling of the building.

3.12. Effect of the site

The surfaces and the surface qualities of the ground and the buildings effectively raise or lower the temperatures of its surroundings as function of their reflectivity or albedo (35) and the conditions of vegetation present (36). Surfaces of surrounding structures contribute to the radiation gains into the indoor spaces through reflection of solar radiation, significantly in warm climates (37). The surroundings can have a positive effect on the heat gain of a building as a result of the shade they provide. Trees and surrounding buildings form an effective means of shading buildings and thus moderating indoor temperatures (38)(39) the effect of which can be regulated through planned landscaping (40).

Convective gains and losses are related to ventilation and the pattern of air movement which is also affected by site conditions. The relative closeness and spread of buildings affect air flow patterns and hence convective gains and losses (41)(42)(43)

3.13. Principles of Passive Cooling.

The main objectives that outline the strategy for passive cooling are (44)(45)

1. Prevention of Heat Gain
2. Protection from effects of heat gain.
3. Promotion of cooling through heat loss.

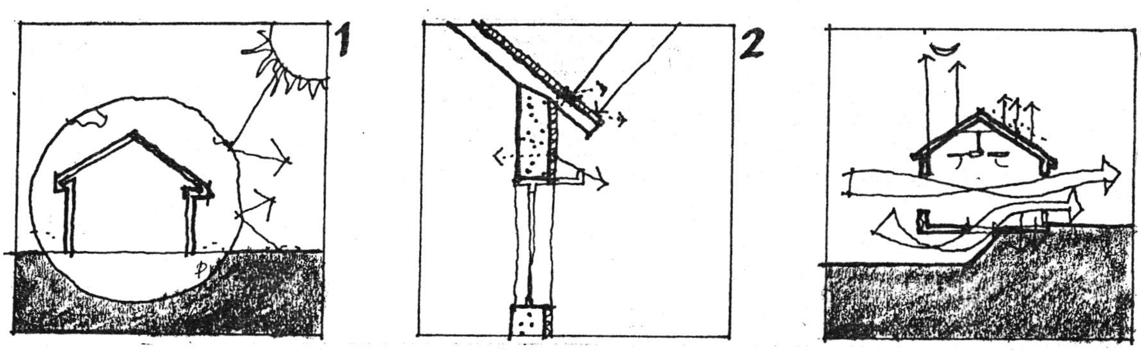

Fig 3.7. Principles of Passive Cooling (after Yannas)

Heat gain of the building fabric occurs primarily as a result of solar radiation. Protection from solar radiation is through shading of the building surfaces and the openings. Given the portions of surfaces that need to be shaded and the times when this shading is required devices and means can be designed using solar charts and sunpath diagrams (46)(47)(48)(49)(50). Reduction of reflected radiation component by careful landscaping of site surroundings promotes passive cooling at the level of the building exterior (51). On the building fabric itself, the use of insulation* in the outer layers of the fabric prevents the passage of heat into the materials itself.

The heat gained by the building is transmitted through the materials of the fabric into the interior spaces. The use of materials of high thermal capacity reduces the impact of heat gain by delaying the process of heat flow into the indoors. This is particularly relevant where the diurnal swing is large and heat flow into the building is delayed up to the time when outdoor temperatures are low (52)(53)(54).

Heat gained by the building fabric raises the temperature of indoor spaces. The third objective of passive cooling is to promote the loss of excess heat by natural means into the environmental heat sinks; the air, the ground and the sky (55). This can be achieved though evaporation, radiation, conduction or convection or a combination of these means.

3.14. Passive Cooling Options

Passive cooling relies on removal of heat from a building or space to an environmental sink using any or a combination of the modes of heat transfer.

Ventilative Cooling

Ventilative cooling relies on removal of heat from a space by convective or natural air flow through it. Active means such as ceiling or exhaust fans may be used to induce ventilation. Air movement raises the upper limit of comfort temperatures and induces cooling of occupants through evaporation of sweat. Ventilative cooling is also a means for cooling of the building structure. This is particularly useful in arid climates where night ventilation is employed to cool buildings of high thermal mass. (56)(57)(58). In warm humid climates air flow through spaces and over occupants is more relevant for thermal comfort.

Table 3.6 .Design considerations for passive cooling

Option	Method	Preliminary design considerations	Element design
Ventilative Cooling	induced air flow natural air flow	site exposure vegetation other buildings orientation combination with evaporative cooling	wind tower solar chimney water spray openings -orientation -size -location -control -protection
Evaporative Cooling	water spray standing water	humidity rain water supply roof pond spray on wall /roof	roof pond -size -insulation sprinklers fountains stream
Radiative Cooling	from building surfaces from ground (to cool the earth)	roof wall exposure to sky	colour material surface cover (for exteriors)
Conductive Cooling (earth coupling)	direct indirect (earth pipes)	extent of contact which surfaces what depth	wall roof whole partial dampness -water table condensation -material underground pipe -material -fan
Shading	overhangs projections trees	walls windows horizontal surfaces whole building orientation times sunpaths light	size exposure extent tree heights materials

Radiative Cooling

The sky acts as a heat sink of infinite capacity to absorb radiant heat energy from building surfaces. Radiative cooling depends on temperature differences and is more effective for nocturnal heat loss when the sky is cooler and the daytime gains by a building can be radiated out. 1000-2000 KJ/m^2 can be radiated to the sky per night from a surface having a temperature of 21°C on clear summer nights (59)(60). This is a clean process and does not have an impact on surroundings. Radiative cooling is related to surface temperatures and lowers the mean radiant temperature of a space.

Evaporative Cooling

Passive cooling through evaporation is a adiabatic process and does not involve loss or gain of energy. The evaporation of a liquid requires latent heat which is taken from a building surface or space causing sensible cooling. In order for a space to be cooled deliberate introduction of the process may be required unlike heat loss through radiation or ventilation where it takes place as a natural consequence of physical processes (61)(62). Evaporative cooling means are also adopted in passive cooling devices such as desert coolers (63).

Conductive Cooling (Earth Coupling)

The earth is a reservoir of heat with a very high thermal capacity. Temperatures below the ground are stable and at certain depths constant throughout the year. For exchange of heat with the ground the area and extent of contact with the ground may be manipulated, up to where the whole building is subterranean (64)(65). Depending on the climate of a place earth coupling may be used for either passive cooling or heating. There are other indirect processes of using the heat exchange potential of the earth such as underground pipes.

3.15. Passive Cooling and Climate

The applicability of passive cooling options depends on the ability of the local climate to sustain their adaptation in the design of buildings. Traditional buildings, in many cultures and in Bangladesh have incorporated passive cooling methods as part of the building's response to local climate and the resultant manifestation described the architecture of the place (66)(26). Modern building design, given the climate of Bangladesh and comfort requirements may consider some approaches as being more effective, while others have partial applications. While the emphasis is on cooling, the means adopted for the same require consideration regarding its effectiveness in terms of the climatic elements that interact with it.

High humidities for most of the year restricts the potential for evaporative cooling. Radiative cooling has to consider exposure to the sky and during the rainy season cloud cover. Coupling with earth is practised in the rural mud houses and is effective but require consideration for associated dampness. Ventilation, recognised as having the most potential as a cooling resource, particularly for promoting thermal comfort in people has to consider air flow patterns at site and the design of openings. The use of thermal mass depends on diurnal range which for a considerable part of the year is low. Shading from solar radiation and the use of insulation offer possibilities in prevention of gains.

The context of the urban environment presents variations from the climatic pattern of the region as a whole and requires separate considerations. Within urban areas, site conditions in dense urban areas require micro climatic considerations, particularly from the points of heat storage, reflected radiation and air flow patterns.

3.16. Design for Passive Cooling.

The use of passive cooling options in design for urban houses in Bangladesh has to consider, other than the climate of the region and of the site, local building practices and materials and the possibilities they offer. They must also consider technicalities of building design specifications, details and the potentials or limitations of passive cooling methods.

3.16.1. Designing for Ventilation.

Ventilation in buildings has three functions (67):

-to replace used air
-to cool the occupants by evaporation or convection
-to cool the building

Air has to be replaced for health requirements and this function is necessary for all buildings. Cooling by evaporation requires the passage of air over the body and sufficiently low humidity to allow evaporation. Heat from building interior may be removed by air flow where the temperature of the flowing air is lower.

In Bangladesh this takes place through openings in the building. For effective and unobstructed air flow buildings that are one room deep are more permeable such as in houses in the rural areas (68). Characteristically buildings in hot and humid regions are light and porous (70). In some locations they may be raised on stilts to allow air flow all around (69). In the urban areas local air flow directions and speeds need to be considered and the design of openings have to optimise whatever air flow is available. Where there is insufficient scope for ventilation with normal air flow, it may be induced through introduction of design elements.

3.16.2. Wind Towers

The use of traditional wind towers have been reinterpreted in modern buildings to bring in or to let out air (71)(72). They rise above buildings and are oriented to the prevailing wind direction to catch the wind and pass it through the interior spaces. Alternatively the design may incorporate elements which induce low pressure near the inlet to encourage air flow through pressure difference. In dense sites where there is little air flow, particularly at lower levels such means may be adopted and adapted to the design of houses.

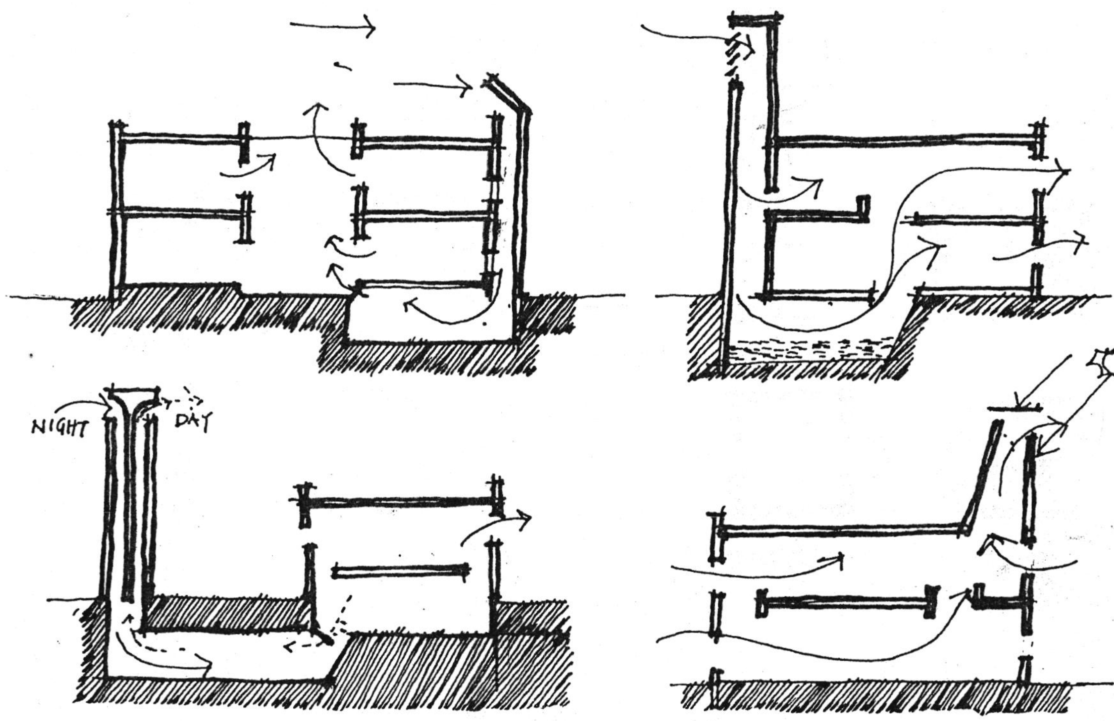

Fig 3.8. Wind towers and solar chimneys (after Bowen and Baker)

3.16.3. Solar Chimneys

Air movement may be brought about by using solar chimneys where the temperature difference due to parts of it heated by the sun creates stack effect ventilation. The design of the building may incorporate solar chimneys within itself as a vertical shaft (73)(74). Solar chimneys can be used in outdoor spaces to improve site climate and the air may be cooled further through evaporative cooling using micronisers (75). Solar chimneys have potential use in Bangladesh although it will require consideration in materials use. The use of micronisers requires technical support yet unavailable at general levels.

3.16.4. Ventilation through openings

For normal ventilation the major considerations are to do with openings pertaining to their:

-orientation
-position
-location
-size and
-control.

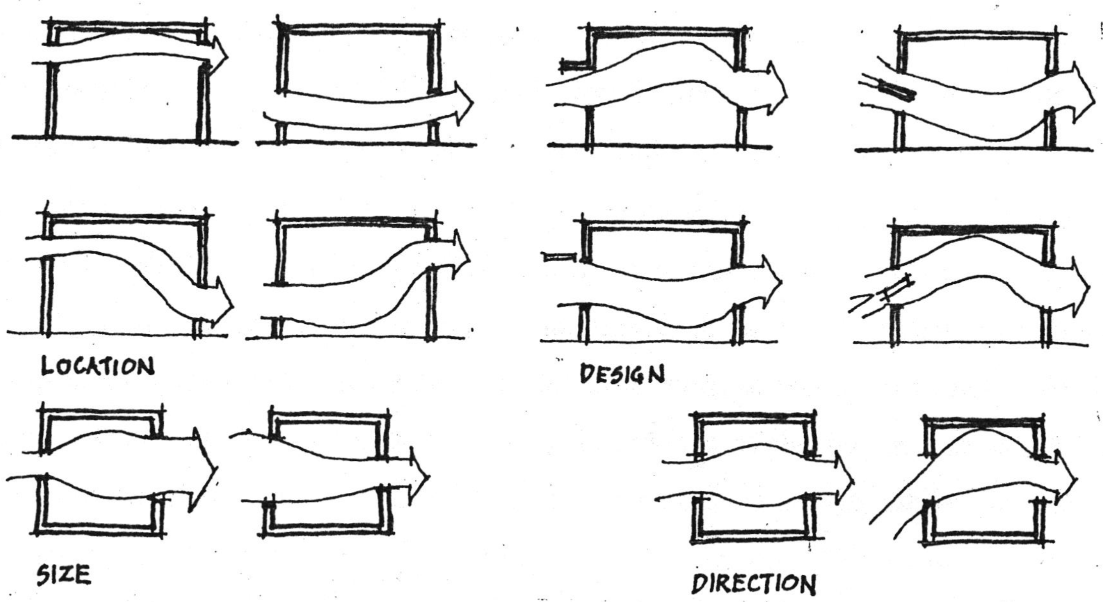

Fig 3.9. Air flow through openings (after Evans, Koenigsberger, Givoni and European Passive Solar Handbook)

To allow air to enter a room, the openings must be oriented to the breeze direction. To facilitate unobstructed air movement landscape elements such as trees, hedges and walls may be used to direct air flow. Variations in internal flow will occur depending on relative sizes of inlets and outlets their disposition and whether the air flow direction is perpendicular or at an angle to it. (76)(77)(78). In Bangladesh an important consideration is the design of the shading device which affects air flow indoors and the design of the aperture itself. For security, and protection from insects windows have grills and fly netting which reduces the potential of normal air flow (78).

3.16.5. Design with Thermal Mass

The heat storage capacity of building materials can be used to moderate the effects of outdoor heat to create comfortable and cooler indoor spaces. The important properties of materials that are to be considered are the thermal resistance and the heat capacity (78)(79). The resistance is to moderate heat flow from external to internal surfaces and the thermal capacity is to store heat and control the fluctuation of indoor temperatures. The use of thermal mass is particularly effective where both external temperatures and diurnal ranges are high. The hot dry period between March and May are appropriate for the use of thermal mass, particularly in the north west of the country. Passive cooling in such situation can be further enhanced by removal of heat accumulated during the day by night ventilation (80)(78)(56)(58). The use of thermal mass has different consequences in warm humid periods where diurnal swings are low and the use of materials having high thermal capacity may elevate night-time indoor temperatures. The use of thermal mass, however, may have advantages during the cool period for warmer interiors at night (81). Where used, high mass buildings in hot humid areas should have insulation to increase resistance to heat gain. The preferred location of the insulating layer is to the outside of the building envelope (82). Building construction in urban areas use brick and concrete extensively where the walls are built brick by brick using manual and concrete is cast on site. This allows variation in thickness of the wall and roof elements easily and hence the variation in thermal mass.

3.16.6. Roof Ponds

Roof ponds help in passive cooling by utilising the thermal capacity and evaporative potential of water through the introduction of a water mass on the roof. Roof ponds can also help in passive heating. In cooling it is particularly useful in places where sensible cooling loads are high, outdoor temperatures are too high for ventilative cooling and dehumidification is not a major concern (83). The water on the roof has removable insulation panels which for cooling are kept closed during the day to protect from solar gains. At night the panels are removed for the water to loose heat through radiation to the sky and also through evaporation, the loss being less from the latter (84). A shaded roof pond has a comparable performance (85). A highly conductive ceiling will cool as a result of evaporation from the roof and the use of a ceiling fan further facilitates cooling of the indoor spaces. The insulating layer is not needed if the water can be circulated to and from another storage tank elsewhere in the building (86). The wet roof pond system uses water spraying on the roof for evaporative cooling. The roof pond system requires manipulation of the insulating panels manually or by mechanical means. The sizing of the roof pond depends on whether it is to be used for cooling or heating. (87).

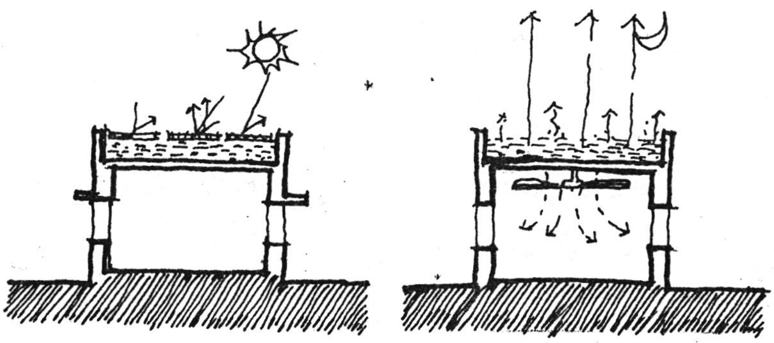

Fig 3.10. Roof Pond

In Bangladesh the high humidities reduce the evaporative cooling potential of roof ponds. In the rainy seasons cloud cover reduces the radiative cooling potential. The optimal use of all properties of roof ponds are in the hot dry period. At other times its thermal capacity can be utilised for control of heat gain through roofs.

3.16.7. Earth Coupling.

The fact that the earth is a heat sink of enormous capacity makes it a potential passive cooling resource. It is more effective as a heat sink than the atmosphere in overheated situations (88). Conductive heat exchange takes place between the ground and the building unless negated by insulation. In structures with mud floors the effect is direct. The cooling aspect of the earth is extended by creating contact with more building surfaces, walls and roofs. Direct coupling involves the direct transfer of heat between the building and the earth. Indirect earth coupling uses air cooled by passing it below ground in underground pipes for convective cooling of indoor spaces. Winds towers may be used as an aid to earth coupling.

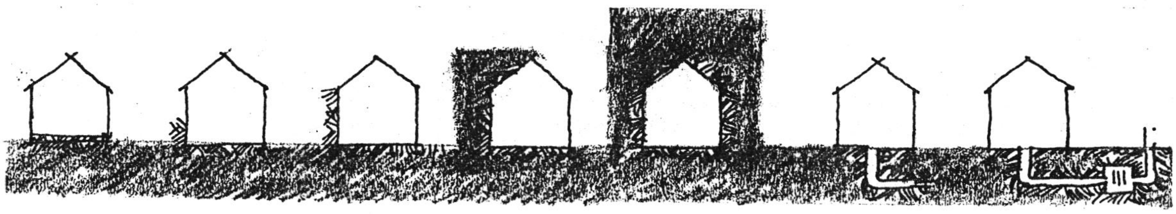

Fig 3.11. Earth Cooling

The cooling potential of the earth is supplemented by adopting means to allow the earth itself to cool further, through shading, radiative and evaporative losses and prevention of gains by solar radiation.(89)(90). The use of earth on roofs is a variation of the roof pond system. In hot humid climates moisture in the earth can cause dampness in building surfaces that are bermed and its application is more appropriate in hot dry regions (91).

In Bangladesh traditional houses benefit from earth cooling directly because of earthen floors. The method has potential use in urban houses where the ground floor is in contact with the earth. Low water tables requires considerations for dampness and the use of protective layers which will reduce conduction potential. Earth berming has to consider problems of light. Use of underground pipes will require dehumidification of the cooled air.

3.16.8. Shading

Shading of a building offers the first line of defence against gains from solar radiation. Requirements vary from shading of the whole building to shading of walls and openings. General shading requirements can be determined from temperature data to the times when conditions are above comfort levels (92).

The means to shade range from strategies to shade a whole site to shading of a particular areas at a particular times. In hot dry regions shading is of importance at the level of whole settlements and building layouts are dense for mutual shading (42). In warm humid areas close spacing of building is restricted by air flow requirements and self shading is possible through choice of building shape and form (93). Shading design considerations and the architectural options depend on consideration of location and space types (94).

Table 3.7. Considerations in shading device design

Space and element type	Space	Considerations	Shading device options
exteriors	pathways gardens pavilions courtyards	topography surrounding buildings vegetation walls	overhead plane roofs trellises pergola vertical plane perf. screen trees
interiors	living spaces leisure spaces working spaces	opening size opening type light requirements building geometry orientation heating /cooling tilt	window blinds curtains jalouise sun screens canopies awnings veranda recess
walls/elements/roofs	exterior walls exterior fixtures roofs	building geometry orientation colour conductivity of materials vegetation shape/geometry of adjacent spaces	projections overhangs surface plantations eaves veranda horizontal plane double roof

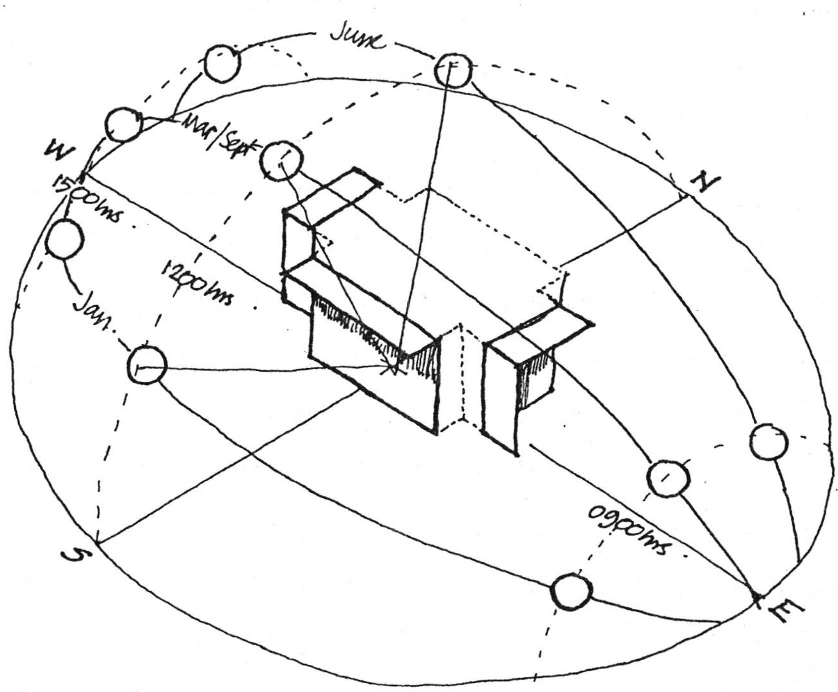

Fig 3.12. Sun path and general shading device considerations for Dhaka, Bangladesh

The path of the sun in the Bangladesh requires both horizontal and vertical projections for east and west faces of a building and horizontal projections for the south. North faces see the sun only for brief parts of the year.

3.16.9. Vegetal Shelter.

In the humid tropics where vegetation is abundant and grows easily its use for passive cooling is an appropriate use of local resources. Rural homesteads in Bangladesh make use of trees for shading and wind flow regulation (95). Plantations on roofs are a protection against solar gain. Evapotranspiration from leaves cool the surroundings as part of a natural process.. The resultant effect is a cooler micro climate. Particular kinds of vegetation can be used as a part of the building components to supplement passive cooling. Creepers that grow on walls protect it from radiation. The use of vegetation on roofs result in lower indoor temperatures as compared with tar or gravel surfaces (96). The low thermal capacity of plants do not allow heat to accumulate. In Bangladesh trees and creepers grow very easily but often create problems in building maintenance. Their use for passive cooling has to be supported by adequate maintenance and consideration for light.

3.17. Environmental Building Design in Bangladesh.

Building design in the predominantly rural areas of Bangladesh are climate responsive because of adaptation over time. Rapidly developing urban areas of the fifties and sixties presented an hitherto unfamiliar context for building design. The lack of trained personnel in the building design discipline lead to insensitiveness towards climatic issues. Since the last two decades trained architects have been increasingly involved in building design and consciousness about climatic design has increased. The construction of houses, however, is handled by unskilled labour, specially in the private sector. This in combination with the narrow range of building products available in the country are major considerations in the application of passive cooling techniques.

3.17.1. Research

The present state of research in climatic design consist of a few academic studies Ventilation of building blocks for adequate inlet velocities have been studied and the optimum spacing for the same has been identified as twice the height of the blocks by Muktadir (43) as opposed to recommendation of six times the height in other literature (97). Building design characteristics for ventilation of low rise urban housing are mentioned in general terms by Ali (98). Potential of urban streets in warm humid regions as a cooling resource with reference to historical precedents is the subject of discussion by Ahmed (99). The shading patterns of buildings in some typical urban housing layouts identify locations for activity spaces in a study by Mallick (100). The study of the thermal characteristics of some buildings over a limited time period identify shading of both the building surfaces and openings as a key elements in heat gain control (101). Another research identifies considerations in window design for solar control and comfort (102). Particular aspects of heat gain control through roofs have been explored through experiments in insulation using hollow blocks on roof surfaces (103) and a more vernacular approach using inverted earthen pots (104). Activity on environmental aspects of building are on the activities agenda of two institutions namely the Bangladesh University of Engineering and Technology and the Housing and Building Research Institute. The latter is more concerned with control of building costs.

3.17.2. Passive cooling of top floors using earthen pots for roof insulation.

As an issue related to the concern of this thesis an experiment to explore alternative means of roof insulation was carried out by the author. Earthen pots commonly used for storing food in Bangladesh were inverted and laid out over a concrete roof of a room in a top floor flat. The gaps were filled with sand and covered with a thin cement concrete layer over a polythene sheet. Subsequent measurement of temperatures in the room and an adjoining one without such insulation showed a difference of nearly 4°C at peak afternoon periods. The difference in surface temperatures were substantially higher. Given that insulation materials are not available in the country and the commonly used method of lime terracing is expensive, this is a viable method which optimises the use of local technology.(see appendix 8 for detailed paper on the subject)

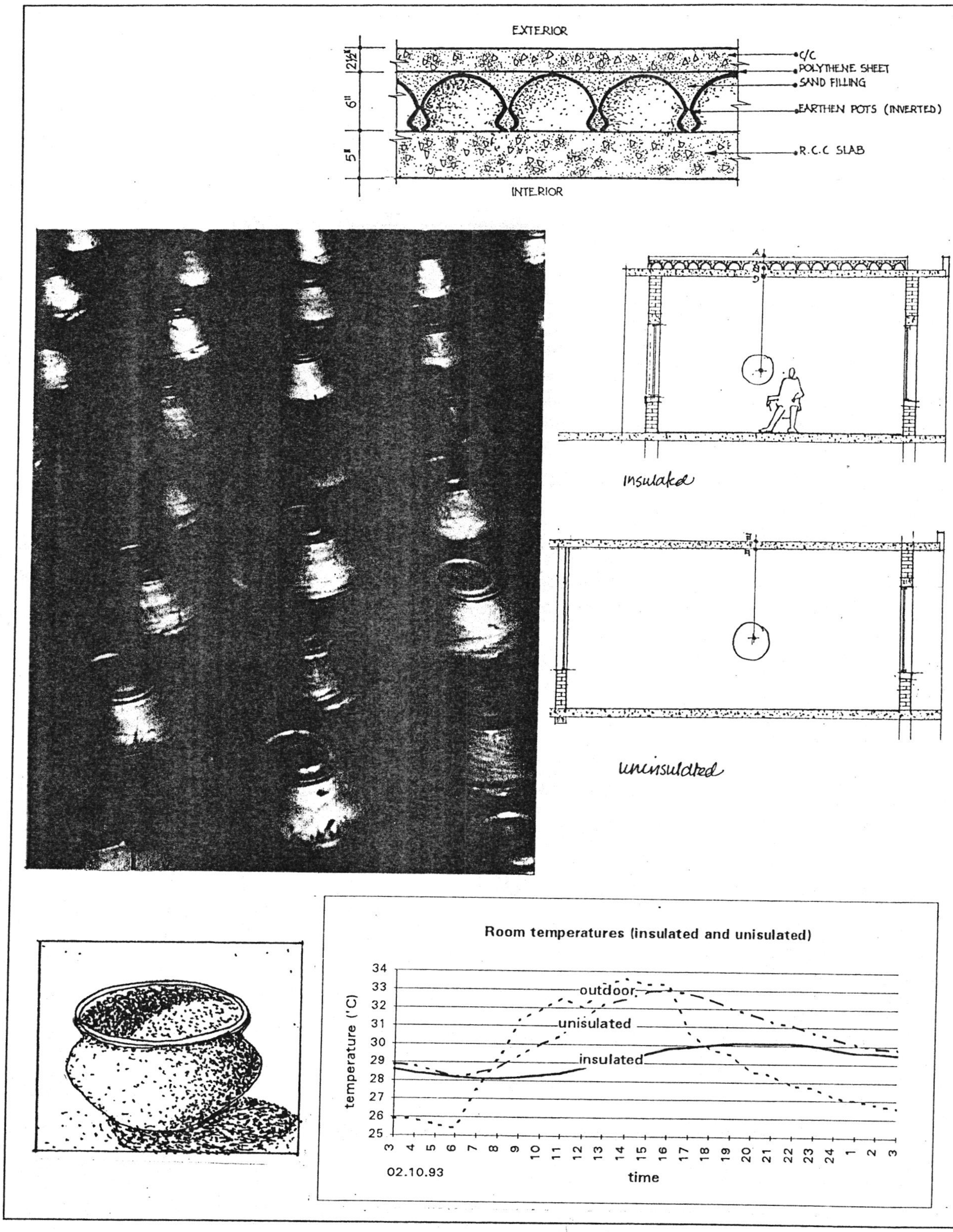

Fig 3.13. The use of earthen pots for roof insulation and its effects

3.18. Building Design and Considerations for Passive Cooling..

The various levels of building design and the corresponding considerations for optimising its passive cooling potential can be set out as a series of tasks that the architect may refer to in the design process. The adaptation of particular means for passive cooling require informed knowledge about the particular site and relate to the way the total design is conceived by the architect incorporating other functional and visual qualities.

Table 2.8. Design considerations for Passive Cooling.

	Solar Control	Heat Gain Control	Promotion of heat loss
Siting	Orientation to avoid sun Shading by other structures, trees	Consideration of reflected radiation from ground (surface qualities, materials) Heat gain from air flow.	Air flow Exposure to environmental heat sinks Evaporative cooling of site
Building Form and Internal Layout	Self shading Minimising exposure to sun through manipulation of building shape (surface to volume ratio)	Thermal buffering of living spaces (use of verandahs) Isolation of heat sources (thermal zoning)	Narrow or staggered plan shape for ventialtion Connection to ground Exposure to sky (optimisation of radiative losses)
Element Design	Overhangs Sunshades Louvers Double roof Surface texture Vegetation	Thermal mass Insulation Cavity walls Colour Materials Reflective roof Shaded glazing	Window /opening design and orientation for air flow wind tower/solar chimney floor-ground contact roof-sky exposure (roof ponds)

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CHAPTER FOUR

Comfort in Context

4. COMFORT IN CONTEXT

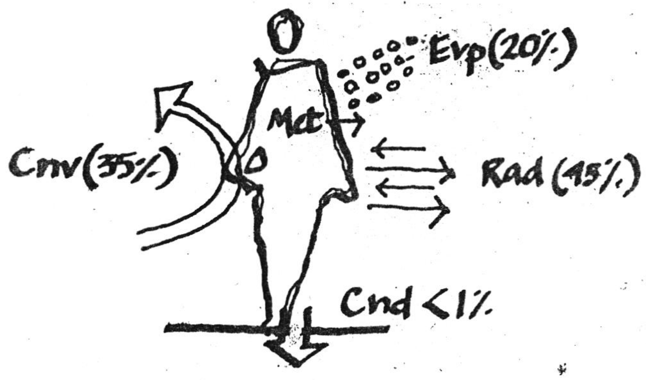
4.1. Introduction

The basic concern of the architect or designer is to provide an indoor environment where the most of the occupants are comfortable. While the idea of a comfortable environment for all would involve the consideration of individual preferences there are a set general conditions in which a majority of the people would be at ease. They relate to air and radiant temperatures, air flow, humidity etc. Many attempts have been made to determine the values of these variables that would provide a comfortable environment. The following sections evaluates these conditions, on the basis of existing knowledge. On the assumption that comfort requirements of people depend on geographic location and the climate thereof, habits, attitudes and importantly the ability to adjust to local conditions, the subsequent sections evaluate the responses of a field study on comfort in Bangladesh. The understanding thus developed are used in part to evaluate building performances in later parts of the thesis.

4.2. Definitions

The definitions of thermal comfort emphasise on the notion of thermal neutrality i.e. the conditions under which the human body is in a state of thermal equilibrium with its surroundings (1)(2)(3)(4)(5) and the "absence of discomfort". In terms of occupants in a building it is best defined as the conditions where most of the people are unaware of the thermal conditions around them and do not feel the need to adjust to it.

Physiologically, comfort is related to the body's thermoregulatory system where the heat exchanges between the human body and its surrounding maintain deep body temperature at 37°C and skin temperature within the range of 31 to 34°C. The exchanges are through the processes of evaporation, convection, radiation and to a lesser extent conduction between metabolic heat production and the outside conditions. The human body is able to adapt to a wide range of outdoor conditions, while maintaining it own thermal equilibrium mainly through the mechanisms of control of skin temperature and sweat secretion.



$$Met - Evp \pm Cnd \pm Cnv \pm Rad = 0$$

Fig 4.1 The body's thermoregulatory system

Comfort as a sense is associated with many unquantifiable factors. The state of comfort is also a state of mind which depends on the psychological aspects of human behaviour and a person in distress is unlikely to feel comfortable even in a thermally agreeable environment. Factors influencing comfort are related to olfactory, auditory, and visual senses. Comfort is influenced by geographic location and long term acclimatisation to a particular environment. Cultural differences account for different preferences (6)(7). Differences in socio economic conditions in the developing countries are also said to account for differences in comfort sensations although this has no empirical basis (8).

4.3. Factors Influencing Thermal Comfort.

External factors that contribute to or influence the sensation of comfort can be categorised as personal and environmental variables. The effects of these can be directly perceived by the human body and can be expressed in quantifiable terms. Personal variables relate to factors that are a result of human behaviour and habits, environmental variables relate to factors that define the conditions of the natural environment.

4.3.1. Personal Variables.

Metabolic rate: The energy released by the digestion of food by the body is converted to work and heat which interacts with the external environment. The heat produced by the body is a function of activity levels. Human activity is classified according to heat produced per square meter of body surface (from Dubois equation) and is referred to as met (9). The scale of reference for human activity is 1 met, the metabolic rate of a person when seated (60 W/m^2). Metabolic rates for some common activities are given in table 4.1

Table 4.1. Metabolic rates for common activities

Activity	W/m^2	met
sleeping	40	.7
reclining	45	.8
seated	60	1
walking		
leisurely	100	1.7
slow	115	2
fast	220	3.8
reading	55	1
writing	60	1
lifting	120	2.1
cooking	95-115	1.6-2.0
house cleaning	115-200	2.0-3.4
heavy machine work	235	4
shovelling	235-280	4.0-4.8
dancing	140-255	2.4-4.4
tennis	210-270	3.6
wrestling	410-505	7.0-8.7

Higher metabolic rates result in higher heat production and the ability to feel comfortable when it is cold or more uncomfortable at higher temperatures.

Clothing: The type of clothing worn by a person forms an intermediate layer of insulation between the body and the exterior and therefore effects thermal sensations, more the insulation less the external temperature that a person is able to feel comfortable in. Thermal insulation value of clothing is expressed as clo. 1 clo roughly corresponds to the insulation value of a normal winter business suit (0.155m^2K/W). Light summer clothes as is common in tropical environments have a clo value of 0.5.

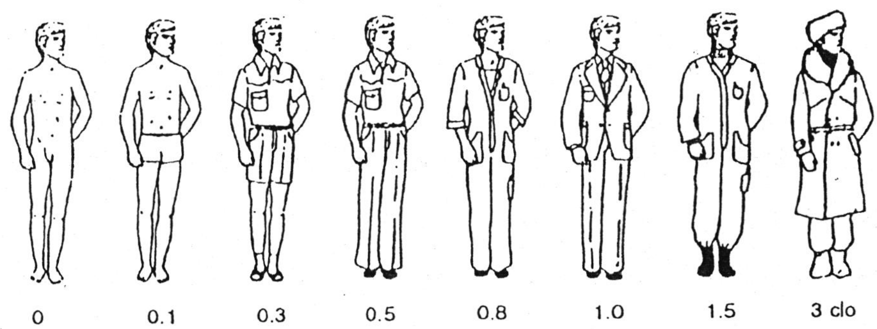


Fig 3.2. Clo values for typical clothing. (*source: European Passive Solar Handbook*)

4.3.2. Environmental Variables.

Comfort is directly affected by some of the elements of the natural environment, changes in which are associated with changes in the sensation of comfort.

Air temperature influences heat gains or losses of the body through convective heat exchanges and respiration and directly effects the comfort status of a person.

Mean radiant temperature is an indicator of the combined effect of the temperatures of surrounding surfaces which affects the radiative heat loss of the body. Outdoors, this exchange also takes place with the radiant heat from the sun. Low radiant temperatures can contribute to the cooling of the body even if the air temperature is high.

Air movement affects both the convective heat exchanges and the rate of evaporation of moisture from the body's surface. This depends on the temperature and moisture content of the air. In the tropical areas air movement is of particular importance as it is able to cool down the body through evaporation of sweat when air temperature is high.

Relative humidity or the relative moisture content of the air affects the rate of evaporation from the skin and lungs and vapour diffusion through the skin. The relative humidity of the surroundings is related to the evaporative cooling potential of the body and hence comfort. The moisture content of the air is also related to wettedness of the skin which also affects the sensation of comfort. In humid environments high moisture content reduces the potential for sweat evaporation. High humidities contribute indirectly to comfort through problems of mould growth, mites etc. whereas low humidities can cause discomfort by the drying of mucous membranes (10).

4.4. Thermal Indices

To define conditions which are perceived as comfortable by people several descriptions that consider the combined effects of a number of variables on thermal comfort have been derived for use by designers. Some of these relate more readily to architects, while others are more relevant to air conditioning and heating engineers or professionals concerned with aspects of human behaviour.

Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) (2).

Based on the heat exchanges of the body with the thermal environment Fanger has derived means of determining their comfort status. Predicted mean vote (PMV) provides an estimate of how cool or warm a particular environment will feel based on the mean value of the votes of a large group of people voting on a seven point thermal sensation scale where the central vote corresponds to the condition of thermal neutrality. Since there are significant differences between people and for any mean value of the votes there may be a number of people who are not in agreement. Predicted Percentage of Dissatisfied (PPD) gives the percentage of people who are dissatisfied with the given environment. There is a relationship between PPD and PMV which is least for neutral votes and increases with progressively warmer or cooler sensations. It is important to note that the basis for these derivations used subjects exposed to artificially controlled environments.

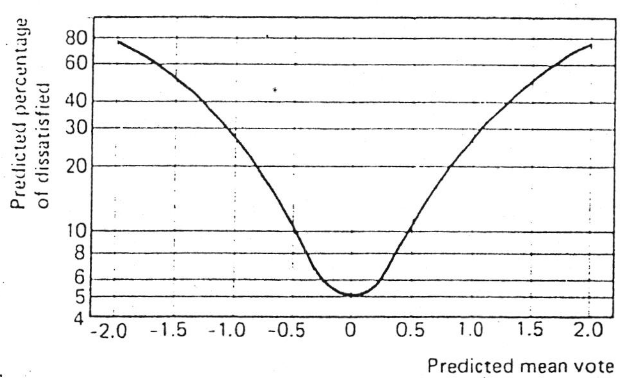


Fig 4.3. Relationship between PMV and PPD

The Bioclimatic Chart.

The Bioclimatic Chart proposed by Olgyay (11) presents the required conditions for comfort for as a range of dry bulb temperatures and relative humidities graphically called the comfort zone. For the designer they may be interpreted as conditions that have to be met to provide comfortable occupancy in indoor spaces. Adjustments to this zone can be made for air movement and radiation effects given the values of clo and met. This is related to conditions observed in the temperate regions of the United States and an elevation of the lower perimeter of the summer comfort line by 3/4°F (0.4°C) for every 5° change towards lower latitudes from 40°N is proposed. The chart has since been modified by several authors to accommodate other considerations (12)(13)(14).

The comfort zone is also plotted with different combinations of variables in the psychrometric chart (15) and on nomograms of effective temperature (16).

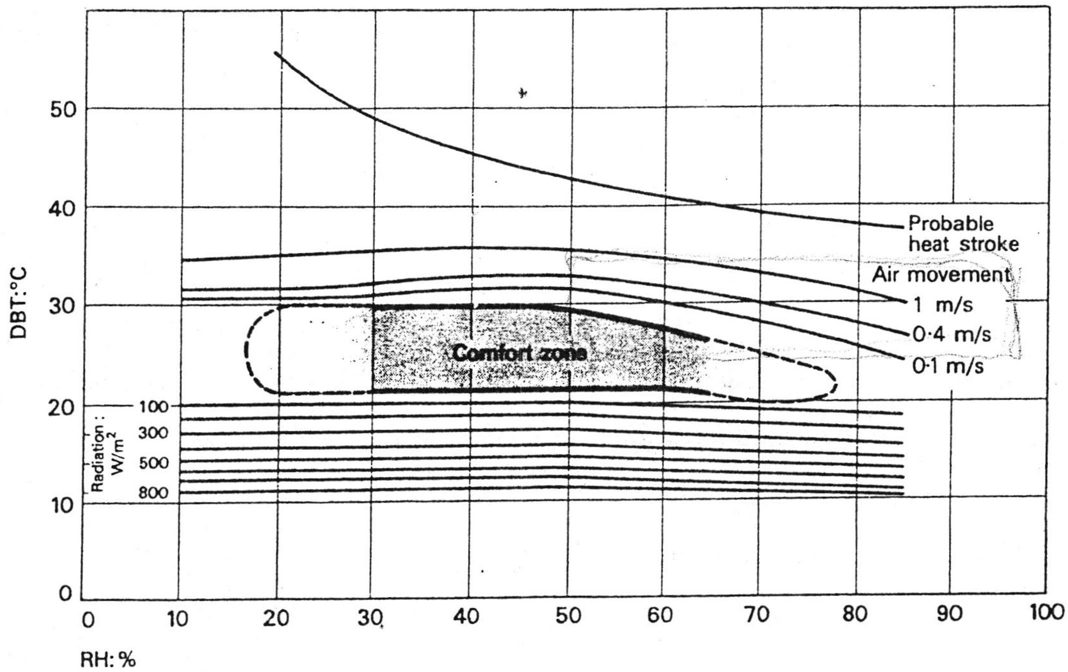


Fig 4.4. The Bioclimatic Chart (after Olgyay and Koenigsberger)

Neutral Temperature.

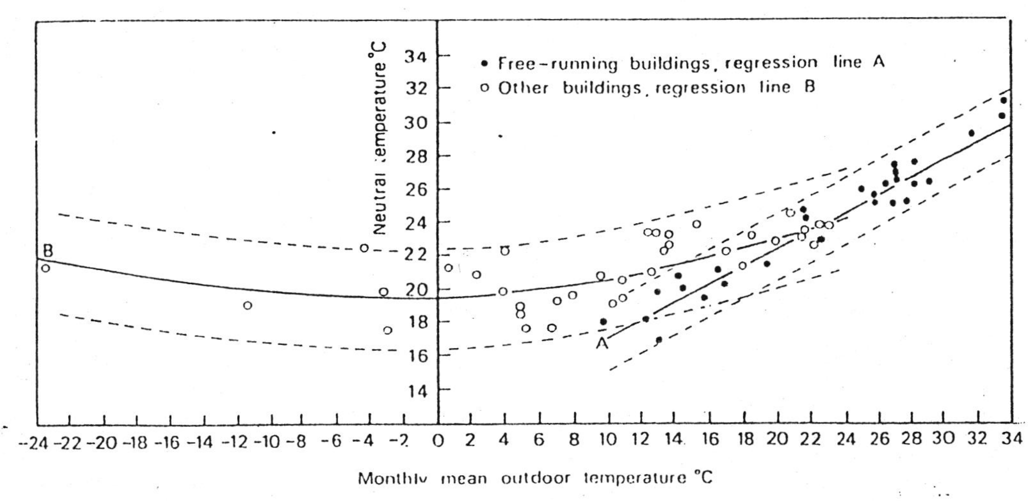


Fig 3.5. Relationship between comfort and external temperatures (after Humphreys)

On the basis of a statistically established relationship between comfort and outdoor temperatures the concept of neutral temperature was introduced by Humphreys (17). This has particular reference to free running buildings in conditions where the outdoors are not extreme. The neutral temperature is given by:

$$T_n = 11.9 + .534T_o$$

where T_n is the neutral temperature when the outside temperature is T_o. This was later modified by Auliciems (18) for warmer climates to:

$$T_n = 17.6 + .31\ T_o$$

Comfort conditions are within a range of $\pm$ 2.5°C above and below this point for 50% relative humidity.

Effective Temperature and Corrected Effective Temperature

This combines the effect of air temperature, relative humidity and air movement into one scale called the effective temperature (19). It describes the temperature of a still saturated atmosphere which in the absence of radiation produces the same effect as the atmosphere in question. This was later modified to include radiant temperatures in a new scale called the corrected effective temperature (20)

Equivalent Warmth

This relates air temperature, humidity and radiant temperatures with individual responses from subjects and the surface temperatures of the skin and clothing (21). The equivalent warmth scale is reliable for assessing comfort for low humidities in temperatures up to 35°C and higher humidities for up to 30°C. This takes little account of cooling by air movement in high humidities

Equatorial Comfort Index.

Developed in a tropical environment (Singapore).This index combines air temperature, humidity and air movement with responses from acclimatised subjects into a formula and graphically into a nomogram (22).

Tropical Summer Index

The Tropical Summer Index (23) follows along the lines of the equatorial comfort index but dealing with subjects in the Indian sub continent and combining observations indoors and outdoors. This combines the effects of dry and wet bulb temperatures with globe temperature and air velocity into one index for evaluating comfort. The results are discussed later with reference to comfort in the tropics.

Predicted Four Hour Sweat Rate (P4SR).

This is concerned with thermal stress at high temperatures and the rates of sweat secretion that occur as a result. It involves relationships between clothing, metabolic rates, air temperature, humidity, air movement, and the mean radiant temperature with the assumption that similar sweat rates produced the same physiological stress (24). It is relevant for high temperatures (above 28°C) but does no take full account of the cooling effect of air movement at high humidities (16).

Heat Stress Index.

This index evolved under assumptions similar to P4SR where the heat stress experienced by subjects under different conditions of activity was measured in relation to environmental measurements (25). The results are indicative of thermal sensations between 27 and 35°C and 30 and 80% relative humidity but not of a comfort zone (16).

4.5. Comfort in the tropics

Comfort indices and the comfort zone, having been developed through experiments and work in temperate climates or for concern with particular situations in other environments, their adequacy for in general is inherently restricted and require reconsideration when applied for tropical climates (23)(26)(27).

The people of the warmer regions, because of acclimatisation have tolerance for higher temperatures and are adjusted to high humidities (23)(14)(28)(29)(30). Because in these regions people wear clothing of lower insulation value convective heat loss is increased and in combination with air flow through clothing of loose disposition comfort is attainable at higher temperatures (31). Acclimatisation to an environment may determine neutral conditions rather than heat balance (32). Conditions of humidity defined for comfort are based on problems associated with moisture such as mould growth and does not necessarily relate directly to comfort. In tropical environments, in airy and well lighted buildings such problems may not occur (33).

The reconsideration of established indices such as the PMV have been suggested when applied in warm climates (32). Givoni proposes upper limits of up to 90% for comfort in tropical regions (14) and higher outdoor temperatures of more than 35°C for building having high thermal mass. Sharma and Ali in their study of Indian subjects suggest temperatures above 30°C for comfort, although upper limits of relative humidities are restricted to 70%. The effect of air flow on comfort is also limited by certain assumption related to the inconvenience it causes e.g. situations where it results in paper blowing about, whereas in hot climates people may be willing to put up with such inconveniences for comfort. Some studies carried out in tropical situations suggest higher values of comfort temperatures (34)(35)(36)(37)(26)

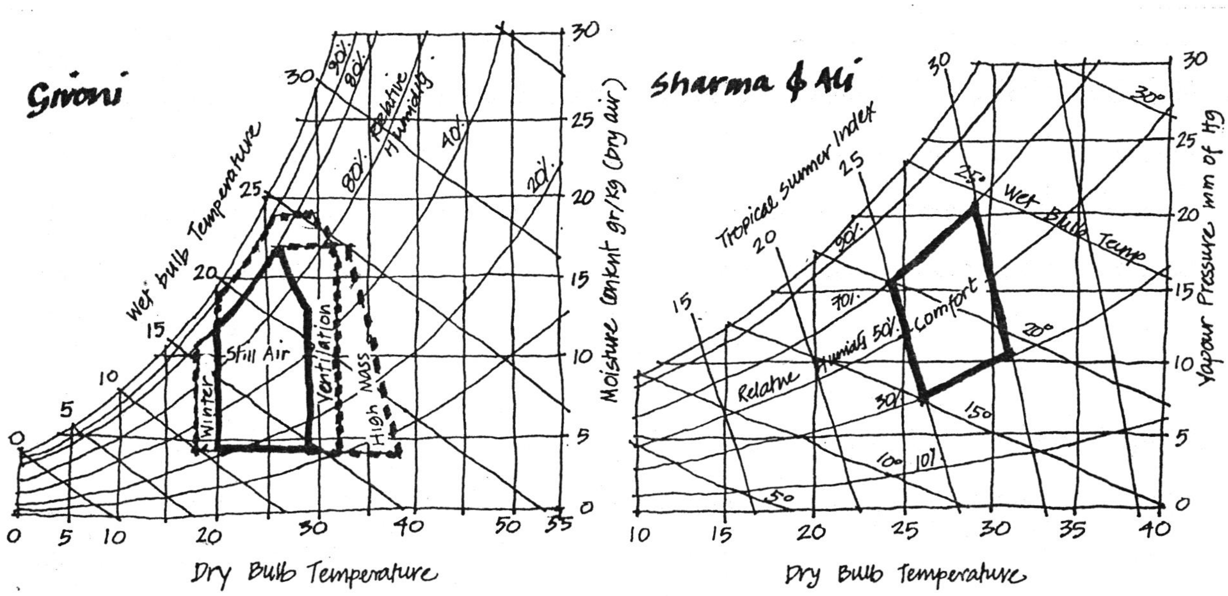


Fig 4.6 Adaptation of comfort zone in warm climates (after Givoni, Sharma and Ali)

Building design in warm and hot climates add to occupant comfort through sensitivity to the climate in their design. Cooling is brought about through the use of heavy or light construction, large openings, contact with the ground etc.

4.7. Thermal Comfort in Bangladesh: Field Investigations

People in Bangladesh experience high temperatures and humidities for most of the year and very high humidities in the rainy season. The conditions that define thermal comfort for these people vary from conventional definitions of comfort because of long term acclimatisation to such environments (17)(38)(39). It is evident that considerations for thermal comfort in warm environments has to take into account the responses to higher temperatures and the effects of building design (23)(40)(41)(14). In the case of Bangladesh it is also important to consider the effect of high humidities for the reason that people have been living under such conditions and may have adapted to its presence. There have been no studies which investigate the aspects of thermal comfort in Bangladesh which directly involved responses from subjects. Research so far considers thermal comfort as a related issue in other aspects of environmental design and draws mainly from established theories (42)(43)(44). A recent study makes some general comments on comfort in various regions of the country on the basis of evaluation of data from meteorological stations where the hot humid and the cools seasons are seen to more agreeable in terms of comfort than the hot and dry period (37).

The following sections discuss the results of a field investigation involving comfort assessments of occupants of urban housing with an aim to identify conditions for comfort and factors that contribute to it.

4.7.1. Methodology

The study subjects were mostly university students in their early twenties and some older people where the monitoring work was done by the students. Over a number of days the subjects were asked to record their comfort sensations and corresponding values of personal and environmental variables on the forms provided. Initially the forms required each assessment on a separate sheet but later this was modified to 'comfort diaries' where several assessments over a number of days were made (Appendix 1 and 2). The two assessment periods covered February-April and July- October, 1993 which includes a brief part of the cool period but mainly the hot dry and hot humid periods.

The measurements were made with digital thermometers, a digital temperature-humidity meter and a whirling thermometer. Globe temperatures were measured with blackened table tennis balls over the sensors of the digital thermometers appropriate for measuring warmth indoors in low air velocities.(45). Air velocity was measured using a rotating vane anemometer Two sets of instruments were available to the respondents which were passed on from one to the another over the whole period of measurements.

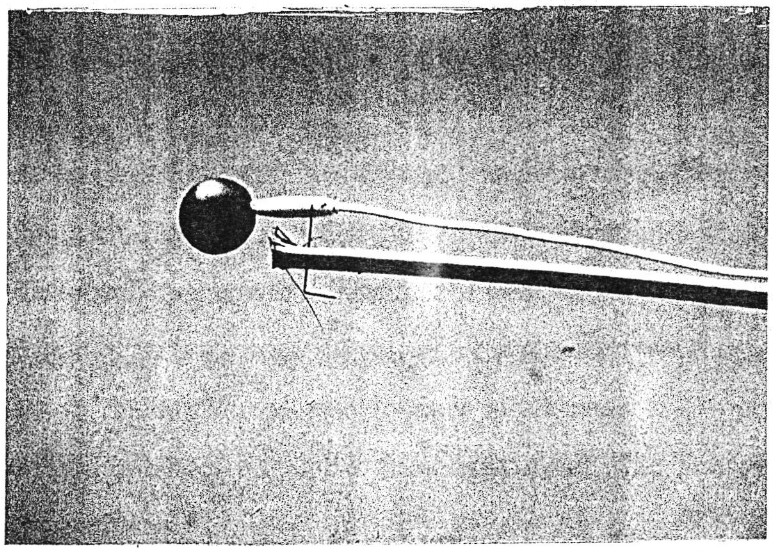


Fig 4.7. Modification of digital thermometer to measure globe temperature.

The comfort observations were recorded in the homes of people as they went about their daily activities.

4.7.2. The Thermal Sensation Scale.

Thermal sensation were recorded on the basis of a seven category scale after the Bedford and ASHRAE scales of thermal sensation (46)(47). It relates to the sensations of comfort as in the Bedford scale and borrows from the ASHRAE scale for description of the outer categories. The middle three categories accommodate the comfort range. Asymmetrical scales were not considered because of the risk of bias as indicated by Humphreys (48).

-3	-2	-1	0	1	2	3
Cold	Cool	**Comfortably Cool**	**Comfortable**	**Comfortably Warm**	Warm	Hot
		[	**COMFORT ZONE**	]		

4.7.3. Environmental Variables

The environmental variables measured are the ones typically associated with analysis of comfort namely the bioclimatic chart - **Air Temperature, Relative Humidity, Globe temperature,** and **Air movement.** Some modification were made in their recording over the two periods. Initially conditions of solar radiation were noted but it was noticed that there was no case where the subjects exposed themselves to direct solar radiation. Subsequent recordings did not include consideration for radiation.

The movement of air was not actually measured in each case. The ceiling fan being a common fixture in most houses the speed setting of the fan regulator was noted. As there is no published data about the air movement values of such fans the air velocity generated by ceiling fans in different settings was measured in a number of rooms and the results obtained were used to replace the fan speed values in the analysis (Appendix 3). Air flow from the outdoors was indicated as similar flow from a fan. The **External Temperature** was measured in some instances.

Table 4.2 Average values of air movement for fan speed settings

Fan speed setting	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Average
Slow (S)	.17	.17	.12	.14	.14	.16	**.15 m/s**
Medium(M)	.3	.29	.31	.28	.3	.32	**.3 m/s**
Fast (F)	.54	.39	.42	.5	.42	.43	**.45 m/s**

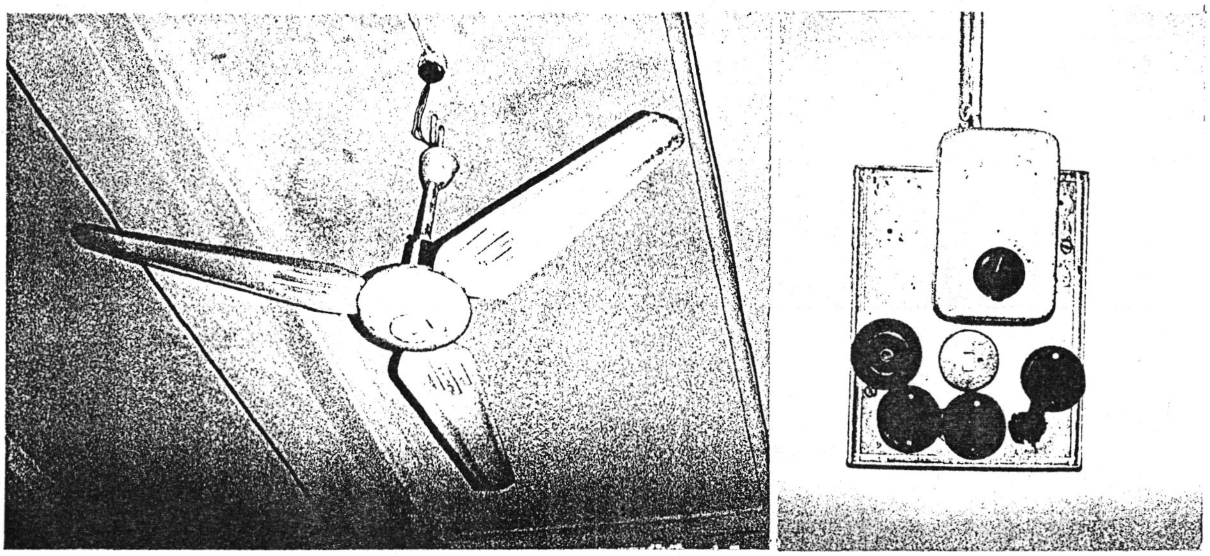


Fig 4.8. The ceiling fan and regulator

4.7.4. Personal Variables.

Clothing and activity levels were recorded as the main variables. **Clo** values corresponding to local preferences of dress and **Met** values for common domestic activities. Other details of age and, sex were recorded for reference as well as the location within the house where observations are made. In the first form the time in spent in a location of the observations was noted. In the diary the respondents were instructed to take readings only after *being in a place for at least 20 minutes.*

The range of activities and clothing of the respondents fall within a narrow range of values. All activities reported are common domestic functions and the hardest work is cooking (3 met). Clothing values are within an even smaller range, the maximum values do not exceed 0.5 clo for both sexes, for females it is almost always 0.5. For males it is as low as 0.1 but only in a few instances. The type of clothing worn promotes comfort in their styles. The traditional panjabi pyjama of the males consists of a light cotton tunic worn over loose pyjamas. The female preference of the saree is a 6 meter long fabric worn wrapped around the body but is loose in disposition and leaves areas exposed to air movement.

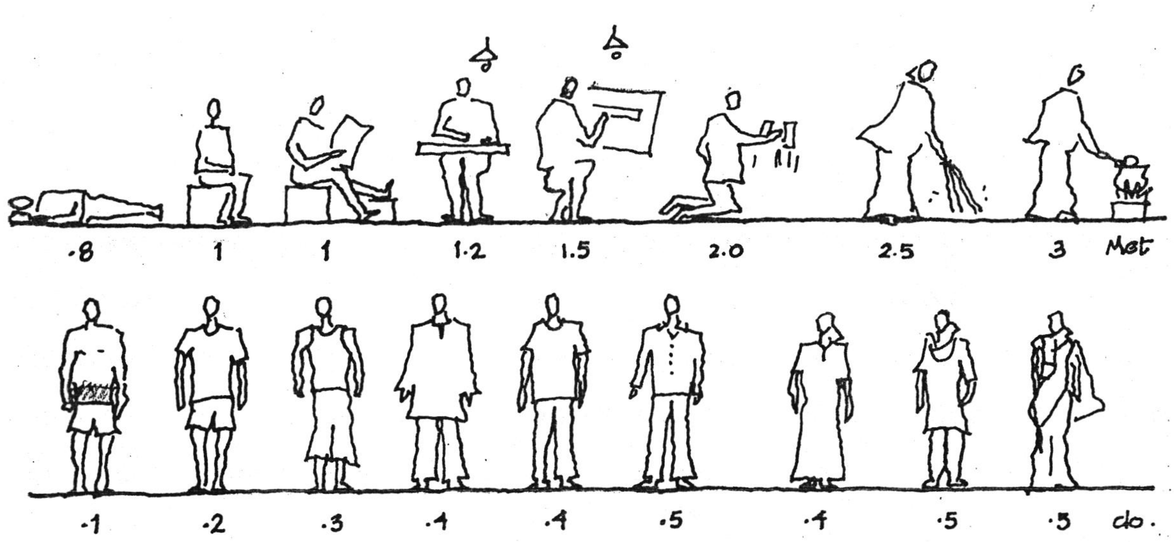


Fig 4.9. Typical domestic activity ranges and clo values.

Fig 4.10. Summer clothing

4.8. Analysis of Comfort Conditions.

The evaluation of comfort conditions are based on the analysis of relative humidity and air temperature values of the comfort votes. The three central votes, comfortably warm, comfortable and comfortably cool are used to define comfort parameters. The details of all the observations are given in Appendix 5.

4.8.1. Votes and Temperature.

The temperature range for each voting category rise with ascending votes, to a lesser extent with the warmer than the cooler ones. Although it is a seven category scale the extreme two categories were not voted for except once where the sensation was recorded as hot. The colder sensations are for larger temperature differences about neutral conditions than corresponding warmer votes.

Table 4.3. Votes and air temperature (no or slow air movement)

Vote	Average temperature in range
-2	26.4°C
-1	28.5°C
0	29.2°C
1	29.7°C
2	30.6°C

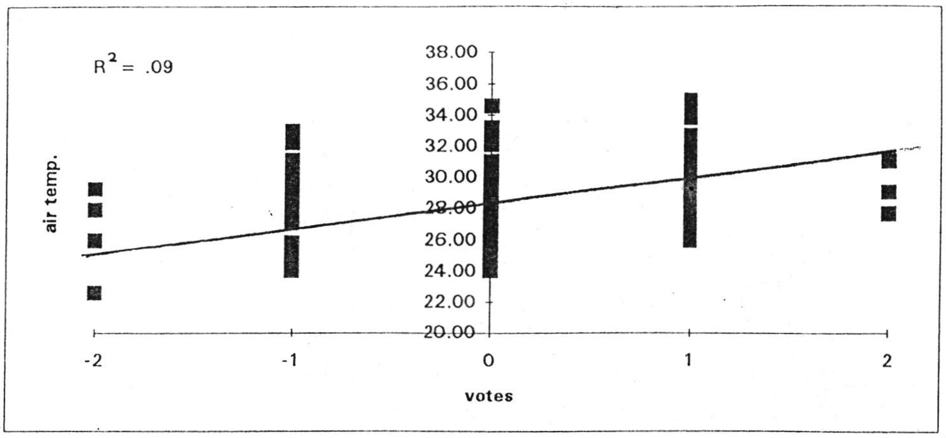


Fig 4.11. Votes and air temperature

4.8.2. Location, Activity Rate and Comfort.

Given the fact that more than 50% of the observations were made in bedrooms it was assumed that the location of observations may have some bearing on comfort conditions. Cross referring the data from other locations with exclusively that of bedrooms show that location within the house does not effect comfort conditions.

The range of activity is narrow, between 0.8 and 1.2 met for more than 75% of the situations. For the common activities there is no significant difference in comfort temperatures. For met levels higher than 1.5, of which there are not many instances, there is an increase in comfort temperatures but not consistently in all cases.

4.8.3. Comfort conditions with no air movement.

The air temperature and relative humidity conditions for the three central votes without the presence of any air movement range between 24°C and 35°C and 53.1% and 95% R.H. for all activity and clothing ranges. For people in sedentary conditions or engaged in very light work and dressed in clothes of insulation value not below 0.4 or above 0.5 clo this range narrows down between 24°C to 32°C. Within this range, sensations relating to comfortably warm start at around 27°C but temperatures describing comfortably cool and comfortable are included in the whole range.

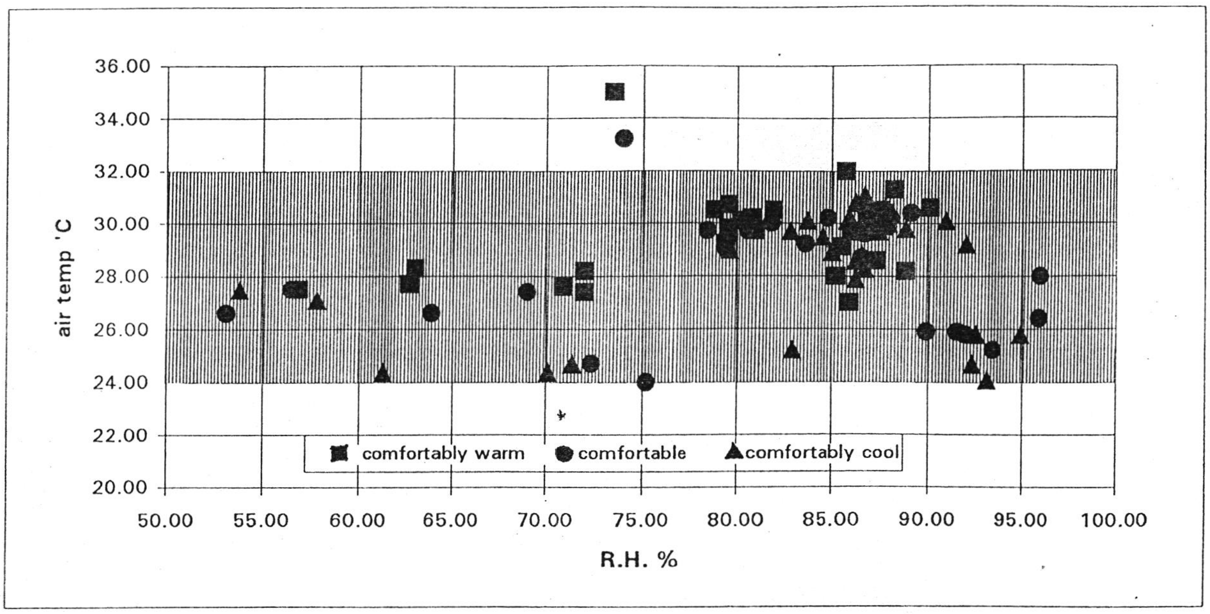


Fig 4.12. Comfortably cool, comfortable and comfortably warm with no air movement (shaded area for 0.8-1 met and 0.4/0.5 clo.)

4.8.4. Influence of Air Movement

For little air movement up to 0.15m/s generated by ceiling fans in slow settings there is no appreciable change in comfort temperatures and the mean comfort temperature increases by less than 1°C and the range of temperatures for both are close.

For air movement in the order of 0.30 m/s when ceiling fan settings are at medium, there is a rise in both the upper and lower limits of comfort temperatures by more than 2°C extending to humidity conditions above 90%. For even higher velocities of 0.45m/s in the fast setting there is an elevation in the upper and lower limits by less than 1°C. This change is mostly for humidities lower than 80%, below 65% tolerances increase by 2°C.

Table 4.4. Comfort range and mean comfort temperatures for different air speeds

Fan speed setting	Average speed	Comfort range	Mean comfort temperature
none	0	24°C - 32°C	28.9°C
slow	.15m/s	24°C - 33°C	29.5°C
medium	.3m/s	26.4°C - 35.2°C	30.9°C
fast	.45m/s	27°C - 35.8°C	31.6°C

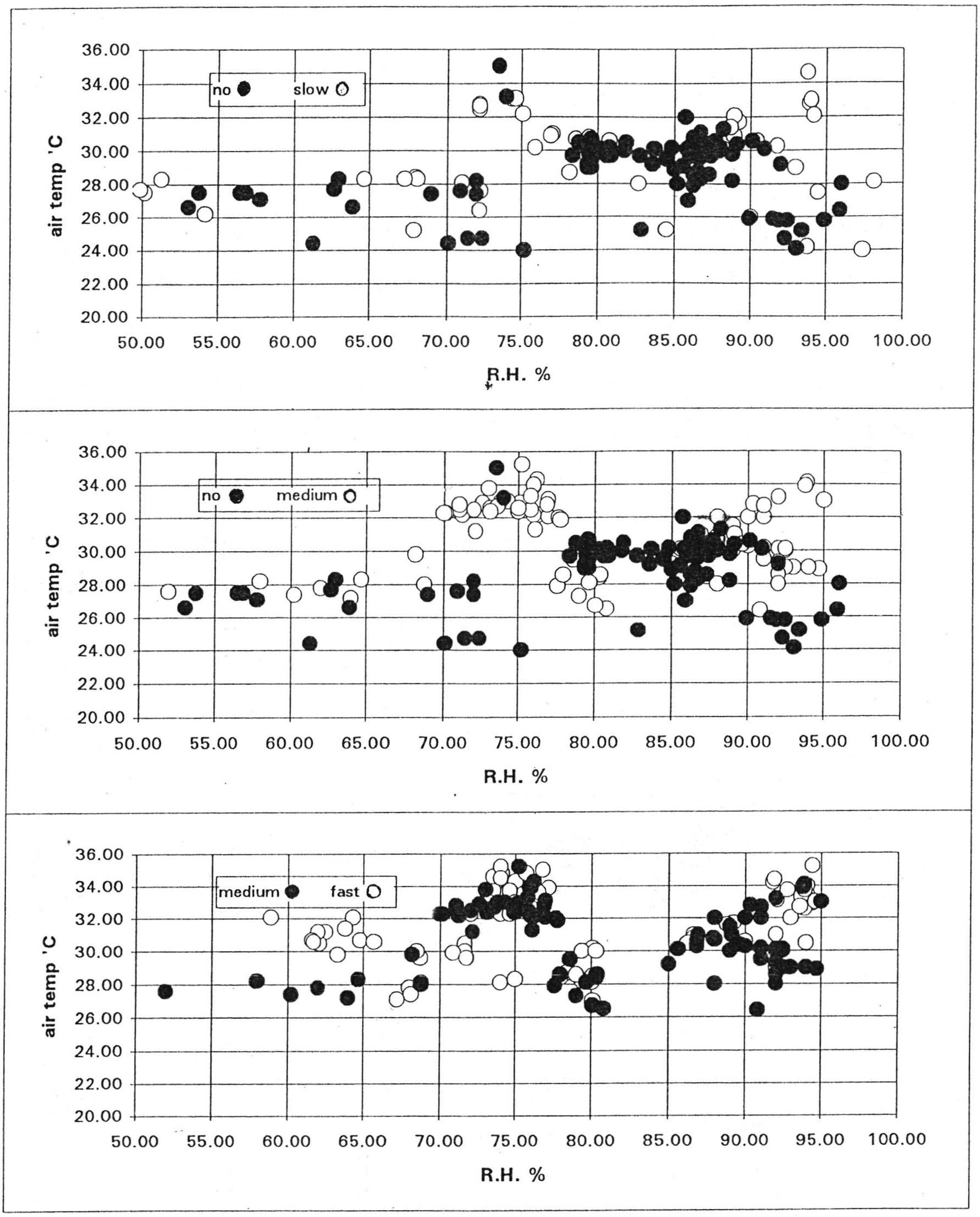


Fig 4.13. Comfort conditions and air movement (in fan speed settings)

4.8.5. Humidity and comfort

Under all conditions of the field study there is a marked tolerance for high relative humidities up to 95%. The humidity tolerance vary with air movement. For comfort in the absence of any air flow temperatures below 28°C are related to humidity conditions up to 95%, with higher temperatures the corresponding relative humidity is 90% or lower. With all conditions of air flow (including slow air movements) humidities up to 95% is tolerated and in some isolated cases humidities reach close to 98%. The effect of humidity on discomfort diminishes with air flow.

The relative humidity values correspond to absolute humidity values of between 23 to 28 g/Kg, likely to lead to wettedness of the skin (30). Relief in such condition is brought about by the style of clothing which is loose and leaves parts of the body exposed for possible evaporation with air movement.

There were very few instances of humidities below 50% in the observations and comfort (or discomfort) in low relative humidity could not be ascertained.

4.8.7. Radiant Temperature and Comfort.

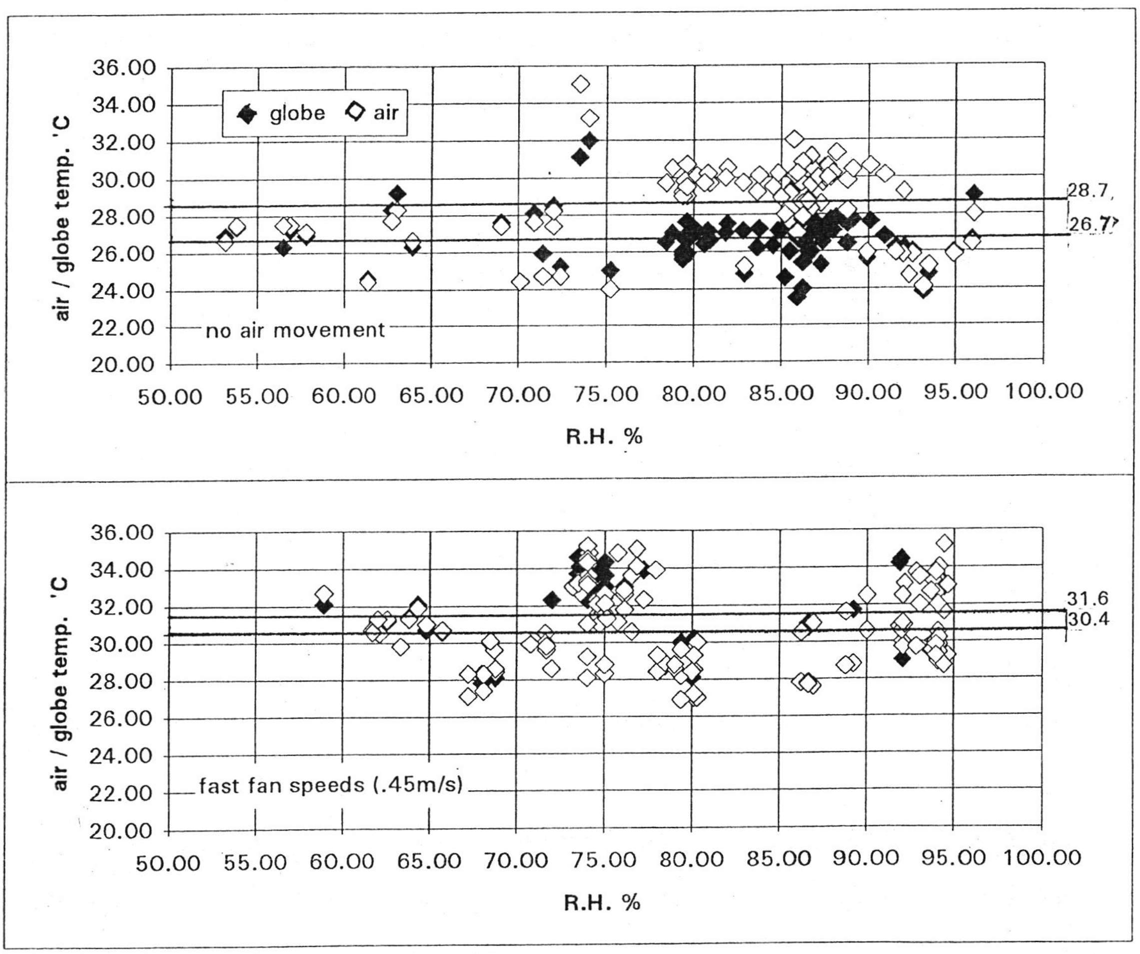


Fig 4.14. Globe and air temperatures for no air movement and .45m/s fan speeds.

As a general trend in all situations of the field study the globe temperature was lower than the air temperature. This is likely due to design aspects, as walls in most houses are of masonry and the floors concrete slabs with smooth finishes which accounts for low mean radiant temperatures, this is probably more so in ground floors where there is the additional cooling effect due to earth contact and in upper floors where the roof slab is not exposed to radiation from the sun.

For no air movement globe temperatures are noticeably lower than the corresponding air temperature, the differences diminish with increased air flow when the circulating air results in higher globe temperatures.

4.9. Radiant Temperature as a descriptor of Comfort

Regression analysis using comfort votes as a dependent variable against the environmental variables, individually and in combination yielded the best relationship with globe temperature. No significant increase in the value of R^2 could be obtained for combinations of variables.

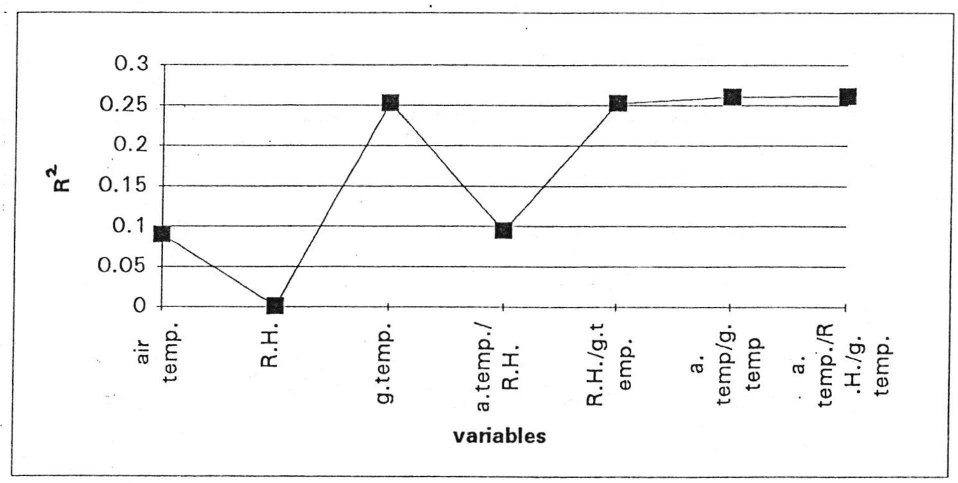


Fig 4.15. Values of R^2 for comfort votes regressed with environmental variables.

For globe temperatures 25% of the variations could be explained (R^2=.25). Whereas R^2 in regression analysis explains the proportion of variations the acceptability of a lower value in this case can be explained by the nature of the two variables. Comfort votes are whole numbers (....-1, 0 1, 2 ...) and globe temperatures for these vary in a straight line parallel to the x axis and the extreme values are far apart resulting in a smaller value of R^2.

Using the formula for the regression line

$C.V. = T_g \times .18 - 5.11$, where

C.V. is the comfort vote and Tg is globe temperature.

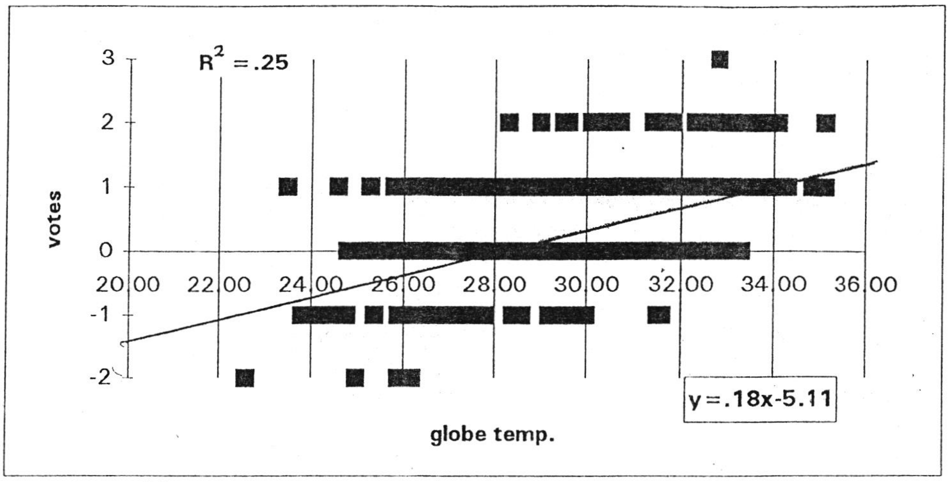


Fig 4.16. Scatter diagram for globe temperatures

Using the equation to calculate the votes from values of globe temperature and comparing them with the measured votes (by rounding up fractions to the nearest whole number) 41% of the total range of votes corresponded with calculated values. The level of accuracy. increases to 60% when only the neutral votes (0) are compared.

The estimations of globe temperature values for all the three central votes show a close relationship with measured values for all conditions of air movement.

Table 4.5 . Calculated values of globe temperatures

Vote	Corresponding value of Tg
-1	22.8°C
0	28.3°C
1	33.9°C

Narrowing down the relationship between globe temperature and comfort for still air conditions the equation of the regression line is given by

$C.V. = T_g x .29 - 8$

Range of temperatures that describe comfort conditions by this formula is a close enough description of measured data to be acceptable (24.1-31°C). Globe and air temperature when regressed for conditions of no air movement also shows a good relationship (R^2=.42). A multiplication factor of 1.04 for the globe temperature gives the corresponding air temperature (given by slope of the regression line where the intercept is the origin) establishes the relationship between air and globe temperatures where the lower and upper limits of comfort air temperatures are only slightly higher than suggested by the observed conditions.

Table 4.6. Calculated values of globe and corresponding air temperatures for no air movement

Vote	Corresponding value of T_g	Corresponding value of T_a (T_g *1.04)
-1	24.1°C	25.06°C
0	27.5°C	28.6°C
1	31°C	32.24°C

4.10. Conclusions : Comfort in the context of urban housing

Air temperatures for comfort with no air movement and for people wearing normal summer clothing, engaged in normal household activity indoors are within the range of 24 and 32°C, for relative humidities between 50 and 95%. Clothing styles and preferences contribute to comfort. The type of clothing favoured by both men and women are light and loose in disposition, thereby promoting comfort by allowing air flow in parts of the body not exposed.

During the winter months particularly at daytime there is no significant change in clo value. During the night and on particularly cold days the clo value may go up to 1 and the subsequent comfort temperature lowered by 2°C. This situation is more valid for the colder northern parts and makes less difference in the coastal areas.

In the absence of air flow people feel comfortable even in high humidities. In a location where humidity is generally high for most of the year this is an expected response. This tolerance to high humidities is lower in still air conditions. With air flow relative humidities up to 95% is tolerated. The skin wettedness which results from high moisture content of the air is a condition people are adapted to and clothing styles lessens its impact on comfort.

The response at lower humidities is not sufficiently clear because during the course of the observations the relative humidity was rarely below 50%. Other studies, namely the bioclimatic chart would suggest comfort at even 30%. If acclimatisation explains the tolerance of high relative humidities it is possible that people not used to low humidities, as is the case in Bangladesh, may feel uncomfortable should such a situation occur.

Radiant temperature, because of construction and shading is usually lower than the air temperature indoors as well as outdoors. This has a bearing on comfort and may be the reason why people feel comfortable when air temperature readings are high, particularly in still conditions. The type of housing construction favoured in urban areas contribute to comfort because of the use of relatively heavy construction because of the popularity of brick masonry. Other factors that contribute to low radiant temperatures is contact with the ground and shading, and at personal level direct contact with cold surfaces such as when walking barefoot at home. Of all other environmental variables radiant temperatures is the best indicator of comfort.

Little or slow air movement up to .15m/s makes very little difference to comfort temperatures. The mean comfort temperature for this range is **28.9°C**. For higher velocities of .3m/s and up to .45m/s the upper and lower limits of comfort temperatures increase between 2-3°C and mean comfort temperature increases to **31.2°C.** For a general situation which has the potential use of a fan or exposure to comparable air flow the average comfort temperature can be said to be **30.1°C.** The comfort temperature is probably higher for higher air velocities. Depending on the distribution pattern of air flow generated by the ceiling fan a person may choose a location where the air velocity is appropriate to his or her subjective needs. In terms of ceiling fan usage it can be said that unless the setting is medium or fast its use at lower speeds does not contribute significantly towards improving conditions.

The fact that people feel comfortable at the temperature and humidity conditions described does not necessarily mean that they are preferred. They are a result of long term exposure to such conditions and are tolerable. There is probably a difference between tolerated conditions and aspired conditions and if air conditioned buildings are a measure of it cooler temperatures are aspired for.

The study is limited in scope to the occupants of urban housing only. People who enjoy and are aware of the benefits of devices that promote comfort such as the ceiling fan. For the rural poor who are not aware of, or experienced to such conditions the tolerance levels may be higher.

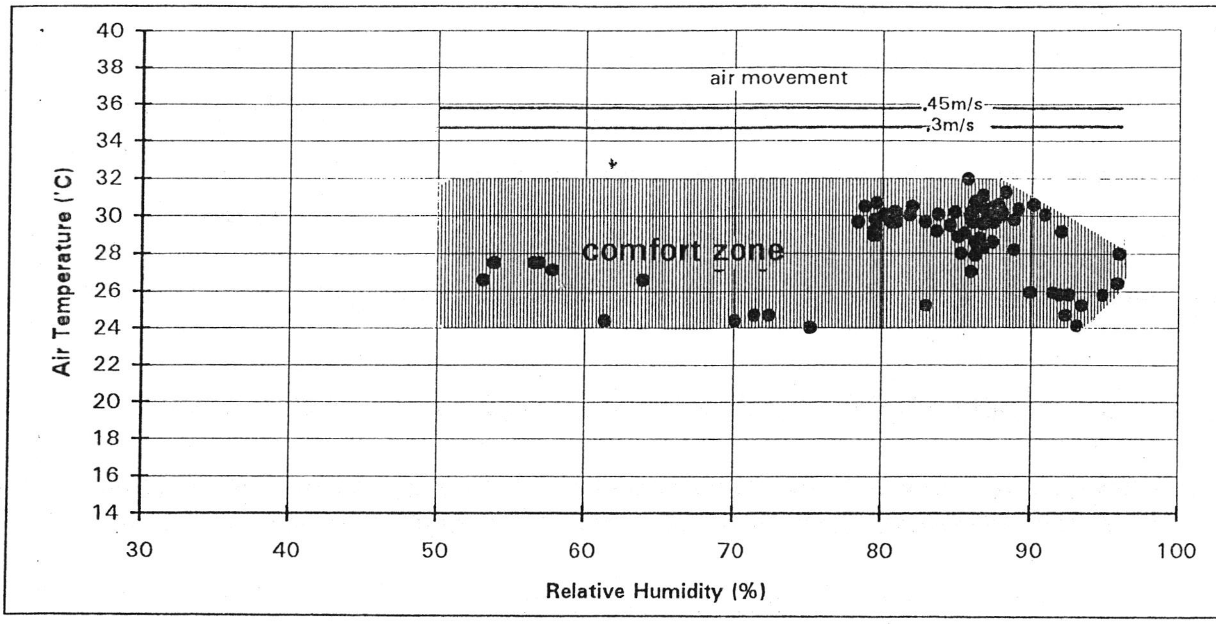


Fig 4.17. Summer comfort zone for Bangladesh

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CHAPTER FIVE

Thermal Performance of Urban Housing

5. THERMAL PERFORMANCE OF URBAN HOUSING

5.1. Introduction

The following sections analyse the observations on occupant comfort and thermal behaviour of ten different case study houses in Dhaka. Their design descriptions (Appendix 7). represent the commonly occurring typologies of urban houses. A survey of the occupants opinions regarding their own of comfort in these houses identifies possible design features that contribute to comfort (or discomfort) and the conditions that promote it. The measured thermal data provides the basis for an empirical evaluation of comfort and the factors that contribute to thermal behaviour. The comparative analysis between the cases have reference to the common design features. The thermal conditions in the houses are affected by internal heat gains the effect of which are evaluated for three of the examples. The indoor conditions are measured and compared with simultaneously occurring outdoor conditions. The outdoor measurements provide the context of the site as a contributor to indoor thermal behaviour and offer the potential of comparison between different sites. The design parameters considered for the simulations studies in the following chapter are based on the analysis here.

5.2. Design characteristics of urban housing.

The thermal behaviour of a building and the corresponding indoor comfort performance depends on a multitude of factors. Construction, orientation, geometry, materials, colour, landscaping etc. are some of the features a designer can manipulate to create a desirable internal environment (1)(2)(3)(4)(5) within a given climatic context.

The building envelope, its design and the materials with which it is constructed have a direct bearing on the internal thermal environment. In Bangladesh common construction typologies of urban housing do not employ a very wide range of materials (see chapter 2) and certain combinations for the main elements of the building fabric are more common then others (table 5.1).

Table 5.1. Combinations of materials in common typologies of urban housing.

Wall	Floor	Roof*	Ceiling	Occurrence
125mm brick plastered/unplastered	floor finish over concrete slab earth	concrete		common
		C.I. sheet	bamboo mat board	single storey only
250mm brick plastered/unplastered/ cladded	floor finish over concrete slab	concrete	none	common
		hollow block		uncommon
375 mm brick plastered/unplastered/ cladded	floor finish over concrete slab	concrete	none	common
		hollow block		uncommon
500 mm brick plastered/unplastered	floor finish over concrete slab	concrete	none	common (old structures)
		hollow block		uncommon
C.I. sheet	floor finish over brick soling earth	C.I. sheet	bamboo mat board	common single storey only
bamboo mat	mud	C.I. sheet	bamboo mat	single storey informal housing

* *some roofs have an insulation layer of 75mm lime concrete over the concrete slab*

At the level of building, the designer is able to manipulate design variables in order to achieve the environmental criteria which promote thermal comfort indoors (6)(7). Starting at the design of the landscape in the immediate environs of the building the control over design elements and the extent of their manipulation extend to the fenestration, orientation, design and location of openings, in the exterior of a building (8)(9)(10). Thickness of building components specially brick walls vary and some buildings have more mass resulting in differences of thermal behaviour.

5.3. Design references of case studies.

The case studies are selected considering the common typologies as described. Other than the building itself the choices consider the characteristics of the site in which they are located. The possible effects on thermal behaviour are considered as functions of the following aspects of design:

-Site
-Orientation
-Exposure
-Construction

5.3.1. Site

The site represents the existing immediate environment of the building over which control through design is limited. It is the smaller context within the greater context of the urban environment (11). The closeness of the surrounding buildings, their relative heights, materials, the nature of surface cover and the location of trees and other physical attributes influence site behaviour and consequently the internal environment.(12)(13). The sites in the case studies can be classified into three types:

Dense: These are locations where buildings are very close to each other, the distance between them being less than their heights and the ground cover is mostly paved with few trees. within dense sites there are three types in terms of geometrical profile, buildings of similar height as that of the case study, of lower height and taller buildings (explained in greater detail in section 5.16.1.)

Moderate: In these the buildings are spaced apart at distances which are between the height and twice the height of the building. The ground cover is a mixture of paving and earth. Some are government residential colonies, where buildings are spaced at regular intervals.

Open: This term has been used in a relative sense. Sites where there are no buildings within close proximity of the reference building are in this category. Buildings laid out on more or less open ground with little paving are included in this group and top floor housing in moderate sites are considered as being relatively open.

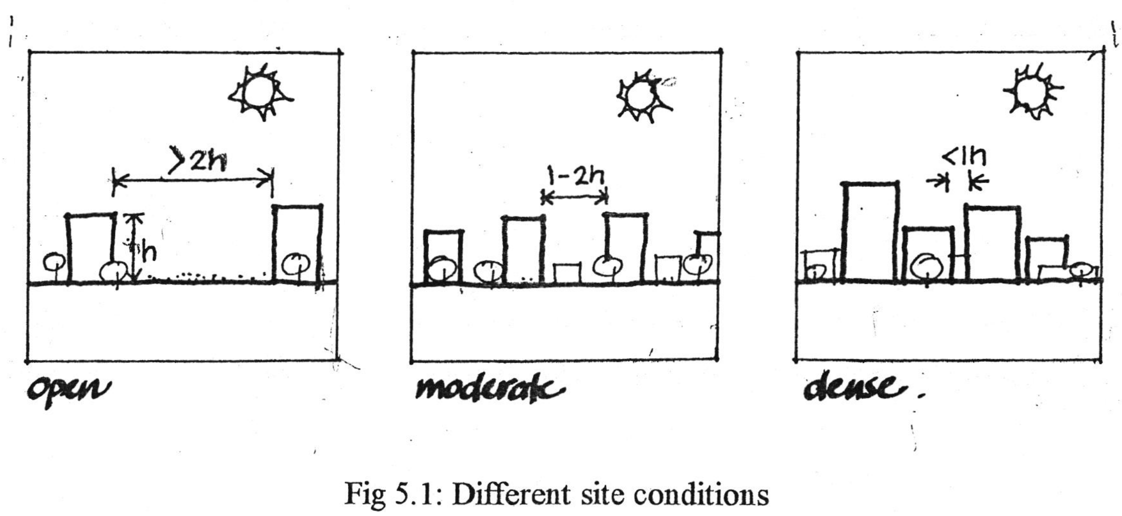

Fig 5.1: Different site conditions

5.3.2. Orientation

Orientation of the houses were considered as a factor which influence internal conditions. In cases of dense sites the direct effect of orientation is not so apparent. The primary orientation consideration is that of the window wall.

5.3.3. Exposure

In the urban situation, especially with flat buildings the exposure of a house is considered as an aspect of influence on thermal behaviour. Top floors are exposed to radiation through the roof whereas intermediate floors have the insulation effect provided by other floors and ground floors are subject to heat exchanges with the earth. Ground floors have more shading from surrounding structures and trees.

5.3.4. Construction (materials and thermal mass)

The construction of the houses refer to the thermal mass of the structure. The materials employed and the thickness of walls and slabs determine the thermal inertia of the structure. The response rate of high mass buildings to heat is slow as compared to lighter construction. The temperature swing inside a high mass building is also less (14)(15)(16). Older urban housing often made the use of heavy masonry construction with high ceilings while in the recent examples the trend is towards lighter construction. The case studies are categorised into three types in terms of construction typology, mainly in terms of wall construction. Heavy, medium and light construction, all use brick masonry of different thicknesses[1].

5.4. The case studies

The final choice of the case studies had to consider the practical problem of availability of the houses for the detailed measurements and observations and the co-operation of the occupants. 10 examples were selected from 23 possibilities in the intial search (Appendix 5), detailed descriptions of which are given in table 5.2.

1. Light construction is meant in a relative sense, being buildings with wall thickness comparatively less than the other two categories. A light building here is heavier than what is conventionally understood as light in other literature.

Case ref:	Room	Building	Site density	Orientations		Construction		Shading
				wall	window	walls	roof / ceiling	
1	2nd floor bedroom	3 storied office/residence	open	south	south	250 mm brick exposed exterior	150 mm r.c.c. +75mm lime	verandah
2	gr. floor bedroom	1 storied residence	dense	north	north	125 mm brick plastered	corrugated iron/bamboo mat	overhang
3	1st floor bedroom	2 storied residential flats	dense (low structures)	south	south	125 mm brick plastered	150 mm r.c.c exposed	overhang
4	2nd floor bedroom	5 storied residential flats	moderate	east north	east north	125 mm brick plastered	150 mm r.c.c. floor above	overhang
5	1st floor bedroom	2 storied residential flats	dense	south	south	125 mmbrick plastered	150 mm r.c.c. exposed	verandah
6	2nd floor bedroom	4 storied residential flats	moderate	south west	south	125 mm brick exposed exterior	125 mm r.c.c floor above	overhang
7	gr. floor bedroom	4 storied residential flats	moderate	west south (partial)	west	375 mm brick plastered	150 mm r.c.c. floor above	none
8	gr. floor bedroom	4 storied residential flats	moderate	south east (partial)	south	375 mm brick plastered	150 mm r.c.c floor above	none
9	5th floor bedroom	6 storied residential flats	moderate	south	south	125 mm brick plastered	150 mm r.c.c + 75 mm lime	overhang
10	gr. floor bedroom	5 storied residential flats	moderate	south east	south east	250 mm brick plastered	115 mm r.c.c floor above	overhang

Table 5.2. Description of case studies

5.5. Occupant survey

3 occupants from each of the 10 case studies were asked to give their opinions about how comfortable they were in their houses at different times of the year. The objective was not to quantify comfort but to identify conditions which contributed to it.

5.5.1 The Questionnaire

The occupant responses are gathered through a distributed questionnaire (occupant survey in appendix 6). The occupant's age and sex and the basic occupancy pattern in a typical workday is considered. They were asked to record subjective evaluations of their sense of comfort during the day and at night for the three seasons in the year, the hot dry period from March to June, the hot humid period from July to early October and the cool period from October to February. The hot humid period, by other definitions starts in June which here is included in the hot dry period. This is because **(a)** in reality parts of June is hot and dry and **(b)** the June prior to this survey was unusually dry and the respondents remember it as that. The times defined are meant only to act as guidelines as the people recognise the seasons from experience rather then specific months.

Table 5.3: Temperature and humidity conditions for Dhaka specific to the seasons in the questionnaire. (after data from met office)

	mean temperature / swing	humidity range
Hot dry period	28.3°C / 10°C	60% - 80%
Hot humid period	28.3°C / 5.6°C	85% - 90 %
Cool period	20.7°C / 12.7°C	70% - 80 %

The comfort scale used in the questionnaire is a variation of the one used in the comfort assessments in chapter 4 of seven ranges of thermal sensation. Instead of ranging from -3 to 3 the range here varies on a scale of 1 to 9 with written annotations. This modification was a result of some people finding it difficult to relate to negative values.

The year round pattern of use of the ceiling fan, a common feature of urban houses, was included in the questionnaire as an indicator of air flow preferences. Other factors that contribute to comfort (or discomfort) were discussed with some occupants and are based on observations.

To get a broader understanding of the nature of comfort experiences of the respondents, they were asked to comment on their observations in situations other than their present one. This was to extend the scope of the survey and to get an understanding of what the respondents thought were important to improve or aggravate comfort.

5.5.2. Observations

Table 5.4.. Summary of comfort responses.

house ref	occupant age/sex	hot dry period		hot humid period		cool period		ceiling fan operation
		day	night	day	night	day	night	
1	52 m	H	W	W	C	C	C	except cool period
	46 f	H	W	W	C	C	C	except cool period
	23 m	H	W	W	C	C	C	except cool period
2	52 m	W	C	C	C	C	Cl	except cool period
	46 f	H	W	C	Cl	Cl	Cl	except cool period
	19 f	H	C	Cl	Cl	Cd	Cd	except cool period
3	52 m	W	W	C	C	C	C	always
	80 m	W	W	C	C	C	Cl	except cool period
	47 f	H	W	W	C	C	C	except cool period
4	25 m	C	W	C	C	Cl	Cd	always
	48 f	C	W	C	C	Cl	C	always
	21 f	C	W	C	C	Cl	Cd	always
5	50 m	H	W	W	W	Cl	Cd	except cool period
	23 f	H	H	W	W	Cl	Cd	except cool period
	20 m	W	W	C	C	Cl	Cd	except cool period
6	26 m	W	C	H	W	C	Cd	except cool period
	19 f	H	W	W	C	Cl	Cd	except cool period
	43 f	H	W	W	C	C	Cd	always
7	23 m	W	W	W	W	C	C	except cool period
	28 f	H	H	W	W	C	Cl	except cool period
	56 f	H	H	H	H	Cl	Cl	except cool period
8	21 m	W	C	C	C	C	Cl	except cool period
	45 f	C	C	C	C	C	Cl	except cool period
	51 m	C	Cl	C	Cl	C	Cl	except cool period
9	17 m	W	W	C	Cl	Cl	Cl	except cool period
	18 f	W	W	W	C	C	C	except cool period
	38 f	C	W	W	W	C	Cl	except cool period
10	57 m	W	W	W	C	C	C	except cool period
	42 f	W	W	C	C	C	Cl	except cool period
	24 f	W	W	C	C	C	Cl	always

Key: H-*hot*, W-*warm*, C-*comfortable*, Cl-*cool*, Cd-*cold*

Comfort in the seasons

In the hot dry period a majority of the occupants of the houses either feel warm or hot, although some feel comfortable at times none of the houses are reported to be comfortable at all times. In the hot humid period sensations vary mostly between comfortable and warm in most cases, the former usually at night. Some people report feeling cool at times. In the cool period almost all the houses are agreeable to live in. During the day most respondents felt comfortable or cool in their houses and even cold in some cases. At night the houses are mostly cold or cool but for sleeping people use blankets or quilts and are able to be comfortable. For the whole year the occupants are generally more comfortable in the hot humid period and uncomfortable in the hot dry period.

In the hot dry period the people reported comfortable conditions almost equally for both day and night-time occupancy. In the hot humid period people feel more comfortable at night. In the cool period the instances of daytime comfortable occupancy was double than that at night.

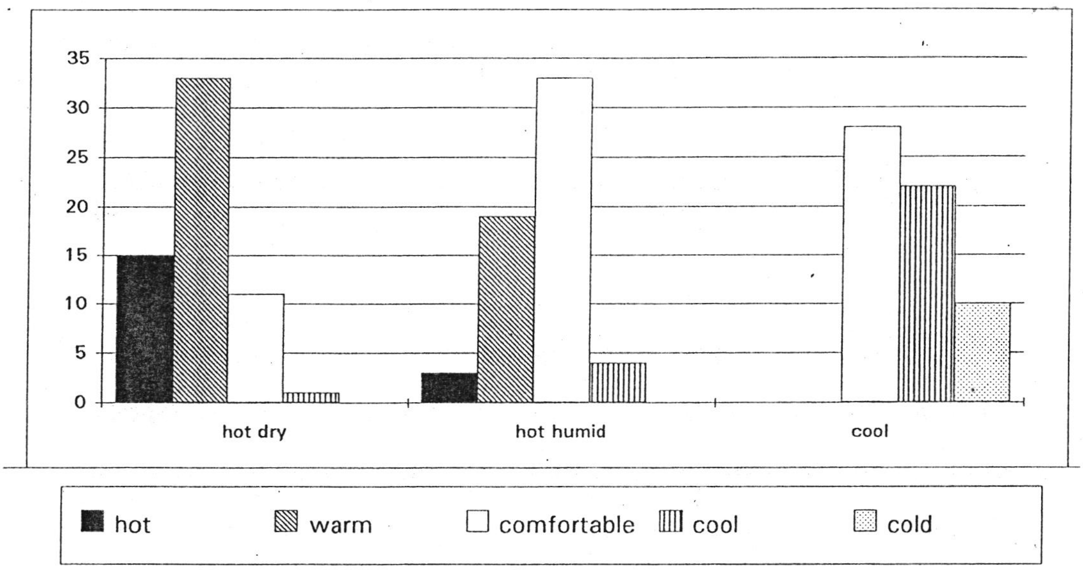

Fig 5.2. Comfort responses in the three seasons (60 responses per season)

Air movement and comfort

Air flow for comfort is provided by the ceiling fan, a common element in all houses. Its use is maximum in the hotter periods and in few cases, all year. Although the people identify air flow as an important contributor to comfort, the scope of air flow through windows is restricted by two factors. The fact that all windows have security grilles and in lower floors they are kept closed for privacy and security. Spot measurements of air velocity in some rooms yielded very low values even when it was high outdoors.

Exposure and comfort

Notwithstanding the problem of reduced air flow because of closed windows people in ground and intermediate floors are generally better off than top floors. In the top floor condition are usually warmer except for flats in the relatively taller buildings where air flow is unobstructed and is able to provide relief. Ground floors, however, have the problem of dampness.

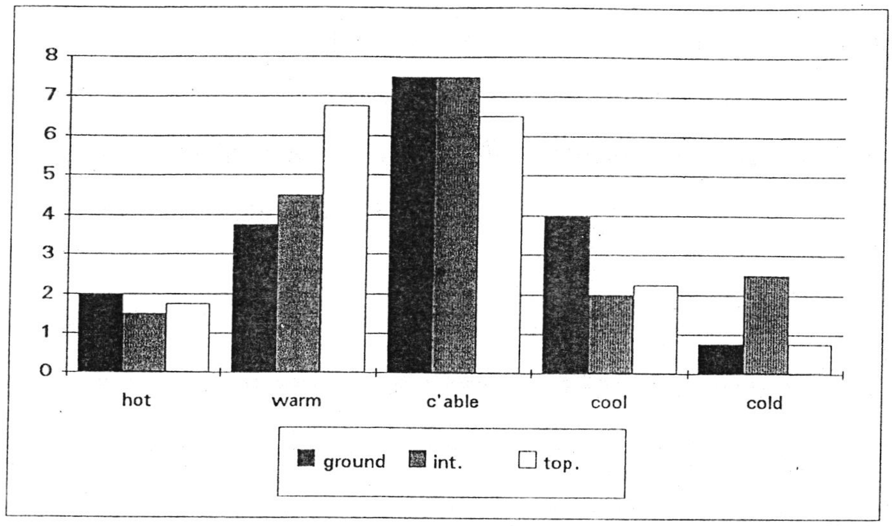

Fig 5.3: Comfort responses and floor location (averaged to 18 responses per type)

Building construction and comfort

The responses vary with the construction type of the houses in the survey. The range in sensations include all (from cold to hot) in the light and medium structures. In the lighter structures the occupants tend to feel warmer in general.. There are no instances of people feeling cold in the houses with heavier construction. The instances of people feeling comfortable is most in the heavier and medium constructions and less in lighter construction.

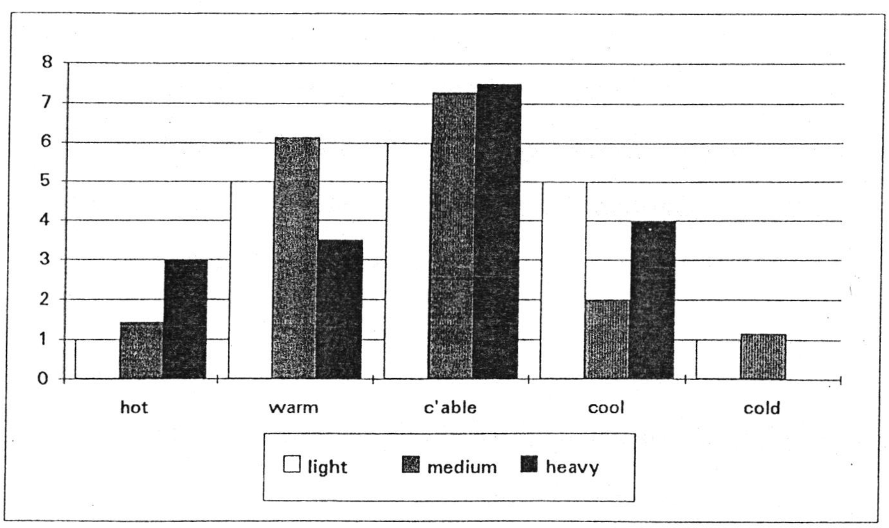

Fig 5.4. Comfort response and construction type (averaged to 18 responses per type)

Orientation and comfort

The two houses with heavier walls in the survey have different orientations and although both are in similar settings the comfort responses vary. West orientation receives solar radiation from the sun when outdoor air temperature is high. The responses of the occupants of the west facing house reported being warmer whereas the occupants of the south oriented house had little to complain. The occupants of a house facing east found their houses to be generally cooler at all times.

Site and comfort

Houses in dense sites are uncomfortable more often than the ones in open sites except where the house in question could benefit from the shade of surrounding structures or trees. The nature of the immediate surrounding also has a bearing on the comfort situation. Hard surfaces pavements as opposed to grass and open ground. In response to the question on preferred attributes of the house the occupants identify shading of the site by trees as an important criteria.

Comfort in the cool period

Being a hot climate the conditions in the cool season are often underemphasised. According to the survey, conditions in this season at times can be uncomfortable and experiences can extend to feeling cold. Some houses are reported to be cold at night or even during the day, while others are more close to the comfort range.

Internal heat

Unlike traditional houses most modern houses have the kitchen as an integral part of the internal layout. Although the use of heat generating domestic equipment is not a common occurrence, the cooking process is elaborate and heat generating. The kitchen is a source of internal heat gain and in some cases appreciably so.

Experience and preferences

The respondents were of different ages. Students in their early twenties, older head of the household, the housewife and in some cases older relatives. The younger respondents tended to be more at ease with their living environment nor did they have much experience of other situations. Some older respondents identified preferable situations from experience such as more open sites, the presence of air flow, the shading provided by trees, higher ceiling heights, ground floors, larger windows and a better sense of security vis a vis the scope for opening them. One respondent felt rural houses with thick mud walls were more comfortable even without a ceiling fan.

5.5.3. Summary of survey findings

The house is a modifier of the external environment by virtue of its design some aspects of which contribute to comfort. It is evident, from the results of the survey and also from common knowledge that some houses are more comfortable than other because of differences in design features. No single feature acts in isolation as an influence on indoor conditions, they are a result of combinations where some may have more influence than others. Inspite of high humidities, the hot humid period is when people are most comfortable. Through long term experience of their own homes and observations of other situations the occupants have their own perceptions of design and environmental features that will contribute to comfort.

5.6. Occupant behaviour, occupancy patterns and comfort.

Apart from occupancy patterns as described by the occupants in the survey the general conditions of occupancy and space use in urban houses is an important consideration for the evaluation of comfort. The patterns described here also consider general aspects other than those from the survey findings (24).

Given the domestic habits of families, the house is rarely unoccupied at any time of the daily cycle. It is only in the recent past that urban women have been involved in gainful employment, the older generation of women stay at home. Domestic help for household tasks is common. Family and household are not always synonymous in Bangladesh and there is the odd relative or guest in the house, sometimes permanently. The bedroom is a commonly occupied space in the house and its functions include activities other than only sleeping. It is important for the house to be comfortable at all times particularly from late afternoons throughout the night when most of the household is at home.

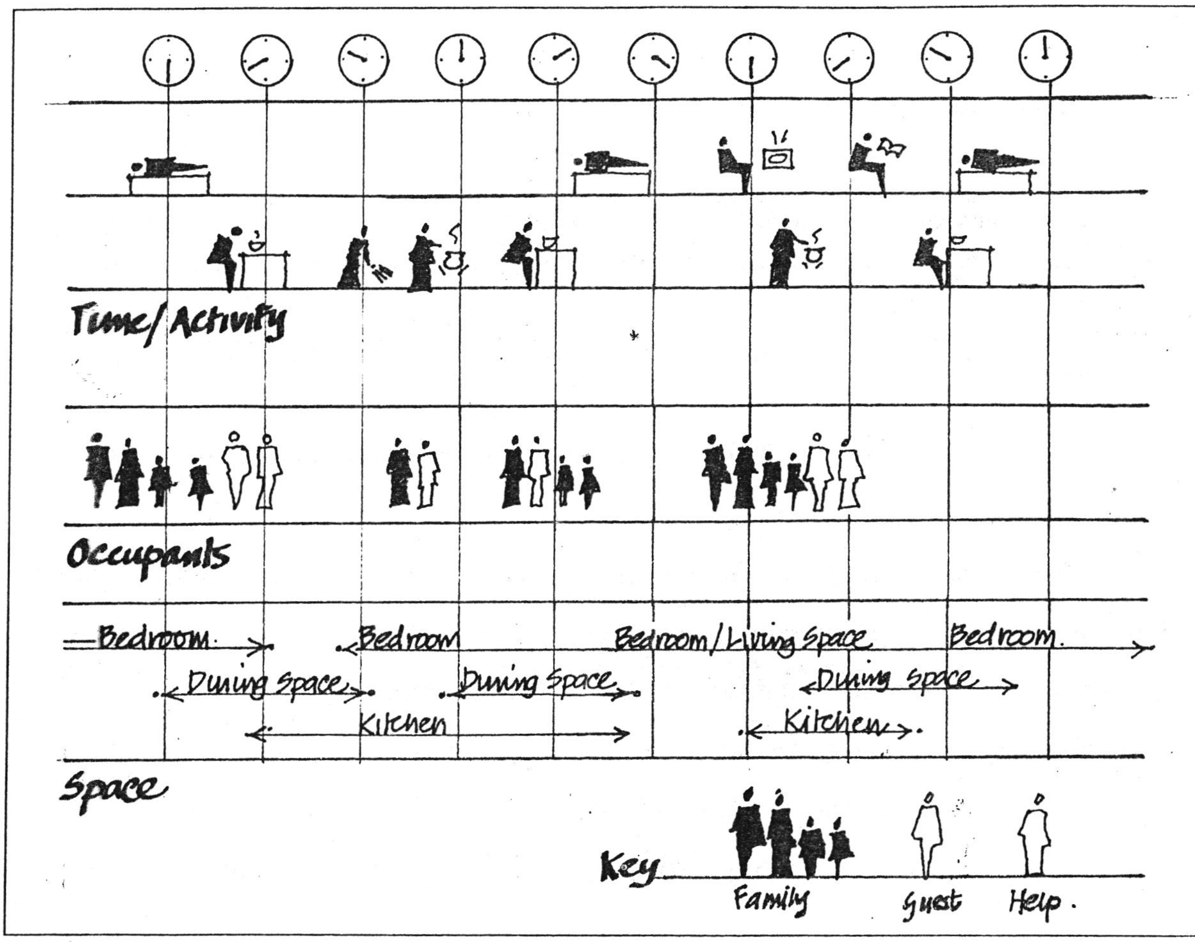

Fig 5.5: Typical occupancy patterns and space use

5.7. Thermal data of the case studies: measurement periods

Temperature measurements were made in the ten buildings in three different periods of the year, the hot humid (in September), the cool (in January) and the hot dry period (in April). Each observation period covered a twenty four hour cycle with the main readings at three hourly intervals. The day in April is representative of a hot day when temperatures are high and the swing large, the day in September is a typical day of the hot humid period, the average temperature for that period is slightly higher than the average for the season but the swing is typical, in January it is representative of a cold day in the cool period. Table 5.5. compares temperatures of these three days with seasonal values.

The hot humid and the hot dry period together cover more than nine months of the year of which the hot humid period lasts six. The cool period barely covers three months. Together the measurements are able to provide a yearly profile of the performance of each case. (Appendix 7)

Table 5.5. Meteorological data for the test days compared with seasonal data.

Days	**Average Temperature**	**Swing**	**Seasonal Average**	**Seasonal Swing**
April, 09 (hot and dry)	31.9°C	9.4°C	28.1°C	10.3°C
September. 07 (hot and humid)	29.8°C	5.7°C	28.3°C	5.6°C
January, 18 (cool)	16.9°C	14°C	20.7°C	12.7°C

All the observations were made on the same days to allow comparison.

The observations is each case measured both interior and exterior site temperatures, using digital max min thermometers. Spot readings of humidity were made but do not always correspond with temperature readings. Spot measurements of air velocity were made both in the interior and exterior. Field notes refer to materials, ground surface qualities, building features of particular importance and the behavioural characteristics of the occupants, particularly adjustments made to improve comfort.

5.8. Analysis of thermal data.

The thermal behaviour of each case is analysed on the observations of two aspects

1. The daily indoor temperature patterns as it compares with outdoor conditions in the three periods of the year
2. The yearly fluctuation of temperature.

The analysis primarily attempts to answer the question "*How do the houses feel to live in?*" through considerations of the following points

1. Times of the day when the house is warm or cool and how it relates to the sensation of comfort and with occupancy patterns.
2. Relationship with the exterior. How the exterior compares with the interiors, better or worse and at what times.

3. Consistency of conditions indoors or whether thermal sensations vary over time i.e. the temperature swing
4. The changes in indoor temperatures in the seasons; changes in comfort conditions in the house over the whole year.

The comfort assessments are based on the findings in Chapter 4 and relate to comfort in no or slow air movement for people engaged in sedentary activity and wearing normal summer clothing and corresponds to an air temperature range between 24 - 32°C. Assessment of winter comfort does not consider heavier clothing as this is not a consistent behavioural aspect. The fact that people are able to improve conditions of comfort by adjustments to clothing is noted. A summary of indoor and outdoor conditions in terms of temperatures and comfort conditions are given in tables 5.6 and 5.7. (detailed graphs for each case is given in appendix 7)

5.9. Patterns of thermal behaviour

Daily pattern

Most of the house were cooler than the exterior in the early mornings until about midday after which the indoors are warmer. This is different with the building where the construction is heavy in the ground floors (case 8) or with a lighter structure in the top floor (case 9) where the indoor temperatures are lower or close to the exterior at all times in the warm periods.

Seasonal pattern

The differences in conditions between September (lower temperatures lower swings) and April (higher temperatures, higher swings) is noticeable in most cases. Although the difference with the exterior may be higher, indoor temperatures in April are higher and usually above comfort levels in the afternoons and evenings. In September the outdoor temperature is lower and and with lesser difference between indoor and outdoor the possibility of comfort is better. This is with the exception of the heavier buildings (cases 7 and 8) where with different outdoor conditions the indoor temperatures in the two periods are comfortable. This also true for another ground floor flat of medium construction (case 10) and the light top floor flat (case 9).

Table 5.6. Summary of indoor and outdoor temperatures for the case studies.(detailed temperature graphs for each case are given in appendix 7)

Case:1	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	33.2°C	35.9°C	31.4°C	32°C	22.6°C	26.3°C
Minimum	27.2°C	25.2°C	28.8°C	27.2°C	19.6°C	14.7°C
Range	6°C	11.7°C	2.6°C	4.8°C	3°C	11.7°C

Case 2	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	33°C	34.2°C	31.2°C	31.2°C	22.9°C	23.7°C
Minimum	28°C	25.6°C	28.8°C	27.2°C	19.2°C	16°C
Range	5°C	8.6°C	2.4°C	4°C	3.7°C	7.7°C

Case 3	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	35.9°C	36.1°C	33.2°C	34.1°C	23°C	25.8°C
Minimum	29.3°C	24.8°C	29.5°C	27.4°C	19.2°C	14.1°C
Range	6.6°C	11.3°C	3.7°C	6.7°C	3.7°C	11.7°C

Case 4	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	32.8°C	33.5°C	32.3°C	32.5°C	24.1°C	24.5°C
Minimum	26.8°C	25.2°C	29°C	27°C	19.8°C	14.2°C
Range	6°C	8.3°C	3.3°C	5.5°C	4.3°C	10.3°C

Case:5	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	36.5°C	35°C	33.3°C	32.8°C	20.7°C	19.7°C
Minimum	30.2°C	24.3°C	31.4°C	28.3°C	17.6°C	12.3°C
Range	6.3°C	10.7°C	1.9°C	4.5°C	3.1°C	7.4°C

Case 6	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	33.8°C	37.1°C	32.1°C	32.6°C	24°C	27.1°C
Minimum	29.5°C	26.2°C	29.6°C	27°C	19.5°C	15°C
Range	4.3°C	10.9°C	2.5°C	5.6°C	4.5°C	12.1°C

Case:7	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	31.5°C	36.9°C	31.4°C	32.3°C	20.6°C	23.4°C
Minimum	29.3°C	25.8°C	30.1°C	27°C	19°C	11.1°C
Range	2.2°C	11.1°C	1.3°C	5.3°C	1.6°C	12.3°C

Case 8	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	31.8°C	36.8°C	30.7°C	32.3°C	21.7°C	26.3°C
Minimum	29.1°C	24.8°C	29°C	27.1°C	20.6°C	14°C
Range	2.7°C	12°C	1.7°C	5.2°C	1.1°C	12.3°C

Case 9	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	31.2°C	34.7°C	31.8°C	32.3°C	23.6°C	26.5°C
Minimum	26.7°C	24.8°C	27.7°C	27.1°C	21.1°C	15.6°C
Range	4.5°C	9.9°C	4.1°C	5.2°C	2.5°C	10.9°C

Case :10	April		September		January	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
Maximum	32.9°C	35.5°C	30.7°C	31.7°C	21.7°C	23°C
Minimum	29°C	24.8°C	29.6°C	27.4°C	20.5°C	13.4°C
Range	3.9°C	10.7°C	1.1°C	4.3°C	1.2°C	9.6°C

Table 5.7. Summary of comfort conditions in the case studies (occurrences of temperatures between 24 and 32°C are identified as comfortable)

Case1	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable	warm	warm/comfortable	comfortable
September	comfortable	comfortable	comfortable	comfortable
January	cool	comfortable	cool	cool

Case 2	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable/ warm	warm	warm /comfortable	comfortbale
September	comfortable	comfortable	comfortable	comfortable
January	cool	cool	cool	cool

Case 3	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable/ warm	warm	warm	warm /comfortable
September	comfortable	warm	comfortable	comfortable
January	cool	cool	cool	cool

Case 4	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable/ warm	comfortable/ warm	comfortable	comfortable
September	comfortable	comfortable	comfortable	comfortable
January	cool	cool	cool	cool

Case 5	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable	warm	warm	warm /comfortable
September	comfortable	warm	warm	comfortable
January	cool	cool	cool	cool

Case 6	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable	hot	warm /comfortable	comfortable
September	comfortable	comfortable	comfortable	comfortable
January	cool	cool	cool	cool

Case 7	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable	comfortable	comfortable	comfortable
September	comfortable	comfortable	comfortable	comfortable
January	cool	cool	cool	cool

Case 8	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable	comfortable	comfortable	comfortable
September	comfortable	comfortable	comfortable	comfortable
January	cool	cool	cool	cool

Case 9	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable	comfortable	comfortable	comfortable
September	comfortable	comfortable	comfortable	comfortable
January	cool	cool	cool	cool

Case 10	morning 0600 - 1200	afternoon 1200 - 1800	evening 1800 - 0000	night 0000 - 0600
April	comfortable	comfortable	warm /comfortable	comfortable
September	comfortable	comfortable	comfortable	comfortable
January	cool	cool	cool	cool

Indoor temperatures in September are more conducive to comfortable living than April or January. This is important from the point of view of year round performance since the conditions in September closely match the conditions for up to 6 months of the year. Although in January the analysis show that temperatures in all the house are generally cooler than comfort, the occupants may feel comfortable by wearing clothing of higher insulation value and with the use of warm bedding at night. Summer comfort depends on air flow and the individual has little control over natural ventilation and has to rely on the ceiling fan.

Yearly patterns

Over the whole year maximum indoor temperatures vary within 10°C in almost all cases (except 9 where it is about 14°C). A major part of this change occur between the hottest and the coldest period which is about 3 months (January -April) with corresponding changes in comfort sensations. The change between April and September is less, about 3 - 5°C of which between the months of June and September there is practically no change. The houses that are comparatively warmer than others in the hotter periods are also cooler in the cool period (cases 3 and 5)

Indoor and outdoor temperatures

The fluctuation of indoor temperatures in comparison with the exterior are related to the comfort performance of the houses. Houses which have a low swing as compared to the exterior are more comfortable (cases 7, 8 and 10). In one example comfort is achieved with a high indoor swing because the minimum temperature is low (case 9). The indoor temperature swing in other cases are between 1/3 to 2/3 of that of the outdoors.

Occupancy

From the point of view of occupancy the highest temperatures are reached in the afternoons when occupancy is low. The evenings are warm in April when outdoor temperatures are also comparably warmer. In some cases this extends well into the night (cases 5 and 3) when most household members are at home. The cooler periods are in the mornings when occupancy is lowest. Where the house faces east (case 4) the mornings are warmer. In the cooler period the conditions between day and night have different consequences i.e. it is more comfortable in the afternoons than at night.

5.9. Comfort rating

On the basis of comparison of indoor temperatures and the periods when they are within the comfort range, a relative comfort performance rating of the houses can be made. The points in consideration and the sequence of priority in which they are considered for this rating are:

1. The incidence of comfort temperatures indoors
2. How much do temperatures vary within the comfort range i.e. if they extend to sensations of coolness in the hot periods thus providing relief
3. Incidences of temperatures warmer than comfort and whether they occur in both the warm seasons
4. How long do these sensations of discomfort/warmth last.

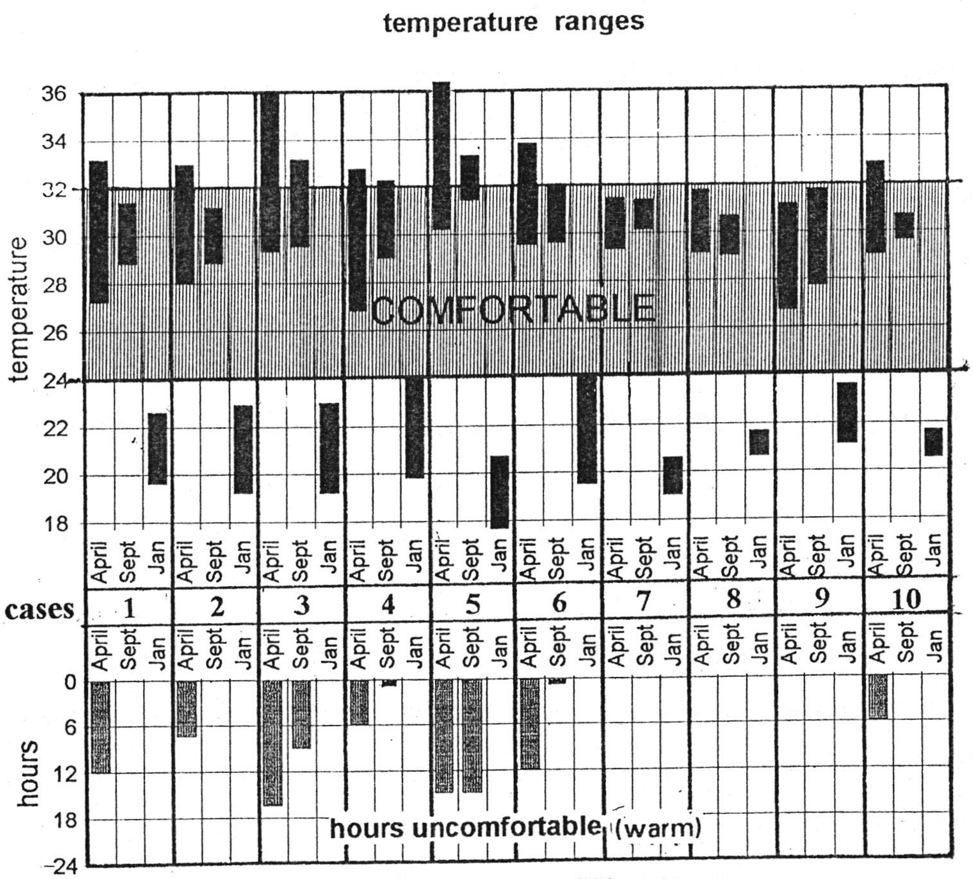

Fig 5.6. Comfort rating basis

<u>Good Performances</u>

Case, 9: *Always within comfort range, lower temperatures*

Cases 8 &7: *Always within comfort range, slightly higher temperatures*

Uncomfortable at times for short periods

Cases 10 & 2: *Uncomfortable in the hotter periods only for 4-7 hours*

Uncomfortable for longer periods or in both September and April.

Cases 4, 1, & 6.: *Uncomfortable for up to 12 hours in April or also uncomfortable at times in both September and April, cool in the cool periods.*

Uncomfortable for most of the time

Cases 3 & 5: *Hot for extended periods in September and April, cool in the cool period.*

The rating emphasises the two warm periods since it is warm for most of the year and also because the observations indicate that in the worst of the cool periods indoor conditions are below comfort temperatures when it is easier to make subjective adjustments for comfort..

There is a temperature range between the cool and the warm periods within which these houses operate i.e. between the cool and warm sensations. They are in the transition periods between the hot and the cool months, namely the later parts of October, November, December and early February (see chapter 3) when all the houses are generally comfortable.

The houses on ground floors or of heavier construction show a better comfort performance in general. Case 9 a top floor flat of light construction also has a good performance.

5.10. Relative humidity and comfort.

Comfort assessments in Chapter 4 indicate that the perception of comfort of the people are not affected by high relative humidities. thus it was not a major consideration in the assessments of the case studies The relative humidity in the case study periods are mostly within the range described as comfortable. There are some general observations about the conditions of humidity and possible bearings on comfort.

The relative humidities fluctuate least in the September observations, where the average fluctuation of humilities for all cases is 14.6%. The maximum humidity recorded is 89% and the minimum 55% in different situations, mostly being in the 70's and 80's. These conditions are unlikely to cause discomfort for reasons of humidity alone. In the hotter April period the average fluctuation for all cases is much higher at 39%, the maximum being 92% and the minimum 42%. In January average fluctuations are 32.5% for all cases, the maximum recorded in any case was 90% and the minimum 40%, instances of lower humidities are more in January than in April.

Table 5.8 . Relative humidities in the case studies and from meteorological data (%)

Case ref.		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**met**
April	max	90	87	77	86	* 80	88	90	89	92	91	88
	min	48	50	42	58	50	55	49	43	50	44	50
Sept	max	85	89	82	78	75	79	79	81	88	85	89
	min	67	70	75	65	55	60	71	70	72	70	64
Jan	max	90	82	70	79	77	86	65	72	78	76	92
	min	54	44	48	40	40	50	41	55	45	43	40

The relationship between humidity and comfort in the bioclimatic and psychrometric charts refer to humidities as low as 30% as being acceptable (17)(18). In the comfort assessments there were rare instances of relative humidities below 50%. It is possible to infer, given the unfamiliarity with lower humidities, there may have been subjective instances of discomfort in lower humidities had they to occurred.

There are more instances of high humidities in April as well as lower values. In September there is more occurrences of higher humidities. The range of indoor relative humidities are lower than the outdoor range in September and January therefore people indoors are less likely to be uncomfortable. Unrecorded instances of higher relative humidities may have occurred, which if above 95% may cause discomfort.

5.11. Air movement and indoor comfort.

Spot measurements of air movement were made in all the case studies, to observe its effect on comfort. Ceiling fans though present in all rooms, were kept off during the period of observations to restrict conditions as close as possible to natural. The restrictive effect of window grilles and nettings were observed (19)(20).

The measurements of air movements display certain traits. Air flow in most cases were low or negligible. The maximum air flow measured at any instance was .8m/s, this was in an upper floor for a brief period (case 4). The potential for air flow indoors increases with height from the ground. The air flow indoors in ground floors is low. Indoor air movement for comfort in lower floors is unreliable because the outdoor air movement is erratic and unpredictable and it changes direction and velocity constantly.

Table 5.9. Conditions of air movement in the different situations (values are averages from several spot measurements)

Case ref.	max. indoor velocity (m/s)	max. outdoor velocity (m/s)	% of outdoor velocity	floor	opening details
1	.1	1.28	7.81%	2nd/top	grill/net
2	.01	.66	1.51%	ground	grill
3	0	.26	0%	1st/top	grill
4	.8	2.5	32%	3rd	grill
5	0	.7	0%	1st/top	grill/net
6	.7	1.2	58.33%	3rd	grill
7	0	1.4	0%	ground	grill/net
8	0	1.9	0%	ground	grill/net
9	.7	1.16	60.34%	5th/top	grill
10	.4	1.3	30.76%	ground	grill

Wherever there is noticeable air flow outside its value is greatly diminished indoors to be of effect. This is because of the presence of security grills on all windows without exception, sometimes in combination with insect netting. On ground floor windows are usually closed for privacy and security during the day, in some cases also at night.

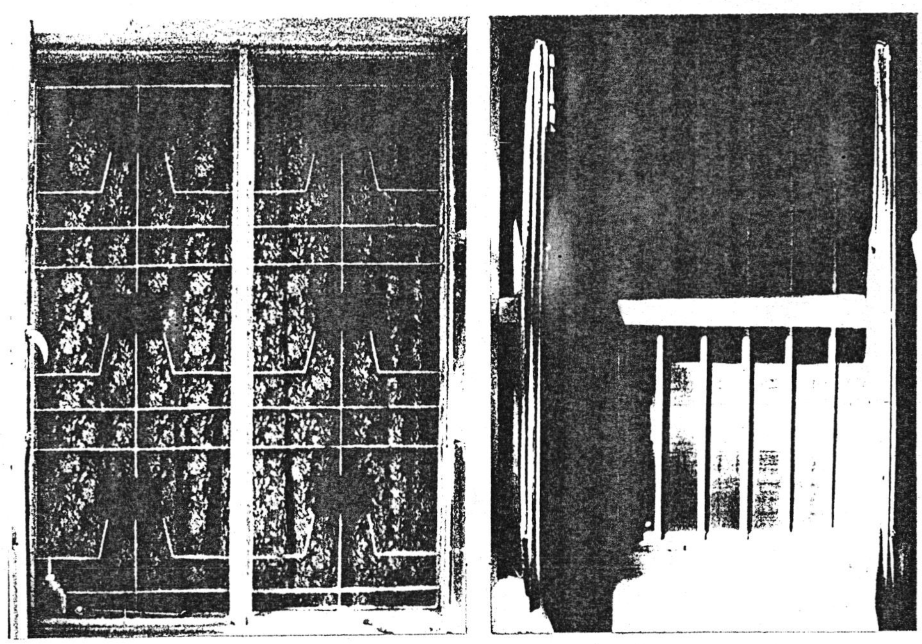

Fig 5.7. Window grilles and netting

In top floors, particularly higher ones and or ones in relatively open sites there is at times air movement which in itself can induce comfort but it is rare for this to be a continous phenomenon. In dense sites (case 5) upper floors are very much like ground floors. In rooms high above (case 9) air flow is reliable and quite high at times. Even in such situations restrictions may occur in the presence of verandas or nettings (case 1).

The ceiling fan provides the only reliable source of air movement and is a helpful aid to comfort. All situations have the potential for indoor comfort with the use of the fans except where the indoor temperature is above 35°C (case 5 in April) where even at maximum speeds average air velocity is not sufficient to induce comfort (chapter 4).

5.12. Comparative studies.

The choice of case studies considered aspects of design which allow comparison of thermal behaviour with regard to differences in design and the context of site.

5.12.1. Sites conditions

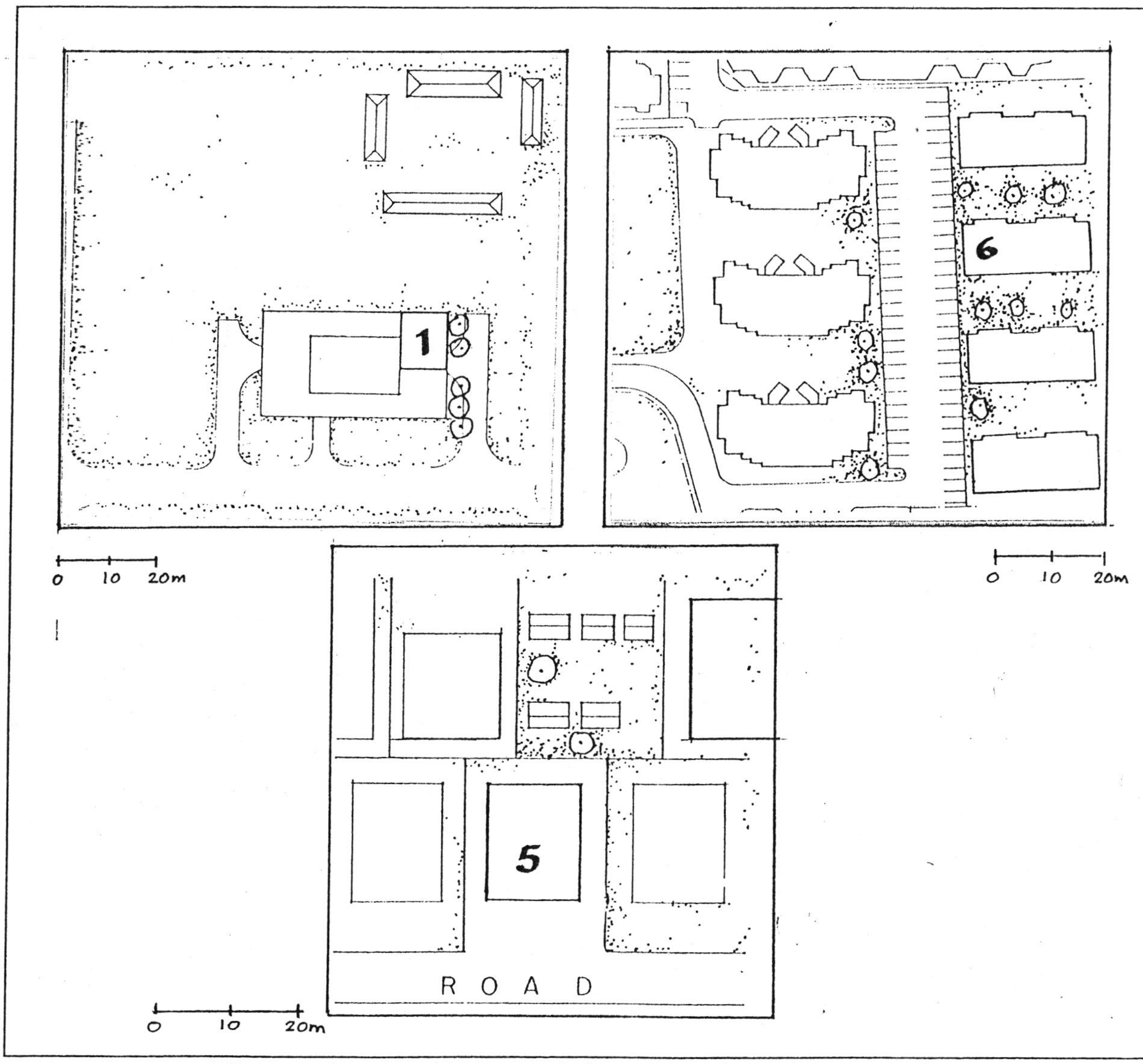

Fig 5.8. Open, moderate and dense sites (cases 1, 6 and 5)

To compare the effect of site conditions on indoor temperatures, buildings having similarities in aspects other than site conditions were compared. The three site categories are dense, moderate and open as described earlier. The conditions observed are indicative of the influence of the site on indoor thermal conditions.

Cases 1, 6 and 5 belong to open, moderate and dense site conditions respectively. While 1 and 5 are top floor rooms, 6 is not but has an exposed western wall and lesser shading on south. The extra radiation thus received compensate for the radiation on the roof for the others. All cases have southern window orientation.

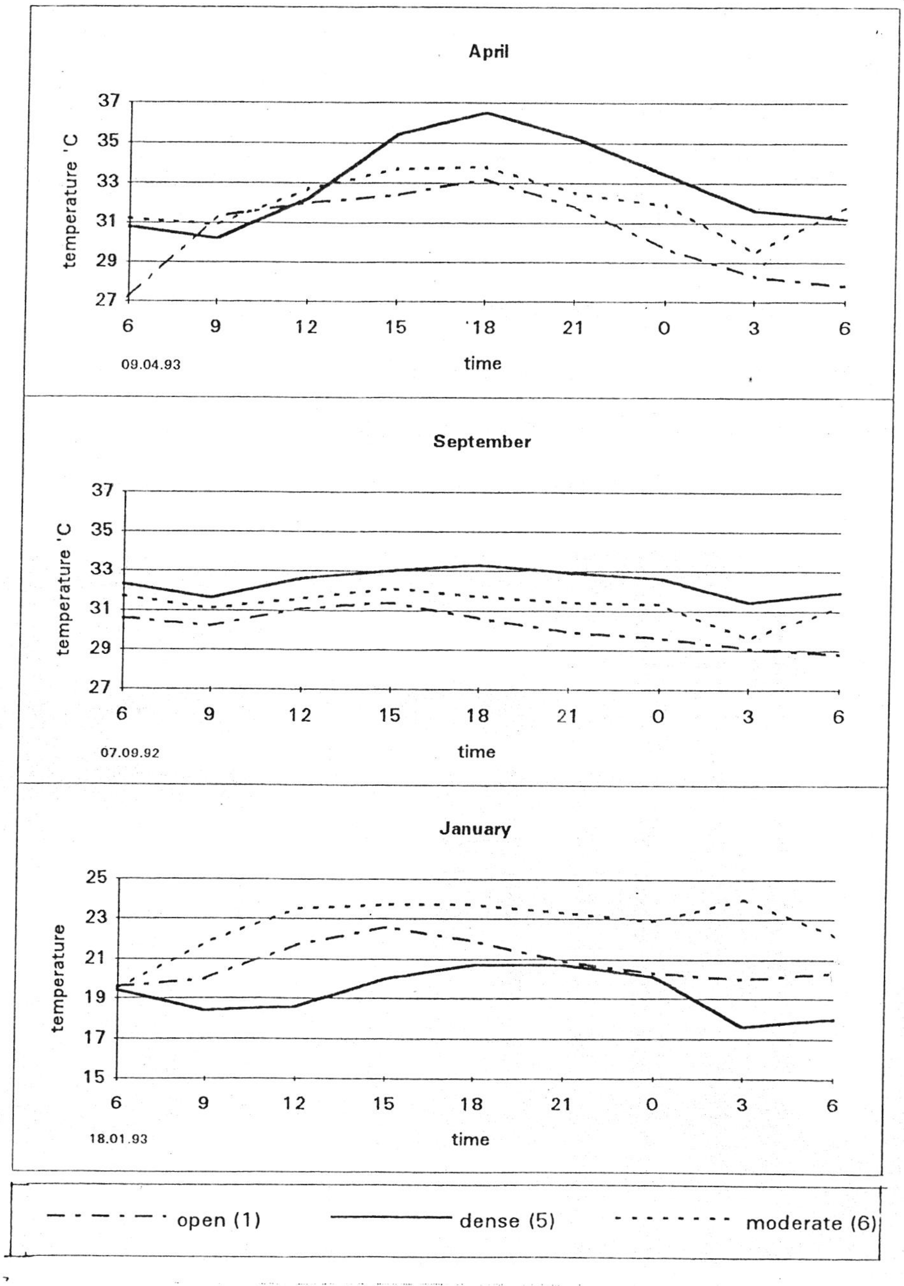

Fig 5.9. Indoor temperatures in different site conditions

The room in the dense site is warmer than the others in the warm periods and colder in the cool period. In the hot periods maximum daytime indoor temperature differences between the open and dense situation is more than 3°C at 1800 hours and a comparable difference exists all evening and through the night. The room in the moderate site is warmer than the one in the open site but by less than 1°C. Higher fluctuations occur at particular instances. In the cool period the dense situation is cooler at all times and the moderate situation warmest mostly at night. This warmth can be partially explained by the heat accumulation of the west wall by day and dissipation at night.

Table 5.10. Average day and night time temperatures in different sites

	April		September		January	
	Day	Night	Day	Night	Day	Night
Open (1)	31.22°C	30.16°C	30.78°C	29.6°C	21.16°C	20.68°C
Moderate (6)	32.46°C	31.9°C	31.64°C	31.04°C	22.44°C	23.22°C
Dense (5)	33.02°C	33.58°C	32.56°C	32.42°C	19.42°C	19.42°C

Within the category of dense sites there are two different situations which display different responses indoors. Case 3 is a dense site but the surrounding structures are lower than the building observed and have corrugated iron roofs. Case 5 is in a site where the buildings are close to each other but of similar height and geometry.

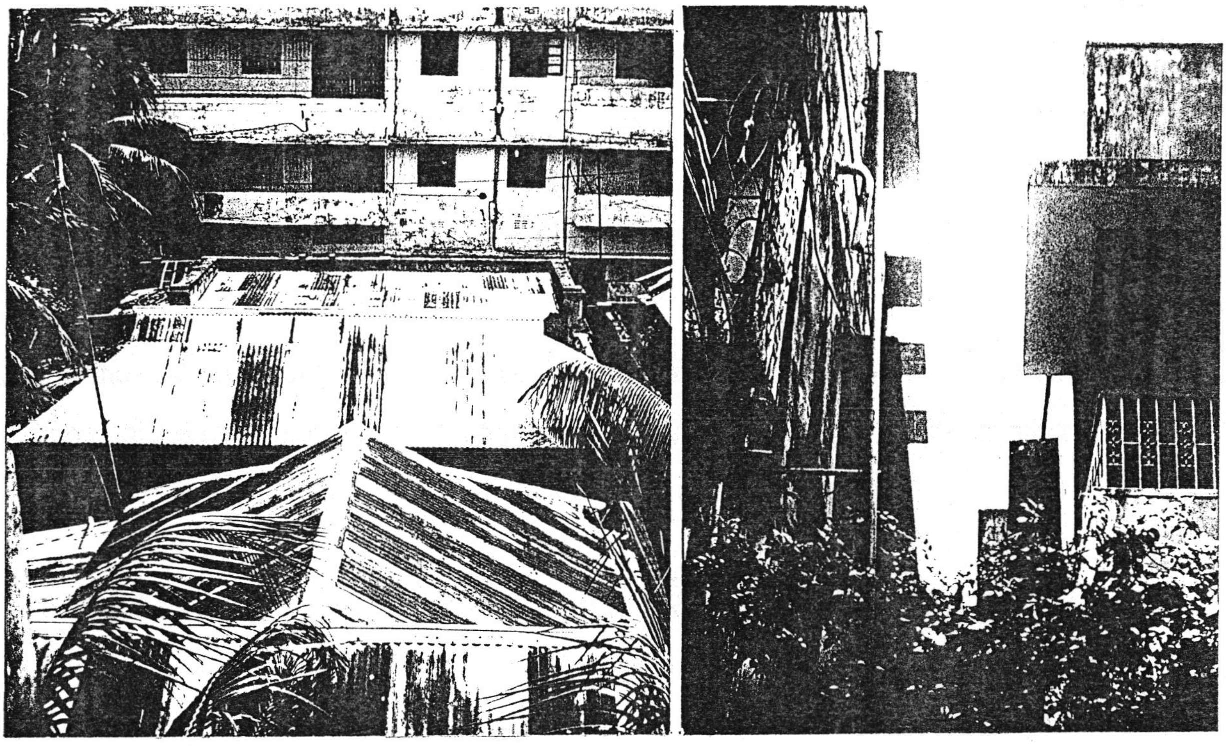

Fig 5.10. Two types of dense sites.

The maximum temperatures in both cases are close but the nature of the pattern varies. The heat from the surrounding roofs cause the interior in case 3 to heat up earlier in the day whereas case 5 is warmer in the later part of the day and continues to be so for most of the night. In the cool period case 3 is warmer than 5. From the point of view of occupancy case 5 is warm when occupancy is at a peak (night) whereas 3 is warm in the mornings when most people are out. The important observation to note is the effect heat gained from surrounding roofs.

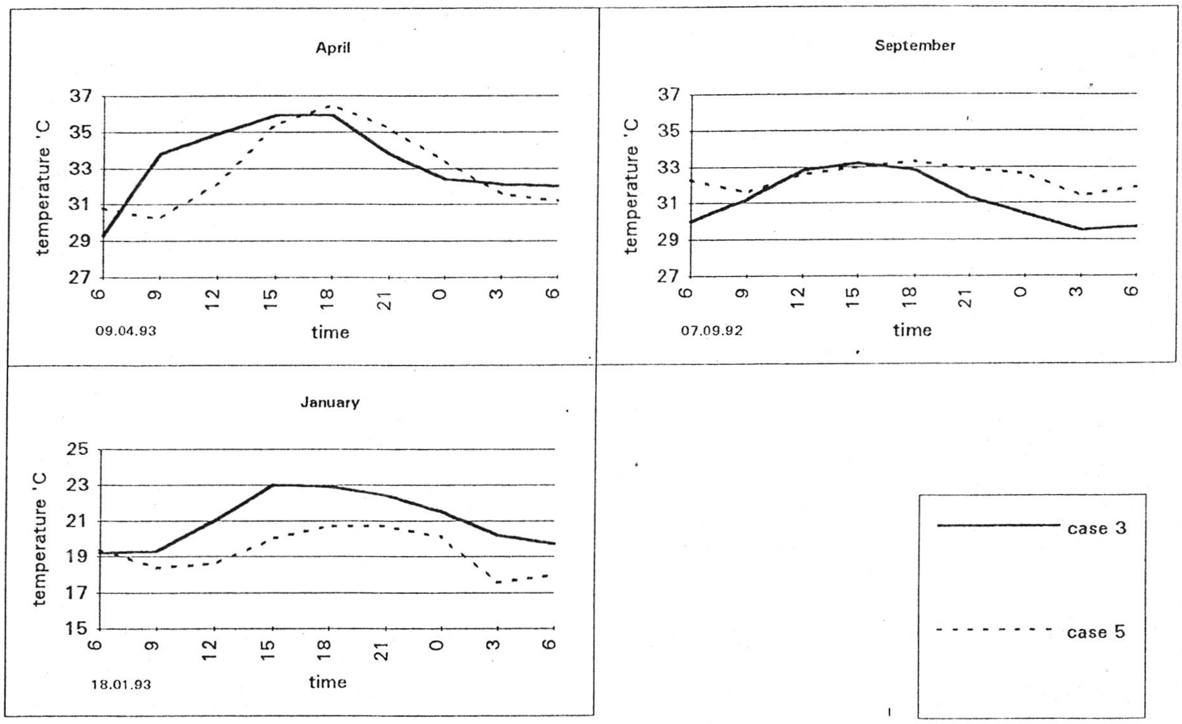

Fig 5.11. Indoor temperatures in two dense sites.

5.12.2. Orientation

From the case study examples it is difficult to identify all the different orientations which are comparable simultaneously. The comparisons on orientations are made in parts which are then combined to arrive at some general conclusions.

A room facing south (case 6) is always warmer than the one facing east (case 4) except for brief periods in the morning when the latter receives direct radiation. It is warmer considerably only during the daytime in the hotter periods by about 1.5°C. Daytime temperatures in September are close. In the cool period the southern room is similar to the eastern room during the day. The blank western wall of the south oriented room radiates heat inwards at night.

Table 5.11. Average day and night temperatures for east and south orientations.

	April		September		January	
	Day	Night	Day	Night	Day	Night
East (4)	30.98°C	28.3°C	31.36°C	29.86°C	22.22°C	21.26°C
South (6)	32.46°C	31.9°C	31.64°C	31.04°C	22.44°C	23.22°C

Cases 7 and 8 are both heavy construction ground floor houses in moderate sites. The swing in indoor temperatures in both cases are low but the west facing room (case 7) is slightly warmer than the south facing one (case 8) during the summer months. The difference in temperatures is more at night in September and during the day in April. In January the southern room is warmer by between 1 and 2°C.

Table: 5.12. Average day and night time temperatures for west and south orientations

	April		September		January	
	Day	Night	Day	Night	Day	Night
West (7)	30.72°C	30.44°C	30.88°C	30.72°C	20.12°C	20.04°C
South (8)	30.08°C	30.38°C	30.44°C	29.64°C	21.34°C	21.26°C

The difference that occurs between the two orientation situations is very much affected by the nature of construction. Relatively heavier construction results in stable thermal conditions inside and the effect radiation on the wall is reduced.

There is one example with a northern orientation (case 2) but it cannot be compared with another since a situation with similar conditions but a different orientation does not occur in the case studies. From the fact that the north face of building receives little direct radiation it can be assumed that it would be cooler that a southern counterpart.

The effect of orientation on indoor temperatures are examined in greater detail in Chapter 6.

5.12.3. Exposure

Cases 3, 6 and 10 are compared to evaluate the effect of exposure on thermal behaviour. They all have a southern orientation and are of medium construction and except 3 they are in moderate site 3 is in a dense site the effect of which has been observed earlier and considered here.

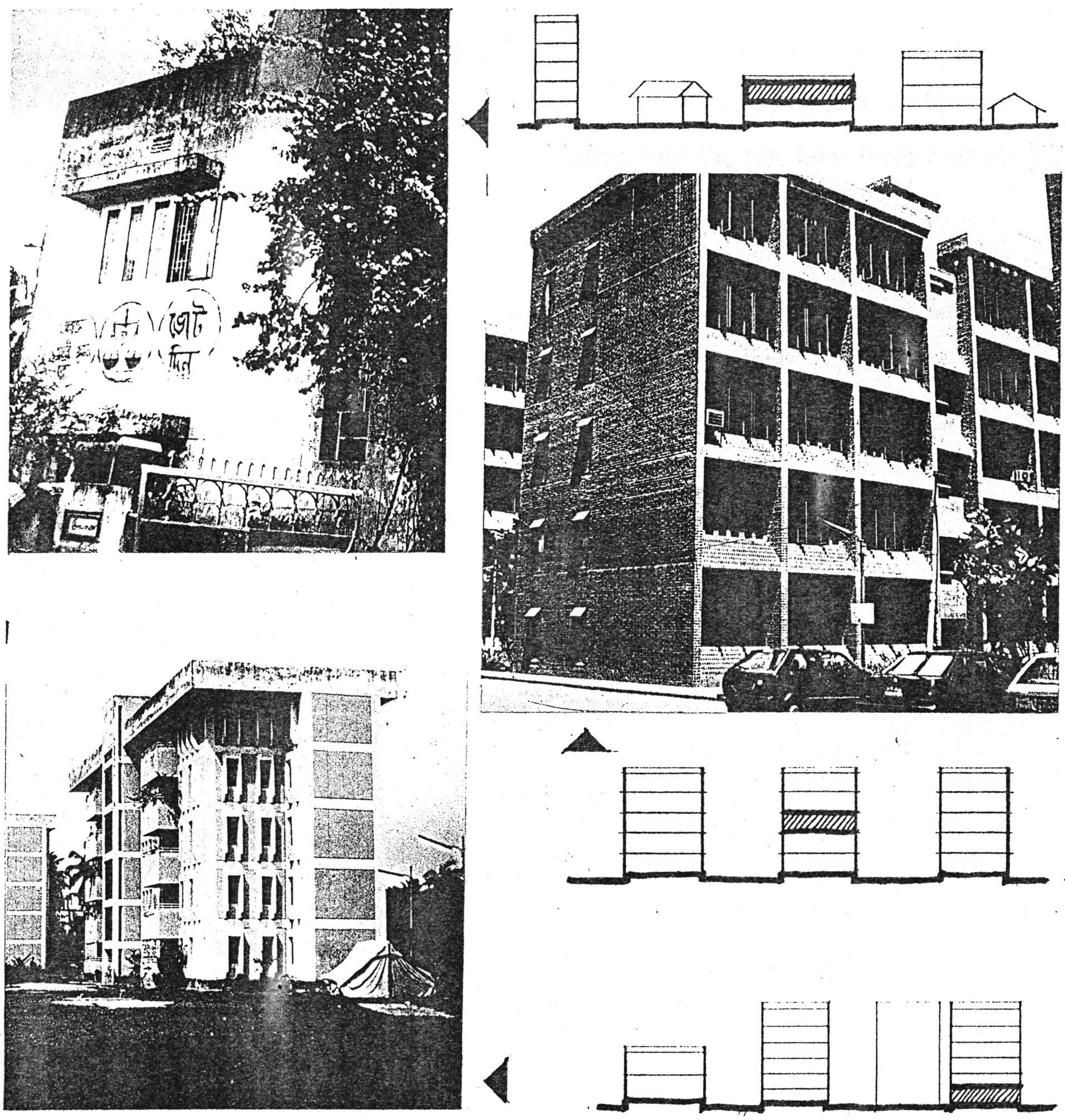

Fig. 5.12. Top, intermediate and ground floors (cases 3, 6 and 10)

Table 5.13: Average day and night time temperatures for top, intermediate and ground floors.

	April		September		January	
	Day	Night	Day	Night	Day	Night
Top (3)	33.96°C	33.24°C	32°C	30.74°C	21.08°C	21.34°C
Intermediate (6)	32.46°C	31.9°C	31.64°C	31.04°C	22.44°C	23.22°C
Ground (10)	31.16°C	31.28°C	30.58°C	29.96°C	21.22°C	21.3°C

Because of its exposure to radiation (21) the top floor is the warmest in the summer months. Ground floors, because of losses to the ground (22) are cooler by 3 to 4°C, intermediate floors are cooler than top floors by about 1°C in the hotter periods and the difference prevails for most of the day and night. In September the differences are less between floors , about 1°C and the top floor is hotter during the day only. At night it cools down at instances to temperatures lower than the intermediate floor. In the cool season however, the intermediate floor is warmer than the ground floor by up to 2°C. The average conditions of the ground and the top floor are same with the top floor being warmer by more than 1°C during the day.

From the comfort point of view top floors are above the comfort threshold for most of the hot periods, the lower floor have better chances of being comfortable.

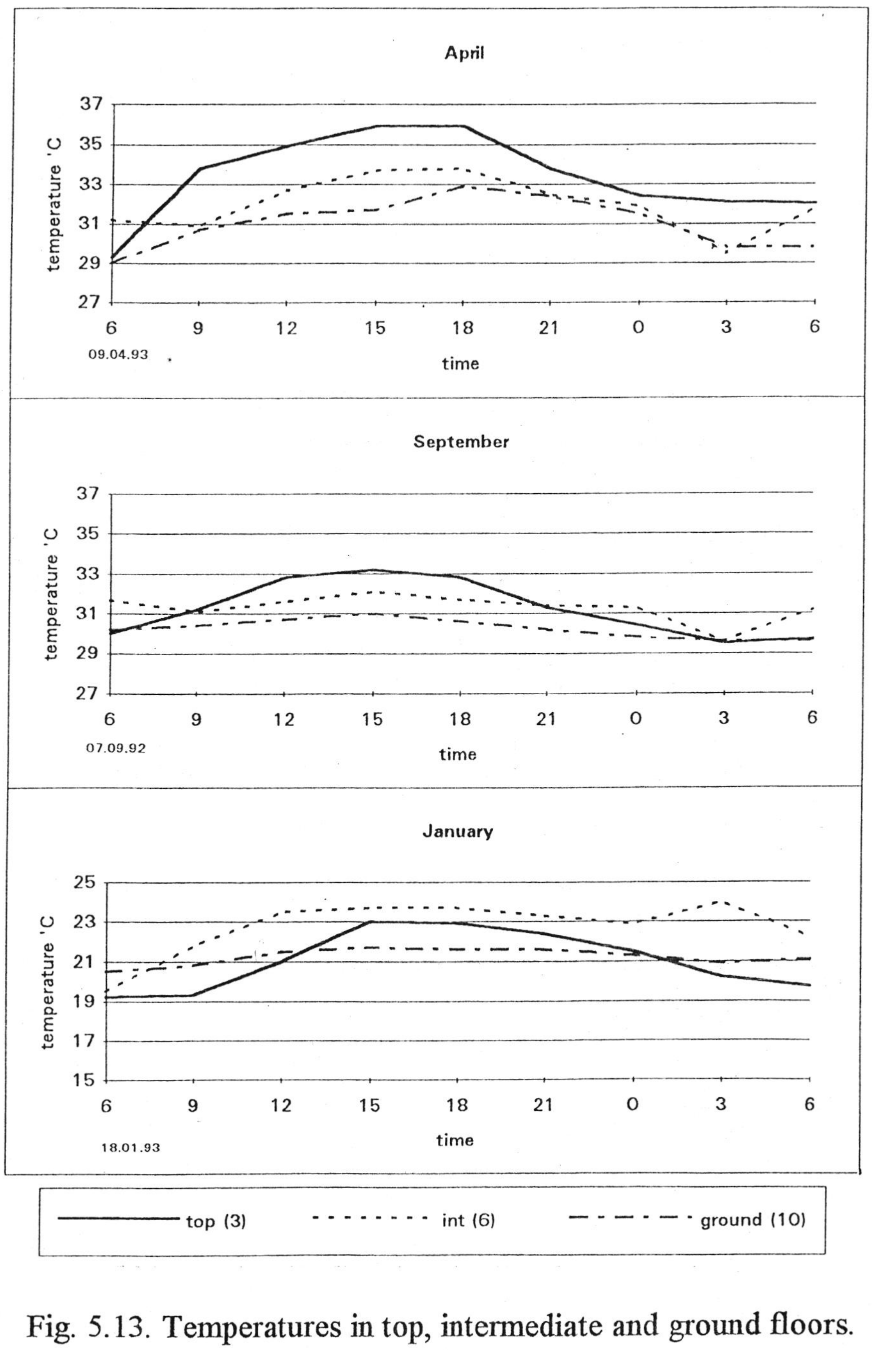

Fig. 5.13. Temperatures in top, intermediate and ground floors.

Heat gain in top floors

Top floors are particularly vulnerable to heat gain from solar radiation because of exposed roofs. There is the practice of adding a 75mm layer of lime terracing on top floor concrete roofs to insulate it as well as to create a run off for rain water.

Case 1 is a top floor situation with lime insulation, while 3 has an exposed concrete roof. Comparison between the indoor performance in the warm periods show differences of up to 3°C in April and 1°C in September in the peak hours. Site conditions of the uninsulated case contribute to indoor temperatures, therefore in a comparable situation the differences would probably be less.

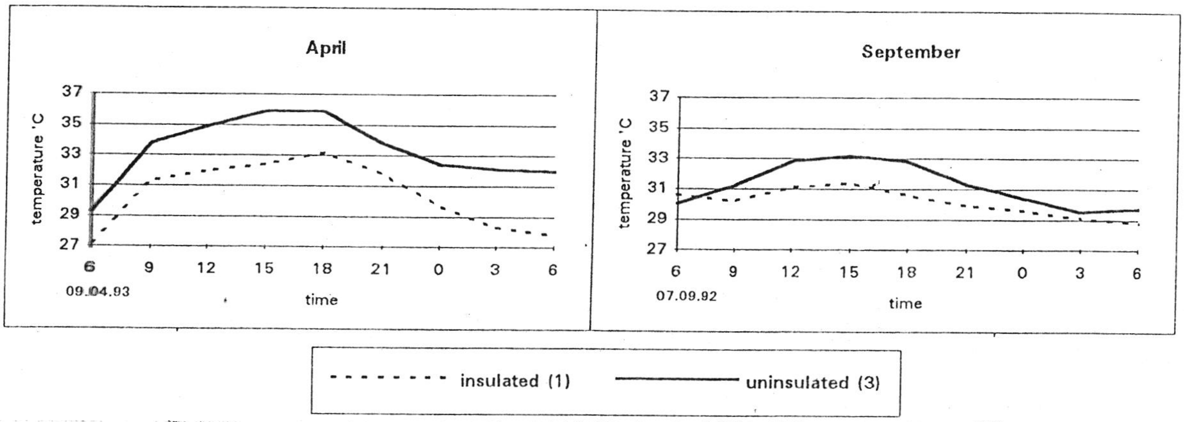

Fig 5.14: Temperature indoors for top floors with and without insulation.

5.12.4. Building construction (thermal mass)

Cases 2, 10 and 8 are buildings with 125, 250 and 375mm walls and are termed as light, medium and heavy construction. Case 2 has a corrugated iron roof which is shaded. Other characteristics are comparable.

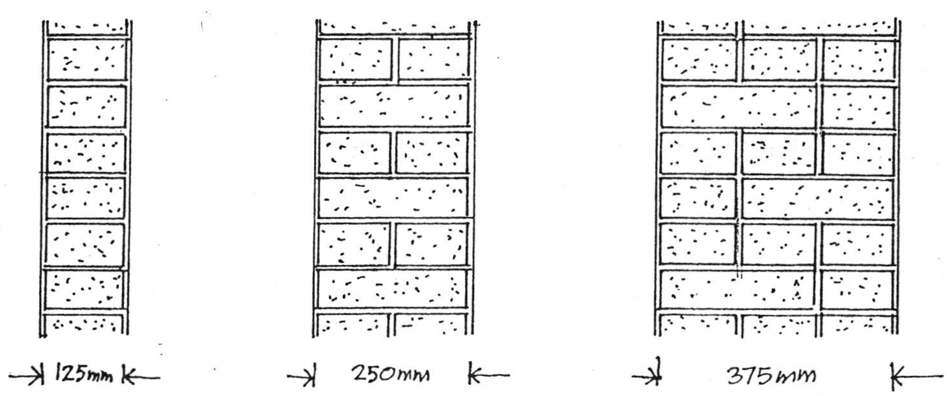

Fig 5.15. Walls sections in heavy, medium and light construction.

Table 5.14: Average day and night time temperatures for heavy, medium and light construction.

	April		September		January	
	Day	Night	Day	Night	Day	Night
Heavy (8)	30.08°C	30.38°C	30.44°C	29.64°C	21.34°C	21.26°C
Medium (10)	31.16°C	31.28°C	30.58°C	29.96°C	21.22°C	21.3°C
Light (2)	31.24°C	31.06°C	30.68°C	30°C	21.16°C	21.02°C

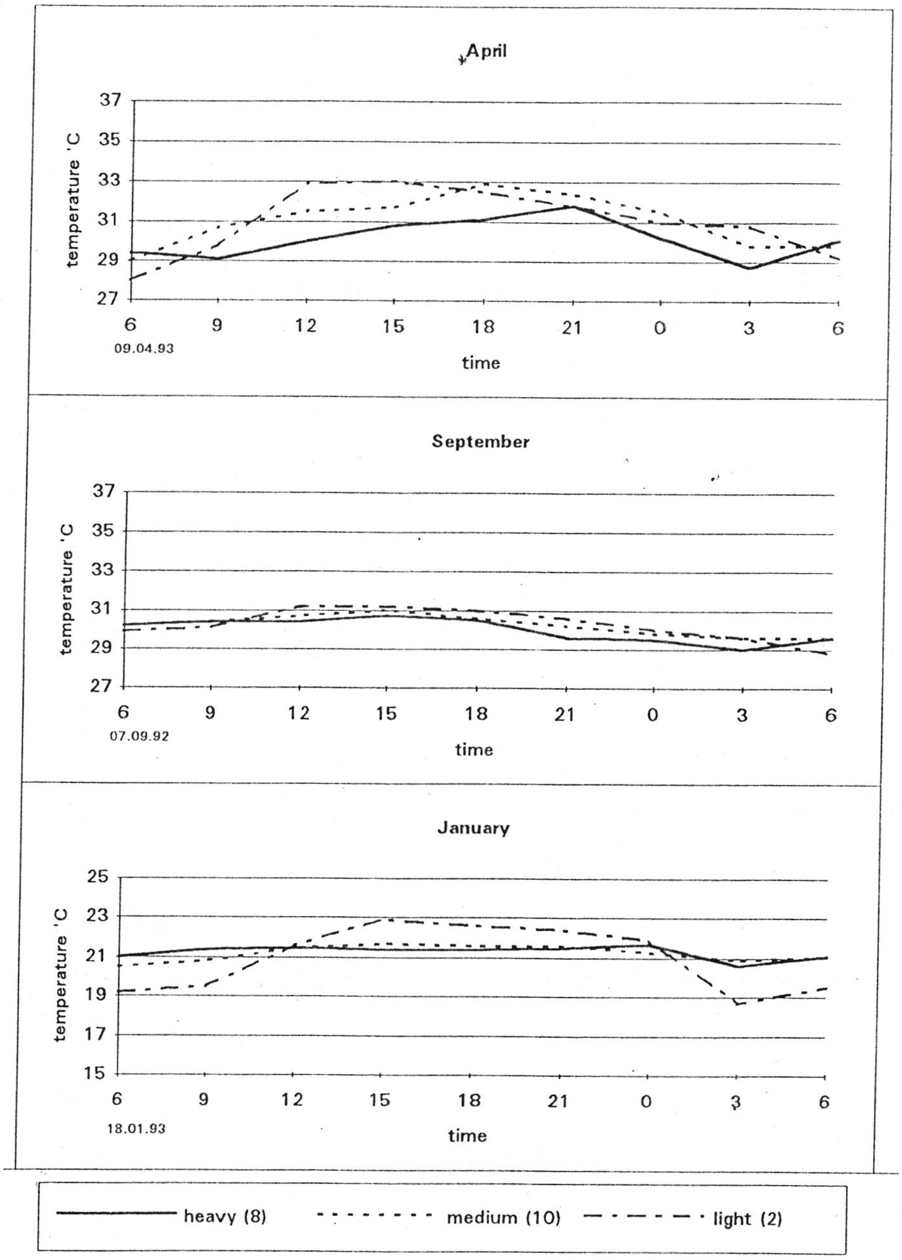

Fig 5.16: Indoor temperatures for heavy, medium and light structures.

The temperatures in the room with heavier construction are the coolest and the light construction warmest with the medium construction in between in terms of average temperatures. The differences in temperature between them depend on the time of the year. In the hotter April period in the afternoon hours there can be differences of 1.5°C between each. At night the temperature in the light structure falls below that of the medium for a few hours. The heavier structure is always comfortable as opposed to the other two which can be hot during this period. In September they have the same pattern but the differences are negligible. During the daytime in the cool period the light structure is warmer than the other two but cooler at night.

5.13. Internal heat gains and influences.

5.13.1. Equipment and processes.

It is not common for Bangladeshi household to have many equipment that generate significant heat gains. Heat gains from refrigerators cannot be a general consideration as only affluent households have them. Significant from the point of heat gain indoors is that generated from the cookers in the kitchen because of cooking preferences that require fairly extensive use of heat.

5.13.2. The kitchen as a source of heat gain

In traditional houses the kitchen was an isolated unit separated from the main house. There are two reásons for this. The activity involves elaborate preparation and processes, generates waste and it is not desirable for it to be visible from other areas, secondly cooking in traditional households is an exclusively female activity, hence the requirement for privacy (23)(24)(25). Heat generation is not a consideration because cooking is actually done outdoors in the yard. Kitchens are a part of the house in urban examples and heat generated from it is a source of gain for other spaces. Depending on the cooking habits of the household this gain can occur more than once a day.

5.13.3. Influences of heat gain from the kitchen

Temperature measurements in all the rooms including the kitchen were made in three houses for a twenty four hour period. They have different design features, example 1 (case 7) is from an early urban flat typology, example 2 (case 3) is a modern flat and the location and planning of the kitchen is more in line with modern standards, in example 3 (case 2) the location of the kitchen was intended to be temporary but it has remained in place for a long time.

The average temperature of the kitchen is higher than the average temperature of the other space in varying degrees. In example 1 the kitchen is 2.25°C warmer than the rest of the house on average, in examples 2 and 3 it is warmer by 1.5°C. At the time when the kitchen temperatures are at its peak, differences with the cooler parts of the house can be up to nearly 4°C.

The effect of the heat from the kitchen is most in the room adjoining it and it diminishes with distance from it. In the two examples where the kitchens have allocated locations the space that suffers most in the dining space and the temperatures closely follow that of the kitchen. In example 3, where the kitchen has a arbitrary and temporary location it is the adjoining bedroom.

Depending on the use pattern of the kitchen the occurrence of peak temperatures can be once or twice in the daily cycle. The households in examples 1 and 3 cook their food twice a day, hence there are two instances of peak temperatures, whereas in example 2 cooking is a once a day routine and there is no evening peak.

5.13.4. The influence of design.

The effect of kitchen temperatures on the rest of the house are related to the design and location of the kitchen and the layout of the rest of the spaces. Examples 3 and 2 have relatively larger kitchens with sizeable openings, whereas 1 has a small kitchen with a small window and the walls are of thicker construction. The temperatures in the latter fluctuate less and the heat is contained for a longer time. In the others the rise in temperatures are quick to fall.

In all the examples the kitchen in an integral part of the layout, more so in examples 1 and 2. Modern design attitudes also support the traditional notion of the kitchen as being a negative space and therefore tend to allocate least favourable spaces to it. This also because the kitchen is not associated with living functions but is only a workplace. The occupancy patterns of the households show that a considerable time is spent in the kitchen by the female members of the family and the domestic help but not the male members. The fact that heat generated from it affects the thermal behaviour hence comfort performance of the rest of the spaces make it an important planning consideration

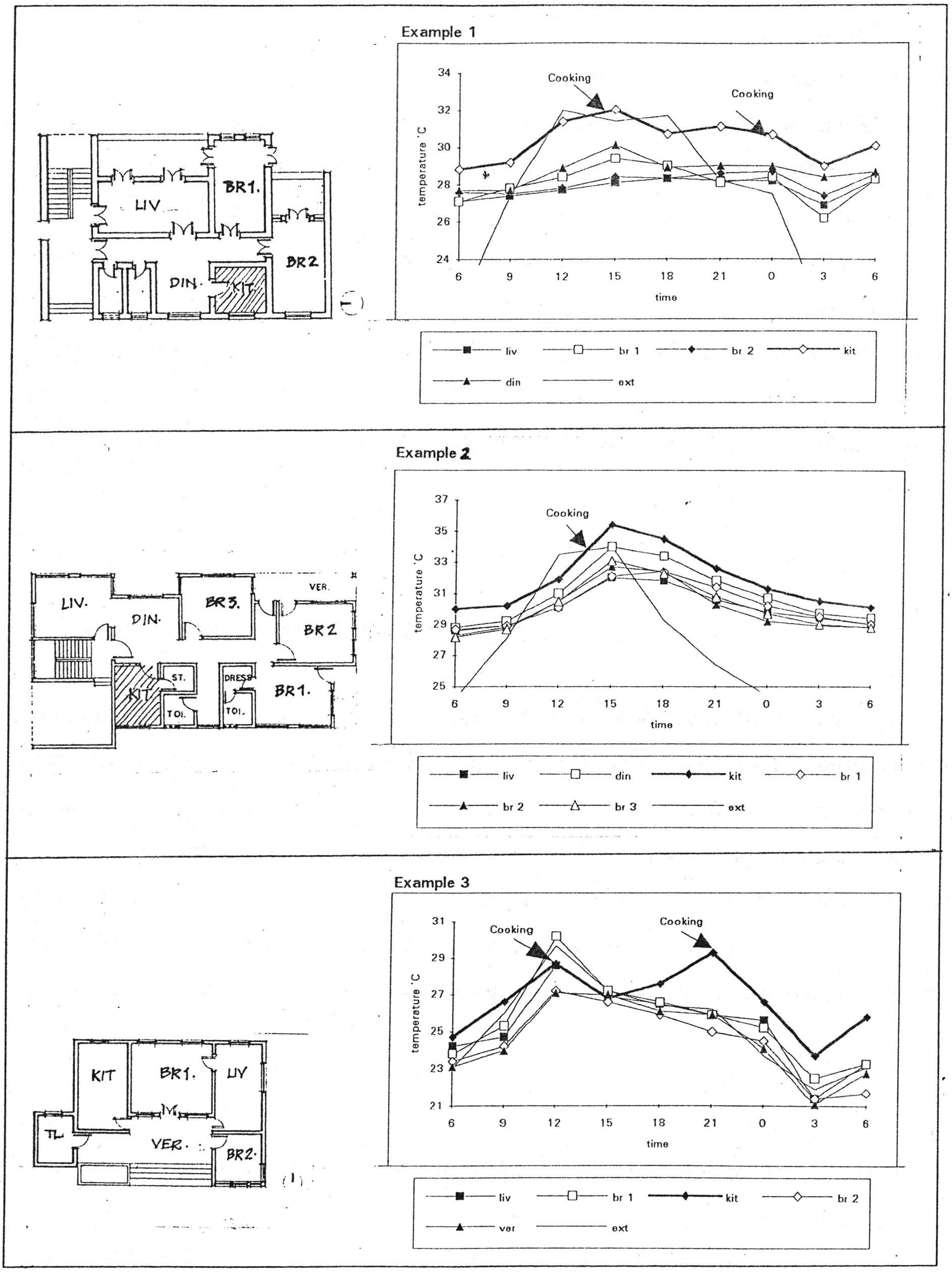

Fig 5.17. Influence of kitchen temperatures.

5.14. Environmental variables and comfort performance

Thermal comfort depends on conditions of temperature, air movement and relative humidity as the main environmental variables. The measurements of relative humidities in the case studies in the different periods in relation to comfort criteria show little influence on comfort of the occupants. Air movement has a greater influence on comfort. In the spot measurements of air movement it was seen that because of the design of openings i.e. the use of grilles and netting there is a significant reduction in the air velocity indoors Other than four houses (cases 4, 6, 9 and 10) air movement cannot make any contribution to indoor comfort. Air movement is an unreliable element in urban environments particularly in dense conditions. In ground floors, for reasons of privacy and security people keep their windows closed and there is little scope for air movement from outside. Ceiling fans are means of providing air movement but there use at all times is a subjective consideration. The thermal and subsequent comfort performance characteristics of buildings should therefore consider air temperature as the primary factor.

5.15. Design features and comfort performance.

Both the thermal behaviour patterns and comfort rating of the case studies show that some of the houses are more comfortable than others. Buildings that have heavier construction, or are in ground floors or are lighter construction on top floors are more comfortable (cases 7, 8, 10 and 9) in the warm periods. In the latter case air flow makes a significant contribution. In the cooler months, however, light buildings are warmer and heavier ground floors are cooler than most others. A lower indoor swing in the case of heavier construction implies steadier indoor temperatures and when comfortable in summer such houses are consistently so.

Site

The site is the given context for any building and is the reference point for building design. Dense sites have the worst indoor conditions in both warm periods as well as the cool period to the extent that indoor conditions are uncomfortable for most of the day. Conditions are better in moderate sites and best in open sites. In dense sites where all buildings are of similar height conditions are worse than where there is extra gain from the roofs of surrounding lower structures.

Orientation

Of the three orientations that could be compared, west has the highest indoor temperatures followed by south and east. In the cool periods south is a warmer orientation. Northern orientations by virtue of being cut from the direct sun for most of the time is likely to have the lowest temperatures although evidence for this could not be had from the case studies.

Exposure.

Ground and intermediate floors are considerably cooler than top floors in the hot dry period. The same trend exists in the hot humid period but with lesser differences. In the cool periods the intermediate floor is warmest followed by the top floor and the ground floor. Ordinary lime terracing can improve the top floor situation but not enough to make it comparable to ground floors.

Construction.

Heavier construction is cooler than the medium construction and light construction is warmest in the warmer periods. Wider fluctuation of temperatures in the lighter construction makes it cooler than medium construction at night. The difference between construction types is not significant in the hot humid period. In the cool period lighter construction is warmer than the other types.

Internal layout and planning

The design of the house with regard to the location of the kitchen is significant to control heat gains from it. The distance of the spaces from the kitchen is related to the extent of influence of kitchen temperatures in most urban houses of compact design. The thermal mass of the building contributes to the internal heat by its heat storage capacity.

5.16 Site climate and design implications

Within the urban field the characteristics of a particular location with regards to the density of buildings, quality of the ground surface, the dynamism of the shading patterns generated by the passage of the sun etc. influence and determine site climate (26)(27)(28)(29) The description of the local climate varies from that of the overall urban climate as given by the data from the meteorological office, usually collected in open locations. While this data can help determine the broader environmental objectives, in reality buildings interact with the site climate. It has been inferred earlier that the indoor temperatures in buildings vary as a result of site conditions.

For the designer of buildings it is important to have an understanding of the conditions that exist at site level to identify design goals more accurately. In the following sections site temperature data from the 10 case studies are compared between themselves and with meteorological data for the same periods to identify patterns of behaviour which are a result of site characteristics.

5.16.1. Site characteristics

The sites are classified as dense, moderate and open on the basis of criteria considered earlier. The conditions of shading at a particular site being an important aspect of local climate dense sites have been further classified further into three types.

i. Where the surroundings structures are lower as compared to the reference building (case 3). In partially developed areas where majority of the structures are one storied, this a common occurrence

ii. Where surrounding structures are similar in height and typology to the reference (case 5) common in private housing in dense urban locations where property division over generations have lead to closer spacing.

iii. Where surroundings are taller and close enough to shade the site in question. (case 2)

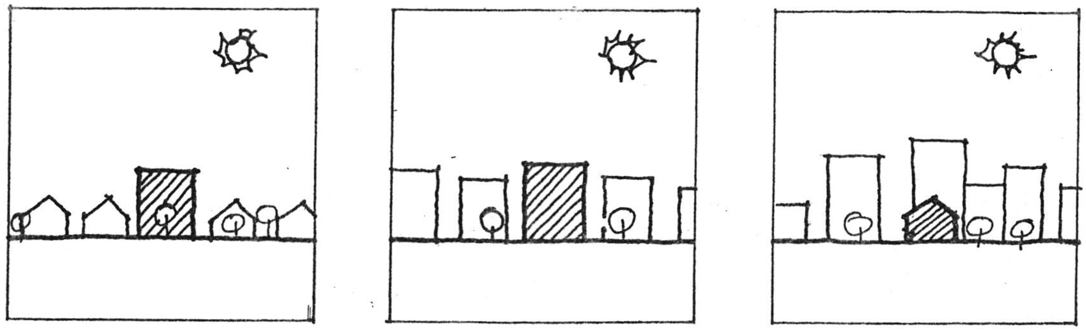

Fig 5.18: Types of dense sites.

5.16.2. Comparison of site and meteorological data.

Site and meteorological data were compared for the three dates (April 9, September 7 and January 18) for different categories of sites on the basis of (a) average temperatures, (b) the temperature pattern during the 24 hour measurement period, (c) and patterns of variation from the meteorological data as given by the differences between site and meteorological data at three hourly intervals. The purpose is to identify similarities of behaviour between sites of similar characteristics and to offer predictability of their thermal patterns on the basis of meteorological data.

The meteorological data used for comparison are the ones for the days corresponding to site measurements.

Table 5.15. Three hourly temperature from meteorological data for reference dates.

time	0600	0900	1200	1500	1800	2100	0000	0300	0600	average	swing
April, 09	32.1	33.8	34.1	36.5	34	31.3	28.2	27.1	30.8	31.9	9.4
Sept, 07	28.2	30.8	32	32.8	31	29.4	29	28.4	27.1	29.8	5.7
Jan, 18	11.9	18	24.2	25	20.1	15.7	14	12.8	11	16.9	14

The comparison of temperature patterns between site and meteorological data is organised on the basis of site typologies as defined earlier. Comparison of temperatures at different sites and the corresponding meteorological data is given in table 5.16.

Table 5.16: Comparison of meteorological data and site temperatures.(Maximum and minimum tempertures in shaded areas)

OPEN SITES

APRIL	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*32.1*	*33.8*	*34.1*	*36.5*	*34*	*31.3*	*28.2*	*27.1*	*30.8*	*31.99*	*36.5*	*27.1*	*9.4*
SITE1	24.2	32.7	34	35.9	33.4	32.2	28.7	26.5	25.4	30.33	35.9	24.2	11.7
SITE 4	26.3	32.1	32.1	33.5	32	30.5	27.4	25.2	27.5	29.62	33.5	25.2	8.3
SITE 9	24.8	30.5	33.8	34.7	33.6	33.6	31.4	29.5	26.2	30.9	34.7	24.8	9.9

SEPTEMBER	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*28.2*	*30.8*	*32*	*32.8*	*31*	*29.4*	*29*	*28.4*	*27.1*	*29.86*	*32.8*	*27.1*	*5.7*
SITE1	28.2	30.5	32	31.8	29.9	28.8	28.2	27.5	27.2	29.34	32	27.2	4.8
SITE4	27.2	32.5	31.2	31.4	29.8	28.6	27.5	27.1	26.3	29.07	32.5	26.3	6.2
SITE9	28.2	31.3	31.7	32.3	30.7	29.3	28.6	27.1	27.4	29.62	32.3	27.1	5.2

JANUARY	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*11.9*	*18*	*24.2*	*25*	*20.1*	*15.7*	*14*	*12.8*	*11*	*16.97*	*25*	*11*	*14*
SITE 1	15.3	22.4	25.6	26.3	20.9	20.1	17.8	14.7	15.3	19.82	26.3	14.7	11.6
SITE 4	14.8	23	24.5	24.2	21.1	19	16.8	14.2	15	19.18	24.5	14.2	10.3
SITE 9	16.3	21.9	26.5	25.2	21.9	20.5	18.5	15.6	16	20.27	26.5	15.6	10.9

MODERATE SITES

APRIL	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*32.1*	*33.8*	*34.1*	*36.5*	*34*	*31.3*	*28.2*	*27.1*	*30.8*	*31.99*	*36.5*	*27.1*	*9.4*
SITE 6	26.7	34.1	37.1	36.8	35.7	30.7	29.5	26.2	27.1	31.54	37.1	26.2	10.9
SITE 7	25.8	32.4	36.9	36	33.8	31.2	30.3	27.2	26.3	31.1	36.9	25.8	11.1
SITE 8	24.8	28.3	32.7	36.8	33.8	31.6	28.9	26.8	25.7	29.93	36.8	24.8	12
SITE 10	24.8	32.8	33.7	35.5	33.5	31.3	29.7	27.8	26.7	30.64	35.5	24.8	10.7

SEPTEMBER	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*28.2*	*30.8*	*32*	*32.8*	*31*	*29.4*	*29*	*28.4*	*27.1*	*29.86*	*32.8*	*27.1*	*5.7*
SITE6	28.1	32.4	32.6	32.4	30.7	29.4	28.4	27	27.6	29.84	32.6	27	5.6
SITE7	27.6	29.6	31.9	32.3	29.8	28.4	27.8	27.6	26.8	29.09	32.3	26.8	5.5
SITE8	28.2	31.3	31.7	32.3	30.7	29.5	28.6	27.1	27.4	29.64	32.3	27.1	5.2
SITE10	28.2	31.4	31.7	31.7	30.4	29.2	28.2	26.9	27.4	29.46	31.7	26.9	4.8

JANUARY	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*11.9*	*18*	*24.2*	*26*	*20.1*	*15.7*	*14*	*12.8*	*11*	*16.97*	*25*	*11*	*14*
SITE 6	15	23	25.9	27.1	21.9	20.4	18.2	15.2	15.1	20.2	27.1	15	12.1
SITE 7	12	15.7	19.4	23.4	19.6	14.9	14	11.1	12.8	15.88	23.4	11.1	12.3
SITE 8	14	19.5	25.2	26.3	21.5	19.3	17.4	14.4	14.7	19.14	26.3	14	12.3
SITE 10	13.4	20.6	22.1	23	20	17.9	15.8	14.9	14.1	17.98	23	13.4	9.6

DENSE SITES

APRIL	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*32.1*	*33.8*	*34.1*	*36.5*	*34*	*31.3*	*28.2*	*27.1*	*30.8*	*31.99*	*36.5*	*27.1*	*9.4*
SITE 2	25.6	29.8	34.2	33.5	32.3	31.6	30.8	28.8	27	30.4	34.2	25.6	8.6
SITE 3	24.8	34.1	36	36.1	33.7	30.3	29.1	28.7	26.4	31.02	36.1	24.8	11.3
SITE 5	24.3	28.6	33.2	35	34.5	32.8	27.8	26.7	26.1	29.89	35	24.3	10.7

SEPTEMBER	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
MET	*28.2*	*30.8*	*32*	*32.8*	*31*	*29.4*	*29*	*28.4*	*27.1*	*29.86*	*32.8*	*27.1*	*5.7*
SITE2	28.4	30.4	31.2	30.8	30.6	29.5	28.6	27.5	27.5	29.39	31.2	27.5	3.7
SITE3	27.5	31.6	34.1	33.5	29.9	28.4	27.9	27.4	27.7	29.78	34.1	27.4	6.7
SITE5	28.4	30.6	32.8	31.6	31	29.9	29	26.9	28.3	29.83	32.8	26.9	5.9

JANUARY	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00	aver.	max	min	swing
Met.	*11.9*	*18*	*24.2*	*25*	*20.1*	*15.7*	*14*	*12.8*	*11*	*16.97*	*25*	*11*	*14*
SITE 2	16.8	18.7	22.6	23.7	22.2	21.8	19.1	16	17.6	19.83	23.7	16	7.7
SITE 3	14.1	18.9	25	25.8	20.6	18.8	16.8	14.9	14.5	18.82	25.8	14.1	11.7
SITE 5	13.5	15.8	19.2	19.7	17.8	15.7	14.6	12.3	12.5	15.68	19.7	12.3	7.4

Open Sites

In categorising open sites certain variations from previous classification (with regard to thermal behaviour indoors) have been made since indoor conditions are not a consideration here. Although the buildings in sites 4 and 9 are in moderate sites because the exterior temperatures were measured at a height from the ground where there is relative openness they are considered as open here..

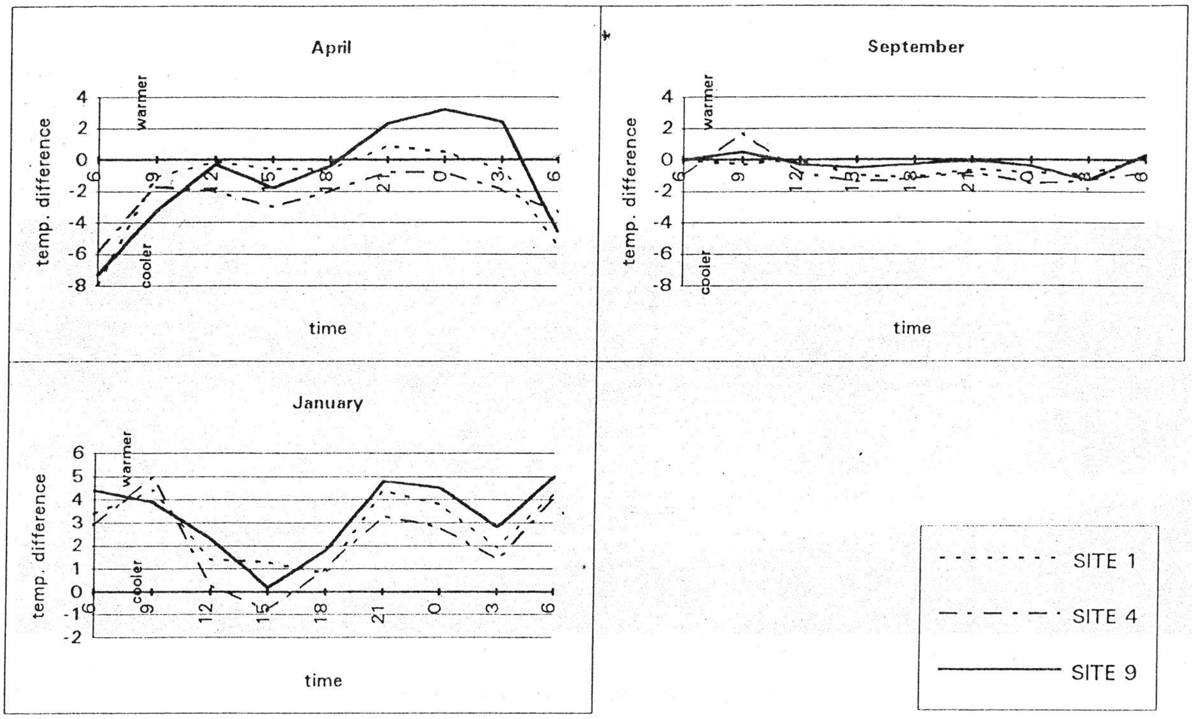

Fig 5.19. Differences between site and meteorological temperatures for open sites.

When meteorological data report high temperatures (April), temperatures in open sites are lower in average. At the beginning of the day the site temperature can be lower by up to 8°C. This difference is lower during the day and at night, temperatures at site are close or higher than the meteorological data. Both maximum and minimum of site temperatures are lower than meteorological data and the swing is comparable.

In September the open sites are cooler on average and consistently so throughout the 24 hour period, fluctuations above meteorological data are temporal and event related. The difference is not large and sites 4 and 9 are warmer for brief instances in the morning when the particular location of the measurements had direct sunshine. Site and meteorological conditions at the beginning of the day (0600 hrs.) are nearly same. Maximum and minimum temperatures are close and there is not much difference in swing.

In the cold day (January) the site temperatures are warmer in average and at all times. In the morning (0600 hrs.) the local conditions are warmer by up to 4°C. The conditions are close in the afternoon hours between 1200 and 1800 hours. Maximum and minimum temperatures are higher at site and the swing is lower.

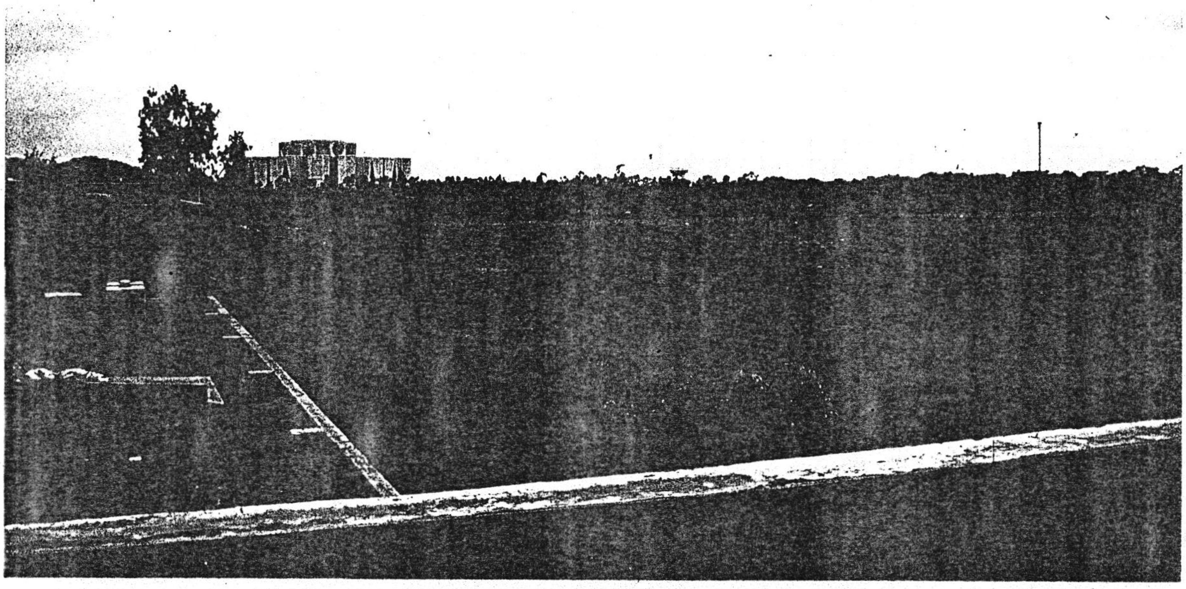

Fig 5.20. An open site (case1)

Moderate sites.

During the hotter periods (April) it is difficult to determine a common behaviour pattern in temperature fluctuations for the whole measurement period in the sites belonging to the moderate category. The conditions depend largely on the individual characteristics of the site. The common trend is that site temperatures in the beginning of the day are cooler by up to 7°C and are slightly warmer between 2100 and 0300 hours. The maximum temperature at site is close to the meteorological but the minimum is lower resulting in a larger swing at site.

Temperatures of moderate sites in September vary differently with meteorological data until 1300 hrs after when site temperature are cooler for the rest of the period. Maximum temperature, minimum temperature and the swing at the sites are very close to meteorological conditions.

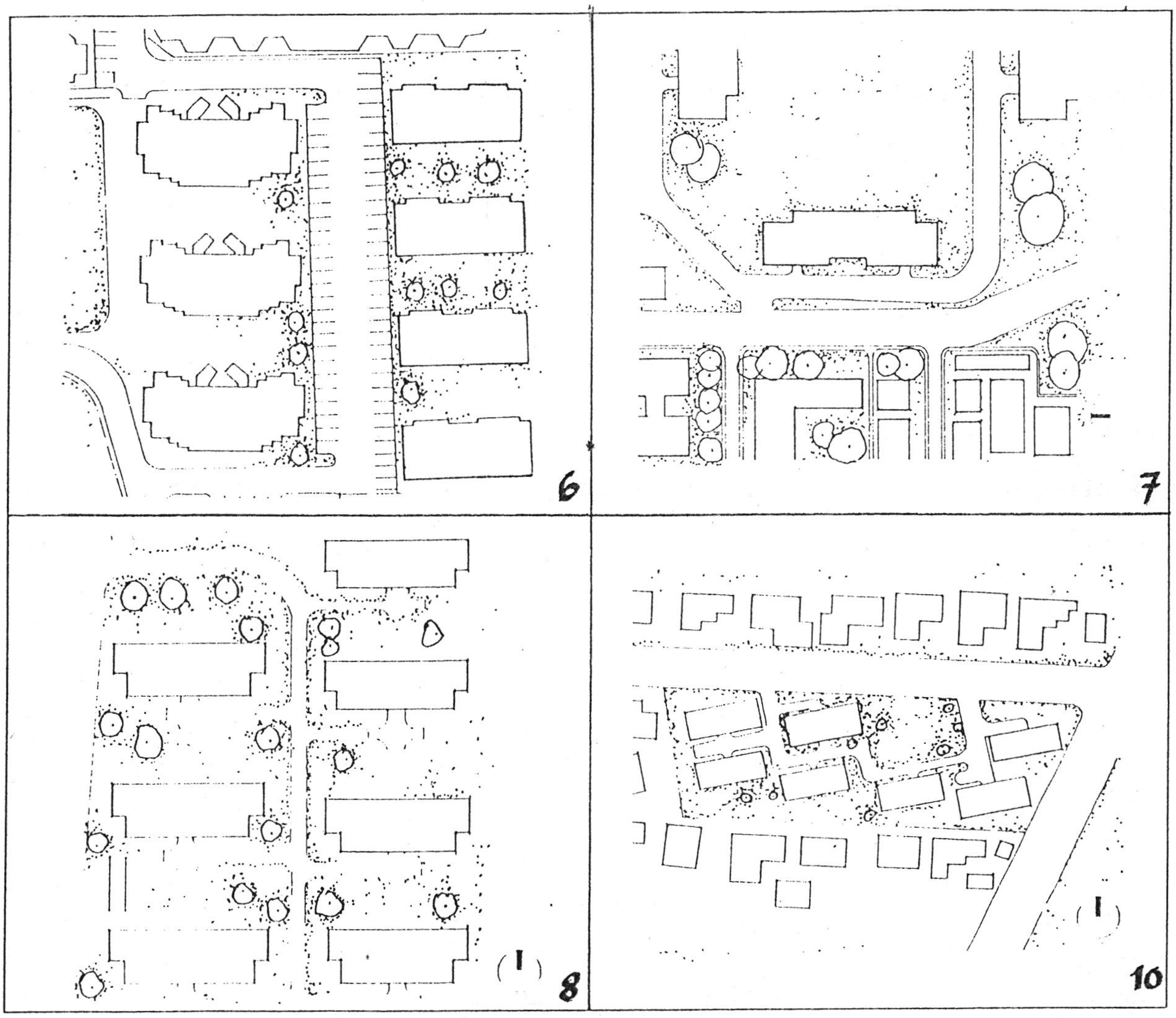

Fig 5.21. Moderate sites

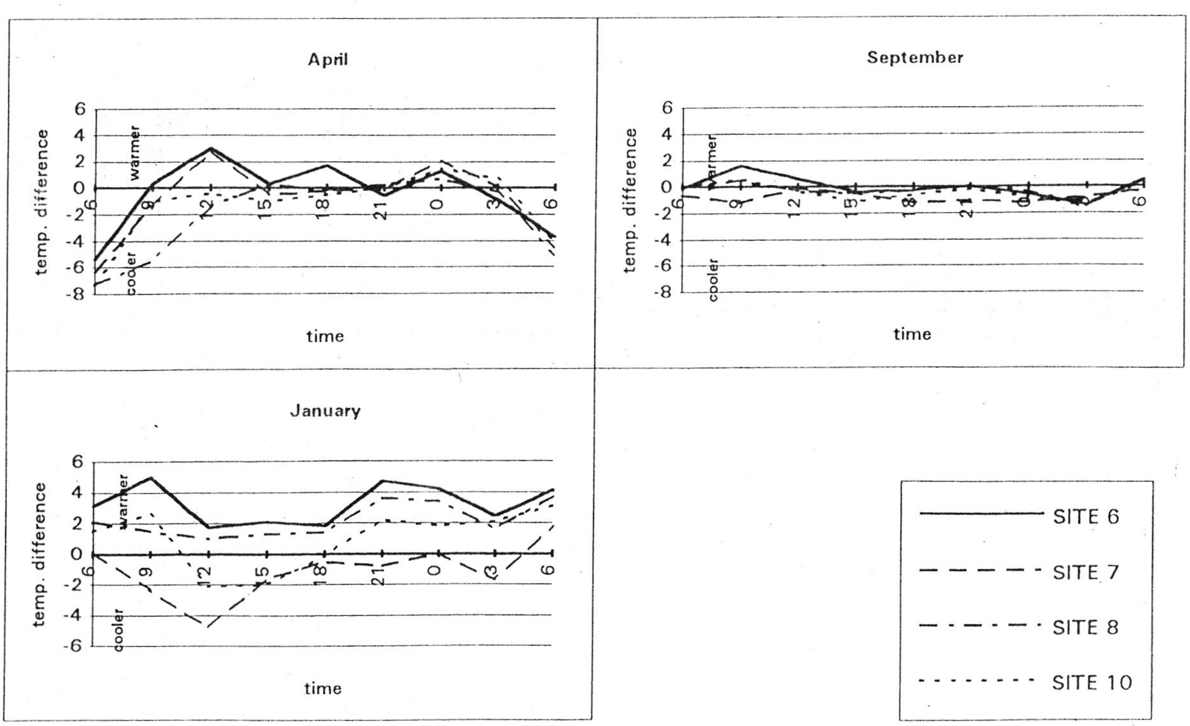

Fig 5.22 : Differences between site and meteorological temperatures for moderate sites.

In the cooler period (January), there is variation in site behaviour during the day. Temperatures in sites 7 and 10 are cooler in parts of the day. More exposed sites (6 and 8) are warmer. In the evenings site temperatures are usually warmer or close to meteorological data. Temperatures at 0600 hrs are warmer by up to 3.5°C. Both maximum and minimum temperatures are lower at site as well as the swing.

Dense sites.

For dense sites the local temperatures depend on the nature of the denseness. Whether the surrounding structures are low (site 3), equal in height (site 5) or if the site is shaded by taller structures and trees (site 2).

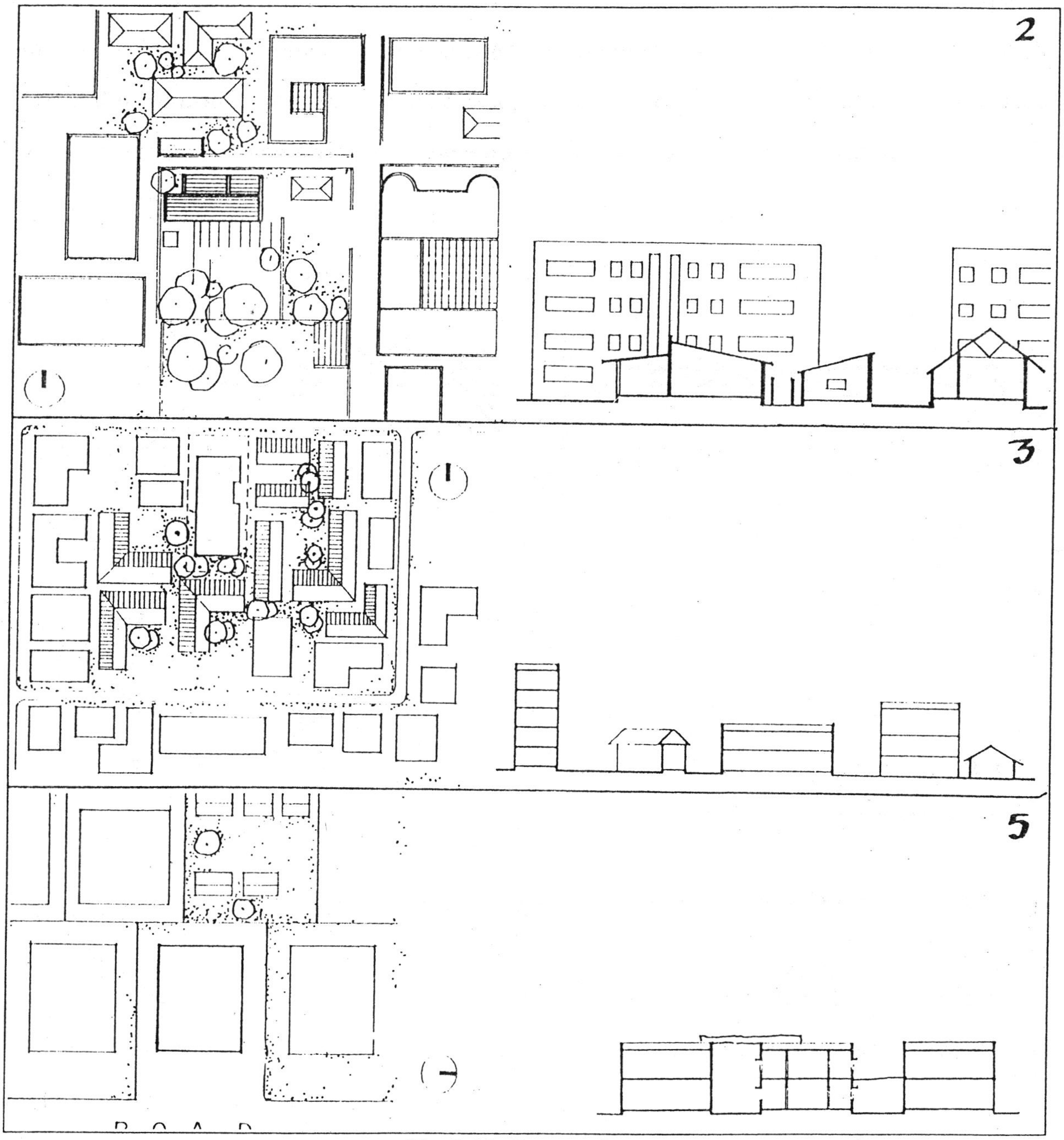

Fig 5.23. Dense sites

In April, because of the heat from the corrugated iron roofs of the surrounding structures temperatures at first floor levels in the exterior of site 3 is warmer than meteorological data in the morning, whereas the other two are cooler. In the evenings after 2100 hrs all sites are warmer but cool down rapidly after 0300 hours to temperatures up to 8°C lower than reported by meteorological data for the city. Both maximum and minimum temperatures are lower at site than meteorological data.

When the diurnal swing is low in September, morning temperatures at site level are close to meteorological conditions. For similar reasons as in April, mornings are warmer in site 3. The shaded dense site (2) is consistently cooler. Where the surroundings are of similar height the site conditions are generally close or warmer than met conditions although the measured location is almost always in shade. Maximum and minimum temperatures of the site and meteorological data are close except where there are lower metal roofed structures where it is higher. The swing in temperature is lower by 2°C for the shaded site and 1°C higher for the site 3.

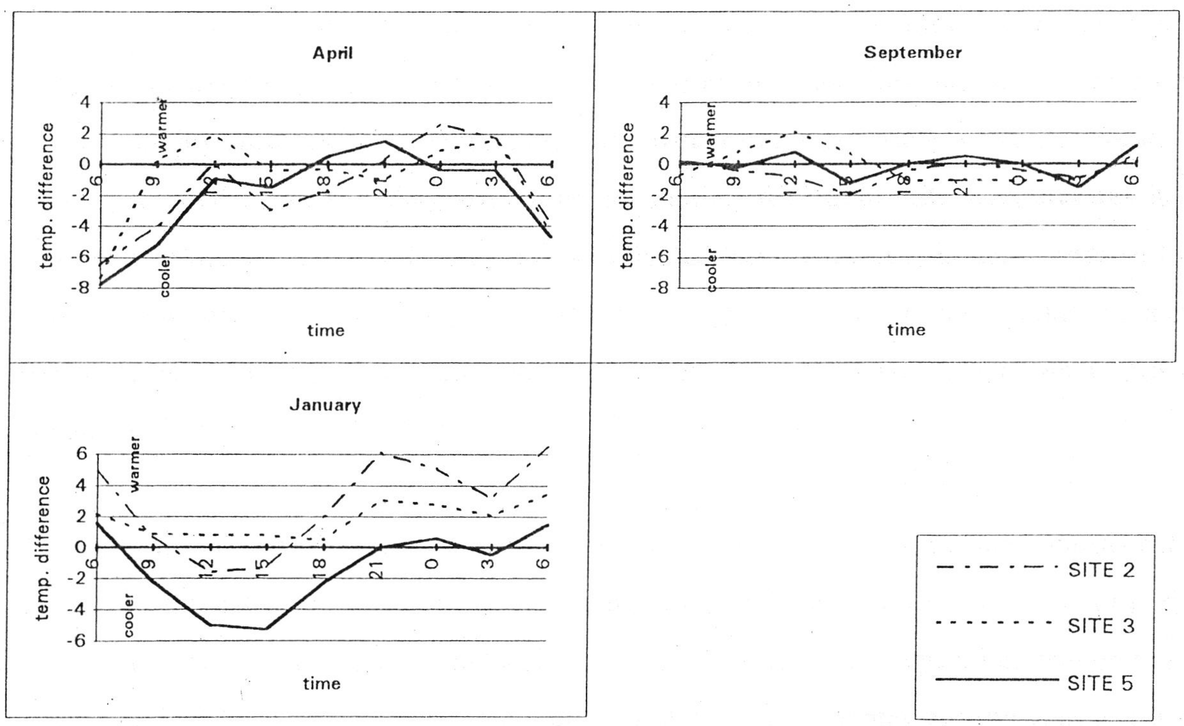

Fig 5.24: Differences between site and meteorological temperatures for dense sites.

In January site temperatures in the early part of the day are warmer than meteorological data but later for a reasonable part of the day they are cooler except in site 3 where it is slightly warmer. Night conditions in site are warmer in varying degrees.

5.17. Patterns in site temperatures.

Temperature data for the city from the meteorological office being the common reference, the patterns of variations from it in different kinds of sites offer a degree of predictability on a general level for open and dense sites. In moderate sites, because of differences in physical characteristics the behaviour is diverse and it is difficult to generalise the measurements for all three periods.

Certain patterns are common for all sites. Early morning conditions in all cases are warmer in the cool periods and cooler in the hot periods and close to meteorological conditions in the hot humid period without deviations. The difference of temperature can be up to 8°C at times. Winter nights are almost always warmer at site level. Night time temperatures in the warm humid periods are slightly cooler.

Unlike the measurements by the meteorological office, where they are made inside a Stevensons screen , measurements at site take into account air flow and the radiative effect of surrounding surfaces. At site direct radiation reaches at a later time of the day because of shade provided by surrounding structures accounting for cooler site temperatures in the mornings in the hot periods. In the cool periods inability of surfaces in dense sites to loose heat quickly at night because of lesser exposure to the sky result in them being warmer in the mornings. The differences are also more when the diurnal swing is larger (April and January)

Temperature pattern of open sites with respect to meteorological data is most consistent for all sites in the category. They are cooler in the hot periods and warmer in the cool periods than what is reported by meteorological data as well as other site types. For moderate sites generalisations are valid for the hot humid period only. Dense sites are the warmest in the hot periods but the predictability depends on the actual physical disposition of the site with respect to surroundings.

Table 5.17 is a summary of temperature difference between meteorological data and measured site data. The expressions are in terms of whether a particular situation is warmer or cooler than meteorological conditions and provides understanding of site temperatures when they need to be interpreted from data for the city. The numbers in brackets marks the maximum differences with the met data in degrees centigrade.

Table 5.17. Summary of differences of site temperatures from meteorological data and assessment of comfort potential of site in comparison.

		temperature					relative comfort potential
		day		night		swing	
		morning 0600-1200	afternoon 1200-1800	evening 1800-0000	night 0000-0600		
open	april	*cooler (7.9)*	*cooler (3)*	*warmer (3.2)*	*cooler (3.2)*	*similar*	*better*
	september	*equal*	*cooler (1.4)*	*cooler (1.5)*	*cooler (1.5)*	*similar**	*same*
	january	*warmer (5)*	*warmer (2.3)*	*warmer (4.8)*	*warmer (4.5)*	*lower*	*better*
moderate	april	*cooler (7.3)* *warmer (2.8)*	*warmer (2.8)* *equal*	*equal*	*warmer (2.1)* *cooler (1.1)*	*larger*	*better*
	september	*warmer (1.6)*	*cooler (1.1)*	*cooler (1.2)*	*cooler (1.5)*	*similar*	*same*
	january	*warmer (3.1)* *cooler (4.8)*	*warmer (1.4)* *cooler (1.6)*	*warmer (4.7)*	*warmer (4.1)*	*lower*	*better*
dense	**april** lower	*warmer (1.9)*	*warmer (1.9)*	*cooler (1)*	*warmer (1.6)*	*larger*	*better*
	april equal	*cooler (7.8)*	*cooler (1.5)*	*warmer (1.5)*	*cooler (4.7)*	*close*	
	april shaded	*cooler (6.5)*	*cooler (1.7)*	*warmer (2.6)*	*warmer (2.6)*	*lower*	
	sept lower	*warmer (2.1)*	*warmer (.7)*	*cooler (1.1)*	*cooler (1.1)*	*larger*	*similar*
	sept equal	*warmer (.8)*	*cooler (1.2)*	*warmer (.5)*	*cooler (1.5)*	*larger*	
	sept shaded	*cooler (.8)*	*cooler (2)*	*cooler (.4)*	*cooler (.9)*	*lower*	
	jan lower	*warmer (2.2)*	*warmer (.8)*	*warmer (2.8)*	*warmer (3.5)*	*lower*	*better*
	jan equal	*cooler (2.2)*	*cooler (5.3)*	*cooler (2.3)*	*equal (.5)*	*lower*	
	jan shaded	*warmer (4.9)*	*cooler (1.6)*	*warmer (6.1)*	*warmer (6.6)*	*lower*	

**within 1 ℃*

note: warmer or cooler for the time periods are based on conditions for most of the time where fluctuating.

The temperature data from the meteorological office can help identify design strategies to achieve comfort temperatures indoors. Temperatures at site are different and may offer better comfort potential as indicated in the table, on the following basis:

i. whether maximum and minimum site temperatures are closer to comfort temperatures in relation to meteorological data.

ii. The temperature swing at site if lower or higher is indicative of the relative stability of comfort temperatures.

Between different kinds of sites, open sites offer the best cooling potential, particularly in the hot dry period when they are cooler than the other categories. Moderate sites are slightly warmer in average than dense sites but day time temperatures in dense sites are higher unless there it is shaded. In the hot humid period all sites behave almost similarly. In the cool period dense sites are generally cooler than the others, particularly at night. It is difficult to say predict the temperature pattern of moderate sites with respect to dense sites as some of them have similar characteristics (table 5.16).

5.18. Site climate and design considerations.

Building design considers meteorological data to determine the basic design strategy. At the level of the site the requirements may vary as a result of the site climate. The differences between sites result in different indoor conditions and some sites may offer better comfort potential. Depending on site conditions some general assumptions about site temperatures as varying from meteorological data may be made.

Considerations of minimum and maximum temperatures at site level for hot and cool days vary significantly from meteorological data. The site temperatures are usually lower in the hot periods and warmer in the cool periods.

Night-time conditions in the site for hot and cool days at site are closer to comfort temperatures than indicated by the meteorological data.

Swing of temperature at site level is mostly lower or equal to that of the meteorological data. In January it is always lower. Since indoor swings are usually lower than the outdoor this indicates the possibility more stable comfort conditions indoors.

As a general state, conditions in residential sites are offer better comfort potential at night than indicated by met data. Open sites are most preferable as they are always better than other types.

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CHAPTER SIX

Optimising Indoor Comfort: Simulation Studies

6. OPTIMISING INDOOR COMFORT: SIMULATION STUDIES

6.1. Introduction

The comparison of thermal performance of the case studies in the previous chapter discusses the effect of changes in aspects of building design on indoor conditions. Because of the simultaneous influences of many different conditions it is difficult to isolate the exclusive effect of one single aspect or the changes of it. Thermal simulation allows study of the effect of changes in one aspect while others remain constant. The observations of simulated behaviour that occur due to changing parameters allow the identification of elements, the reduction or introduction of which in the design contribute to indoor comfort.

The thermal simulations were performed with the dynamic thermal simulation programme SPIEL (1). The interpretation of simulated temperatures as relating to measured conditions of empirical comfort criteria (chapter 3).

6.2. Parameters investigated

Thermal capacity: The effects of thermal inertia was simulated as changes in wall thicknesses. Wall thicknesses vary as a multiple of 125mm , the width of a single brick. Both internal and external walls are subjected to changes in thickness simultaneously as would happen in the commonly used load bearing wall structural system. The brick walls are cement plastered on both sides.

Exposure: The effect of exposure with respect to ground, intermediate and top floors are investigated. Other than gains from the external wall and window, the extra effect of cooling as a result of contact with the ground and the heat gain from roofs on top floors are the main considerations. Slab thicknesses remain constant. Means of heat gain control by manipulation of design elements on the roof are examined separately.

Orientations: The investigation on orientations considers the effect on internal temperature of the cardinal and semi cardinal orientations.

Time periods: The analysis is based on exterior conditions in the three days of the year similar to the case studies. While in the case studies outdoor conditions varied between sites in the same day , the meteorological data provides the common basis for the simulations. The data generated by the simulation program from average temperatures and swings are slightly different.

Table 3.1. Meteorological data used as a basis for simulations.

Days	Average Temperature	Swing
April (hot and dry)	31.9°C	9.4°C
September (hot and humid)	29.8°C	5.7°C
January (cool)	16.9°C	14°C

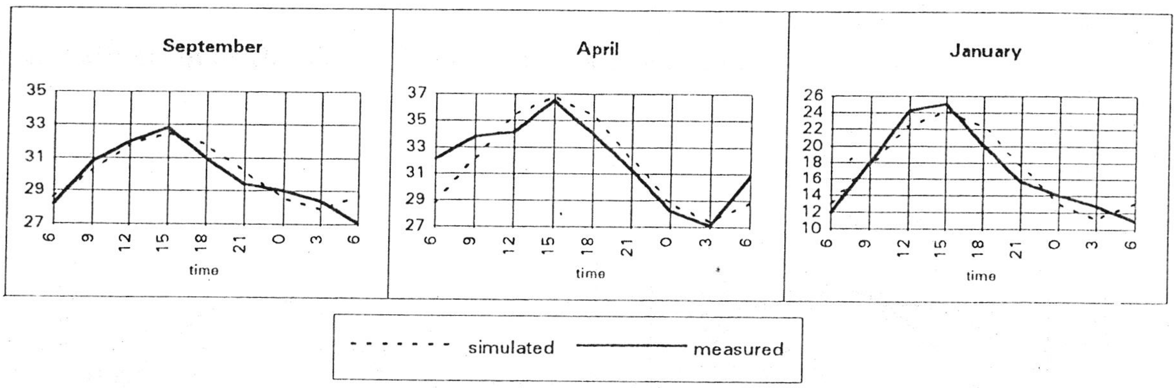

Fig 6.1. Simulated and measured outdoor temperatures (met) for the three periods

6.3. The Building Model

The building model consists of a single zone/space, the parametric conditions of which are varied and generate different indoor temperatures. The situations in the case studies are assumed as basis for determining the size and configuration of the room. Case study No. 6 is considered to be an average size room and a close representation of all others (see Appendix 7). The model has only one wall exposed to the exterior, which would be the case for most of the rooms in any given house or flat. This wall has the window with standard shading of 0.5m projection directly above it. For the simulations the room was assumed to have no supplementary heating or cooling or any internal heat gains.

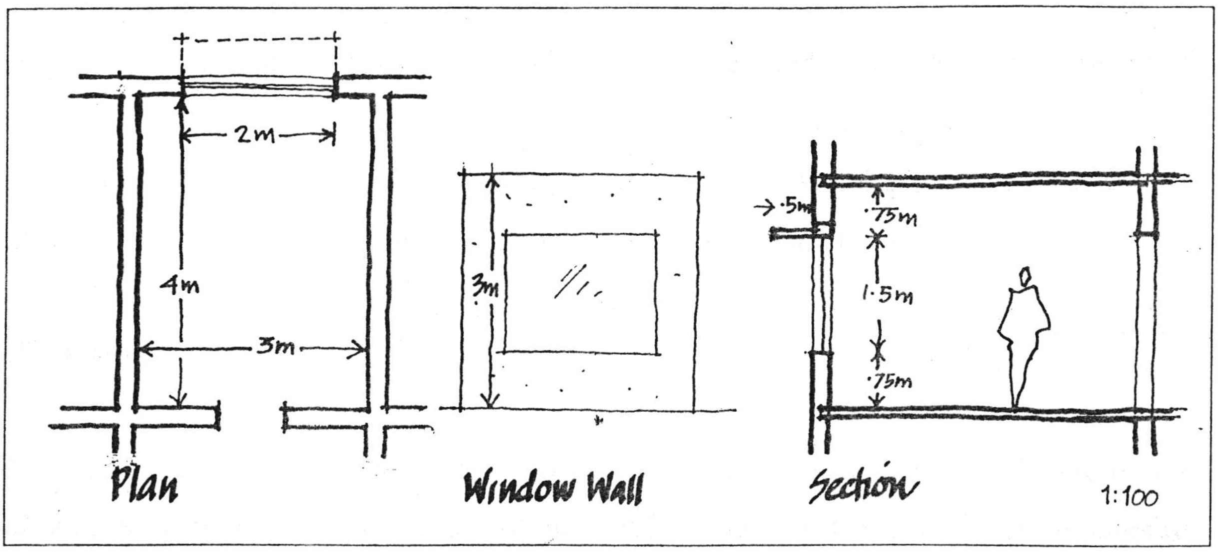

Fig 6.2 Architectural representation of the simulated room

6.4. Validation of the simulations with measured data

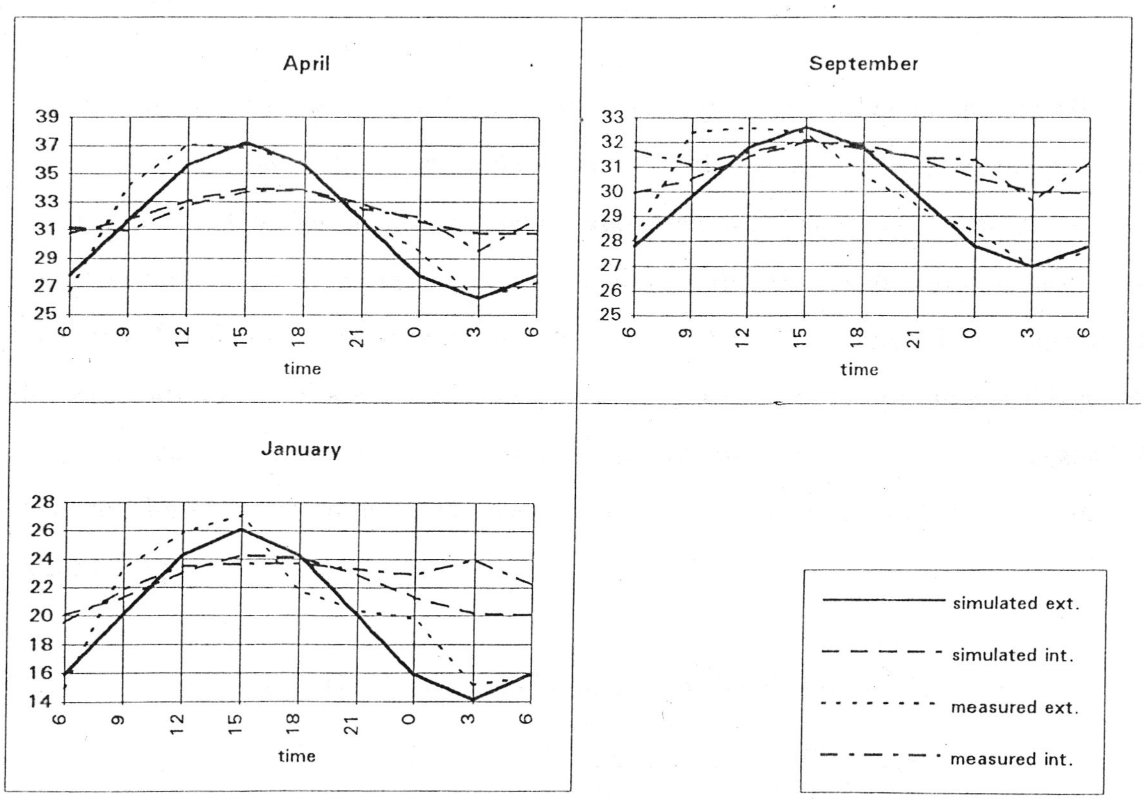

Fig 6.3. Simulated and measured temperatures for case study (no. 6)

In order to validate the compatibility of the programme the conditions of one of the case studies was simulated and the results compared with field data. Adjustments were made for the differences in exterior colour and the particular conditions of the local external temperature. In all three periods the measured external temperatures are higher earlier in the day because of site characteristics where buildings and hard surfaces raise local temperatures. At times windows are kept closed at night thus raising measured room temperatures above simulated data which assumes a constant high air change rate. In January the room used a portable heater for brief periods at night.

6.5. Results

The results are based on indoor temperatures generated for varying conditions of the parameters mentioned. The analysis of the results consider the prevalence of comfort indoors, the time periods when they occur with respect to the comfort temperature range defined in Chapter 3 (24°C-32°C) for still air conditions for normal summer clothing and sedentary activity.

6.5.1. Effect of thermal mass

For a south facing room on an intermediate floor (without the additional cooling effect of the ground or heat gain from the roof) the effect of building mass on indoor temperatures was simulated as a function of the commonly occurring wall thicknesses. On the two hot days the resultant indoor temperatures are a function of differences in outdoor swings and temperatures. The indoors are more comfortable for the September day when temperatures and the swing are lower. The effect of building mass on comfort is noticeable in this period with heavier mass resulting in more comfortable indoor temperatures. The change in temperatures, however, is around a degree centigrade both at the maximum and minimum values for all types.

Table 6.2. U values for different wall thickness (W/m^2°C)

wall thickness	internal	external
125mm	1.30	1.23
250mm	1.08	1.04
375mm	0.93	0.90
500mm	0.82	0.79

In the cool period the indoors are comfortable during the afternoons and early evenings only and the rest of the time they are cooler. The light wall structure is comfortable for up to 8 hours as opposed to the heavier structure which is comfortable for only 3 hours.

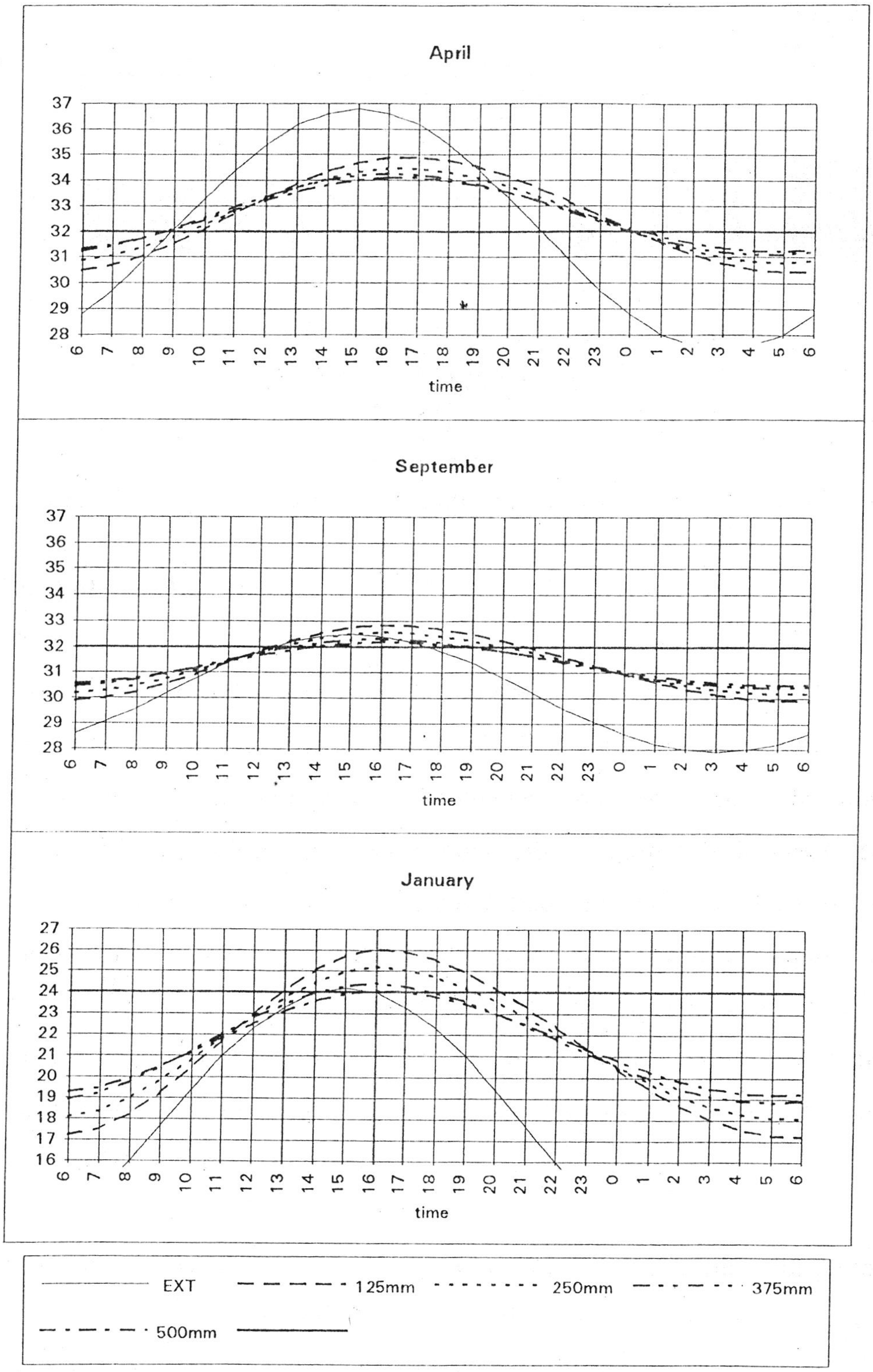

Fig 6.5. Outdoor and indoor conditions for different wall thicknesses for a south oriented room in an intermediate floor.

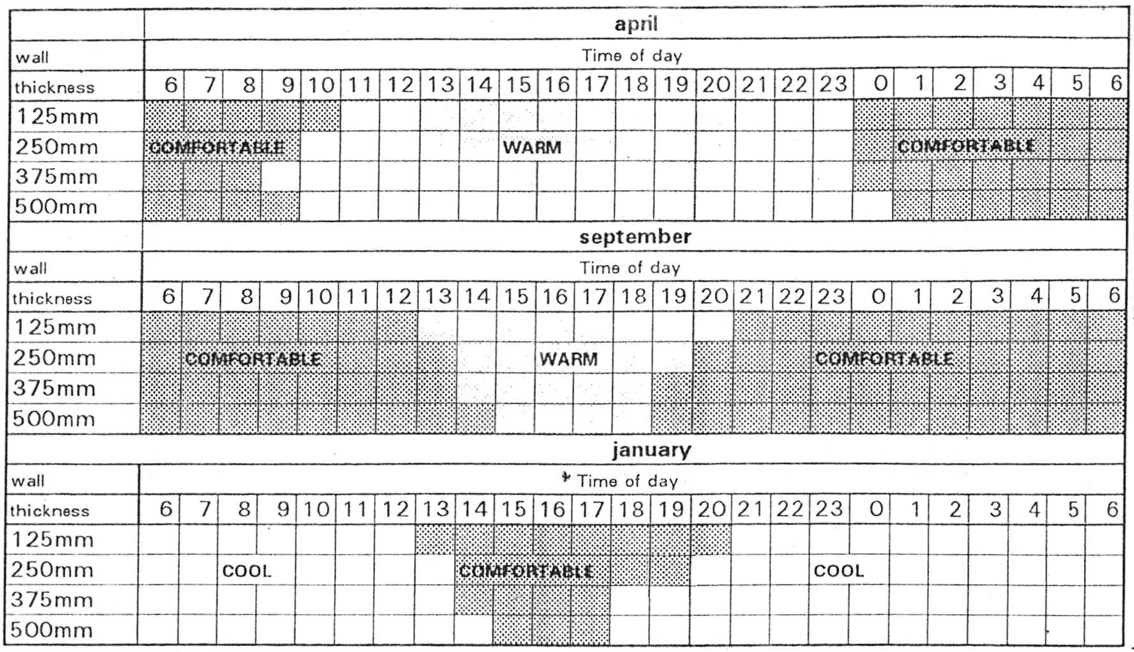

Fig 6.6. Hourly assessment of comfort as a function of wall thickness.

6.5.2. Effect of Orientation.

For a room on an intermediate floor of 250mm wall thickness the effect of orientation on indoor comfort shows little difference between differently oriented rooms in April. In September the indoors are comfortable for longer stretches of time. In rooms with a northern orientation the indoors are always comfortable. For south orientation, except for a few hours in the afternoons the indoors are comfortable for most of the period. Other than the two northerly orientations all other situations are worse. From the point of view of occupancy the west is the worst as the situation is uncomfortable way into the evening. The east oriented room is uncomfortable for a longer period in the mornings when the most of the people are out. it is important to note that the nights are comfortable in both hot periods, at slightly later times in April than in September.

According to the simulations the rooms are rarely comfortable in the cool period. Except for the South and south westerly orientations, which are in the lower fringes of comfort for very small parts of the day all other situations are cold.

Comparison with conditions that are a result of changing building mass indicate that change above or below 250mm wall thickness for the same orientations will result in slightly longer comfortable periods with heavier buildings in September and lighter buildings in January. The conditions remain close in April.

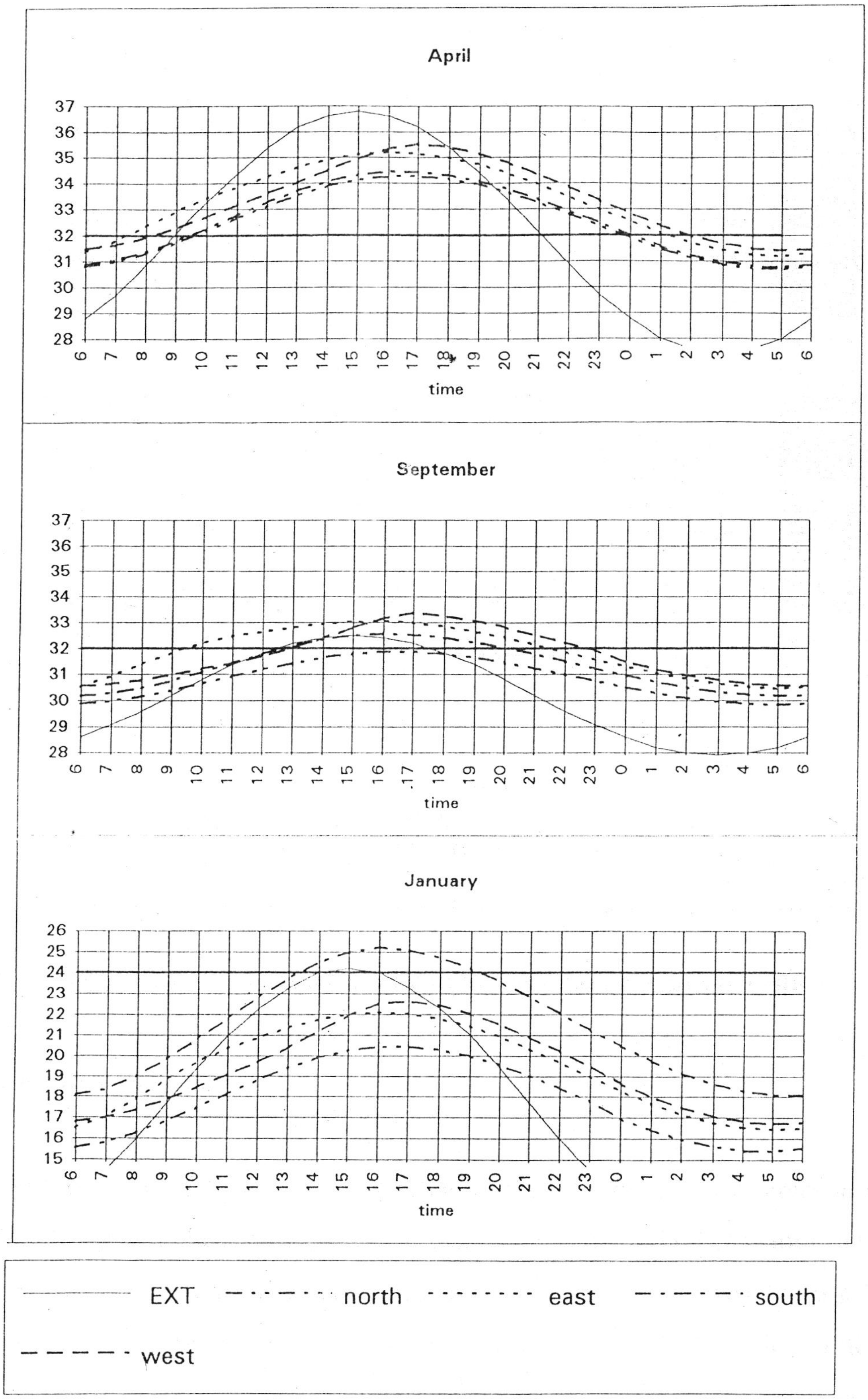

Fig 6.6. Indoor temperatures for different orientations of a room of 250mm wall thickness in an intermediate floor.

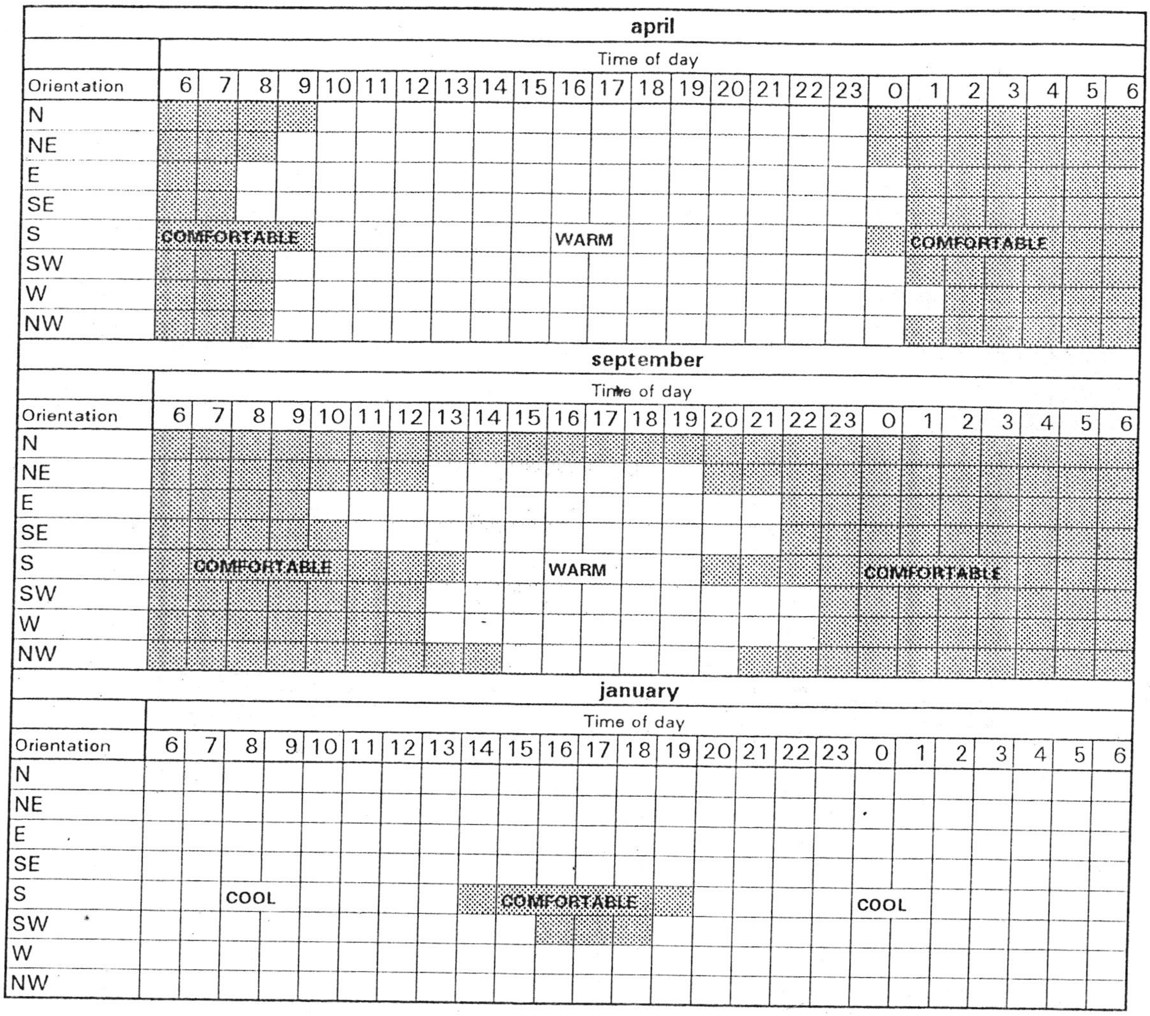

Fig 6.7. Hourly assessment of comfort as a function of orientation..

6.5.3. Effect of Exposure

Contact with ground contributes to the cooling of the interior (2)(3) whereas in top floors exposure of the roof to heat gain from solar radiation results in higher indoor temperatures In April ground floors are comfortable for up to 5 more hours as opposed to top floors and the difference in maximum temperatures are close to 2°C. With similar differences in maximum temperatures in September but lower outdoor temperatures the ground floor is always comfortable whereas the top floor is warmer than comfort between noon and 10 p.m.

Table 6.3.U Values for roof,ceiling and floor(W/m²°C)

Roof	3.4
Ceiling	3.2
Floor	2.6
Ground floor	3.0

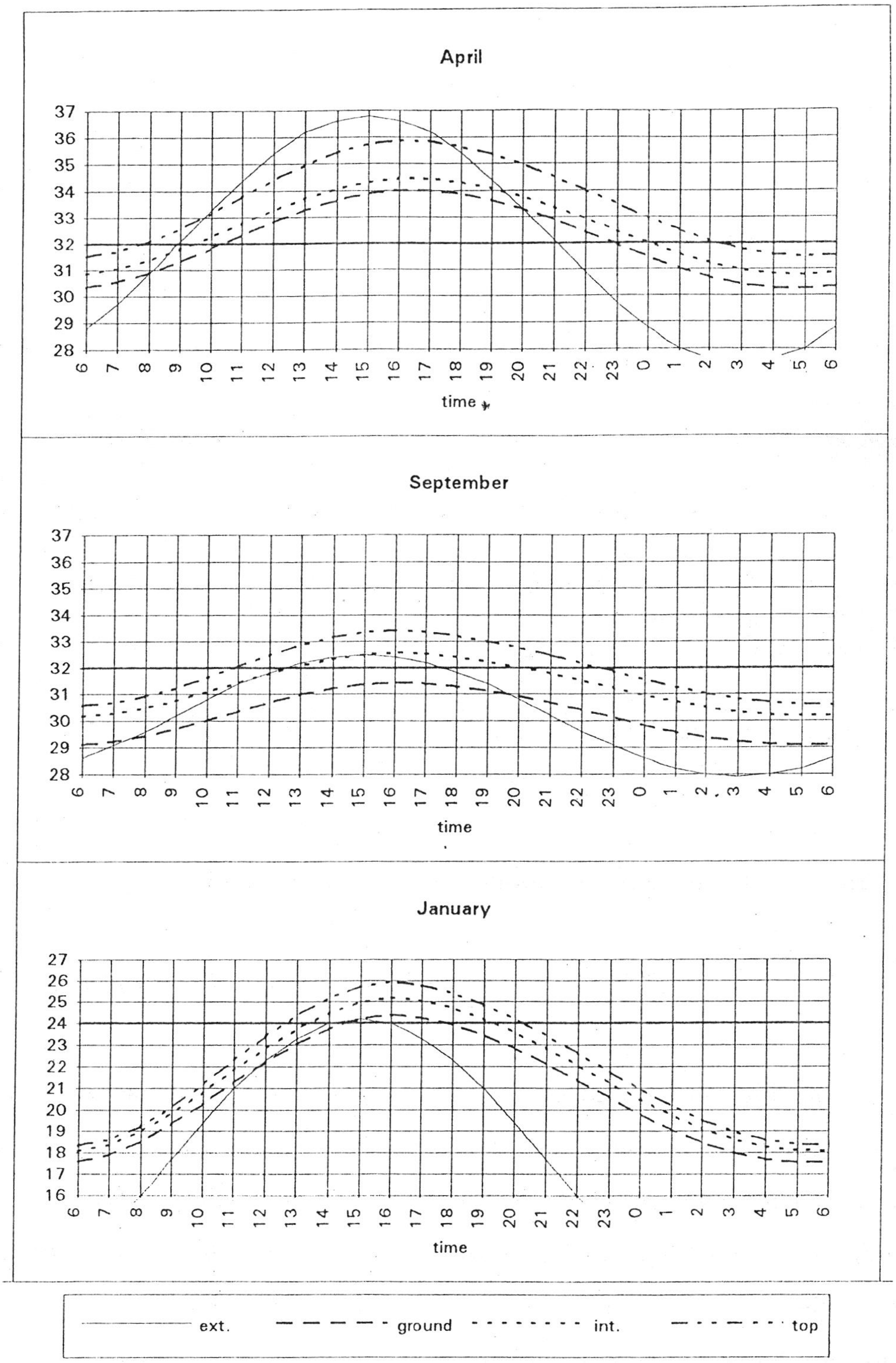

Fig 6.8. Indoor temperatures of 250mm walled rooms on ground intermediate and top floors having south orientation.

Conditions on intermediate floors are in between the two. These conditions assume a top floor concrete slab without insulation but a relatively low absorbtance of 0.3 as with light colours. It is worth noting that with time and weathering the colour of the roof darkens and absorbtivity increases with corresponding increase in heat gains. On the ground floors conduction losses to the ground are through the floor slab which consists of concrete bed and brick soling layer under a high emissivity floor finish.

In the cool period the situation is reversed and the upper floors are warmer hence comfortable for longer periods as opposed to ground and intermediate floors.

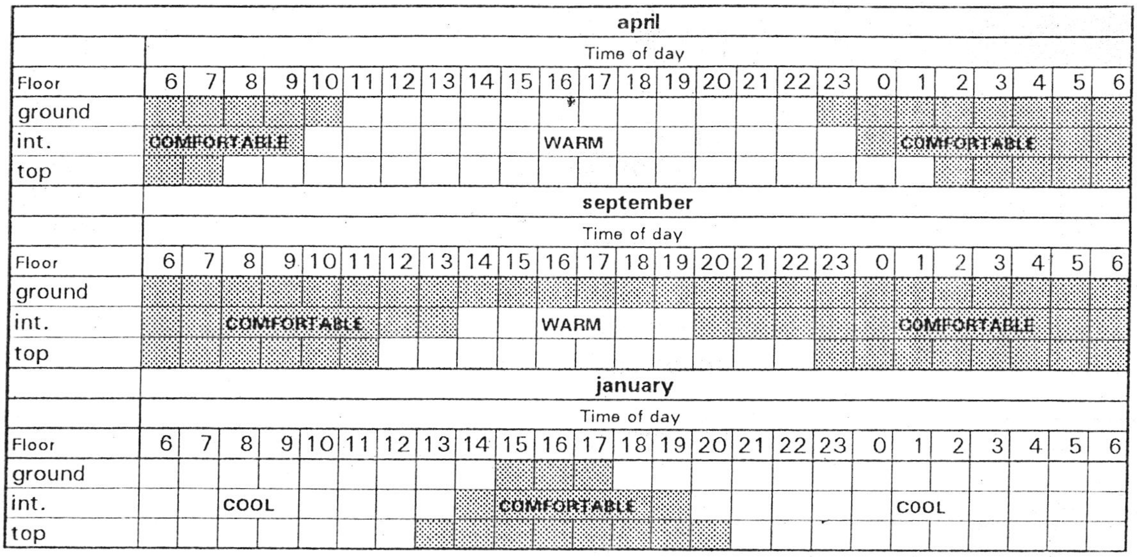

Fig 6.9. Hourly assessment of comfort as a function of exposure

6.5.4. Effect of thermal mass on exposure

Increase in thermal mass, by way of wall thicknesses makes little difference to the cooling potential of the ground in the hotter April period and although temperatures are slightly lower in heavier buildings in the mornings there is a lower incidence of comfort temperatures. In the September period, however, buildings having wall thicknesses of 250mm and 500mm are always comfortable, the latter having slightly higher but steadier temperatures. Conditions in the afternoons in the lighter walled structures are slightly above comfort levels. In the cooler period comfort is extended in lighter structures by a few hours.

On top floors indoor temperatures in heavier structures are always above comfort levels and comfortable periods in the other types are brief for the hotter April period. In September comfort conditions prevail during most of the night and well into the mornings for all situations irrespective of building mass. In the cool periods behaviour is similar for 125mm and 250mm walled structures, the heavier structure is cooler for 2 more hours.

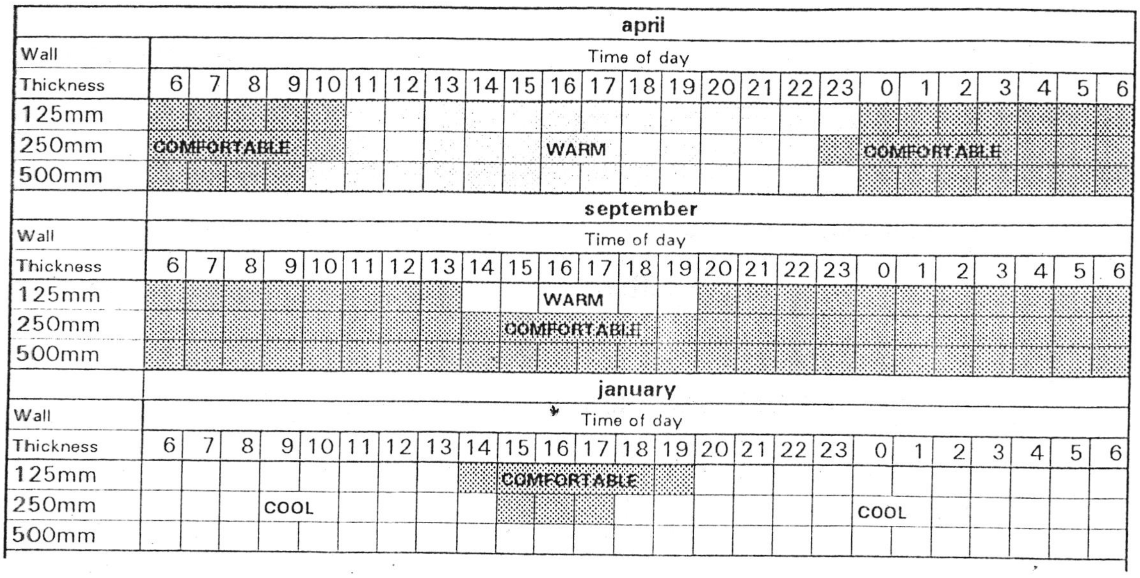

Fig 6.10. Hourly assessment of comfort as a function of thermal mass in the ground floor for a south facing room.

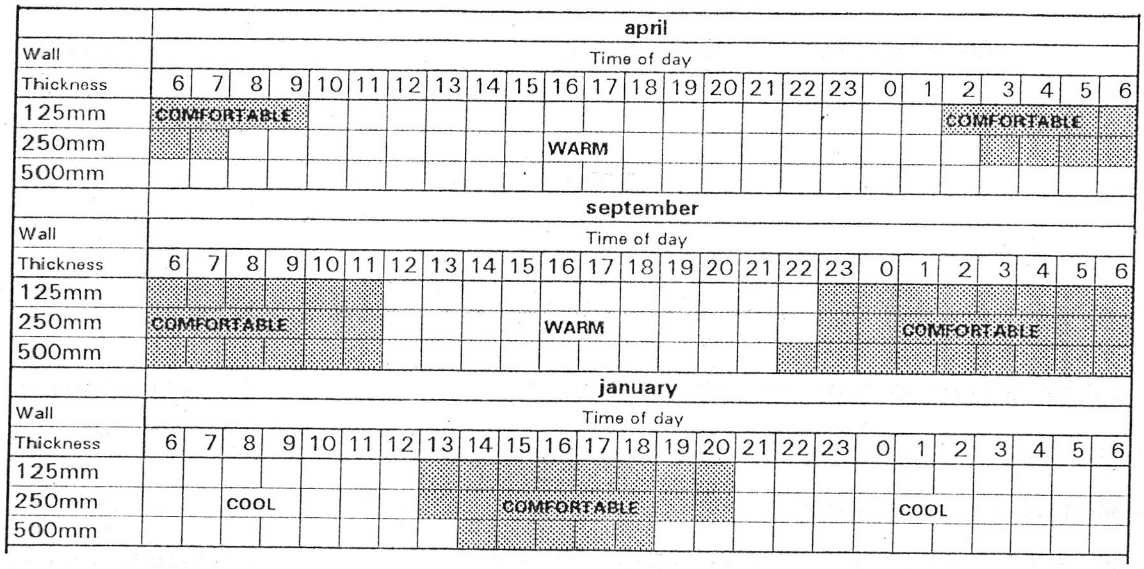

Fig. 6.11. Hourly assessment of comfort as a function of thermal mass in the top floor for a south facing room.

6.5.5. Roof design and indoor temperatures.

Top floor rooms with normal R.C.C. slabs are generally hotter and uncomfortable as opposed to their intermediate and ground floor counterparts even when they are assumed to be fairly new with low absorbtance on the surface. Materials used purely for insulation such as polystyrene are not known or available in Bangladesh and possibilities for control of heat gain exist with the use of alternative materials and methods (4)(5)(6). Four types of roof design were considered to evaluate the result on comfort in top floor rooms:

i) An ordinary concrete roof exposed to radiation,

ii) the same roof but totally shaded,

iii) with a layer of dense lime plaster of weight that will be supported with out any additional reinforcements to either the slab or walls and

iv) a roof made of hollow brick blocks with a layer of plaster on either side.

The last type has recently gained popularity as a roofing system.

Table 6.4. U Values of roof types(W/m^2°C)

Lime terracing	2.5
Hollow block	1.9

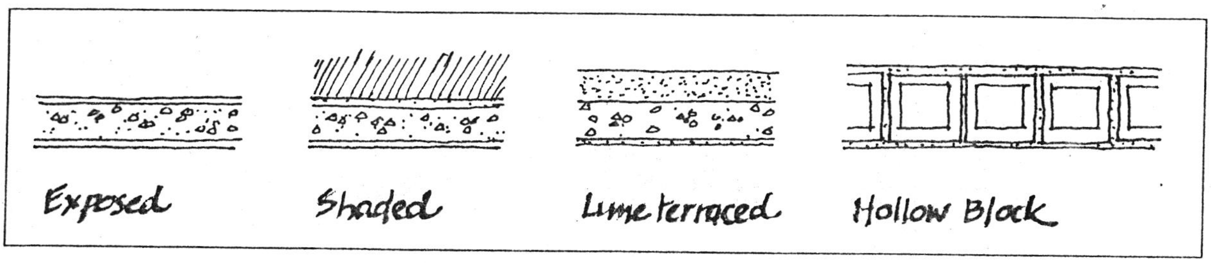

Fig 6.12. Different kinds of roof designs

Indoor conditions with all kinds of roofs in April are close in terms of comfort with the shaded roof performing slightly better. The indoor temperature difference between shaded and unshaded roofs are between 1°C and 1.5°C. Temperature performance of the hollow block roof is slightly higher but comparable to the shaded roof. The performance of the lime terraced roof is close to unshaded conditions. In September, although conditions are warmer than comfort for parts of the day indoor temperatures for all roof types, other than the exposed, are within 1°C of the maximum comfort temperature. With the shaded roof overall comfort performance is better and maximum temperatures are within 0.5°C of the upper comfort limit. In the cool period indoor conditions are cooler than comfort for all types except between 1 p.m. and 8 p.m. Unlike the hotter periods shaded roofs do not make any difference in comfortable periods.

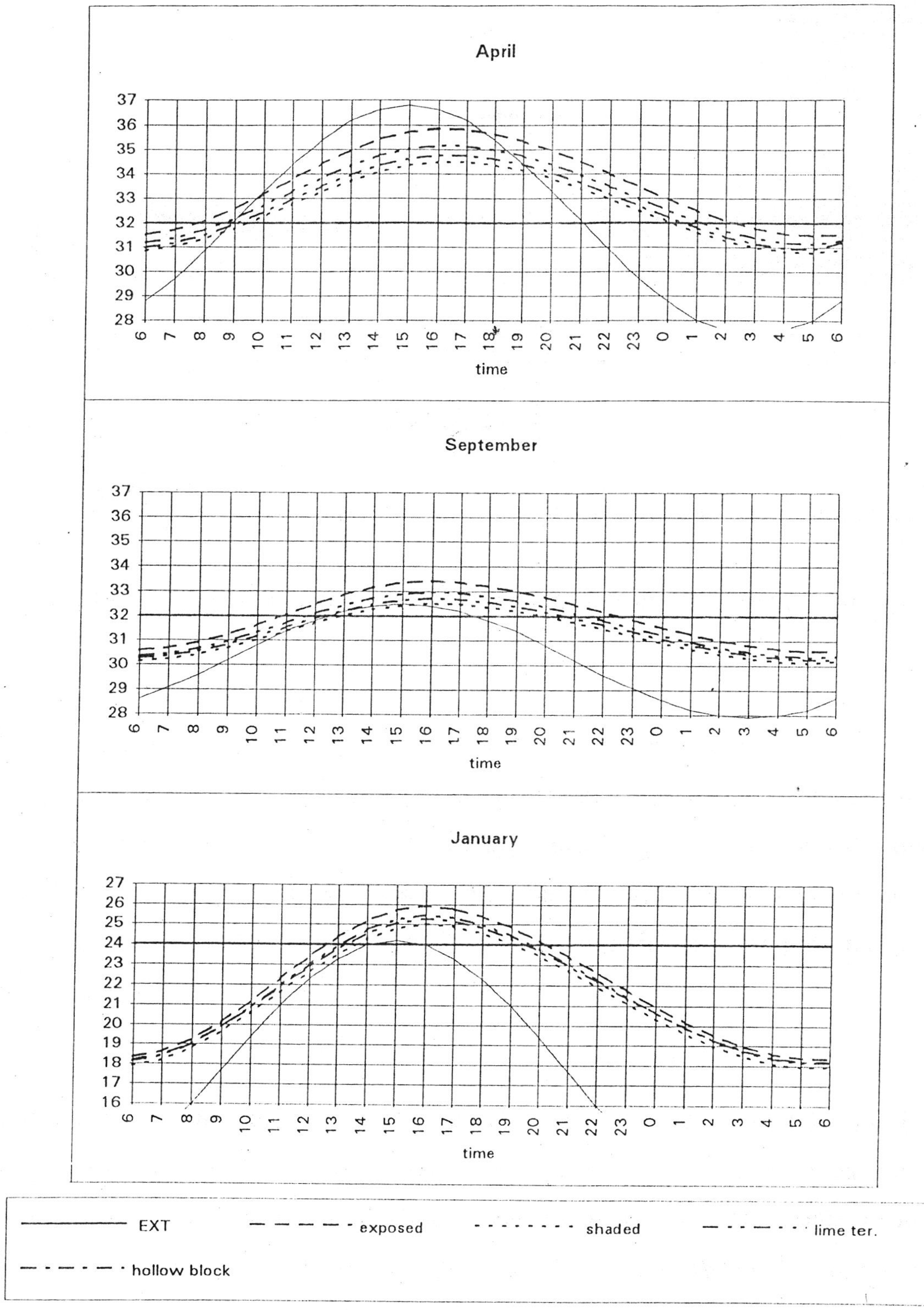

Fig 6.13. Indoor temperatures with different kinds of roofs in a 250mm walled south facing room on the top floor.

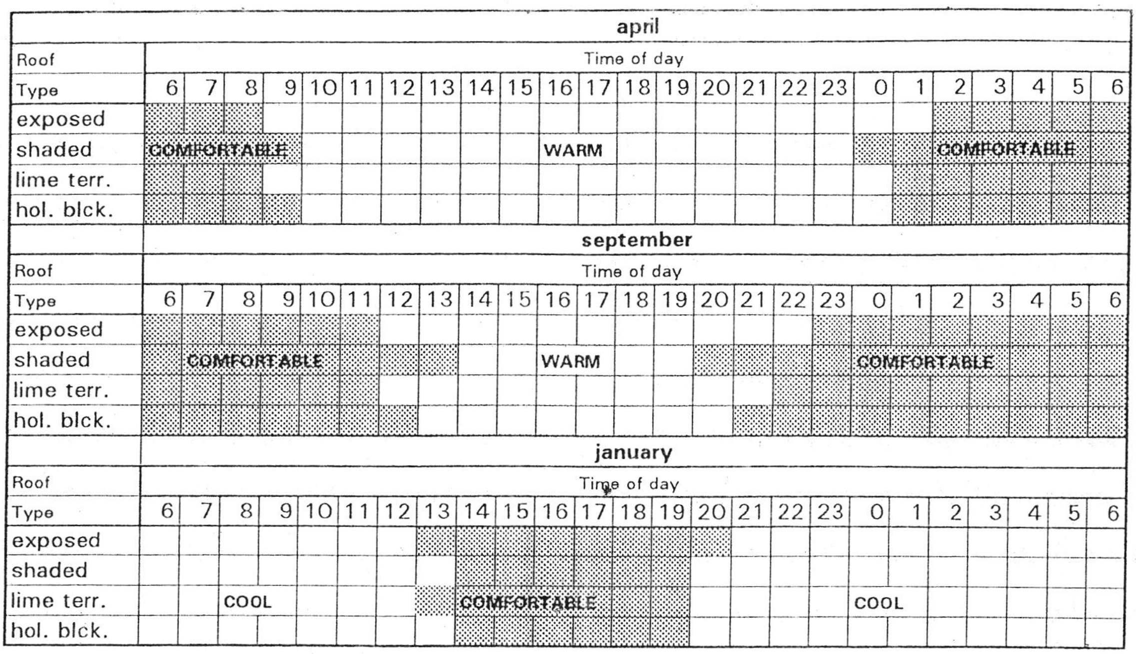

Fig 6.14. Hourly assessment of comfort in top floors as a function of roof design

6.6. Adjustments to comfort performance indicated by simulated temperatures.

The comfort temperatures assume conditions where there is no air movement and for people wearing ordinary summer clothing. The comfort performance of the various situations are therefore not subject to adjustments by individuals for the promotion of their own comfort. In the summer months air flow may be provided by the ceiling fan or through ventilation. In the cooler periods changes in clothing may produce comfort at lower temperatures. The consideration of these factors improve the comfort potential through personal intervention.

The ceiling fan at medium and fast speed settings is able to generate average air velocities of 0.3 and 0.5m/s in a room (Appendix 3). Since temperatures in April and September periods are close to the upper limit of comfort the use of ceiling fans or comparable air motion through natural means will be able to provide a cooler sensation. Where the conditions are above comfort levels air velocity of 0.45m/s can elevate the comfort temperatures to 35°C. In terms of comfort performance in the various time periods, all situations in September have the potential for comfort. In April, except peak periods in top floors with unshaded and lime terraced roofs comfort is provided with ceiling fans or comparable air velocities. It is important to note that the velocities for the ceiling fans are average for a room, at certain locations higher velocities occur and they have better comfort potential. In places where there is air flow from the outdoors in the evenings and at night, conditions will be cooler.

In the whole cool period the general conditions of temperature are not cold enough to require changes of clothing beyond insulation levels of .8 clo. Daytime conditions are mild enough to allow people to operate in ordinary summer clothing. The outdoor temperatures of the day in January on which the simulations are based are colder than usual and a value of 1 clo can be assumed for the early mornings and evenings. This would result in a depression of about 2°C in lower comfort temperatures (7)(8). Exposure to direct solar radiation will also add to comfort. In terms of comfort performance this means, in most cases an extension of 4 more hours of comfortable occupancy and in some cases (ground floors) this will extend to 7 hours. In the ground floor of a 500mm thick walled structure where normally it is always cool this consideration includes up to 9 hours of comfortable occupancy. At night warm enough bedding will be able to provide comfort in all situations. When it is colder the people have the wider options to improve their condition by wearing warmer clothes. In the warmer periods adjustments are difficult because air velocity from fans are limited and air flow through windows cannot always be relied upon.

The analysis of site temperatures data in chapter 5 shows local temperatures to be lower in the mornings as compared to meteorological data for the same period in the hot periods and higher in the cool periods. The simulations are based on meteorological data and although simulated outdoor temperatures are also cooler for the April period, actual differences are more and the indoor conditions are likely to be cooler in summer and warmer in winter for the morning hours.

6.7. Optimisation of comfort potential.

The incidence of comfortable periods and their extension over time depends on the combination of orientation , building mass and location amongst other variables. No single combination is able to provide comfortable temperatures all year round. Given the differences in behaviour over the three periods, situations which are able to optimise the conditions over these periods are the appropriate choices.

The orientation which offers maximum comfortable periods in terms of internal temperatures in summer is north. North is not a preferred orientation because the north face of a building gets the sun for only brief periods in a year and in a wet environment is subject to dampness of walls. The prevalent breeze direction in summer is south and south east and a north facing room is denied the scope for natural ventilation, if any (9). In the hot dry period north and south orientations are comparable and in the cool period south is a better orientation than north. The tradition of preference for a south orientation in Bangladesh is justified as it optimises all considerations.

The combination of aspects and the corresponding comfortable hours that a room can be expected to have in a period extending from the 6th hour of a day to the 6th hour of the next is the basis for the results of Table 6.4. It assumes a southern orientation as a preference. Ground floors are a better option for comfort in the summer whereas top floors are the worst and shading of the roof can help only in particular situations. The indoor temperatures in the cool periods usually present opposite comfort performances than summer. The occurrence of the hours of comfort in terms of time of day and its relevance to occupancy in an important consideration. Comfortable periods in the summer are mostly at night. With increasing comfortable hours the time extends to the mornings, evenings and eventually afternoons. In the winter the comfortable periods are mostly in the afternoons extending to the mornings but rarely into the night. This contradiction of conditions make it difficult to identify a situation which is uniformly comfortable for the whole year.

Table 6.5. Comfortable hours in various situation for a south oriented room.

location	wall thickness									comfortable periods*
	125	250	500	125	250	500	125	250	500	
ground floor					A	A				>18hrs.
										>12hrs
										>4hrs
									N	<4hrs.
inter. floor										>18hrs
										>12hrs
										>4hrs
										<4hrs.
top floor					shaded	A				>18hrs
										>12hrs
			shad							>4hrs
			N							<4hrs.
time	april (hot dry)			sept (hot humid)			january (cool)			

*□4-11 hours -night /night and mornings □12-16 hours - night + mornings/evenings □18-always - afternoons included
A indicated all the time and **N** indicates never

The choice of a particular combination of aspects of design has to consider the relevance of the time periods for which the simulations were made with respect to the whole year. The conditions described in September are typical or close to typical of the humid period which runs for 6-7 months of the year, the April period is for 2-3 months and represents a hot day, the January period is a cold day of the cool period which last 2-3 months. A comfortable situation in September, therefore, is good for half the year a optimal April and January situation in combination is good for the whole year.

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CHAPTER SEVEN

Discussions and Conclusions

7. DISCUSSIONS AND CONCLUSIONS

The previous chapters discussed thermal conditions in urban housing and its relationship to the environmental criteria that are perceived as comfortable by its occupants. The various types of houses measured and analysed show differences in their comfort performance. It is apparent that these differences occur because of differences in design characteristics. The following sections, first, discuss the aspects of design that are relevant to comfort and the factors that influence the thermal behaviour of houses. The concluding sections are design recommendations that will contribute positively to indoor comfort.

7.1. Thermal Comfort.

7.1.1 Considerations of Environmental Variables for Comfort.

Of all the environmental variables that influence comfort, the considerations of some are more relevant than others as issues in the design process.

Air temperature is a reliable indicator of comfort indoors for design purposes. Given that air flow indoors may not be consistent at all times and radiant temperature a function of design, the designer may set comfort air temperatures as target design conditions.

Radiant temperature, has been seen to have a decisive influence on comfort. The shading conditions and the nature of construction are important for lower radiant temperatures, hence comfort. A globe temperature range between 24.1°C and 31°C is able to provide comfortable occupancy without air movement in summer. Corresponding air temperatures are given by

$$T_{air} = T_{globe} \times 1.04$$

With increasing air movement globe and air temperatures are nearly equal. (see section 4.9)

Relative humidities for comfort show marked tolerance for high values in local subjects. Values of relative humidity for comfort are within the range of 50 to 95%. The effect of higher humidities can be moderated by air movement while the actual incidence of humidities lower than 50% is not so common.

Solar radiation affects comfort but in all cases observed there was little incidence of direct radiation indoors. Most houses are well shaded either by surrounding structures, trees or by shading elements on the facade. In densely built up areas where the surrounding surfaces and buildings have high surface albedo reflected radiation can contribute to discomfort.

Air movement is an important contributor to comfort but in the urban situation air flow through windows is unreliable and cannot be assumed as a presence at all times. The ceiling fan is a reliable source of air flow indoors and its use promotes comfort through selection of an appropriate speed setting as desired by an individual. The design of houses may make provision for optimum airflow by natural ventilation but will have to consider it as an added element.

7.1.2 Subjective responses to and general criteria for comfort.

The occupant survey examined the responses of the people about comfort in their own houses (chapter 5). Subsequently, comfort in the same houses was analysed on the basis of measured temperature data compared with the comfort criteria. The occupants responses consider day and night time comfort and the analysis divides the same period into morning, afternoon, evening and night (table 5.4). The survey classifies deviations of sensations around comfort as warm, hot, cool and cold and the analysis refers them only as warmer or cooler than comfort.

Table 7.1. Subjective responses to comfort compared with general criteria.
H-*hot*, W-*warm*, C-*comfortable*, Cl-*cool*, Cd-*cold*
(Respondents sensations are averaged out of three)
gen-*general criteria* **sub.**-*subjective response*

case ref	hot dry period				hot humid period				cool period			
	day		night		day		night		day		night	
	gen	sub	gen	sub	gen	sub	gen	sub	gen	sub	gen	sub
1	W	H	C	W	C	W	**C**	**C**	Cl	C	Cl	C
2	W	H	**C**	**C**	**C**	**C**	C	Cl	**Cl**	**Cl**	**Cl**	**Cl**
3	**W**	**W**	**W**	**W**	**C**	**C**	**C**	**C**	**C**	**C**	Cl	C
4	**C**	**C**	C	W	**C**	**C**	**C**	**C**	**Cl**	**Cl**	Cl	Cd
5	W	H	**W**	**W**	**W**	**W**	W	C	**Cl**	**Cl**	Cl	Cd
6	W	H	C	W	C	W	**C**	**C**	Cl	C	**Cl**	**Cl**
7	C	W	C	W	C	W	C	W	Cl	C	**Cl**	**Cl**
8	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**	Cl	C	**Cl**	**Cl**
9	C	W	C	W	C	W	**C**	**C**	Cl	C	**Cl**	**Cl**
10	C	W	C	W	**C**	**C**	**C**	**C**	Cl	C	**Cl**	**Cl**

In both the occupant responses and analysed data comfort is more easily achieved in the hot humid period than any other part of the year. The analysis of the measured data indicates more incidences of comfortable occupancy in the hot seasons and cooler sensations in the cool period when compared with the responses. This can be explained by the fact that the responses considered subjective opions about comfort in the whole house experienced over the years whereas the analysis is based on data from one room only. The comfort responses take into account the fact that people make adjustments to their state of comfort in the cool period by choice of warmer clothes and bedding, a fact not accounted for in the analysis of the measured data. About half the comfort responses match analysed results, mostly in the warm humid periods. The relationship is better if sensations reported as *hot* and *cold* are matched with *warmer* or *cooler* than comfort in the analysed data.

7.2. Influences of design on indoor conditions.

Comparison of thermal data of the case studies are based on differences in a) orientation b) exposure c) construction and d) site (chapter 5). Other than site conditions, the parametric studies also consider the effect of these design aspects on indoor temperatures (chapter 6).

Orientation

The analysis of the case study examples with regard to orientation could not compare the four orientations together because there were dissimilarities in other characteristics which did not allow a straightforward comparison. The effect of orientation alone is also difficult to determine from the case studies as its influence is not an isolated condition. They however, offer an understanding of it effect. The comparisons of the case study examples show the warmest indoor temperatures in a room oriented west followed by south and east. There was no suitable case where a north orientation could be similarly compared

The effect of orientation as a direct influence is more evident in the simulations (section 6.5.2.). The indoor temperatures are lowest with a northern orientation followed by south, east and west in the hotter periods. North-east and north-west are slightly less comfortable than south but better than all others. In the cool period a room facing south is warmer than the others. Even though north is a cooler orientation, south is preferred orientation since north facades in Bangladesh do not see the sun for extended periods and as a result are mostly damp and wet.

Exposure

Exposure considered ground, intermediate and top floors. In both the case studies and the simulations, the indoor temperatures in ground floors are cooler followed by the intermediate and top floors in both hot periods. The ground floor has added cooling effect as a result of contact with the ground and may also be shaded by surrounding structures and trees, the intermediate floors are buffered by other floors and is exposed to radiation on vertical surfaces only. The top floors have both the roof and walls exposed to radiation.

Measured temperatures in ground and intermediate floors are within comfortable limits in September. In April the ground floor is considerably cooler than intermediate floors. Differences in maximum temperatures between floors are in the order of 2°C in April and 1°C in September. As a whole temperatures in ground floors are more conducive to comfortable occupancy. Corresponding top floors are warm for extended periods. In the cool period top floors, because of the extra heat gained, are warmer.

The addition of a 75mm layer of lime concrete is the practised method of insulation. Measured top floor rooms with and without such insulation show a difference of 3.5°C in peak temperatures in April and 2°C in September. Comparisons of simulated temperatures of top floors where the slab is left exposed, shaded, lime terraced and where the roof is made from hollow blocks show shading of the slab as the best option for lower indoor temperatures, hollow block roofs are slightly better and there is little difference between lime terraced and exposed slabs. The simulations offer better comparative potential since there are influences of other factors in reality not wholly accounted for in the analysis. In the cool period all situations have comparable performances.

Construction (thermal inertia)

The comparison of measured temperatures in light medium and heavy construction (in terms of wall thickness, 125mm, 250mm and 375mm) show the heavier structures to be cooler than medium and light construction but appreciably so only in the hotter April period. The indoor temperatures are nearly similar in September for all. The heavy and medium structures behave similarly in the cool period. In the simulations another situation of a 500mm wall was introduced as it occurs in reality but lacked a suitable case study. The temperature difference between types is slightly less with the simulated cases.

In the survey, responses of the occupants showed more instances of comfortable occupancy in buildings with heavier construction. The comparison of thermal performance of all the case studies also confirmed this opinion. A direct reading of temperatures in all cases do not seem to show appreciable differences to justify these opinions. The reason for this preferences can be ascribed to the fact that heavier buildings have a lower indoor swing of temperatures and the prevalence of comfortable occupancy is steadier and more predictable.

The effect of thermal inertia in the way of increased wall thickness show little difference in comfort performance for ground and top floors in April. Lighter 125mm walled structures are warmer and therefore perform better in the cool period. Unlike in the ground floor, structures with 500mm walls in top floors are always warmer than comfort in April.

Site

Comparison of indoor temperatures in rooms under different site characteristics show that in dense sites the indoor temperatures are hotter than in moderate or open sites, the latter having lowest temperatures. A difference of about 3°C in maximum indoor temperatures occurs between structures in open and dense sites in April. The indoor temperatures in the dense site is also coolest in the cool periods when it is warmest in moderate sites.

The differences in indoor temperatures can be explained by the variations in outdoor conditions. The outdoor temperatures in different sites vary when compared between themselves and with the common reference of the meteorological data. In both hot periods site temperatures in open conditions are generally cooler than moderate and dense sites particularly in the early mornings and at night. In the cool period when outdoor temperatures in open and moderate sites are warmer than meteorological data some dense sites are consistently cooler which results in colder indoors. In dense sites close spacing between buildings results in trapped heat from surrounding surfaces which is not removed because of lack of air flow. In the cool period, for the same reason direct solar radiation does not reach the site as easily as open or moderate sites.

In dense sites, where the surrounding structures are lower and have corrugated iron roofs, the reflected heat result in higher site, and consequently indoor temperatures of adjoining buildings which are more than a similar situation where buildings are of equal height. In the

the evenings the surrounding roofs cool down as quickly as they heated up and temperatures are lower.

Internal heat gains

The cooking process is heat intensive and kitchen temperatures are significantly higher that other spaces. The heat in the kitchen contributes to the temperatures of other spaces The extent of the effect depends on the proximity of the space in relation to the kitchen i.e. the effect diminishes with distance from it. The pattern of use is of relevance in this regard as some households cook twice daily. The design and layout of spaces have to take this factor into consideration.

7.3. CONCLUSIONS: Design Recommendations for Thermal Comfort.

Ideally indoor temperatures in houses should be within the comfort range all year round. All the houses in the case studies are examples of passive design, indoor temperatures of which vary with the seasons and are different for each example.. This would require the use of active means of environmental control to compensate for occurrences of uncomfortable periods. Some houses perform better than others and the aspects of design that contribute to their performances have been identified in the previous sections.

7.3.1. Design Objectives for Comfort.

Given the climate of Bangladesh the exterior is warm for nine months of the year and in parts of the rest conditions are naturally comfortable or close to it. This is for some periods in November December and February, for brief periods the indoors need to be warm for comfort. In general, for the whole year the emphasis is on cooling. There were no evidence in the examples of design conditions that promote comfort in the warm periods also do the same in the cool periods. Any house which is able to achieve comfort temperatures in the warm periods (9 months of the year) can be considered to be an acceptable house. The cool season is brief and whatever discomfort that occurs is negotiable by way of subjective responses such as changes in clothing or the use of warmer bedclothes at night. Such adjustments are more difficult in the summer.

In the three measurement periods where there are incidences of comfort temperatures in the examples, in the hot seasons they are usually close to the warmer limits and in the cool seasons the cooler limits, of comfort. Improvements are possible through further lowering or raising of temperatures, closer to neutral values.

7.3.2. Design Considerations for Indoor Comfort

The following sections considers the evidence presented in the previous chapters regarding thermal behaviour of different types of urban houses in the case studies and simulations as recommendations for design.

Siting and site layout

The first step in the design process is the evaluation of site conditions as the setting for the proposed building. From the classification used they may either be open, moderate or dense sites. In the urban context all sites are potentially dense even if they are open to begin with. Open sites are preferable as they contribute to cooler interiors. If the thermal design considerations are based on meteorological data then, open sites are likely to be cooler in the warm seasons and warmer in the cool seasons than suggested. They also offer better air flow prospects. Temperatures in moderate sites are closer to meteorological data in terms of average temperatures although the minimum temperatures are lower. The scope for air flow is reduced specially in lower floors, whereas the upper floors may consider it as a positive aspect.

The thermal condition of dense sites depend on the physical description of the density, whether the proposed building is of similar height to the surroundings, lower or higher. Although average temperatures are similar to meteorological data, the fact that dense sites retain heat results in higher temperatures at night thus contributing to discomfort. With similar buildings that are closely spaced, site conditions are also worst and in the cool period the outdoors are cooler than as reported by meteorological sources. Conditions are better where the building is shaded by surrounding structures. A higher structure in a dense site may have higher temperatures at times if the roofs of the surrounding buildings are highly conductive as with corrugated iron. Air flow prospects in dense sites with the exception of higher structures are negligible. Given this fact it is advantageous to design lower structure in dense sites to benefit from shading.

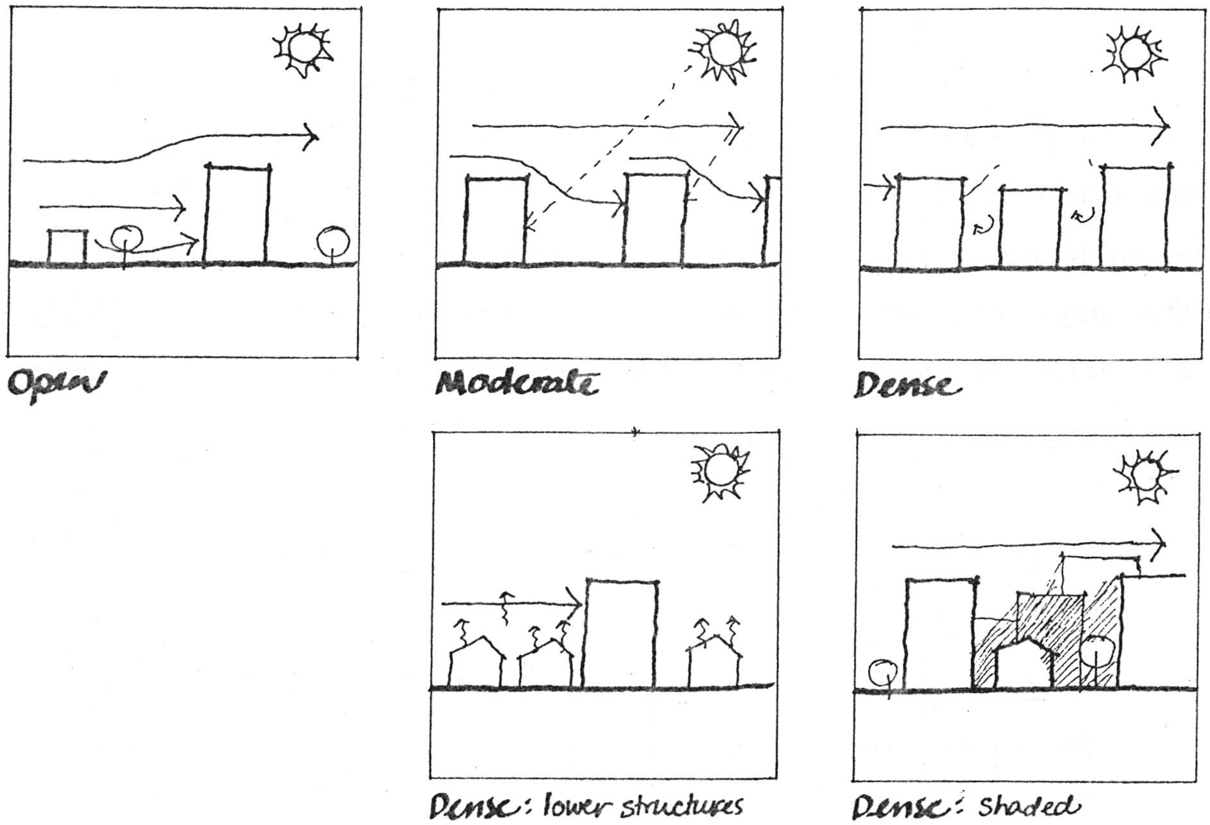

Fig 7.1. Site considerations

Building Orientation

South is the best orientation for a building and its openings, although northern orientations have cooler indoors it is not preferred because of lack of direct sunlight. After south, east orientation is preferred since a building oriented east is warmer in the mornings when the outdoors are relatively cool. West oriented rooms are hot in the afternoons as combined effects of solar radiation and higher outdoor air temperatures. The effect of a good orientation may be totally negated by dense sites, particularly where buildings are of similar height.

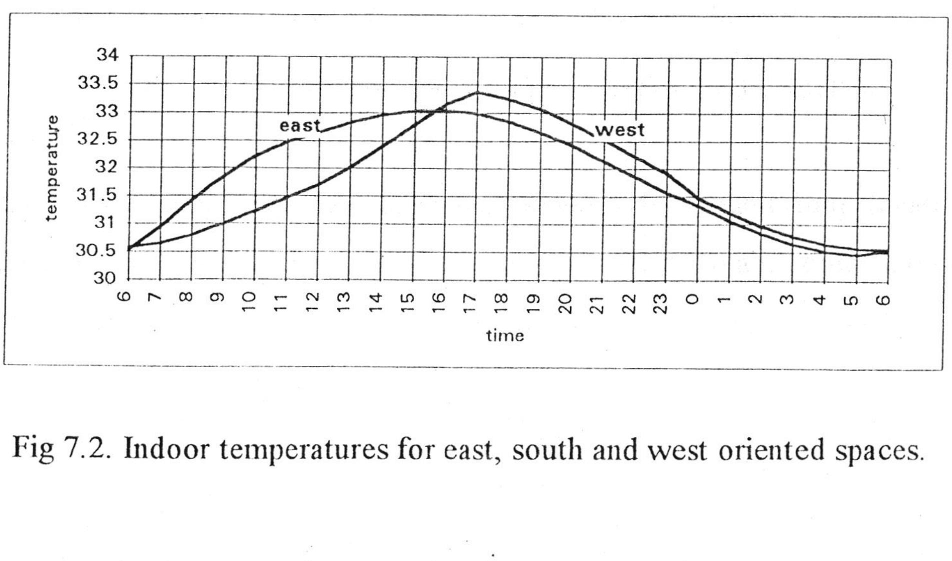

Fig 7.2. Indoor temperatures for east, south and west oriented spaces.

Internal Layout and Planning

Internal layout has to consider orientation as a major factor. From air flow considerations a linear building of single room depth is ideal. In urban areas this is difficult to achieve given plot sizes and division geometry. The spaces that are most lived in, usually the bedrooms, should be oriented south. Departure from the current trend of having rectangular building plans will allow parts of the house to be cross ventilated and make it possible for parts of the house to be shaded by itself.

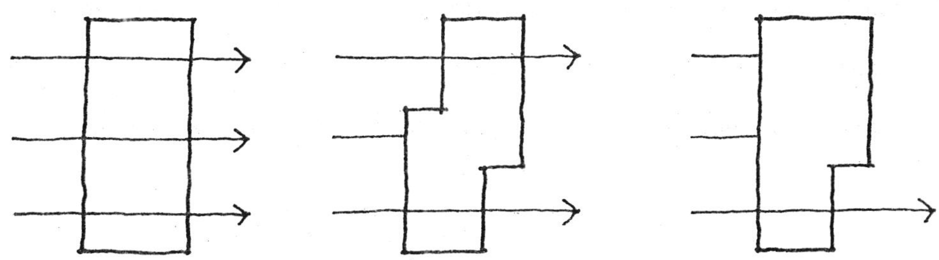

Fig 7.3. Plan shapes to facilitate ventilation

Locating the kitchen deserves more consideration than given. A non rectangular staggered arrangement will allow it to dissipate heat through cross ventilation, otherwise it will need to be thermally buffered from other living spaces.

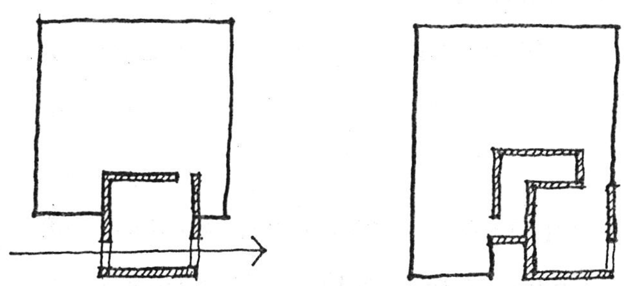

Fig 7.4. Ventilation and thermal buffering of the kitchen

Where the house is more than a storey high or includes the ground floor, locating bedrooms and other living spaces in lower floors will result in them having cooler interiors. If there are good air flow prospects at higher levels the choices may include upper floors.

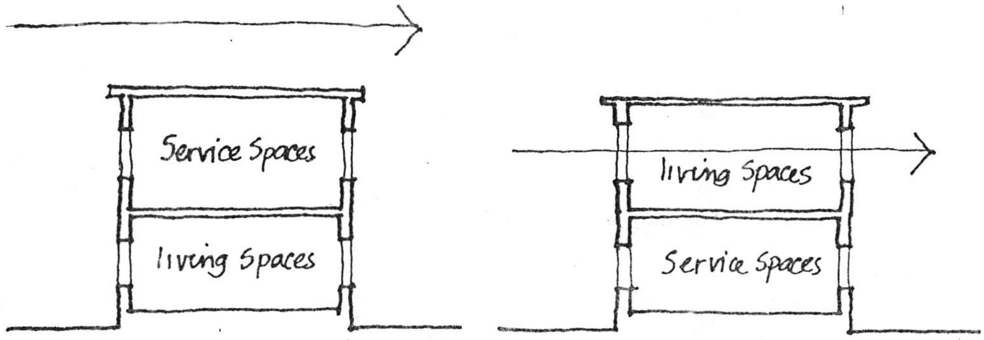

Fig 7.5. Considerations for locating functions

Building Construction

The nature of building construction is important in moderating the effect of outdoor temperatures. Thermal inertia of the building fabric can be manipulated most conveniently by varying wall thickness. The use of brick walls constructed manually makes this easy to achieve.

Air flow through openings is restricted because of security considerations in design and privacy requirements. This is particularly true in ground and lower floors where outdoor air flow is unreliable to begin with. The disadvantage to comfort because of this can be compensated by using thicker walls. The lower floors will benefit from walls thickness of 250mm or more. In ground floors thicker walls assure comfort temperatures in the warm periods. Lighter walls would make parts of the day uncomfortable. Wall thickness of up to 500mm are advisable for lower indoor temperatures. Upper floors can have lighter walls in combination with larger openings to allow air flow. In a building few stories high the walls can be progressively lighter upwards.

Thicker walls also contribute to lower radiant temperatures to promote comfort. In the cool season heavy walls have the opposite effect and indoors are colder.

External surfaces which are exposed to heat from solar radiation may be insulated to protect the indoors from its effects. Insulation materials are not used in Bangladesh but alternative means may be used. Cavity walls by means of constructing another layer outside the main wall can be an effective means for insulation but at added cost.

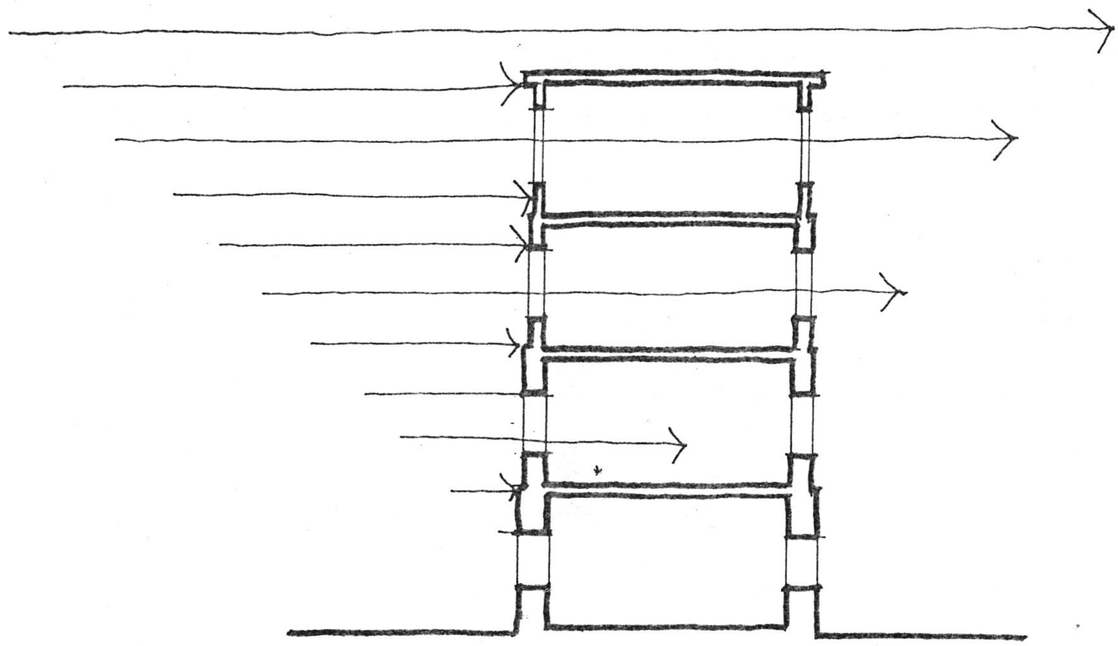

Fig 7.6. Wall thickness as a function of building height and air flow.

Roofs

Roofs are a source of heat gain for top floors. Temperatures in top floors can be substantially higher than corresponding lower floors. The heat gain effect of standard concrete roofs can be best reduced by shading it, preferably by another roof. The indoor temperatures of a space with a shaded roof is comparable to a that of a space in an intermediate floor. Using a highly reflective external surface of the upper roof and a low emmitance surface on the inside will increase the reflected component of the incoming radiation and reduce the radiant heat transfer between the two roofs. Whatever heat is trapped between the two layers it can be removed by allowing sufficient gap for air flow. This is a cost intensive method which can be justified through a secondary use of this outer roof.

Flats are often constructed in vertical stages and the roof of a future flat may be constructed early to shade the roof of an existing one. The lack of space on the ground has now made it common for people to hold social gatherings on the roof, an added protection over it will serve both social functions as well as improve environmental conditions in the floor below.

Where double roofs cannot be constructed, the next best alternative is to have a hollow block roof construction where the air gap results in lower indoor temperatures. Other means may include increasing the thermal inertia by making the slab thicker at considerable structural costs. The traditional practice of lime terracing is not very effective in terms of structural costs. The traditional practice of lime terracing is not very effective in terms of lower temperatures. The use of inverted earthen pots over roof surfaces have been tried with appreciable results to reduce the heat gain indoors

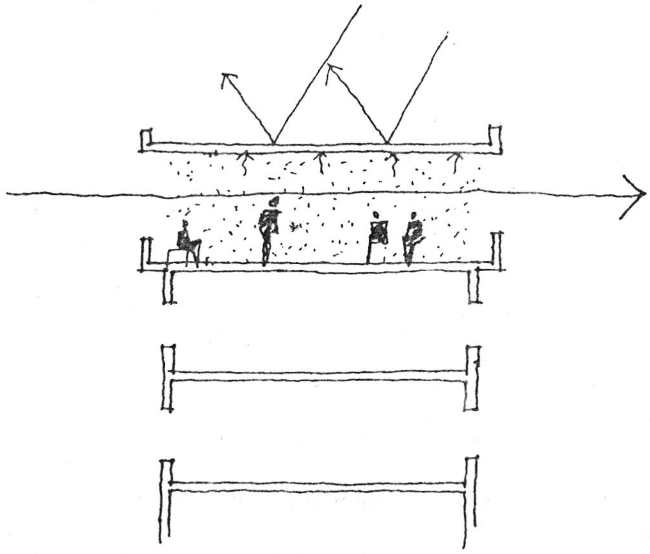

Fig 7.7. Social and environmental functions of a double roof.

Corrugated iron roofs is used for single storey structures. Its highly conductive nature contributes to quick rise of indoor temperatures in the warm periods. This effect can be reduced by the use of ceilings for insulation. Where available, insulating materials can be coupled with such roofs. Corrugated iron roofs affect the indoor temperatures of neighbouring buildings taller than itself. This can be controlled by making the surface of the roof less reflective at the cost of increased absorption by the roof itself.

Shading

All examples of housing were observed to employ shading means as protection from heat gain from direct and diffuse radiation which also contributes to lower radiant temperatures. Windows have projections to shade them, some houses have projected roofs and floor slabs to shade walls. The shading elements need to be more purpose designed. The use of horizontal projections is more relevant for south walls and windows. West and east surfaces also needs vertical projections for protection from low morning and afternoon sun. North facing walls are exposed to the sun only between mid April and mid August and the effect is appreciable in May June and July. Shading on north facades is important to offer some protection from diffuse radiation. Verandas are a common element in all buildings and have the potential to shade openings and walls. The practice of shading walls with projected roofs and slabs is losing popularity for reasons of preferences in style. It may be reintroduced to improve environmental conditions. Shading devices also offer protection from moderate rains.

7.3.3. Application of Passive Cooling Options

Where indoor temperatures are above comfort levels or where they are near the upper limits of comfort, other passive cooling means may be improved or introduced to improve performance.

Induced Air Flow. Spaces where openings do not suffice for air flow needs can benefit from the introduction of the use of alternative means such as wind towers. This is of relevance to ground and lower floors. Ordinarily all houses a few stories tall have stairwells which often rise above the main structure. They may be used to serve the function of wind towers by orienting openings at the top towards the breeze direction and channelling air flow to the lower floors.

Roof ponds. Ordinarily all houses have overhead water tanks to make up for insufficient pressure of the normal water supply. The shape is mostly cubical which may be modified to serve as a roof pond which will add to the thermal capacity of the roof. The evaporative cooling potential is reduced because of high humidities. Cloud cover in the humid period restricts the radiative potential but the top of this adapted roof pond may have a retractable cover to take advantage of nights when the sky is clear.

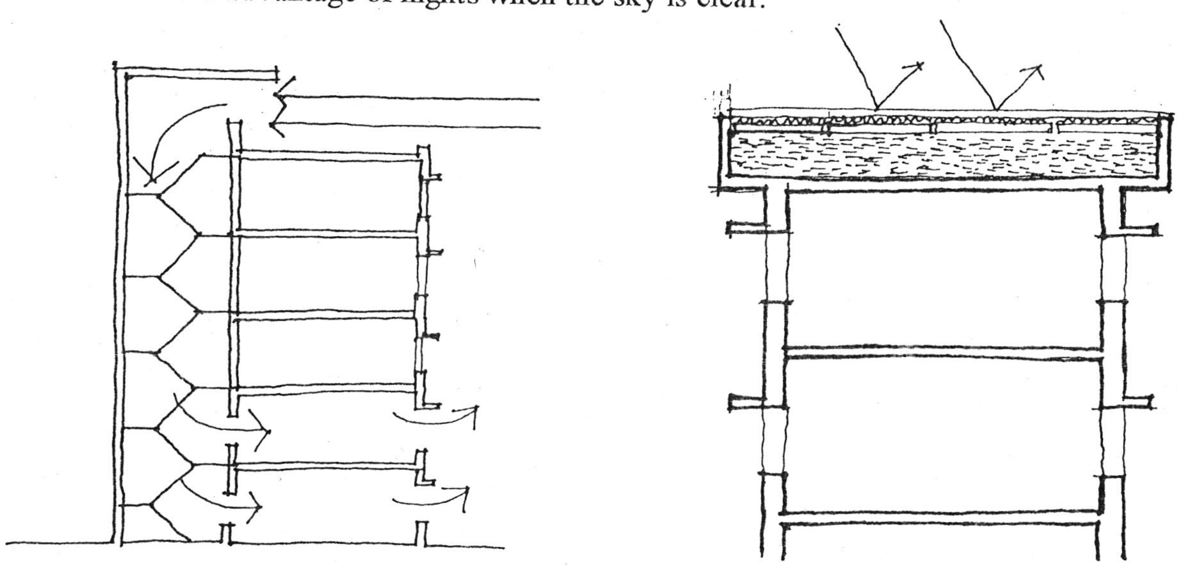

Fig 7.8. Wind towers and roof ponds as integral parts of the design.

Vegetation. Plants grow very easily in the hot humid climate and buildings may take advantage of their passive cooling potential. Apart from plants on the ground to shade a building or site. Plants and creepers may be grown on walls and roof to shade them. This is relevant for roofs particularly corrugated iron ones where plantation on them will reduce heat gain and reflected radiation component which affects surrounding buildings.

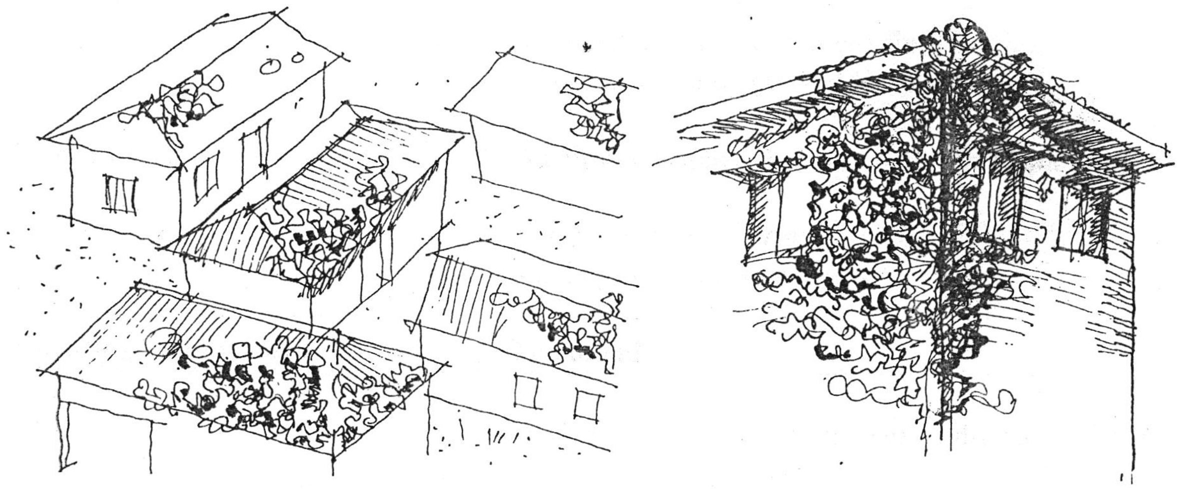

Fig 7.9. Vegetal aid to passive cooling

Earth Cooling. By virtue of their location ground floors are able to take advantage of cooling through contact with the ground. The potential of earth cooling may be further explored by using earth pipes. The high moisture content of the ground will require means to remove excess humidity.

Table 7.2. Design considerations for comfort.

Siting and site layout	**To consider**
Open sites:	Air flow on all floors Cooling action of ground floors
Moderate sites:	Air flow on upper floors Reduced air flow at ground floors Cooling action of ground floors
Dense sites:	Air flow on upper floors only is surroundings are low Cooling action of ground floors Shading by other structures

Building Orientation	**To consider**
	South as a preferred orientation and/or local air flow

Internal layout and planning	**To consider**
For dense and moderate sites (with reduced air flow)	Living functions on lower levels Services on upper levels
Where there is air flow at upper levels	Living function on both lower and upper levels
For ventilation	Narrow depth of plan or offset arrangement to allow cross ventilation
For kitchens	Ventilation Thermal buffering

Building Construction	**To consider**
	Heavier construction in ground and lower floors Lighter construction on top and near top floors (larger openings)
Top floors	Shaded roofs , hollow block roofs, reflective roofs

Shading	**To consider**
West and east facades	Vertical and horizontal shading devices
South facades	Horizontal projections
North facades	Minimum (from diffuse and reflected radiation)

7.4. Recommendations for further research

The concern of this thesis has been identification of design aspects of urban housing in Bangladesh that are likely contributors to indoor comfort. The nature of these aspects are considered in general terms and are seen as an interface between the outdoors and indoors. In the course of the investigations. particulars design features could be identified the effect of which deserves concern. The criteria for comfort are also derived from local observations. The discipline of architectural design involves the consideration of a host of issues all of which have environmental connotations in some way or other. This thesis is intended to be a primary source for future concern with design issues in further detail, some of which are mentioned below:

A holistic evaluation of **thermal comfort** needs to consider the behaviour of people in all types of buildings in both urban and rural areas and in all seasons. Of particular note are evaluation of peoples responses to warmth and humidities. The latter needs to investigate the biophysical response to high values and also the way people adapt in terms of socio cultural and subjective responses.

The use of **building materials and methods** with regard to their thermal properties need to be investigated for a detailed recommendations for their uses. Given the developing status of the country the emphasis is on the use of local materials and the adaptation of building practices which optimise local resources. Element design in buildings need further quantification.

Air flow is an important parameter for comfort and in urban areas difficult to achieve in side buildings. Means to optimise its potential both at site level and inside building in way of design of openings need detailed investigation.

High rainfall and moisture content is characteristic of the local climate. This gives rise to problems of direct infiltration of rain and associated problems of dampness, particularly in lower floors. Whereas lower floors are better from comfort temperatures they often suffer from damp floors. Methods to control the same and protection from driving rain are areas that need investigation.

Although the luminescence of the sky is high and the use of artificial light is not common during the day, adequate **daylight** in deep plan buildings is sometimes difficult to achieve, particularly when the sky is overcast. Building design either has to consider lesser depths or identify means for adequate light in deep buildings.

Buildings, in general do not consider means of **passive cooling** as deliberate inclusion in the design process whereas existing indoor conditions have the scope for improvement of comfort performance with such input. Passive cooling methods and techniques need effective consideration of local climate and means. This aspect will do well by looking into methods used in traditional buildings for adaptation in contemporary structures.

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APPENDICES

1. Comfort Assessment Form
2. Comfort Diary
3. Fan Speed Data
4. Comfort Field Data
5. Case Study Search Sheet
6. Case Study Inforrmation and Thermal Data Sheets
7. Case Study Descriptions Temperature Graphs, and Temperature Data.
8. Papers

Appendix 1: Comfort Assessment Form

THERMAL COMFORT ASSESSMENT

Name.____Age.____________________Sex____________

Location.____(room/building)

Date/Time____________________________________

1. Circle the condition you feel closest to on the scale below.

-3	-2	-1	0	1	2	3
cold	cool	slightly cool	neutral	slightly warm	warm	hot

2. How long have you been in your present location?

3. **Clothing**
(mention the type of clothes you are wearing over normal underclothing e.g. shirt and trousers, pyjama and punjabi, salwaar kameez, saree etc. If you need to wear more or less for comfort make a note of it. The CLO value is not for you to fill)

____CLO____________________

4. **Activity**
(Mention what you are doing at the time of the observations. e.g. lying down, seated, reading, writing, housework, cooking etc., if for comfort you are doing otherwise make a note of it.. The MET value is not for you to fill.)

____MET____________________

5. Record the following readings from the instruments provided in relation to your comfort condition recorded above (1).

AIR TEMP.________________________**GLOBE TEMP**____________________________**R.H.**__________

6. **AIR MOVEMENT**

Is the ceiling fan on? at what speed? **FAST** **MED** **SLOW**

7. **RADIATION**

Is there any direct sunshine on you?

8. Other adaptive means for comfort (if any)

Appendix 2: Comfort Diary

London , August 01 , 1993

Dear Collegue,

The attached Comfort Diary forms are a part of my research work on evaluating comfort conditions for people living in the tropics. Some of you may be familiar with similar questionnaires that you filled out for me in February - April this year, this is an extension of that work. I will very much appreciate if could take some of youe time to fill these out for me. Other than filling these out yourselves, you may also record the conditions felt by friends and other members of your family. To do this you will have to. carry with you one or two portable instruments with you. They will be given to you and are handy for carrying at all times.

The objective is to record your comfort sensation as you go about in your daily lives and at any location, at home or at work, preferably indoors. When you are in a room just take some time to think how you feel, cool, warm, hot or just comfortable (neutral). Record your sensation by giving it a value as explained in the instructions and fill in the details asked for along with the readings from the instruments. Expained opposite are fairly detailed instructions about filling out the dairy along with a sample.

Your help will be greatly appreciated and ackowledged as it has been in the past. I am hoping that you may also enjoy it.

Thanks

(Fuad H. Mallick)

Instructions.

The basic details asked for are fairly straightfroward. Each part can be filled out as follows:

Time: The time of day or night when the sensation is being recorded.

Location: Where are you when you are recording. **RECORD OBSERVATIONS ONLY AFTER YOU HAVE BEEN IS PLACE FOR NOT LESS THAN 20 MINUTES**

Comfort Condition: On a scale of -3 to 3 fill in the value you feel closest to:

-3	-2	-1	0	1	2	3
COLD	COOL	COMFORTABLY COOL	NEUTRAL (COMFORTABLE)	COMFORTABLY WARM	WARM	HOT

You may sometimes be in an air conditioned space which will be good oppurtunity to record cold or cool sensationsl. ***But do make a note in the location column that the room is air conditioned***

Air Temperature: The air temperature of the room you are in. This can be measured from the digital temperature/humidity meter by clicking it twice

R.H: The relative humidity of the room. By clicking the same meter once.

Globe Temperature: This has to measured with a digital thermometer with the black ball on the sensor.

Clothing: Mention how you are dressed e.g. shirt and trousers, pyjama panjabi, salwar kameez, saree, etc.

Activity: Mention what you are doing e.g. sitting, reading, lounging, studying, reading, lying down, walking about etc.

Air Movement: If there is any air movement indicate it in this column. You do not have to measure it. If the ceing fan is on mention its speed as SLOW, MEDIUM or FAST. If there is no air movement mention NONE. If there is air movement but no ceiling fan mentally compare it velocity as if there were a ceiling fan and record what may have been its speed .

Ext. Temperature: External temperature. Just step out for a moment if possible and get a recording of the outside temperature.

Note: When you are with a friend or a family member ask him or her about their sensation and record the values on one of the extra sheets. It may be that a friend or family member is with you most of the time you may then do two recordings over this time, but try to avoid doiing both at exactly the same time, take a different time or location for them.

SAMPLE

Date: 05 August, 1993

Time	Location	**Comfort Condition**	Air Temp	R.H.	Globe Temp	Clothing	Activity	Air Movement (fan speed)	Ext. Temp
10:30pm	Studio	1	29°c	72%	29.5°c	Shirt + Trousers	Writing	Med.	30.5°c
1:30 PM	Cafeteria	2	29.3°c	78%	28.5°c	"	Talking	Fast	31.4°c
3:30 PM	B.C (air cond.)	-1	24°c	75%	24.3°c	"	Reading	None	32.1°c
5:15 PM	Living Rm.	0	27°c	78%	27.5°c	Pyjama Punjabi	Lounging	Slow	29.8°c
1:15 Am	Bedroom	0	26.8°c	83%	27.1°c	Lungi	Lying down	Med.	28.3°c

COMFORT DIARY

Name____ Age __________ Sex__________Occupation

Date:

Time	Location	**Comfort Condition**	Air Temp	R.H .	Globe Temp	Clothing	Activity	Air Movement (fan speed)	Ext. Temp

Date:

Time	Location	**Comfort Condition**	Air Temp	R.H .	Globe Temp	Clothing	Activity	Air Movement (fan speed)	Ext. Temp

Date:

Time	Location	**Comfort Condition**	Air Temp	R.H .	Globe Temp	Clothing	Activity	Air Movement (fan speed)	Ext. Temp

Date:

Time	Location	**Comfort Condition**	Air Temp	R.H .	Globe Temp	Clothing	Activity	Air Movement (fan speed)	Ext. Temp

Fan Speed Measurements

Room reference :

Room location :

Date :

Measurements

SLOW SETTING

MEDIUM SETTING

FAST SETTING

all measurements at working plane (1 - 1.5m)

Fan Speed Calculations 1

SLOW

Room 1

.07	.12	.05
.15	.48	.17
.09	.24	.12

Average: .17

Room 2

.33	.22	.33
.01	.46	.12
.06	.02	.05

Average: .17

Room 3

0	.05	.05
.19	.49	.03
.09	0	.14

Average .12

Room 4

.03	.1	.07
.12	.42	.15
.08	.23	.06

Average: .14

Room 5

.08	.18	.02
.15	.39	.09
.12	.21	.02

Average: .1[illegible]

Room 6

.01	.12	.04
.16	.41	.2
.17	.2	.13

Average .16

MEDIUM

Room 1

.13	.25	.5
.21	.77	.17
.13	.39	.15

Average: .3

Room 2

.46	.49	.14
.36	.6	.09
.21	.11	.16

Average: .29

Room 3

.15	.13	.16
.22	.88	.06
.59	.30	.30

Average .31

Room 4

.11	.30	.4
.18	.75	.18
.12	.35	.14

Average: .28

Room 5

.13	.14	.18
.21	.65	.2
.48	.4	.31

Average: .3

Room 6

.18	.27	.15
.35	.72	.28
.27	.25	.41

Average .32

Fan Speed Calculations 2

FAST

Room 1

.18	.13	.33
.44	1.25	.9
.22	.8	.61

Average: .54

Room 2

.46	.48	.22
.05	1.21	.31
.26	.3	.3

Average: .39

Room 3

.20	.27	.35
.39	1.8	.17
.46	.31	.35

Average: .42

Room 4

.16	.13	.25
.38	1.7	.75
.15	.82	.16

Average: .5

Room 5

.12	.25	.38
.35	1.3	.31
.21	.45	.40

Average: .42

Room 6

.21	.35	.18
.45	1.25	.37
.32	.36	.38

Average .43

Fan speed setting	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	**Average**
Slow (S)	.17	.17	.12	.14	.14	.16	**.15 m/s**
Medium (M)	.3	.29	.31	.28	.3	.32	**.3 m/s**
Fast (F)	.54	.39	.42	.5	.42	.43	**.45 m/s**

Appendix 4: Comfort Field Data

Field Data : Comfort Evaluation

Data Ref.	Date	Time	Location	C.Vote	Age	Sex	Air Temp	RH	G.Temp	Clo	Met	Air Movement	Ext. Temp	Ext. Cond
cd1	3.9.93	8:00	bed	-1	23	f	32.50	72.20	28.50	0.50	1.00	s		
cd1	3.9.93	10:30	liv	0	23	f	32.80	72.20	28.40	0.50	0.80	s		
cd1	3.9.93	14:00	din	0	23	f	33.10	71.60	27.90	0.50	1.80	m		
cd1	3.9.93	20:00	bed	0	23	f	32.30	70.10	27.50	0.50	1.30	m		
cd1	3.9.93	22:30	bed	0	23	f	32.30	70.00	27.50	0.50	1.30	m		
cd1	4.9.93	9:00	din	0	23	f	32.00	77.10	29.20	0.50	1.80	m		
cd1	4.9.93	12:00	bed	0	23	f	34.00	76.00	29.90	0.50	1.30	m		
cd1	4.9.93	15:00	bed	1	23	f	34.80	75.70	31.10	0.50	0.80	f		
cd1	4.9.93	18:00	liv	0	23	f	32.90	75.10	31.00	0.50	0.80	m		
cd1	4.9.93	21:00	bed	0	23	f	32.60	75.00	30.80	0.50	1.30	m		
cd1	5.9.93	8:00	bed	-1	23	f	32.20	76.30	30.00	0.50	0.80	m		
cd1	5.9.93	11:00	bed	0	23	f	33.90	76.00	30.60	0.50	1.00	m		
cd1	5.9.93	14:00	din	0	23	f	34.50	75.50	31.90	0.50	1.80	f		
cd1	5.9.93	17:00	liv	0	23	f	33.60	75.00	32.60	0.50	0.80	f		
cd1	5.9.93	22:00	bed	-1	23	f	32.30	74.60	31.50	0.50	1.30	f		
cd1	6.9.93	10:00	bed	0	23	f	33.30	75.80	32.10	0.50	1.30	m		
cd1	6.9.93	12:00	bed	1	23	f	34.80	74.10	33.60	0.50	0.80	f		
cd1	6.9.93	14:00	din	1	23	f	35.80	74.00	33.10	0.50	1.80	f		
cd1	6.9.93	17:00	bed	0	23	f	34.10	73.60	32.70	0.50	0.80	f		
cd1	6.9.93	20:00	bed	0	23	f	33.80	73.00	32.20	0.50	1.30	m		
cd1	6.9.93	0:00	bed	0	23	f	32.90	72.60	31.90	0.50	0.80	m		
cd2	3.9.93	8:30	bed	0	52	f	32.70	72.20	28.90	0.50	1.30	s		
cd2	3.9.93	11:00	kit	1	52	f	33.90	72.00	29.90	0.50	2.00	n		
cd2	3.9.93	14:30	din	1	52	f	33.10	72.60	27.90	0.50	1.80	m		
cd2	3.9.93	20:30	bed	0	52	f	32.80	71.00	26.80	0.50	1.30	m		
cd2	3.9.93	22:00	bed	0	52	f	32.50	71.00	26.60	0.50	0.80	m		
cd2	4.9.93	9:30	din	0	52	f	33.10	77.80	32.70	0.50	1.80	m		
cd2	4.9.93	11:30	liv	0	52	f	32.10	77.00	32.10	0.50	0.80	m		
cd2	4.9.93	14:30	din	1	52	f	34.80	77.90	33.90	0.50	1.80	f		
cd2	4.9.93	18:30	liv	0	52	f	33.90	77.20	32.30	0.50	1.00	f		
cd2	4.9.93	21:30	bed	0	52	f	33.00	76.10	32.80	0.50	1.30	f		
cd2	6.9.93	12:30	kit	1	52	f	35.00	76.10	34.80	0.50	2.00	n		
cd2	6.9.93	14:30	din	2	52	f	35.80	74.00	33.10	0.50	1.80	f		
cd2	6.9.93	16:30	bed	1	52	f	34.50	74.00	34.30	0.50	1.30	f		
cd2	6.9.93	20:30	bed	0	52	f	33.70	73.50	33.30	0.50	0.80	f		
cd2	6.9.93	23:30	bed	0	52	f	33.00	73.20	33.00	0.50	0.80	f		
cd3	12.9.93	9:00	bed	-1	25	m	33.10	77.00	29.30	0.30	0.80	m		
cd3	12.9.93	12:00	bed	1	25	m	33.60	76.50	30.60	0.30	1.30	f		
cd3	12.9.93	15:00	liv	0	25	m	35.20	75.20	31.40	0.10	1.00	m		
cd3	12.9.93	21:00	din	0	25	m	34.00	75.80	30.00	0.30	1.80	f		
cd3	13.9.93	10:00	bed	0	25	m	33.30	74.10	29.20	0.40	2.00	m		
cd3	13.9.93	13:30	liv	0	25	m	35.40	72.90	31.60	0.10	2.00	m		
cd3	13.9.93	16:25	toil	1	25	m	35.00	73.50	31.10	0.10	1.00	n		
cd3	13.9.93	20:00	bath	0	25	m	33.20	74.00	32.00	0.00	1.20	n		
cd3	13.9.93	23:00	bed	0	25	m	33.10	74.40	29.20	0.30	0.80	s		
cd3	14.9.93	3:00	bed	-1	25	m	32.60	73.10	28.60	0.30	0.80	m		
cd3	14.9.93	8:00	bed	0	25	m	32.40	73.10	28.30	0.30	1.00	m		
cd3	14.9.93	20:00	bed	0	25	m	32.30	72.00	28.60	0.40	1.30	f		
cd3	15.9.93	7:00	bed	-1	25	m	32.20	75.10	31.60	0.40	1.30	s		
cd3	15.9.93	10:00	liv	0	25	m	33.10	74.60	31.90	0.40	0.80	s		
cd3	15.9.93	14:00	din	1	25	m	35.10	73.80	32.90	0.10	1.80	m		
cd3	15.9.93	17:00	bed	0	25	m	34.60	73.50	33.20	0.10	0.80	f		
cd3	15.9.93	21:00	bed	-1	25	m	32.40	74.90	31.60	0.10	1.30	f		
cd4	12.9.93	9:30	bed	0	45	f	32.80	76.90	29.00	0.50	1.00	m		
cd4	12.9.93	12:30	kit	2	45	f	34.00	76.10	33.40	0.50	2.00	n		
cd4	12.9.93	15:30	bed	0	45	f	34.30	75.00	32.60	0.50	0.80	f		
cd4	12.9.93	21:30	din	0	45	f	34.00	75.80	30.00	0.50	1.80	f		
cd4	13.9.93	9:30	bed	0	45	f	33.00	74.30	28.90	0.50	0.80	m		
cd4	13.9.93	14:00	din	1	45	f	35.00	73.00	33.10	0.50	1.80	m		
cd4	13.9.93	16:30	bed	0	45	f	34.50	72.70	33.00	0.50	2.20	m		
cd4	13.9.93	23:30	bed	0	45	f	32.60	73.10	32.00	0.50	0.80	m		
cd4	14.9.93	8:30	bed	-1	45	f	32.00	72.60	28.40	0.50	2.20	m		
cd4	14.9.93	20:30	bed	0	45	f	32.50	72.00	29.10	0.50	0.80	m		
cd4	15.9.93	7:30	bed	-1	45	f	32.00	75.00	31.60	0.50	2.00	m		

	cd4	15.9.93	10:30	kit	1	45	f	34.40	74.60	32.60	0.50	2.00	n		
	cd4	15.9.93	14:00	din	1	45	f	35.10	73.80	32.90	0.50	1.80	m		
	cd4	15.9.93	21:30	bed	0	45	f	32.40	75.00	31.30	0.50	0.80	m		
	cd5	8.9.93	8:00	liv	0	54	m	31.90	77.80	30.80	0.50	1.00	m		
	cd5	8.9.93	18:00	bed	1	54	m	34.30	76.20	35.10	0.50	0.80	m		
	cd5	8.9.93	19:30	dis	1	54	m	32.60	76.10	31.80	0.50	1.20	f		
	cd5	8.9.93	22:00	bed	0	54	m	32.20	76.00	31.80	0.20	0.80	m		
	cd5	9.9.93	9:00	din	0	54	m	32.10	77.20	31.10	0.50	1.80	m		
	cd5	9.9.93	17:00	bed	1	54	m	35.00	76.80	34.10	0.30	0.80	f		
	cd5	9.9.93	21:00	bed	0	54	m	33.00	75.00	32.10	0.20	1.30	f		
	cd5	9.9.93	24:00	bed	0	54	m	32.70	74.70	31.00	0.20	0.80	f		
	cd5	10.9.93	8:30	bed	0	54	m	31.30	76.10	30.00	0.40	1.00	m		
	cd5	10.9.93	10:30	dis	0	54	m	32.50	75.80	30.20	0.40	1.20	m		
	cd5	10.9.93	13:45	bed	1	54	m	34.00	75.10	31.30	0.40	2.00	f		
	cd5	10.9.93	17:00	bed	0	54	m	33.70	74.60	32.10	0.20	0.80	f		
	cd5	10.9.93	22:00	bed	0	54	m	32.30	74.00	31.00	0.20	0.80	f		
	cd5	11.9.93	8:00	bed	0	54	m	32.00	77.70	30.10	0.50	0.80	m		
	cd5	11.9.93	18:00	liv	1	54	m	35.20	74.00	33.30	0.40	1.00	f		
	cd5	11.9.93	21:30	bed	0	54	m	33.00	73.80	32.60	0.20	0.80	m		
	cd5	11.9.93	23:00	bed	0	54	m	32.70	73.60	32.00	0.20	0.80	m		
	cd6	2.10.93	15:00	bed	-1	25	f	33.00	94.60	29.20	0.50	0.80	f	32.60	
	cd6	2.10.93	18:30	liv	0	25	f	32.90	94.40	28.70	0.50	1.30	f	32.50	
	cd6	2.10.93	21:15	kit	1	25	f	32.60	94.30	28.30	0.50	1.80	n	31.90	
	cd6	3.10.93	8:30	liv	0	25	f	32.10	94.20	28.00	0.50	1.20	s	33.00	
	cd6	3.10.93	11:30	bed	0	25	f	33.00	94.00	28.90	0.50	1.30	f	31.10	
	cd6	3.10.93	15:30	liv	0	25	f	33.40	94.10	29.40	0.50	1.30	f	33.40	
	cd6	3.10.93	19:00	bed	1	25	f	33.20	93.90	29.80	0.50	0.80	f	33.30	
	cd6	3.10.93	22:00	ver	1	25	f	32.80	93.90	28.80	0.50	0.80	s	32.60	
	cd6	4.10.93	9:30	bed	1	25	f	32.60	93.90	29.20	0.50	1.30	f	32.60	
	cd6	4.10.93	13:00	kit	2	25	f	33.70	93.80	30.70	0.50	2.00	n	33.70	
	cd6	4.10.93	16:00	bed	1	25	f	33.40	93.90	30.00	0.50	0.80	f	33.40	
	cd6	4.10.93	20:30	bed	0	25	f	33.10	94.10	29.80	0.50	1.30	f	33.00	
	cd6	4.10.93	23:00	bed	-1	25	25	32.70	93.60	29.50	0.50	0.80	f	32.60	
	cd6	5.10.93	9:00	liv	-1	25	25	33.00	94.00	29.60	0.50	1.30	s	33.10	
	cd6	5.10.93	12:00	bed	1	25	25	34.10	93.90	30.50	0.50	0.80	m	34.20	
	cd6	5.10.93	15:30	liv	1	25	25	33.90	93.80	30.60	0.50	1.30	m	34.00	
	cd6	5.10.93	20:30	bed	0	25	25	33.40	93.80	30.00	0.50	1.30	f	33.20	
	cd6	5.10.93	1:00	bed	1	25	25	33.30	93.70	29.50	0.50	0.80	f	33.10	
	cd7	9.10.93	10:05	dorm	1	24	f	33.70	93.90	29.80	0.50	1.20	f	29.90	
	cd7	9.10.93	12:30	dorm	1	24	f	34.00	94.10	30.20	0.50	1.00	f	30.60	
	cd7	9.10.93	15:00	dorm	2	24	f	35.10	94.30	31.40	0.50	0.80	f	31.70	
	cd7	9.10.93	17:45	dorm	1	24	f	35.20	94.40	31.60	0.50	1.00	f	31.40	
	cd7	9.10.93	23:10	dorm	0	24	f	34.60	93.80	31.10	0.50	1.20	s	30.50	
	cd7	10.10.93	10:30	dorm	2	24	f	34.10	93.70	30.60	0.50	1.20	f	32.40	
	cd7	10.10.93	14:30	dorm	2	24	f	35.90	94.10	32.50	0.50	1.00	f	32.80	
	cd7	10.10.93	16:40	dorm	2	24	f	36.10	94.30	32.80	0.50	0.80	f	31.20	
	cd7	10.10.93	20:00	dorm	2	24	f	34.80	89.80	31.70	0.50	1.20	f	29.80	
	cd7	10.10.93	0:10	dorm	0	24	f	34.40	91.90	30.60	0.50	1.20	f	29.90	
	cd7	11.10.93	8:50	dorm	2	24	f	33.60	92.10	30.10	0.50	1.00	f	30.20	
	cd7	11.10.93	11:30	dorm	2	24	f	34.20	90.30	31.70	0.50	1.20	f	32.10	
	cd7	11.10.93	14:15	dorm	2	24	f	34.60	89.70	31.80	0.50	0.80	f	32.10	
	cd7	11.10.93	18:30	dorm	1	24	f	33.10	92.10	30.90	0.50	1.00	f	31.20	
	cd7	11.10.93	11:25	dorm	0	24	f	32.80	90.30	30.80	0.50	0.80	m	30.80	
	cd7	12.10.93	9:30	dorm	1	24	f	33.70	92.80	29.70	0.50	1.30	f	30.20	
	cd7	12.10.93	13:30	dorm	2	24	f	35.10	90.70	30.40	0.50	0.80	f	32.10	
	cd7	12.10.93	19:30	dorm	0	24	f	34.20	91.80	30.80	0.50	0.80	f	31.80	
	cd7	12.10.93	22:15	dorm	1	24	f	33.20	92.00	31.30	0.50	1.20	m	30.70	
	cd7	12.10.93	0:30	dorm	0	24	f	32.70	91.00	30.30	0.50	0.80	m	29.30	
	cd 8	17.9.93	0:30	study	1	25	m	29.90	70.80	29.90	0.50	1.30	f		
	cd 8	17.9.93	1:35	study	0	25	m	30.00	71.60	30.00	0.50	1.30	f		
	cd 8	17.9.93	10:30	study	1	25	m	29.60	71.70	29.80	0.50	1.30	f		
	cd 8	17.9.93	11:30	liv	1	25	m	29.60	68.70	29.60	0.50	0.80	f		
	cd 8	17.9.93	17:00	study	1	25	m	30.00	68.50	30.10	0.50	0.80	f		
	cd 8	18.9.93	5:35	bed	0	25	m	30.50	71.60	30.50	0.40	0.80	f		
	cd 8	18.9.93	14:45	study	2	25	m	30.40	65.70	30.40	0.40	1.30	f		
	cd 8	18.9.93	21:00	bed	0	25	m	30.70	64.80	31.00	0.40	0.80	f		
	cd 8	18.9.93	21:30	liv	1	25	m	30.60	65.70	30.70	0.40	0.80	f		
	cd 8	18.9.93	23:30	din	0	25	m	30.80	67.70	31.00	0.40	1.80	f		
	cd 8	19.9.93	7:30	din	2	25	m	31.60	62.70	31.70	0.40	0.80	m		
	cd 8	19.9.93	10:30	din	0	25	m	31.20	62.50	31.30	0.40	0.80	f		
	cd 8	19.9.93	13:30	bed	1	25	m	31.40	63.80	31.30	0.40	0.80	f		
	cd 8	19.9.93	15:15	liv	0	25	m	32.10	64.30	31.90	0.40	0.80	f		
	cd 8	20.9.93	10:30	study	1	25	m	31.20	62.00	31.30	0.50	0.80	f		
	cd 8	20.9.93	11:00	study	1	25	m	29.80	63.30	29.80	0.50	1.00	f		

	cd 8	20.9.93	13:55	bed	0	25	m	30.50	62.10	30.50	0.50	0.80	f		
	cd 8	20.9.93	16:00	study	1	25	m	30.60	61.70	30.60	0.50	1.30	f		
	cd 8	20.9.93	17:00	liv	1	25	m	30.70	61.60	30.70	0.50	0.80	f		
	cd9	6.09.93	9:25	din	0	22	m	28.40	78.10	28.70	0.40	1.80	m		
	cd9	6.09.93	10:10	office	2	22	m	31.20	63.50	32.30	0.40	1.00	s		
	cd9	6.09.93	12:30	lobby	0	22	m	31.90	58.20	32.50	0.40	2.00	f		
	cd9	6.09.93	16:00	liv	1	22	m	28.40	68.00	29.10	0.50	1.00	s		
	cd9	6.09.93	23:00	bed	1	22	m	28.40	80.30	28.70	0.40	0.80	m		
	cd9	7.9.93	9:30	office	0	22	m	28.10	71.00	28.40	0.50	1.20	s		
	cd9	7.9.93	12:00	lobby	2	22	m	31.00	68.00	31.80	0.50	1.00	n		
	cd9	7.9.93	15:30	bed	1	22	m	28.00	88.00	27.80	0.40	0.80	m		rain
	cd9	7.9.93	18:00	office	1	22	m	28.30	63.00	29.20	0.50	1.00	n		
	cd9	7.9.93	0:30	bed	1	22	m	28.50	80.10	29.30	0.40	0.80	f		
	cd9	8.9.93	8:00	din	1	22	m	28.60	77.80	29.30	0.50	1.80	m		
	cd9	8.9.93	11:00	office	2	22	m	33.60	54.00	35.10	0.50	1.20	s		
	cd9	8.9.93	14:00	office	-1	22	m	25.10	58.00	27.80	0.50	1.80	m		a/c
	cd9	8.9.93	17:30	office	2	22	m	27.60	52.00	28.30	0.40	1.00	n		
	cd9	8.9.93	20:25	bed	1	22	m	28.70	78.20	29.30	0.40	0.80	s		
	cd9	9.9.93	8:00	din	0	22	m	28.60	67.40	28.80	0.40	1.80	m		
	cd9	9.9.93	12:00	ver	1	22	m	32.20	71.20	32.80	0.40	1.00	m		
	cd9	9.9.93	17:00	studio	2	22	m	29.10	70.60	30.10	0.40	1.30	s		
	cd9	9.9.93	20:00	liv	1	22	m	26.40	72.20	27.80	0.40	1.00	s		
	cd9	9.9.93	22:30	bed	1	22	m	28.30	75.00	28.80	0.40	0.80	f		
	cd10	6.10.93	8:00	din	0	40	f	27.80	67.70	28.30	0.50	1.80	m		
	cd10	6.10.93	12:00	ver	1	40	f	31.20	72.10	32.20	0.50	1.20	m		
	cd10	6.10.93	17:00	kit	2	40	f	29.00	70.10	30.70	0.50	2.20	s		
	cd10	6.10.93	20:00	studio	1	40	f	27.40	72.00	28.30	0.50	1.00	n		
	cd10	6.10.93	22:30	liv	1	40	f	28.10	74.00	29.20	0.50	1.00	f		
	cd10	7.9.93	8:00	din	1	40	f	27.20	64.00	28.10	0.50	1.20	m		
	cd10	7.9.93	13:30	bed	0	40	f	28.20	58.00	28.80	0.50	1.00	m		
	cd10	7.9.93	16:00	bed	-1	40	f	27.00	80.10	27.20	0.50	0.80	f		
	cd10	7.9.93	21:30	liv	1	40	f	27.40	68.10	28.30	0.50	0.80	f		
	cd10	7.9.93	22:30	bed	0	40	f	28.10	79.70	28.50	0.50	0.80	m		
	cd10	8.9.93	8:00	kit	1	40	f	28.40	54.00	29.30	0.50	2.00	n		
	cd10	8.9.93	15:15	bed	0	40	f	27.80	62.00	28.30	0.50	1.00	m		
	cd10	8.9.93	17:00	kit	1	40	f	28.10	63.00	28.60	0.50	2.00	n		
	cd10	8.9.93	20:40	liv	0	40	f	28.60	78.00	29.30	0.50	1.00	m		
	cd10	8.9.93	22:50	bed	0	40	f	27.30	79.00	28.30	0.50	0.80	m		
	cd10	9.9.93	9:00	bed	0	40	f	28.10	68.80	28.40	0.50	1.00	f		
	cd10	9.9.93	12:00	shop	3	40	f	32.60	81.00	32.80	0.50	1.80	n		
	cd10	9.9.93	18:00	out	1	40	f	28.30	66.10	28.80	0.50	1.80	s		
	cd10	9.9.93	21:00	kit	2	40	f	28.80	74.20	29.50	0.50	1.80	s		
	cd10	9.9.93	0:00	bed	1	40	f	28.20	79.40	29.60	0.50	0.80	f		
	cd11	6.9.93	9:00	bed	0	20	f	28.10	68.80	28.60	0.50	1.20	f		
	cd11	6.9.93	12:00	shop	2	20	f	32.30	81.00	32.50	0.50	2.00	n		
	cd11	6.9.93	18:00	lawn	1	20	f	28.10	64.00	28.80	0.50	2.00	s		
	cd11	6.9.93	21:00	kit	2	20	f	28.80	74.00	29.00	0.50	1.80	s		
	cd11	6.9.93	0:00	bed	1	20	f	28.40	78.00	29.30	0.50	0.80	f		
	cd11	7.9.93	9:00	bed	0	20	f	27.80	68.00	28.30	0.50	1.20	f		
	cd11	7.9.93	12:00	ver	1	20	f	30.10	57.00	32.10	0.50	2.00	s		
	cd11	7.9.93	16:00	friend	1	20	f	27.40	60.20	28.30	0.50	1.00	m		
	cd11	7.9.93	19:00	bed	1	20	f	27.10	67.20	28.30	0.50	1.20	f		
	cd11	7.9.93	23:00	bed	0	20	f	28.10	80.00	28.40	0.50	0.80	f		
	cd11	8.9.93	7:45	din	0	20	f	27.40	63.00	28.30	0.50	1.80	m		
	cd11	8.9.93	15:15	corr	1	20	f	27.80	58.00	28.70	0.50	2.00	s		
	cd11	8.9.93	16:45	bed	1	20	f	27.60	52.00	28.90	0.50	1.20	m		
	cd11	8.9.93	20:00	bed	1	20	f	28.60	79.00	28.80	0.50	1.30	f		
	cd11	8.9.93	22:30	bed	0	20	f	28.70	78.40	28.90	0.50	0.80	f		
	cd11	9.9.93	9:23	din	0	20	f	28.40	78.20	28.80	0.50	1.80	m		
	cd11	9.9.93	10:10	coll	2	20	f	31.80	63.60	32.30	0.50	1.00	s		
	cd11	9.9.93	12:30	schoo	0	20	f	32.10	58.90	32.70	0.50	1.00	f		
	cd11	9.9.93	16:00	friend	1	20	f	28.30	68.10	28.80	0.50	1.00	s		
	cd11	9.9.93	23:00	bed	1	20	f	28.60	80.40	28.70	0.50	0.80	m		
	cd12	3.10.93	8:15	bed	0	22	m	28.60	92.00	29.20	0.40	1.20	m	30.50	
	cd12	3.10.93	11:00	liv	1	22	m	30.10	92.00	32.00	0.40	1.00	m	32.50	
	cd12	3.10.93	12:30	bed	1	22	m	30.60	90.00	32.50	0.50	1.00	f	33.00	
	cd12	3.10.93	15:00	bed	2	22	m	32.00	86.00	33.10	0.50	0.80	f	33.20	
	cd12	3.10.93	19:00	bed	1	22	m	30.00	89.00	31.00	0.50	1.00	m	31.00	
	cd12	4.10.93	9:15	bed	1	22	m	29.00	93.00	31.20	0.40	1.20	m	32.00	
	cd12	4.10.93	13:30	din	2	22	m	33.00	86.00	33.50	0.40	1.80	f	34.50	
	cd12	4.10.93	17:00	bed	1	22	m	30.20	91.00	32.00	0.50	1.00	m	32.00	
	cd12	4.10.93	20:30	bed	1	22	m	30.10	92.00	31.20	0.50	1.20	m	32.00	
	cd12	4.10.93	22:10	bed	0	22	m	29.00	94.00	30.00	0.40	1.20	m	31.50	
	cd12	5.10.93	9:00	bed	1	22	m	29.30	92.00	30.70	0.40	1.20	m	32.00	

cd12	5.10.93	18:00	liv	1	22	m	30.00	92.50	30.70	0.40	1.00	m	32.00
cd12	5.10.93	19:00	bed	1	22	m	30.30	90.00	31.10	0.40	1.20	m	31.70
cd12	5.10.93	21:20	bed	0	22	m	28.10	98.10	29.30	0.40	1.20	s	29.00
cd12	5.10.93	23:30	bed	0	22	m	28.00	96.00	29.00	0.40	1.20	n	28.80
cd12	6.10.93	19:30	bed	0	22	m	29.00	93.00	32.10	0.40	0.80	s	30.10
cd12	6.10.93	9:00	bed	1	22	m	30.10	92.50	32.00	0.40	1.20	m	32.00
cd12	6.10.93	14:00	bed	2	22	m	33.20	87.00	34.10	0.40	0.80	f	34.00
cd12	6.10.93	20:30	bed	1	22	m	32.00	88.00	33.30	0.50	1.20	m	33.00
cd12	6.10.93	22:00	bed	1	22	m	31.50	89.00	32.00	0.40	1.20	m	32.00
cd13	7.10.93	8:00	bed	1	22	m	29.00	92.50	30.20	0.40	1.20	m	30.10
cd13	7.10.93	12:00	class	2	22	m	32.30	90.00	33.00	0.50	1.00	f	33.00
cd13	7.10.93	16:00	class	2	22	m	33.00	92.00	33.50	0.50	1.00	f	34.00
cd13	7.10.93	19:00	bed	1	22	m	30.00	92.00	31.00	0.40	1.20	f	31.00
cd13	7.10.93	22:00	bed	0	22	m	29.00	92.00	29.70	0.40	0.80	f	30.00
cd13	8.10.93	7:00	bed	0	22	m	28.00	92.00	29.30	0.40	1.20	m	29.00
cd13	8.10.93	9:30	bed	1	22	m	29.50	91.00	31.70	0.40	1.20	m	31.00
cd13	8.10.93	13:30	din	2	22	m	32.00	93.00	33.10	0.40	1.80	m	33.70
cd13	8.10.93	18:00	bed	1	22	m	31.00	92.00	32.50	0.40	1.20	f	32.00
cd13	8.10.93	20:00	bed	1	22	m	30.50	94.00	32.00	0.40	1.20	f	31.60
cd13	9.10.93	9:00	bed	0	22	m	29.30	92.00	30.70	0.40	1.00	m	31.70
cd13	9.10.93	10:30	bed	1	22	m	32.00	93.00	33.50	0.40	1.20	f	33.00
cd13	9.10.93	11:30	class	2	22	m	33.00	92.00	33.90	0.50	1.00	f	32.70
cd13	9.10.93	13:30	din	2	22	m	33.20	91.00	33.50	0.50	1.80	f	33.00
cd13	9.10.93	22:30	bed	1	22	m	30.70	88.00	31.80	0.50	0.80	m	31.80
cd13	10.10.93	8:00	bed	1	22	m	32.00	91.00	33.30	0.40	1.20	m	32.80
cd13	10.10.93	10:00	bed	1	22	m	33.00	95.00	33.90	0.40	1.20	m	34.00
cd13	10.10.93	16:00	bed	2	22	m	34.00	98.00	35.10	0.40	1.20	f	35.00
cd13	10.10.93	18:00	bed	1	22	m	32.00	90.00	33.50	0.40	1.00	m	32.90
cd13	10.10.93	22:00	bed	0	22	m	29.00	94.00	30.20	0.40	0.80	f	30.10
cd14	15.11.93	15:30	liv	-1	19	m	31.10	86.70	27.60	0.40	0.80	n	31.00
cd14	15.11.93	17:00	bed	-1	19	m	31.00	86.90	27.60	0.40	1.20	f	30.90
cd14	15.11.93	18:30	bed	0	19	m	31.00	86.60	27.80	0.40	1.00	f	30.60
cd14	15.11.93	20:00	bed	0	19	m	30.80	86.60	27.70	0.40	1.20	f	29.00
cd14	15.11.93	23:30	bed	-1	19	m	30.50	86.20	27.80	0.40	1.00	f	28.00
cd14	16.11.93	11:30	liv	0	19	m	29.20	83.60	26.20	0.40	0.80	n	29.30
cd14	16.11.93	15:30	bed	0	19	m	30.20	84.80	27.10	0.40	0.80	n	32.70
cd14	16.11.93	18:30	bed	1	19	m	30.50	81.90	27.50	0.40	0.80	n	29.20
cd14	16.11.93	22:30	liv	-1	19	m	30.10	83.70	27.20	0.40	0.80	n	27.70
cd14	16.11.93	23:45	bed	0	19	m	30.00	79.40	26.90	0.40	1.00	f	27.30
cd14	17.11.9	12:30	liv	-2	19	m	29.20	81.80	26.20	0.40	0.80	n	29.30
cd14	17.11.9	14:30	liv	0	19	m	29.70	78.40	26.50	0.40	0.80	n	29.30
cd14	17.11.9	19:00	bed	0	19	m	30.20	80.10	27.20	0.40	0.80	f	28.90
cd14	17.11.9	22:30	bed	-1	19	m	30.00	80.30	27.00	0.40	1.20	f	27.90
cd14	17.11.9	23:30	bed	-1	19	m	29.50	78.60	26.80	0.40	1.00	m	28.20
cd14	18.11.93	13:30	bed	0	19	m	29.50	79.60	26.60	0.40	1.00	n	3.40
cd14	18.11.93	15:30	liv	0	19	m	29.60	86.70	27.00	0.40	0.80	n	30.00
cd14	18.11.93	19:00	liv	0	19	m	30.00	81.80	27.00	0.40	0.80	n	29.00
cd14	18.11.93	22:30	bed	1	19	m	30.20	80.80	27.10	0.40	1.20	n	28.90
cd14	18.11.93	23:30	bed	1	19	m	30.50	78.80	27.00	0.40	0.80	n	29.00
cd15	1.11.93	8:30	bed	-1	19	m	29.20	92.00	26.20	0.50	1.00	n	29.50
cd15	1.11.93	10:50	liv	-1	19	m	30.10	90.90	26.80	0.50	1.00	n	30.20
cd15	1.11.93	12:20	liv	2	19	m	31.30	89.80	28.30	0.40	3.00	n	31.20
cd15	1.11.93	16:00	bed	1	19	m	30.90	88.90	28.30	0.50	0.80	s	30.80
cd15	1.11.93	20:00	study	-1	19	m	29.80	88.80	26.40	0.50	1.00	n	30.10
cd15	2.11.93	9:00	study	-1	19	m	30.00	87.90	27.70	0.50	1.00	n	30.00
cd15	2.11.93	15:00	bed	1	19	m	31.70	89.20	29.80	0.50	0.80	s	31.50
cd15	2.11.93	17:00	liv	1	19	m	32.10	88.90	28.90	0.50	1.00	s	31.70
cd15	2.11.93	20:00	liv	1	19	m	31.40	88.70	28.00	0.50	1.00	s	31.40
cd15	2.11.93	22:00	bed	-1	19	m	30.60	87.70	27.50	0.50	0.80	n	30.70
cd15	3.11.93	9:15	bed	-1	19	m	29.80	87.30	26.80	0.50	1.00	n	29.90
cd15	3.11.93	14:50	din	-1	19	m	29.10	86.50	25.90	0.50	1.80	n	29.00
cd15	3.11.93	19:06	liv	-1	19	m	28.80	86.50	26.00	0.50	1.20	n	28.70
cd15	3.11.93	21:22	liv	-1	19	m	28.60	86.20	25.40	0.50	1.20	n	28.50
cd15	3.11.93	23:00	bed	-1	19	m	27.90	86.20	24.00	0.50	1.20	n	27.70
cd15	4.11.93	7:40	liv	1	19	m	27.00	85.90	23.50	0.50	1.20	n	26.40
cd15	4.11.93	9:30	liv	1	19	m	28.00	85.20	24.60	0.50	1.20	n	27.80
cd15	4.11.93	11:00	liv	1	19	m	29.10	85.50	26.00	0.50	1.20	n	29.00
cd15	4.11.93	15:00	liv	1	19	m	32.00	85.70	29.40	0.50	1.20	n	31.90
cd15	4.11.93	21:54	bed	-1	19	m	28.90	85.00	27.10	0.50	0.80	n	28.80
cd16	1.11.93	9:32	bed	0	20	m	30.30	91.80	27.50	0.40	1.00	s	30.10
cd16	1.11.93	12:45	bed	1	20	m	30.60	90.10	27.60	0.40	1.00	n	30.70
cd16	1.11.93	15:03	bed	0	20	m	30.60	90.40	27.20	0.50	0.80	s	30.50
cd16	1.11.93	20:45	bed	0	20	m	30.40	89.60	27.50	0.50	1.20	m	30.20
cd16	1.11.93	21:15	bed	-1	20	m	29.40	89.60	26.30	0.50	1.50	n	29.30

cd16	2.11.93	9:41	bed	1	20	m	31.30	88.20	27.80	0.40	1.00	n	31.20
cd16	2.11.93	15:30	bed	0	20	m	31.70	89.20	28.80	0.30	0.80	f	31.40
cd16	2.11.93	18:29	bed	1	20	m	31.60	88.80	28.70	0.40	0.80	f	31.40
cd16	2.11.93	20:51	din	0	20	m	31.30	88.70	28.40	0.40	1.80	m	31.20
cd16	2.11.93	0:00	bed	-1	20	m	30.10	88.20	27.00	0.30	0.80	s	30.10
cd16	3.11.93	8:36	liv	0	20	m	30.40	89.10	27.70	0.30	1.00	n	30.20
cd16	3.11.93	11:27	bed	0	20	m	30.80	87.90	28.00	0.40	0.80	m	30.70
cd16	3.11.93	18:03	bed	0	20	m	29.70	87.10	26.87	0.40	1.80	s	29.50
cd16	3.11.93	20:32	bed	1	20	m	28.60	87.30	25.30	0.30	1.00	n	28.50
cd16	3.11.93	22:00	bed	0	20	m	28.70	86.50	26.30	0.30	0.80	n	28.50
cd16	4.11.93	8:40	bed	-1	20	m	28.30	86.70	26.00	0.30	1.00	n	28.10
cd16	4.11.93	18:30	bed	-1	20	m	30.10	86.40	27.20	0.40	1.00	s	30.00
cd16	4.11.93	20:30	liv	-1	20	m	30.80	86.20	27.70	0.40	0.80	n	29.30
cd16	4.11.93	22:30	bed	-1	20	m	29.50	84.50	26.30	0.40	1.00	n	29.30
cd16	4.11.93	0:00	bed	-2	20	m	27.90	83.80	25.00	0.40	0.80	n	27.70
cd17	9.11.93	7:15	bed	0	19	m	29.90	87.60	26.90	0.30	0.80	n	29.60
cd17	9.11.93	9:00	liv	1	19	m	30.00	87.40	27.00	0.30	0.80	n	29.80
cd17	9.11.93	20:00	liv	-1	19	m	31.00	86.90	27.60	0.50	1.20	m	29.80
cd17	9.11.93	22:15	bed	1	19	m	30.40	87.70	27.40	0.50	0.80	n	30.00
cd17	10.11.93	2:30	bed	0	19	m	30.20	88.00	27.10	0.40	0.80	n	28.10
cd17	10.11.93	5:30	bed	0	19	m	30.00	87.70	27.40	0.40	1.00	n	28.50
cd17	10.11.93	7:30	bed	-1	19	m	29.90	87.60	26.90	0.40	1.20	n	29.40
cd17	10.11.93	12:20	bed	1	19	m	30.20	87.60	27.00	0.40	1.20	n	30.60
cd17	10.11.93	18:45	liv	-1	19	m	30.60	86.80	27.40	0.50	0.80	m	30.00
cd17	10.11.93	21:00	liv	-1	19	m	30.30	86.80	27.60	0.50	1.00	m	29.90
cd17	11.11.93	7:45	bed	-1	19	m	29.70	87.40	26.50	0.40	1.20	n	29.40
cd17	11.11.93	16:15	bed	1	19	m	30.50	87.50	27.20	0.50	0.80	n	30.60
cd17	11.11.93	21:00	liv	1	19	m	30.40	86.80	27.70	0.40	1.20	n	29.50
cd17	11.11.93	23:30	liv	0	19	m	30.00	87.10	27.10	0.40	0.80	n	28.80
cd17	12.11.93	1:00	bed	-1	19	m	29.70	82.80	27.10	0.30	1.00	n	27.10
cd17	12.11.93	7:15	bed	-1	19	m	29.70	86.10	26.60	0.30	1.20	n	28.50
cd17	12.11.93	9:15	liv	1	19	m	29.70	86.00	26.60	0.30	1.20	n	29.30
cd17	12.11.93	16:45	bed	-1	19	m	30.10	85.80	27.00	0.40	1.20	n	30.20
cd17	12.11.93	17:15	bed	-1	19	m	30.20	85.90	27.00	0.40	1.20	n	29.60
cd17	12.11.93	18:00	liv	-1	19	m	30.10	85.60	27.20	0.40	0.80	m	29.70
cd18	21.11.93	11:10	bed	1	24	f	29.70	80.90	26.60	0.50	1.00	n	29.70
cd18	21.11.93	16:00	bed	1	24	f	30.70	79.60	27.60	0.50	1.00	n	30.60
cd18	21.11.93	18:20	liv	-1	24	f	30.60	80.80	27.60	0.50	0.80	s	30.60
cd18	21.11.93	22:30	bed	1	24	f	30.20	75.90	27.40	0.50	1.00	s	29.50
cd18	22.11.93	0:10	bed	0	24	f	30.70	78.60	27.50	0.50	0.80	s	30.00
cd18	22.11.93	11:50	liv	0	24	f	29.70	80.60	26.40	0.50	0.80	n	29.80
cd18	22.11.93	14:30	bed	1	24	f	30.40	80.90	27.40	0.50	0.80	s	30.40
cd18	22.11.93	16:30	liv	1	24	f	30.10	80.20	27.10	0.50	1.00	n	30.10
cd18	22.11.93	23:00	liv	0	24	f	31.00	77.10	28.10	0.50	0.80	s	30.10
cd18	23.11.93	0:30	bed	0	24	f	30.90	77.00	27.60	0.50	0.80	s	30.00
cd18	23.11.93	8:30	bed	-1	24	f	29.00	79.60	25.90	0.50	0.80	n	28.50
cd18	23.11.93	11:05	bed	0	24	f	29.00	79.40	25.60	0.50	0.80	n	29.10
cd18	23.11.93	14:20	din	0	24	f	30.90	79.60	27.10	0.50	1.80	s	30.90
cd18	23.11.93	19:00	bed	0	24	f	30.00	79.50	26.80	0.50	1.00	s	29.70
cd18	23.11.93	22:35	bed	0	24	f	29.00	79.40	26.00	0.50	0.80	n	28.90
cd18	24.11.93	10:00	liv	0	24	f	29.70	79.40	26.40	0.50	1.00	s	29.80
cd18	24.11.93	12:30	bed	1	24	f	29.20	79.40	25.80	0.50	1.00	n	29.20
cd18	24.11.93	15:30	bed	1	24	f	29.80	79.50	26.80	0.50	0.80	n	29.80
cd18	24.11.93	20:10	liv	0	24	f	29.90	79.50	26.60	0.50	0.80	s	29.80
cd18	24.11.93	23:45	liv	0	24	f	30.80	79.50	27.80	0.50	0.80	s	29.80
additional data from comfort assessments of feb-mar-apr 1993													
ca1	13.2.93	22:50	study	-1	24	m	25.80	94.90	25.90	0.50	1.20	n	
ca1	13.2.93	0:00	liv	0	24	m	26.40	95.90	26.60	0.50	0.80	n	
ca1	14.2.93	12:00	study	-1	24	m	25.80	92.50	26.00	0.50	1.00	n	
ca1	15.2.93	10:50	study	0	24	m	25.80	91.90	25.90	0.50	0.80	n	
ca1	15.2.93	11:30	din	0	24	m	25.90	91.50	26.20	0.50	1.00	n	
ca2	20.2.93	11:30	liv	1	24	f	26.00	90.00	26.00	0.50	0.80	s	
ca2	21.2.93	16:00	bed	0	24	f	25.20	93.40	24.80	0.50	1.20	n	
ca2	20.2.93	21:45	bed	0	24	f	25.90	89.90	25.60	0.50	1.30	n	
ca2	21.2.93	10:10	bed	-1	24	f	24.10	93.10	23.80	0.50	1.30	n	
ca2	21.2.93	22:00	din	-1	24	f	25.20	82.90	24.80	0.50	1.00	n	
ca3	18.2.93	14:30	bed	-1	23	m	27.60	72.30	27.50	0.50	1.00	s	
ca3	18.2.93	16:40	bed	0	23	m	28.00	82.70	28.40	0.50	1.00	s	
ca3	20.2.93	12:10	liv	0	23	m	25.20	84.50	25.50	0.50	1.00	s	
ca3	20.2.93	13:30	bed	1	23	m	26.50	80.80	26.20	0.50	1.00	m	
ca3	20.2.93	14:30	bed	1	23	m	26.70	80.10	26.30	0.50	1.20	m	
ca4	2.3.93	10:00	dorm	-1	23	f	24.70	71.40	25.90	0.50	1.00	n	
ca4	2.3.93	12:10	dorm	0	23	f	25.20	67.90	25.40	0.50	1.00	s	
ca4	2.3.93	14:40	dorm	0	23	f	26.60	53.10	26.90	0.50	1.00	n	

ca4	2.3.93	17:00	dorm	-1	23	f	27.50	53.80	27.40	0.50	0.80	n
ca4	2.3.93	21:30	dorm	0	23	f	26.60	63.90	26.30	0.50	1.00	n
ca5	3.3.93	22:30	dorm	0	23	f	24.70	72.40	25.20	0.50	1.00	n
ca5	3.3.93	12:15	dorm	1	23	f	26.20	54.20	27.20	0.50	1.00	s
ca5	3.3.93	4:10	dorm	1	23	f	28.30	47.70	29.20	0.50	1.00	s
ca5	3.3.93	21:45	dorm	0	23	f	24.00	75.20	25.00	0.50	1.00	n
ca5	3.3.93	18:30	dorm	1	23	f	28.30	51.30	28.20	0.50	1.00	s
ca6	3.3.93	20:50	dorm	0	23	f	27.50	56.50	26.30	0.50	1.20	n
ca6	3.3.93	21:30	dorm	1	23	f	27.50	56.90	27.20	0.50	1.20	n
ca6	3.3.93	23:30	dorm	-1	23	f	27.10	57.80	26.90	0.50	1.00	n
ca6	4.3.93	8:00	dorm	-1	23	f	24.40	70.10	24.40	0.50	1.00	n
ca7	9.3.93	22:30	bed	0	25	m	28.00	68.80	27.50	0.50	1.00	m
ca7	9.3.93	23:30	liv	0	25	m	28.30	67.30	28.40	0.50	1.00	s
ca7	10.3.93	9:30	bed	0	25	m	27.40	69.00	27.60	0.50	1.00	n
ca7	10.3.93	10:30	bed	1	25	m	27.60	70.90	28.10	0.50	1.00	n
ca7	10.3.93	11:00	bed	1	25	m	28.20	72.00	28.50	0.50	1.20	n
ca8	18.3.93	23:15	bed	-1	24	m	27.50	50.20	27.40	0.50	1.00	s
ca8	18.3.93	22:15	bed	-1	24	m	27.70	49.90	27.80	0.50	1.20	s
ca8	19.3.93	5:15	bed	-2	24	m	25.90	60.90	25.90	0.50	1.20	n
ca8	19.3.93	11:15	bed	2	24	m	29.00	43.90	29.60	0.50	1.00	n
ca8	19.3.93	10:45	bed	1	24	m	27.70	62.70	28.30	0.50	1.00	n
ca9	22.3.93	2:15	bed	1	22	f	28.20	88.80	27.50	0.50	1.00	n
ca9	22.3.93	12:18	bed	-1	22	f	27.50	94.50	27.50	0.50	1.20	s
ca9	22.3.93	22:55	bed	-1	22	f	28.30	64.70	27.70	0.50	1.00	s
ca9	22.3.93	11:00	bed	-1	22	f	26.40	90.80	26.80	0.50	1.00	m
ca9	14.3.93	12:30	bed	1	22	f	29.80	68.20	30.60	0.50	1.20	m
ca9	14.3.93	22:55	bed	-1	22	f	28.30	64.70	27.70	0.50	1.20	m
ca10	22.3.93	17:43	bed	-1	22	f	24.70	92.30	24.70	0.50	1.20	n
ca10	22.3.93	19:14	bed	-1	22	f	24.60	89.20	24.70	0.50	1.80	m
ca10	22.3.93	21:15	bed	-1	22	f	24.20	93.80	24.10	0.50	1.20	s
ca10	23.3.93	7:22	bed	-2	22	f	22.60	####	22.60	0.50	1.00	s
ca10	23.3.93	10:03	bed	-1	22	f	24.00	97.40	24.20	0.50	1.00	s
ca11	1.4.93	6:00	bed	1	23	m	28.90	94.70	28.80	0.50	1.20	m
ca11	4.4.93	16:00	bed	1	23	m	31.00	89.10	30.90	0.50	1.20	m
ca11	2.4.93	19:00	din	0	23	m	29.20	85.00	29.00	0.50	1.20	m
ca11	2.4.93	10:00	liv	1	23	m	27.90	77.60	27.60	0.50	1.00	m
ca11	3.4.93	12:30	bed	2	23	m	30.60	78.30	30.20	0.50	1.20	m
ca11	4.4.93	9:30	bed	-1	23	m	24.40	61.30	24.60	0.50	1.00	n

বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়, ঢাকা

ঢাকা বাংলাদেশ
স্থাপত্য বিভাগ

Dear Collegue

This is to seek your help in the collection of some information relating to my research at the Architectural Association Graduate School in London. My work is entitled "Environmental Design Criteria and Guidelines for Urban Housing In Bangladesh". At present it involves the recording of thermal performance of housing typologies.

Attached is a brief data sheet which you will need to fill up and return to me. Once the examples have been selected further information will be required. The final part of the work will involve the actual recording of thermal data.

I look forward to your cooperation and thank you for your help

Please do not forget to write your name and address of the house or flat you are providing the information about.

(Fuad H Mallick)
Assistant Professor
Department of Architecture

Currently
Graduate Student
Architectural Association Graduate School
36, Bedford Square
London WC1B 3ES

Dhaka, August 02, 1992

Department of Architecture, Bangladesh University of Engineering and Technology, Dhaka 1000
Telephone: 500357, PABX 505171-77 Extension 128, 153

Appendix 5 : Case study Search Sheet

This is a preliminary survey to identify certain housing typologies in order to select some examples for an evaluation of their the thermal performance. Please provide a brief description of the house or flat where you live or have access to by providing the information requested.

WALL CONSTRUCTION:

ROOF CONSTRUCTION:

ORIENTATION:

HEIGHT FROM GROUND (mention floor and indicate if top floor):

SURROUNDINGS: Trees and vegetation

dense moderate sparse

paved areas

extensive moderate sparse

In the space provide below please draw a sketch showing the location of your building with respect to to its surroundings e.g. other buildings, trees, roads etc. Please indicate approximate distances.

PLAN

SECTION

THERMAL PERFORMANCE OF HOUSING TYPES

SAMPLE NO:

ADDRESS:

YEAR OF CONSTRUCTION:

REFERENCE NAME:

BUILDING DATA

WALL CONSTRUCTION

SECTION THROUGH WALL
SHOWING MATERIALS
AND THICKNESSES

ROOF CONSTRUCTION

SECTION THROUGH ROOF
SHOWING MATERIALS
AND THICKNESSES

COLOUR OF BUILDING:

BUILDING DATA (CONT)

SITE PLAN

SHOWING LOCATION OF BUILDING IN RELATION TO IMMEDIATE SURROUNDINGS
HATCH BLDG. LOCATION

(LOCATE BUILDING AT APPROXIMATE CENTER)

N

0 100 200 300 400 FEET

SITE SECTION

0 100 200 300 400 FEET

COMMENTS:

3
SAMPLE NO:
BUILDING DATA (CONT)

BUILDING PLAN

PLAN SHOWING EXTERIOR
DIMENSIONS ONLY
HATCH ROOM LOCATION

0 25 50 75 100 FEET

ROOM PLAN

SHOW MAJOR DIMENSIONS ONLY
INDICATE ORIENTATION AND IDENTIFY
EXTERNAL AND INTERNAL WALLS

WALL SECTION THROUGH WINDOW

INDICATE HEIGHTS AND ANY PROJECTIONS
OR SHADING DEVICES

4

SAMPLE NO:

THERMAL PERFORMANCE DATA

RECORDED BY: DATE:

TEMPERATURE HUMIDITY

TIME	INSIDE	OUTSIDE	SURFACE *	MET	DB	WB	%

*IF APPLICABLE

DIRECTION OF AIR MOVEMENT APPROXIMATE VELOCITY

TIME OBSERVED

OBSERVATION METHOD/STRATEGY

OTHER OBSERVATIONS:

CHKD:

5
SAMPLE NO.

OCCUPANT SURVEY

NO. AGE: SEX: OCCUPATION:

OCCUPANCY PATTERN DURING NORMAL WORKING DAY

0600 1200 1800 0000 HOURS

GENERAL OBSERVATIONS ABOUT COMFORT CONDITIONS IN THE HOUSE

HOT PERIOD (MARCH-JUNE)	DAY	1 cold	2	3 cool	4	5 comfortable	6	7	8 warm	9 hot
	NIGHT	1 cold	2	3 cool	4	5 comfortable	6	7	8 warm	9 hot
WET PERIOD (JULY-SEPT)	DAY	1 cold	2	3 cool	4	5 comfortable	6	7	8 warm	9 hot
	NIGHT	1 cold	2	3 cool	4	5 comfortable	6	7	8 warm	9 hot
COOL PERIOD (OCT-FEB)	DAY	1 cold	2	3 cool	4	5 comfortable	6	7	8 warm	9 hot
	NIGHT	1 cold	2	3 cool	4	5 comfortable	6	7	8 warm	9 hot

IS THE CEILING FAN BEING USED YEAR ROUND?

HAVE YOU LIVED IN ANOTHER HOUSE WHICH YOU THINK WAS MORE COMFORTABLE THAN THIS ONE? PLEASE GIVE A BRIEF DESCRIPTION (MENTION LOCATION, SURROUNDINGS, MATERIALS, NO OF STOREYS ETC.)

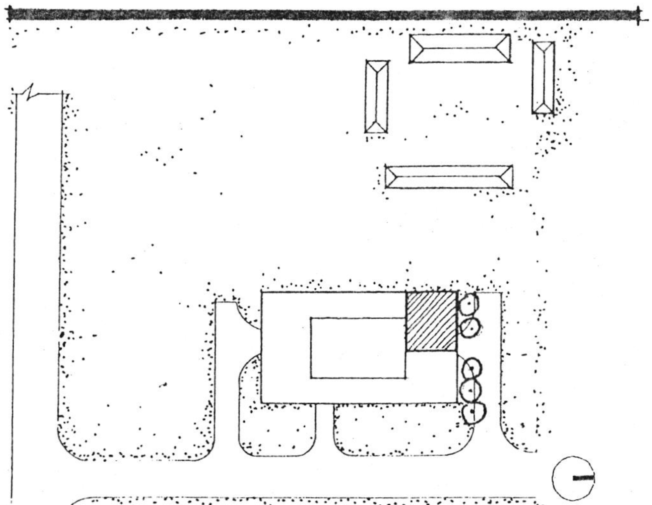
OBSERVATIONS

Appendix 7: Case Study Descriptions , Temperature Graphs and Temperature Data

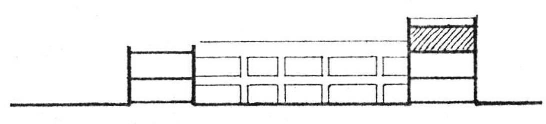
Case Study Nos. 1 - 10

CASE STUDIES

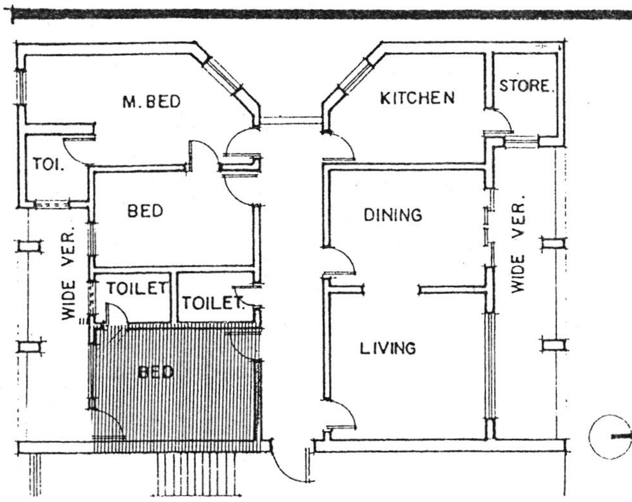
No. 1



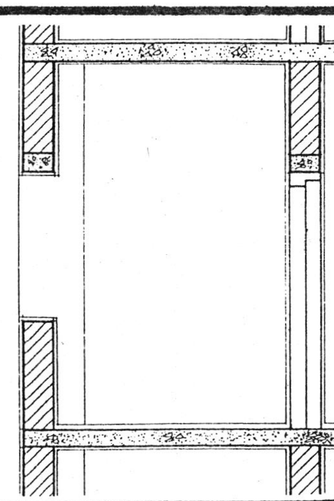
Site Plan SCALE : 0 5 10 20M.



Site Section SCALE : 0 5 10 20 M.

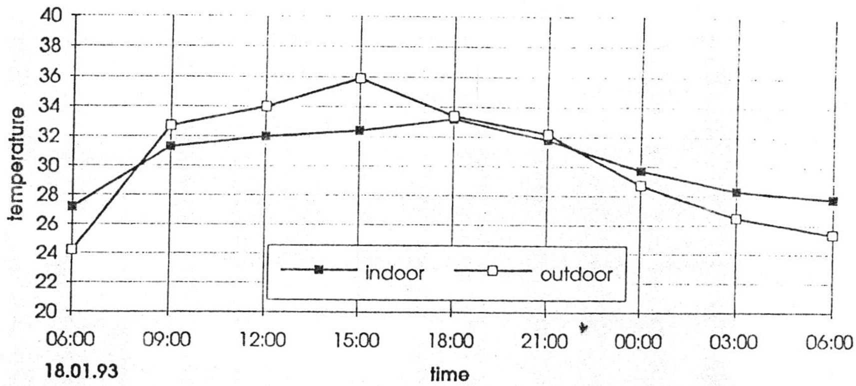


Building Plan
SCALE: 0 2.5 5 M

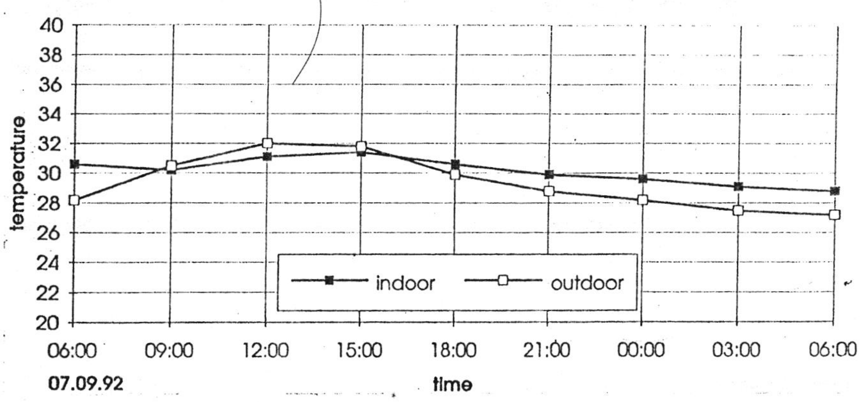


Exterior Wall Details.
SCALE : 0 1 M.

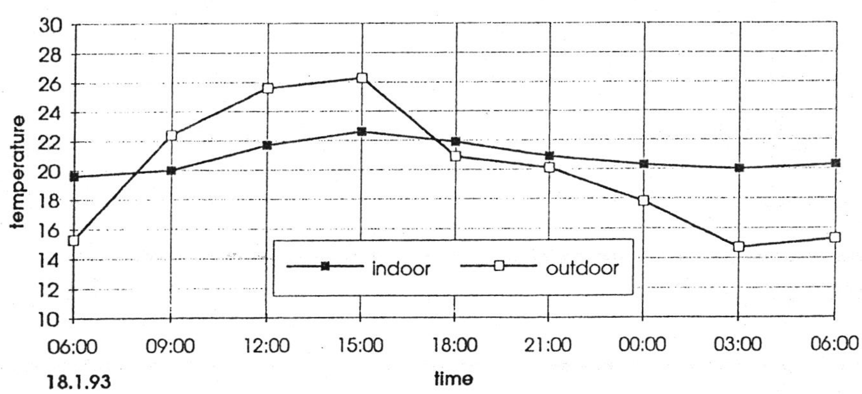
Case 1 (April)



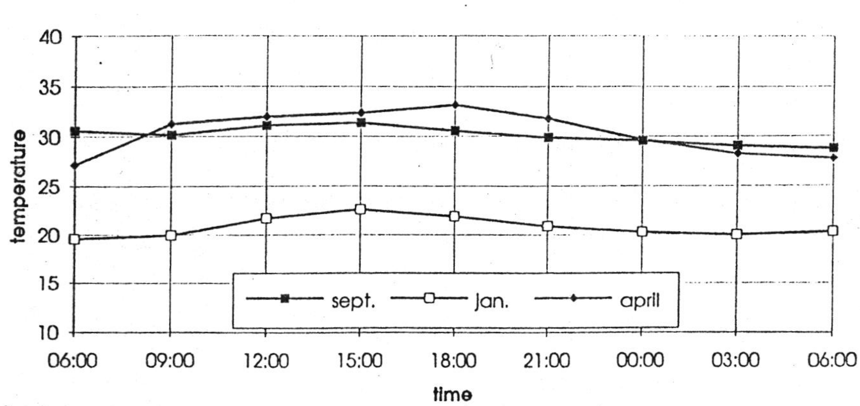
Case 1 (September)



Case 1 (January)



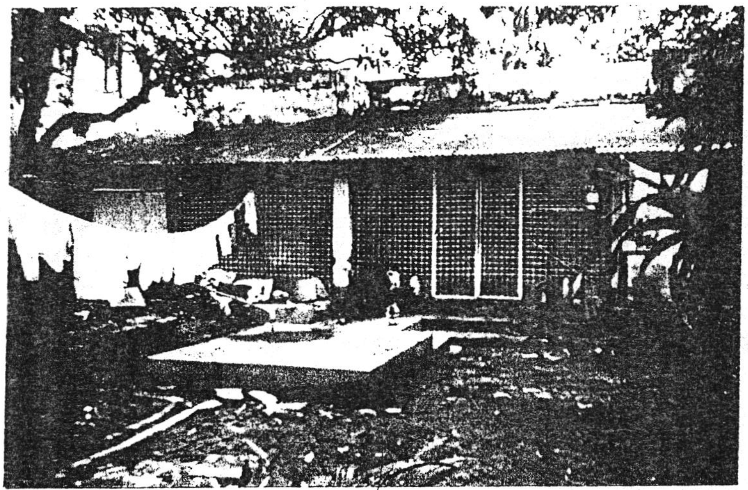
Case 1 (all year)

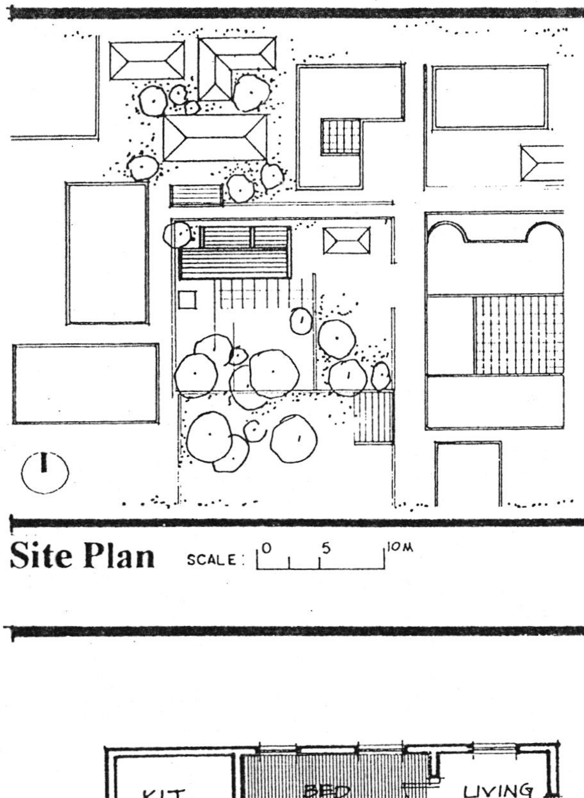


Temperature graphs for Case 1

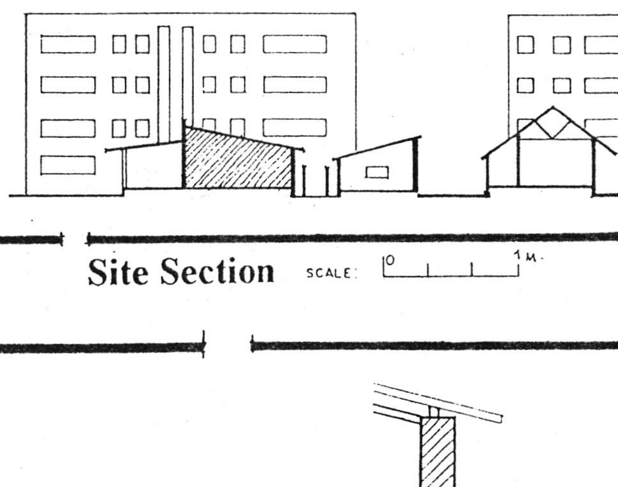
CASE STUDIES

No. 2



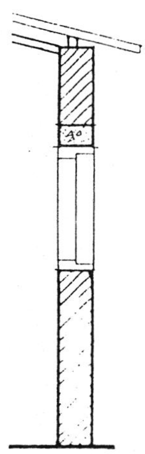


Site Plan SCALE: 0 5 10M



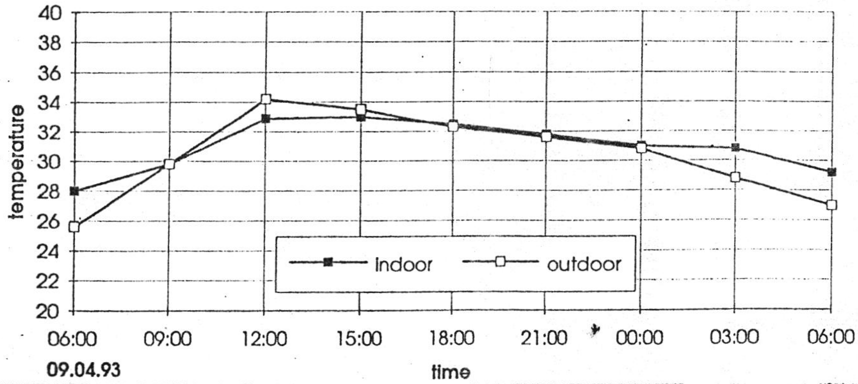
Site Section SCALE: 0 1M.

Building Plan SCALE : 0 2.5 5 M.

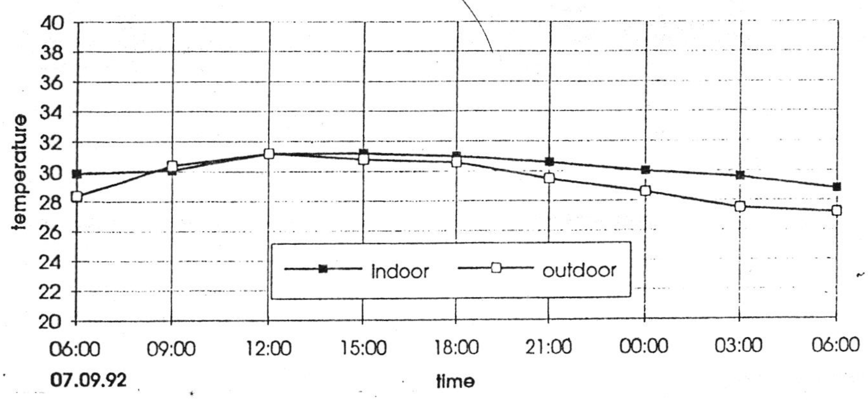


Exterior Wall Details.
SCALE 0 5 10M

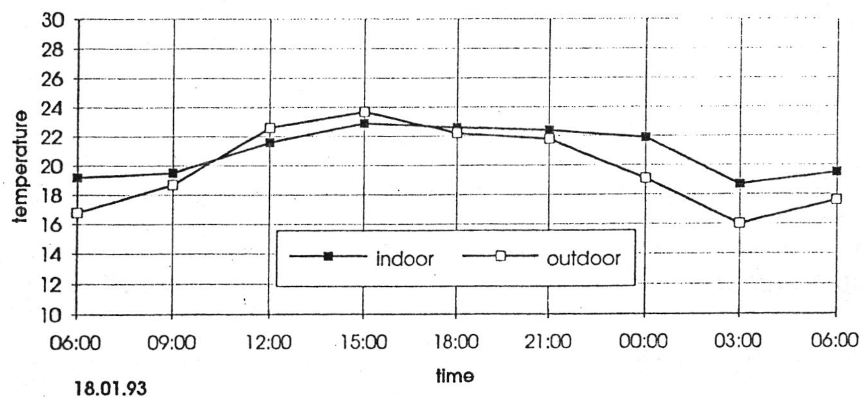
Case 2 (April)



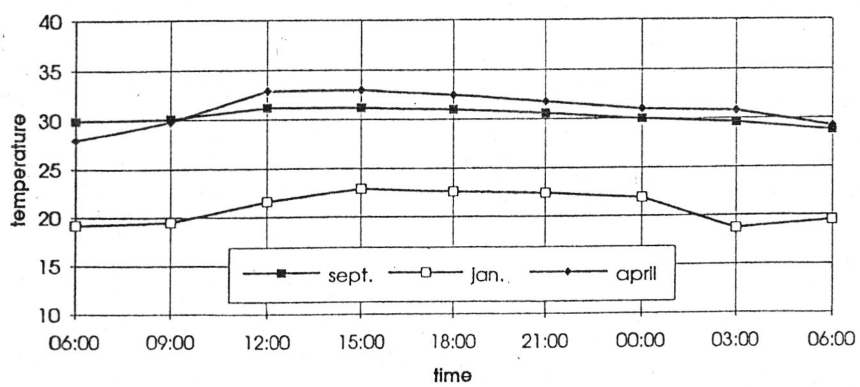
Case 2 (September)



Case 2 (January)



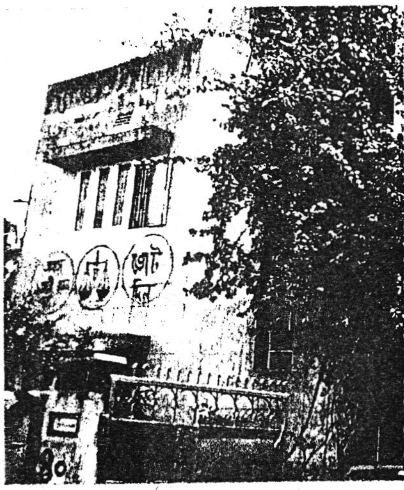
Case 2 (all year)

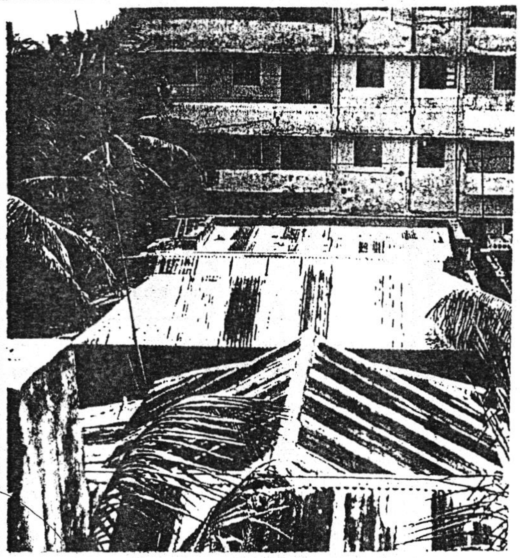


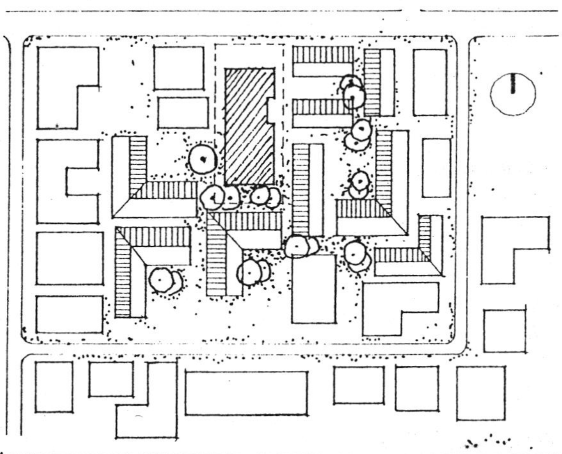
Temperature graphs for Case 2

CASE STUDIES

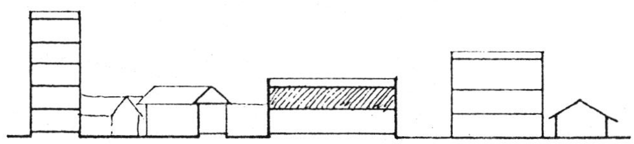
No. 3



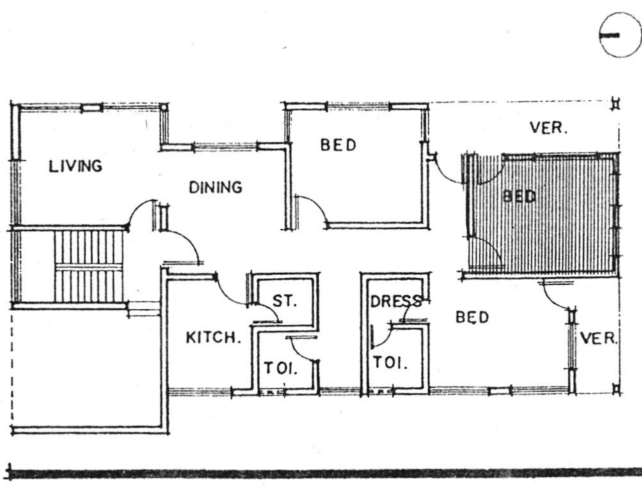




Site Plan SCALE : 0 5 10M

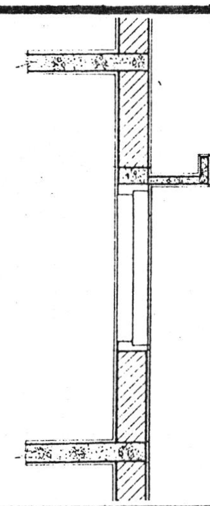


Site Section SCALE : 0 5 10 20M



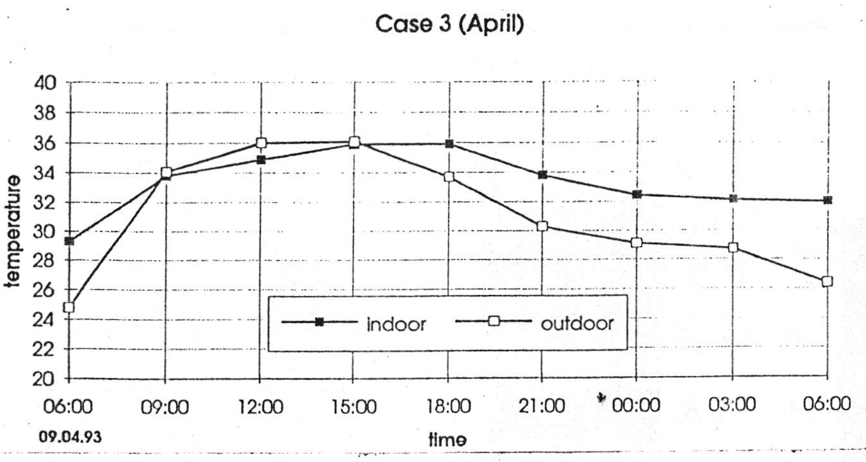
Building Plan

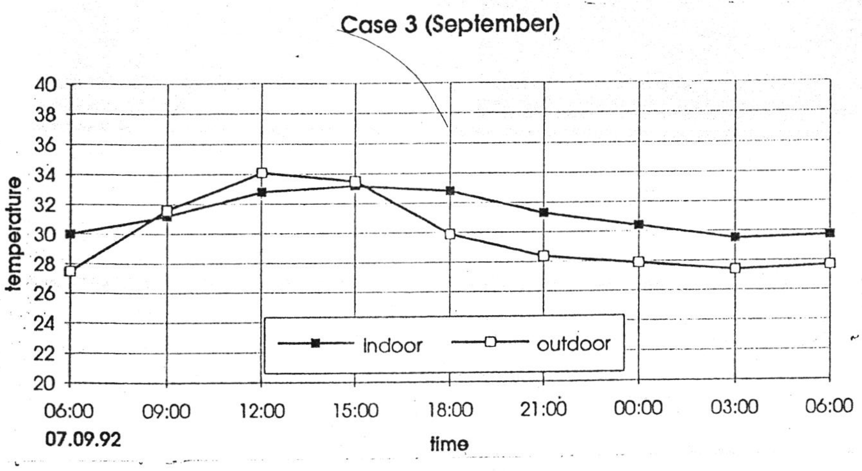
SCALE : 0 2.5 5 M.

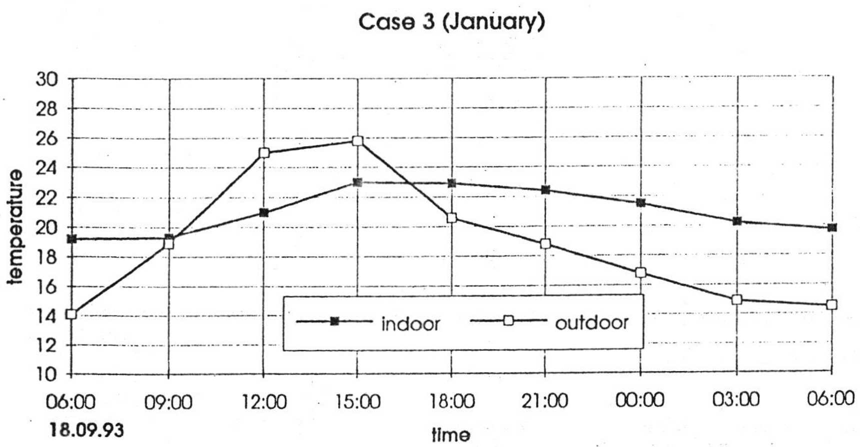


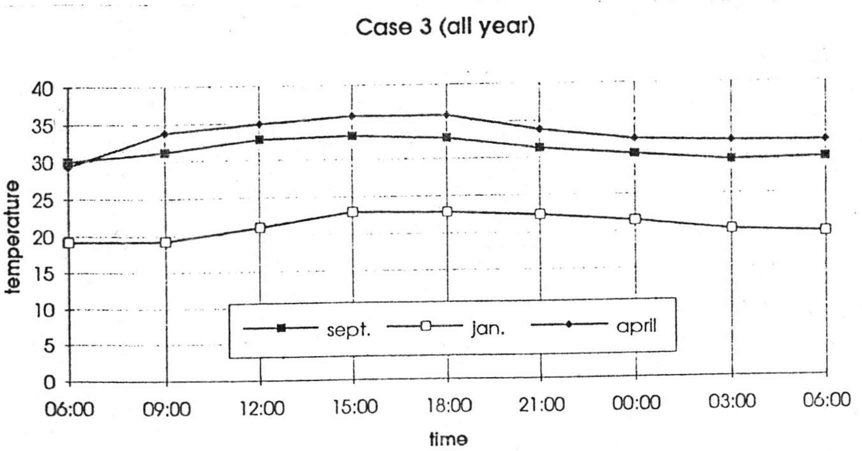
Exterior Wall Details.

SCALE 0 1M.





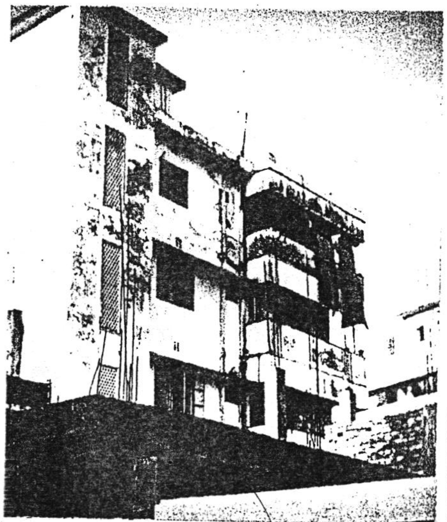


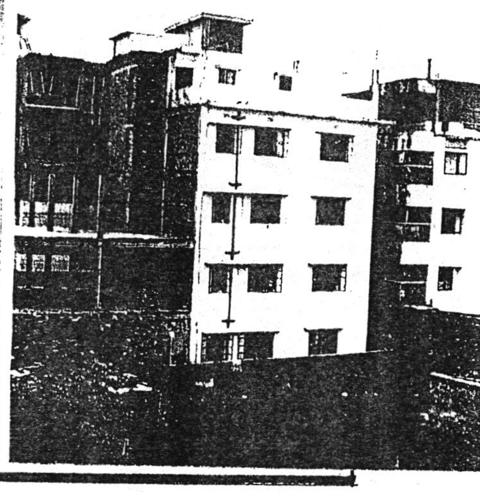


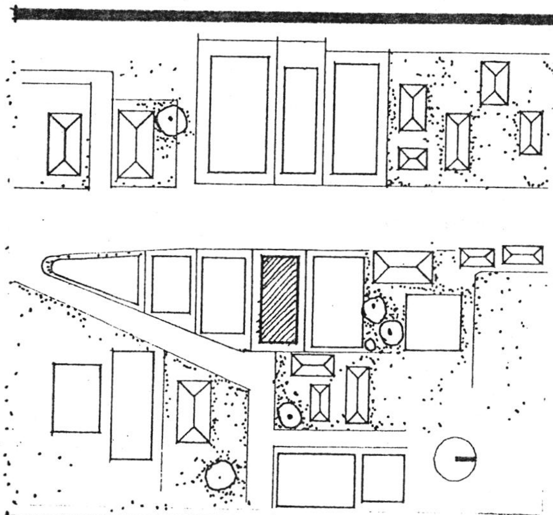
Temperature graphs for Case 3

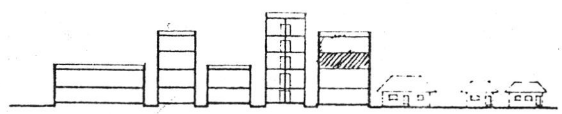
CASE STUDIES

No. 4



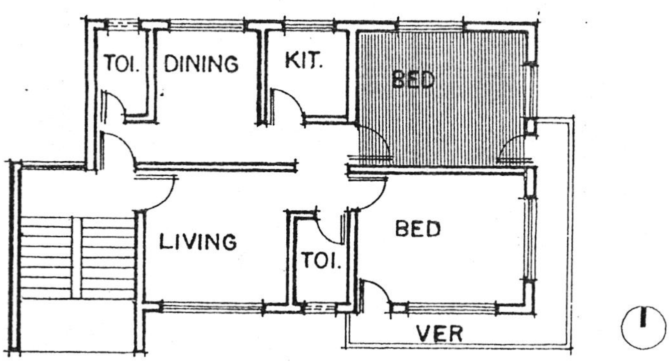




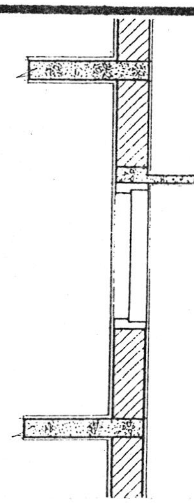


Site Plan SCALE : 0 5 10 20 M

Site Section SCALE : 0 5 10 20 M

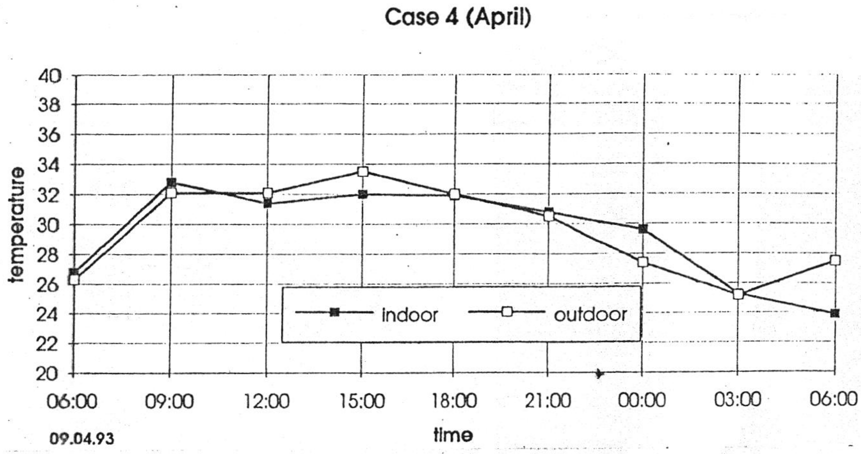


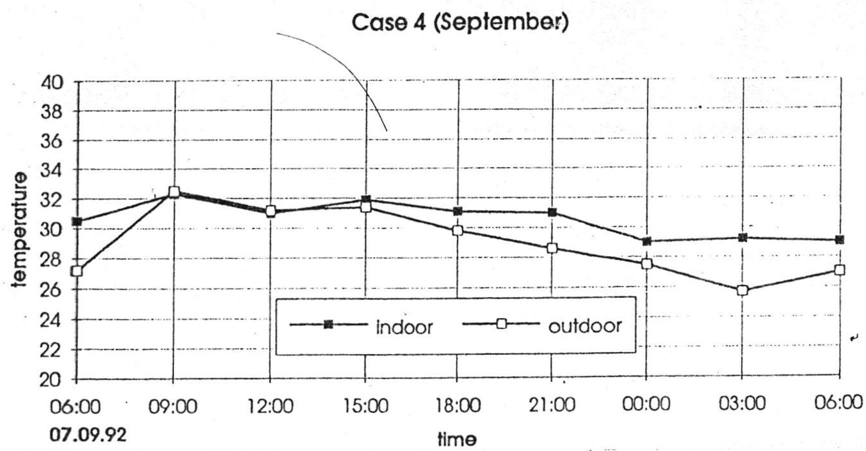
Building Plan SCALE : 0 2.5 5 M.

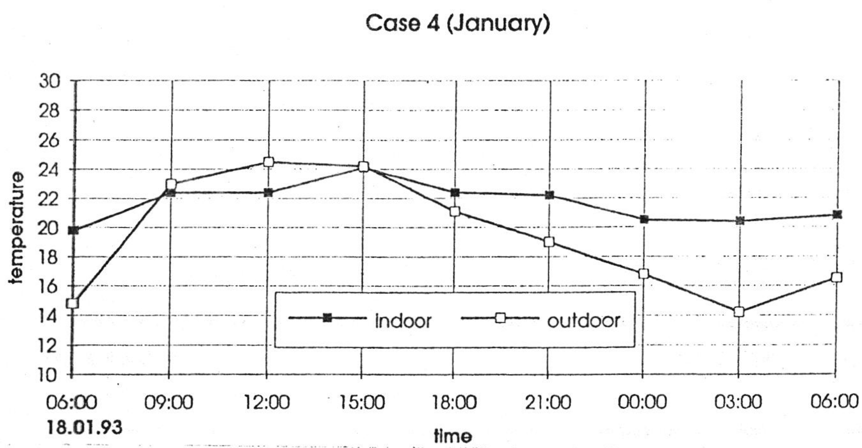


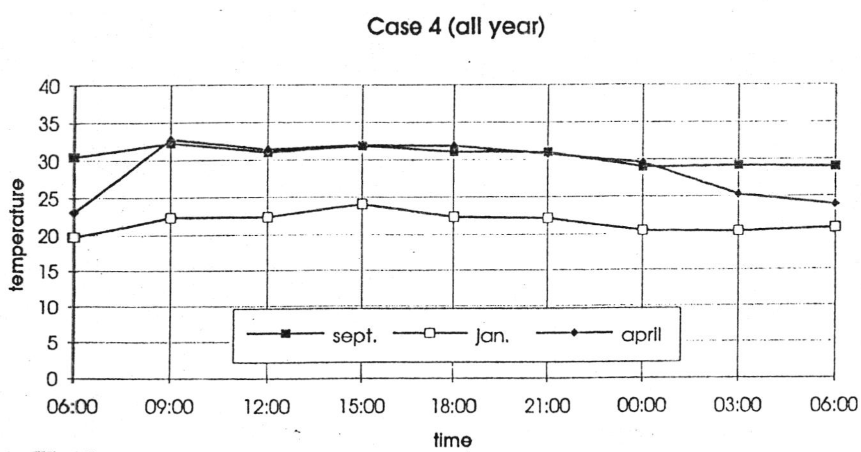
Exterior Wall Details.

SCALE : 0 1 M





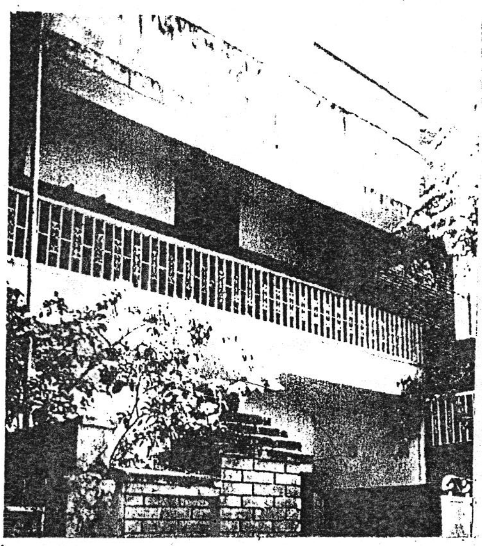


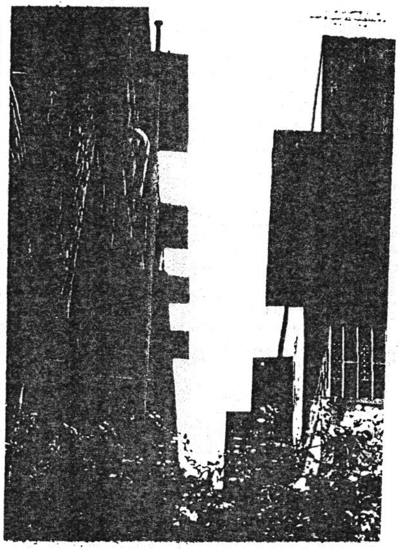


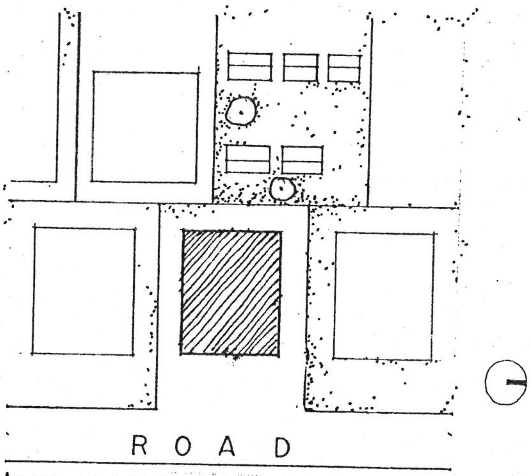
Temperature graphs for Case 4

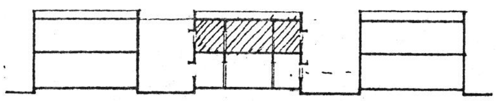
CASE STUDIES

No. 5



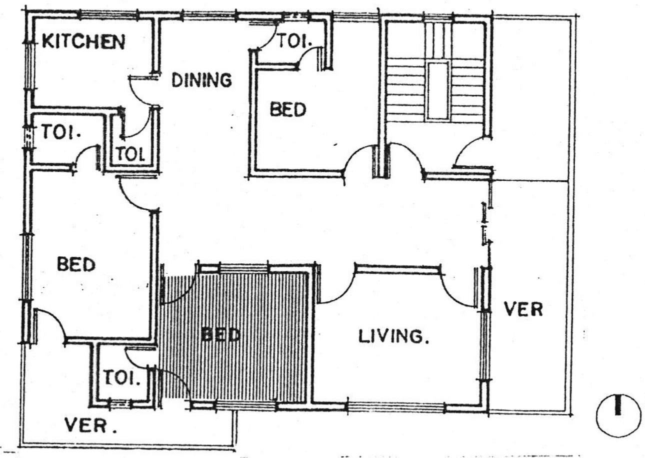




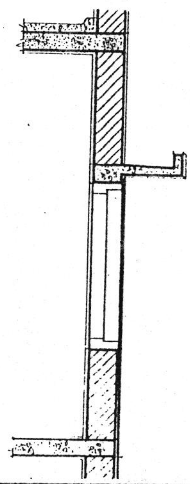


Site Plan SCALE 0 5 10 20M

Site Section SCALE 0 5 10 20M



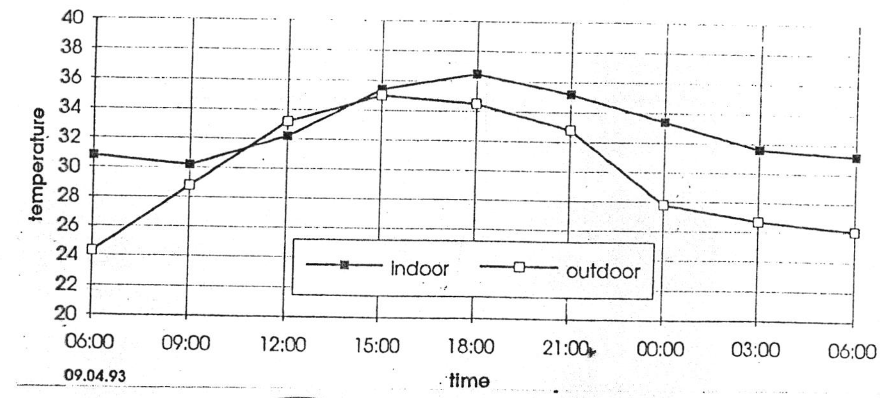
Building Plan SCALE: 0 5 12.5 M.



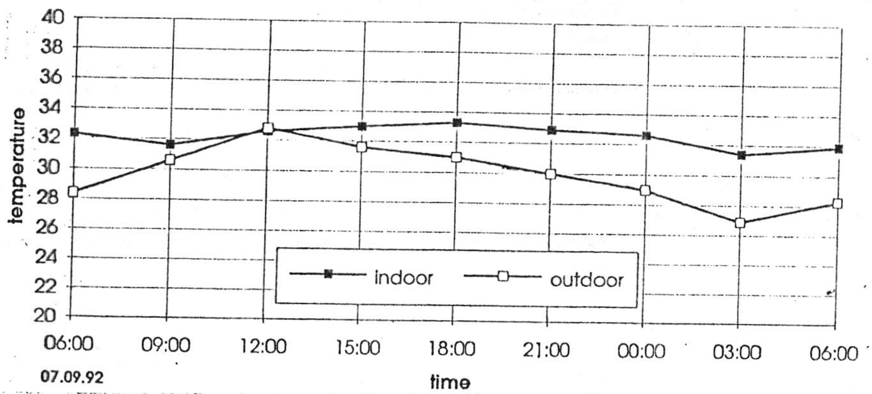
Exterior Wall Details.

SCALE: 0 1M

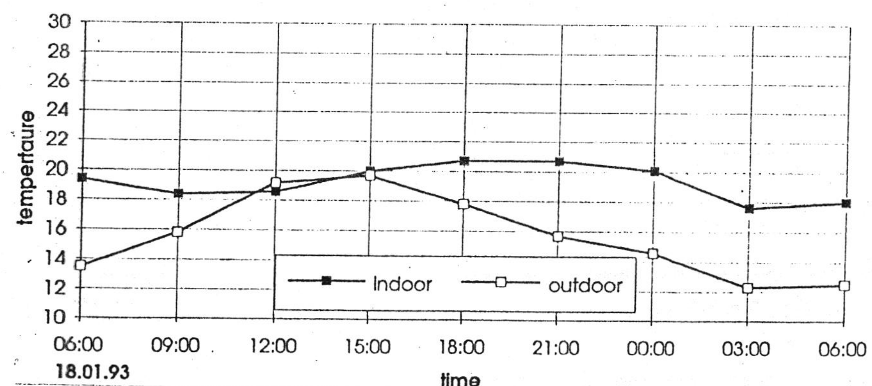
Case 5 (April)



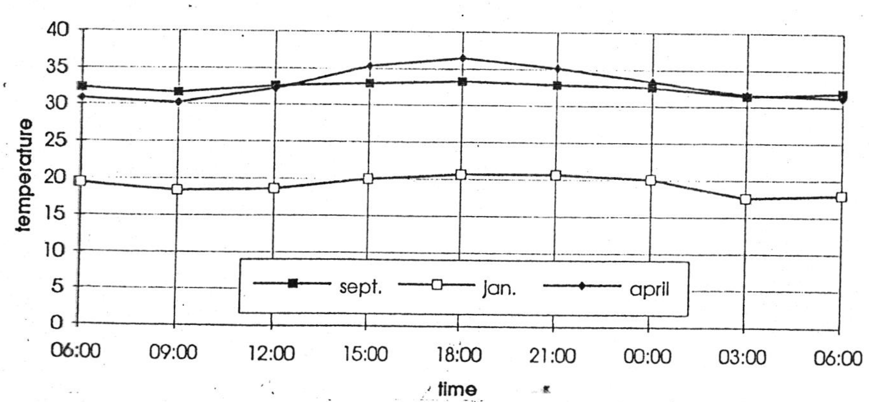
Case 5 (September)



Case 5 (January)



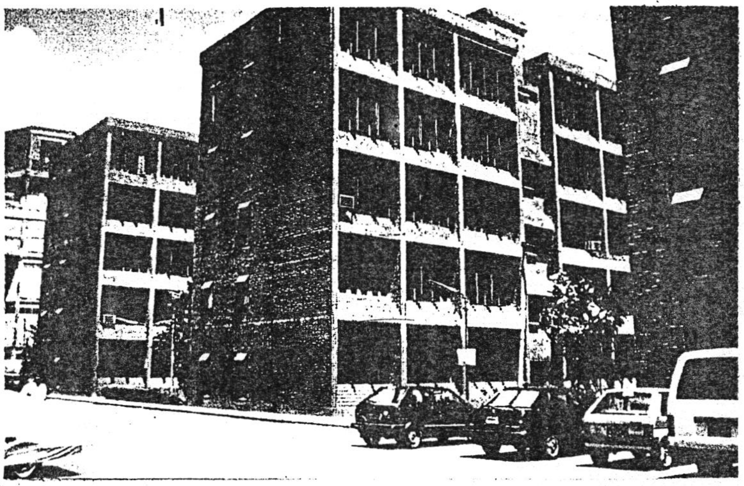
Case 5 (all year)

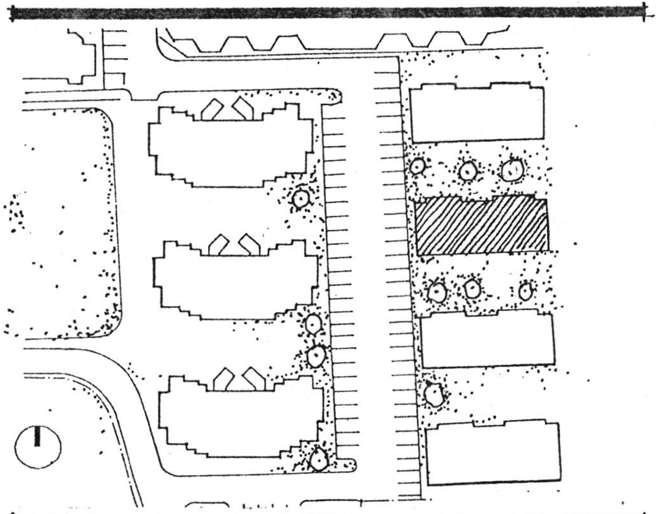


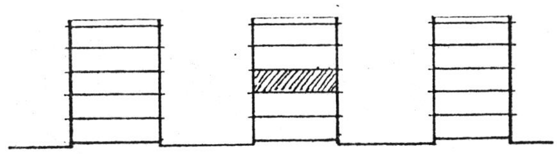
Temperature graphs for Case 5

CASE STUDIES

No. 6

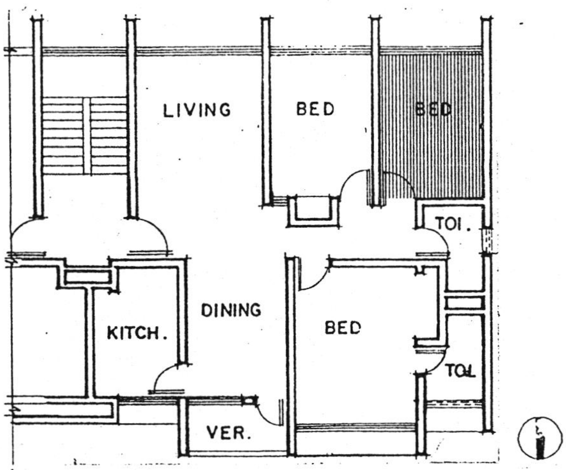




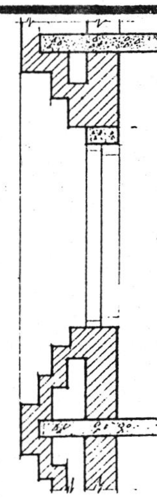


Site Plan SCALE : 0 5 10 20M.

Site Section SCALE : 0 5 10 20 M

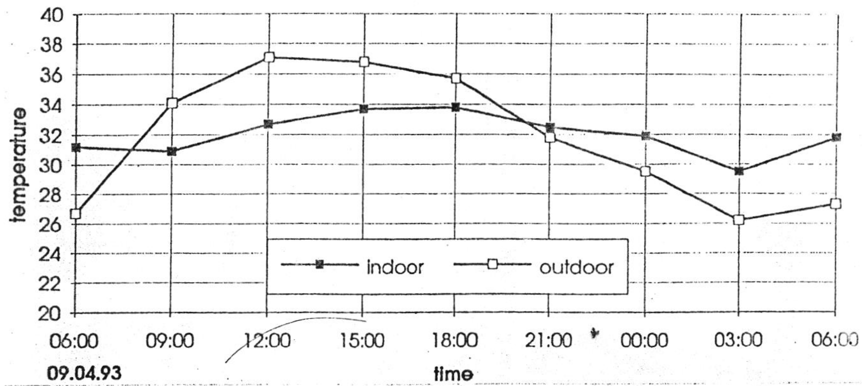


Building Plan SCALE : 0 2.5 5 M.

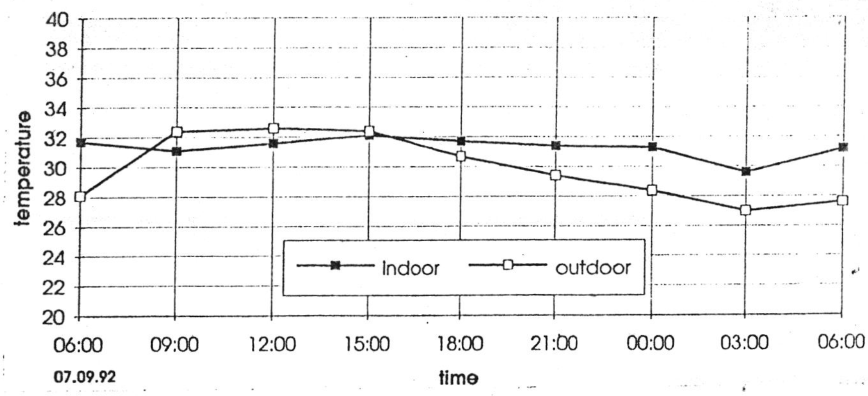


Exterior Wall Details. SCALE : 0 1 M

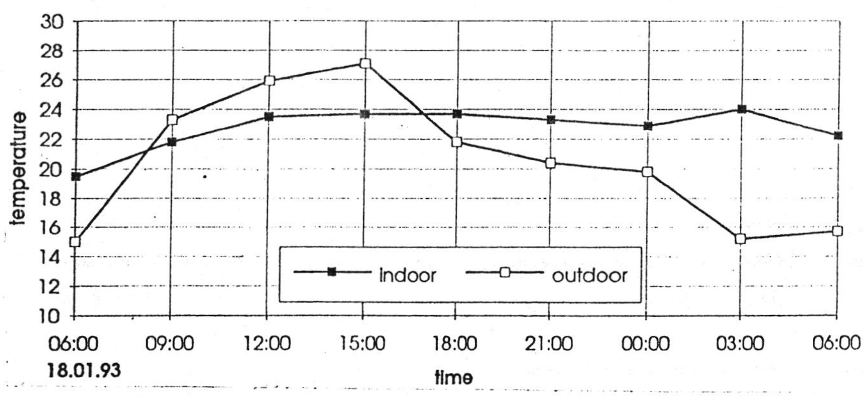
Case 6 (April)



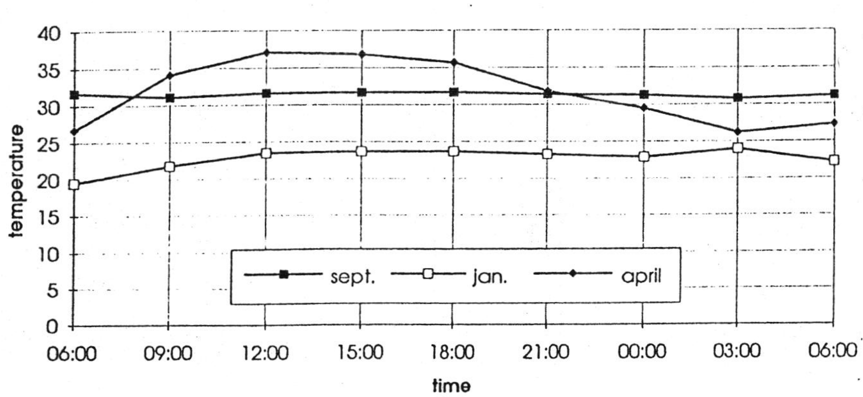
Case 6 (September)



Case 6 (January)



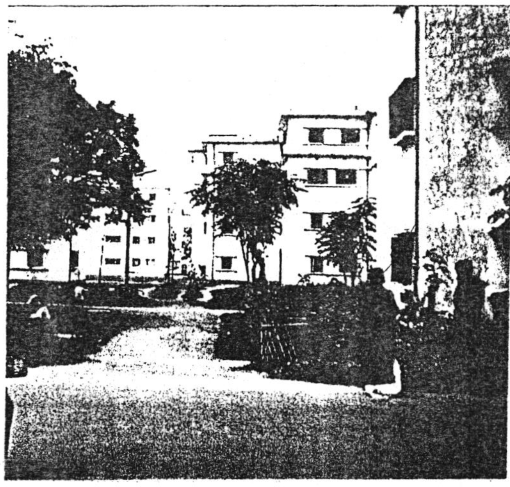
Case 6 (all year)

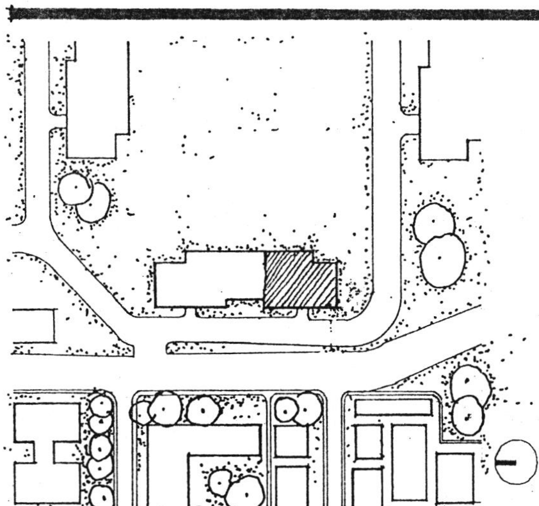


Temperature graphs for Case 6

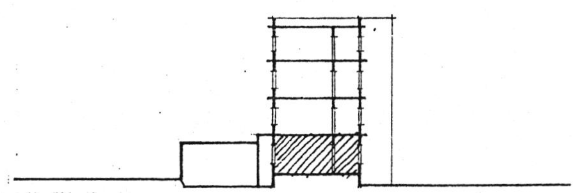
CASE STUDIES

No. 7

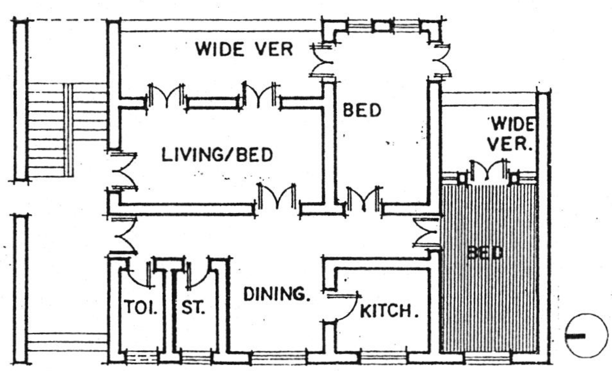




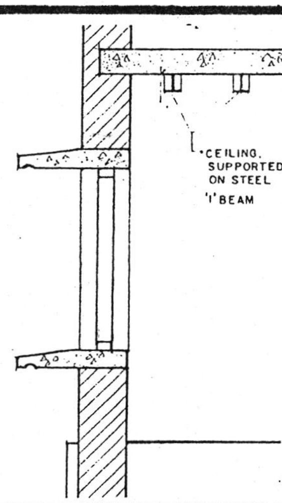
Site Plan SCALE : 0 5 10 20M.



Site Section SCALE: 0 5 10 M



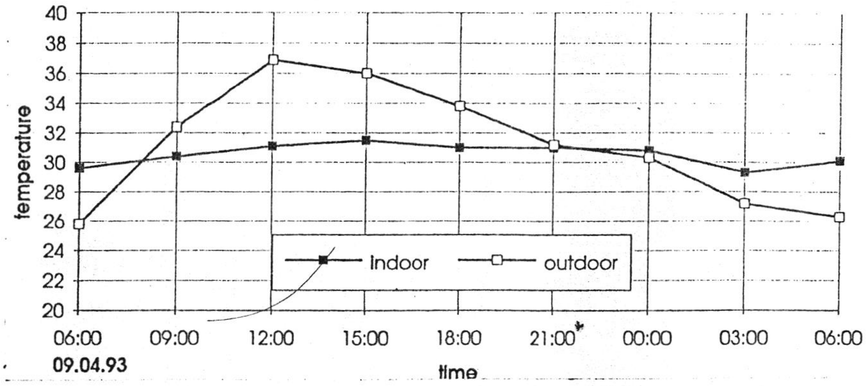
Building Plan SCALE : 0 2.5 5 M



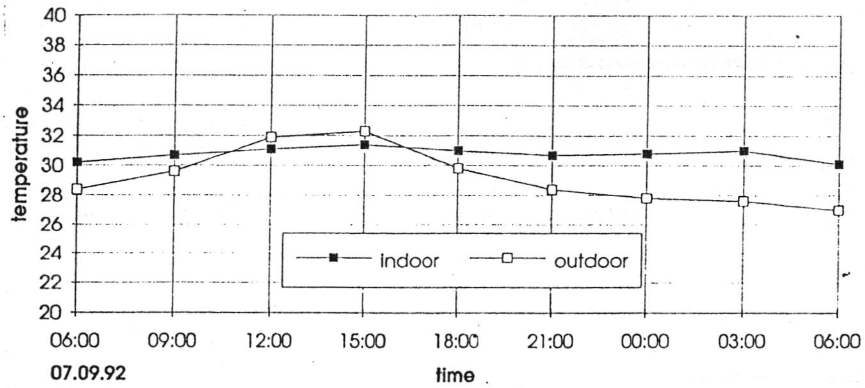
Exterior Wall Details.

SCALE : 0 1 2 3 M

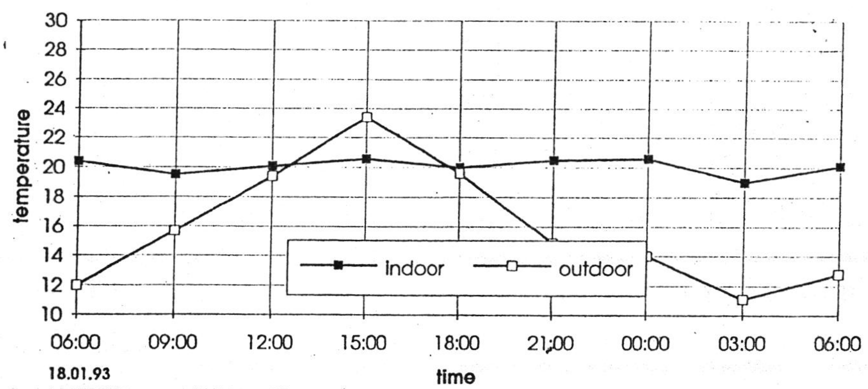
Case 7 (April)



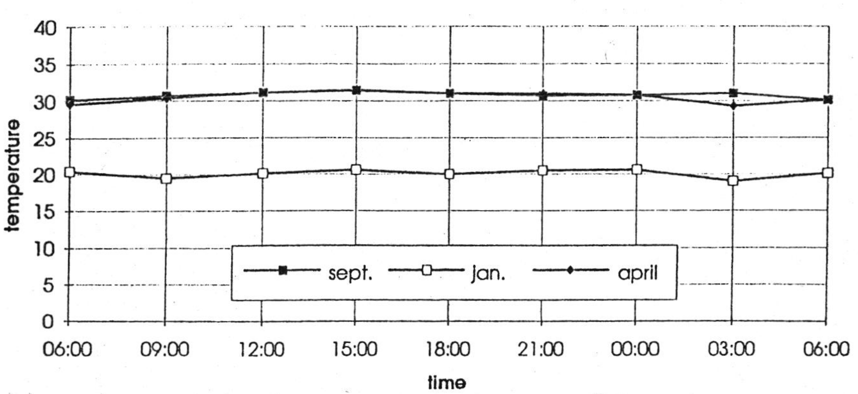
Case 7 (September)



Case 7 (January)



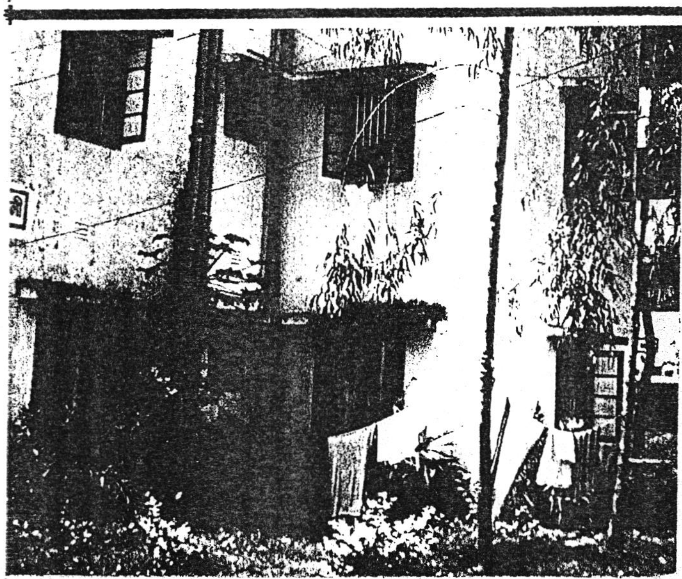
Case 7 (all year)

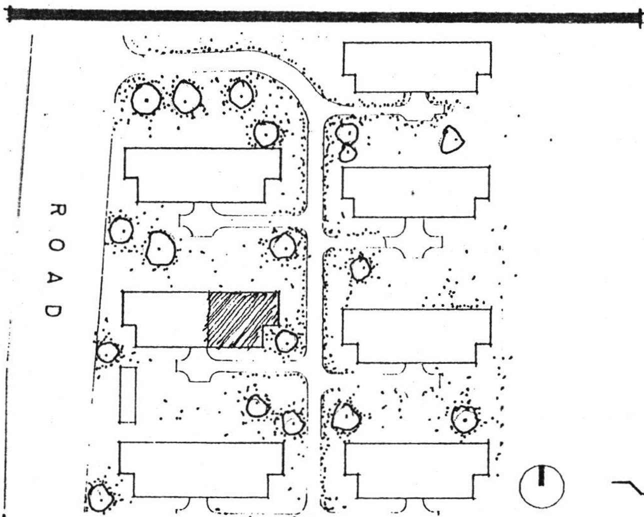


Temperature graphs for Case 7

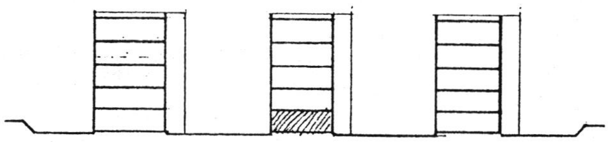
CASE STUDIES

No. 8

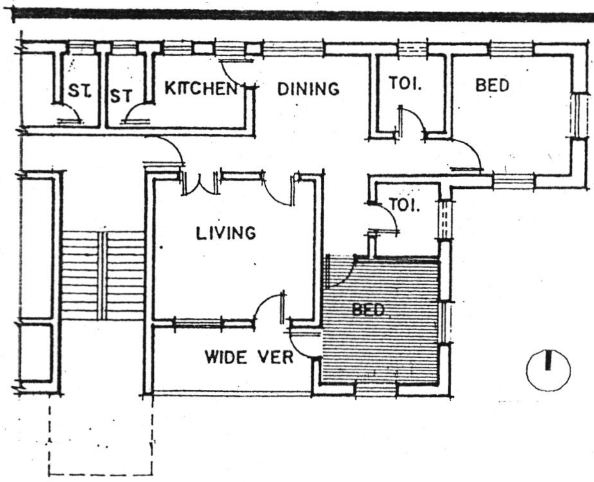




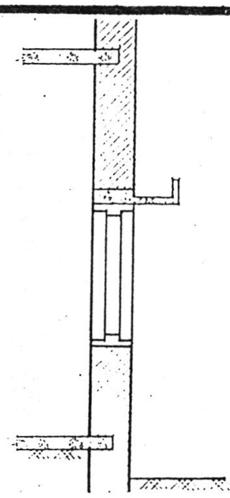
Site Plan SCALE 0 5 10 20 M



Site Section SCALE : 0 5 10 20

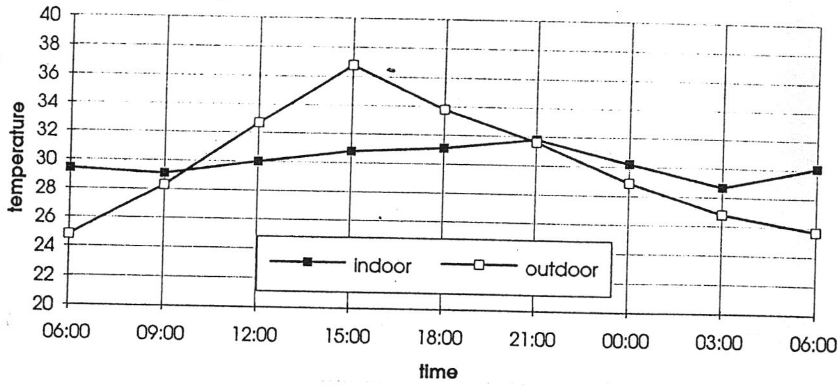


Building Plan SCALE : 0 2.5 5 M

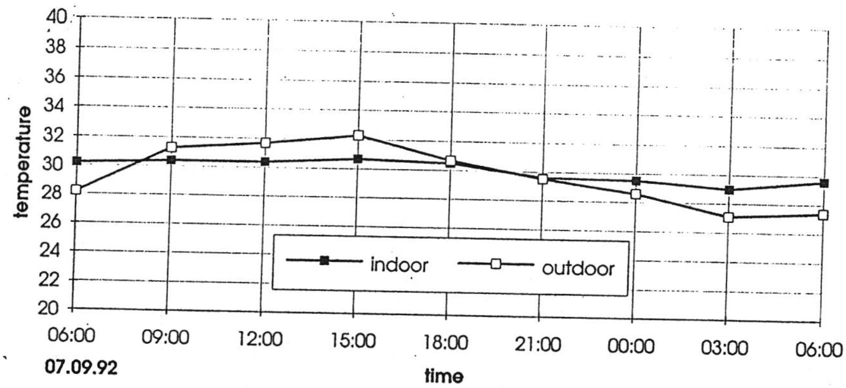


Exterior Wall Details. SCALE

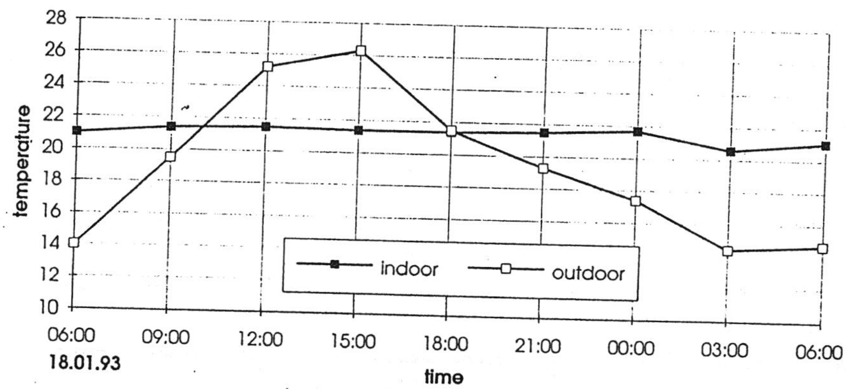
Case 8 (April)



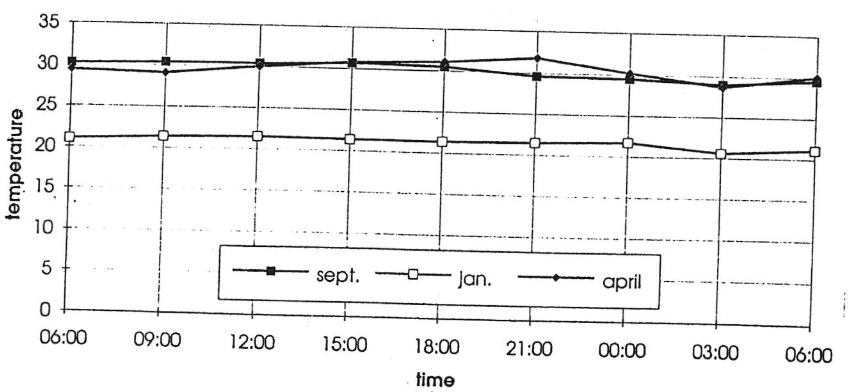
Case 8 (September)



Case 8 (January)



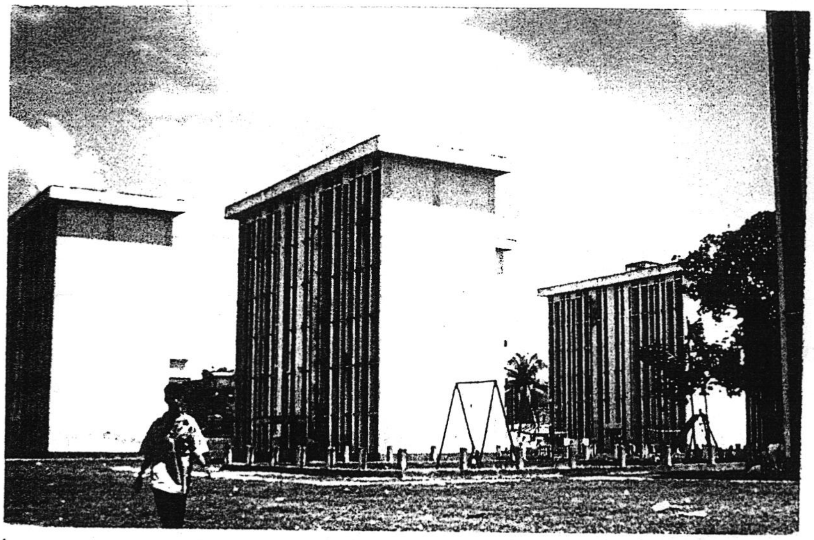
Case 8 (all year)

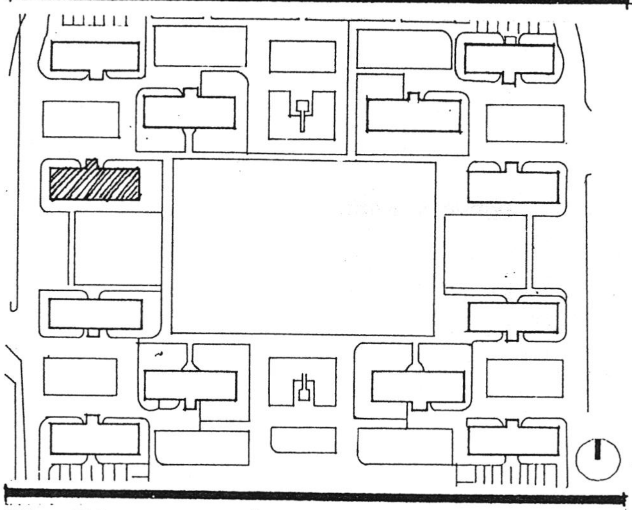


Temperature graphs for Case 8

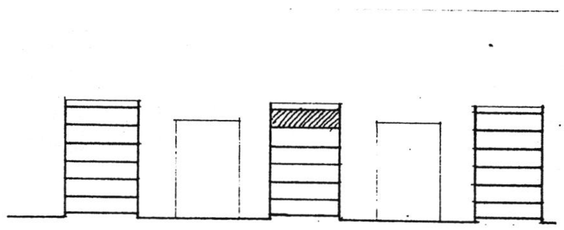
CASE STUDIES

No. 9

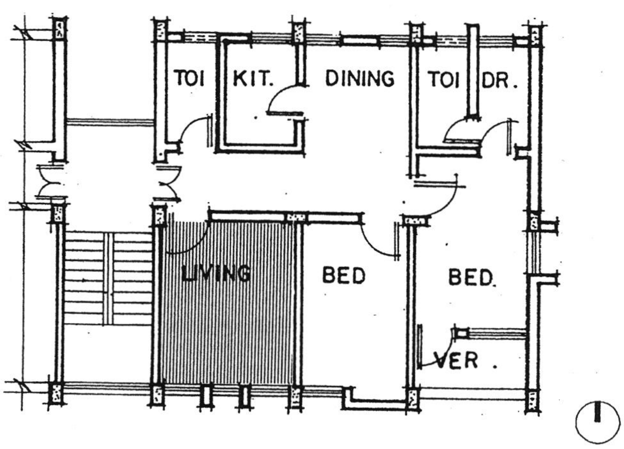




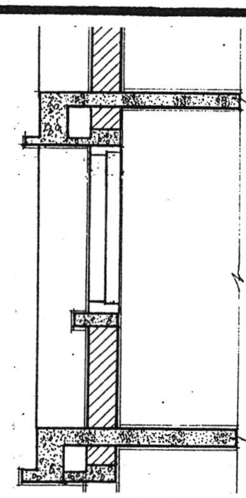
Site Plan SCALE : 0 5 10 20



Site Section SCALE 0 5 10 20

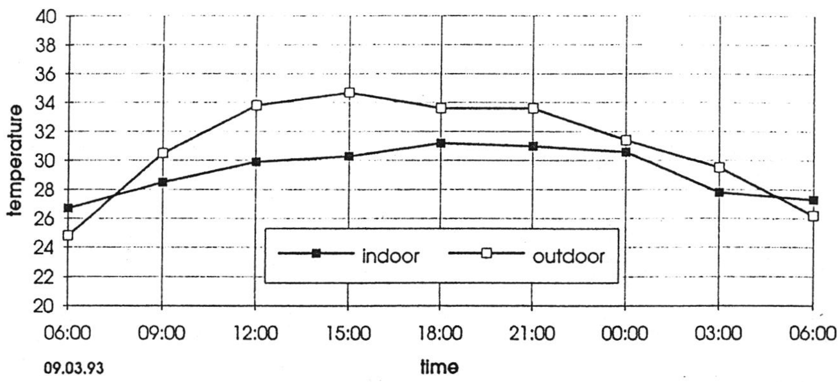


Building Plan SCALE : 0 1 3 5 M.

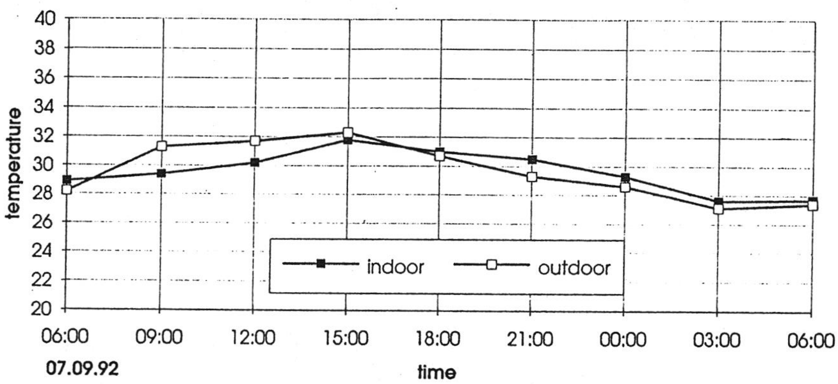


Exterior Wall Details. SCALE : 0 1

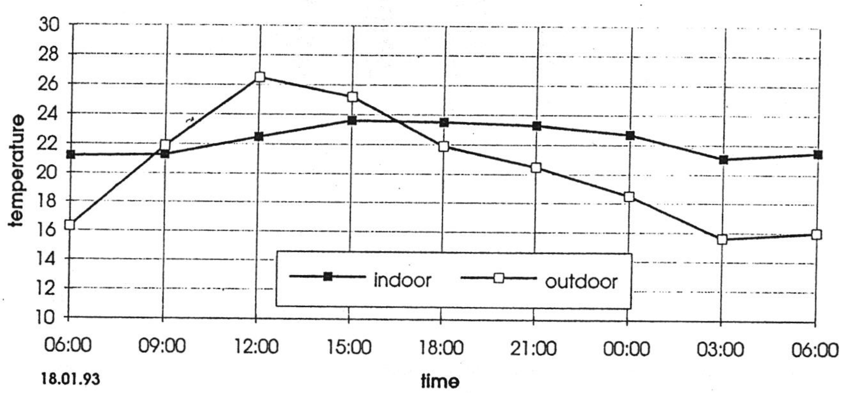
Case 9 (April)



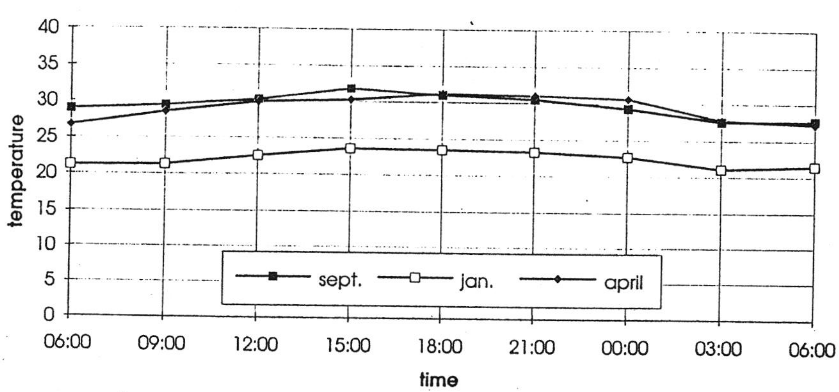
Case 9 (September)



Case 9 (January)



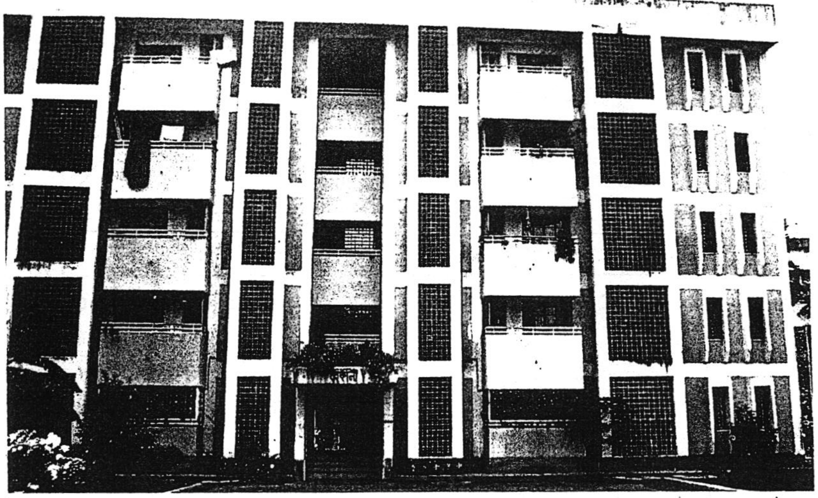
Case 9 (all year)

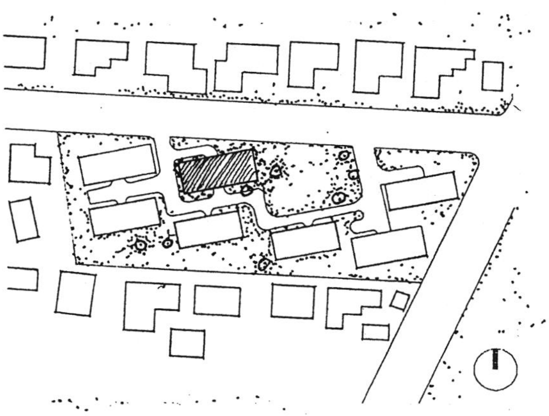


Temperature graphs for Case 9

CASE STUDIES

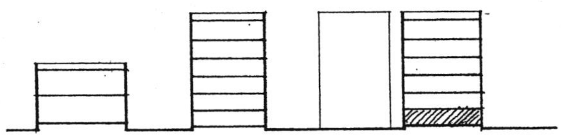
No. 10





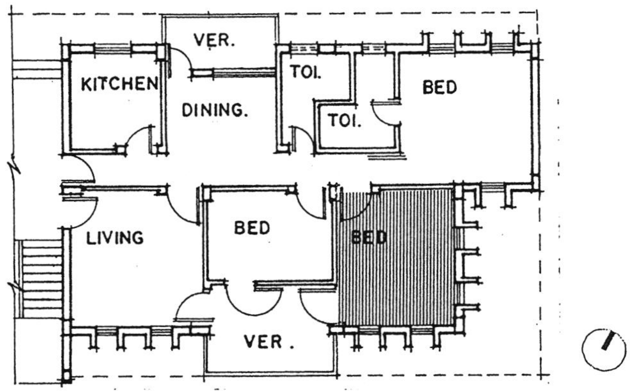
Site Plan

SCALE 0 1 2 4



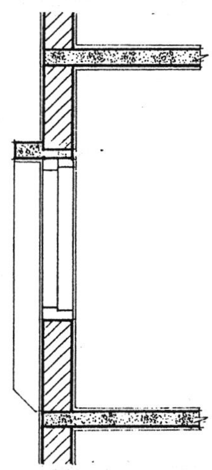
Site Section

SCALE : 0 5 10 20 M



Building Plan

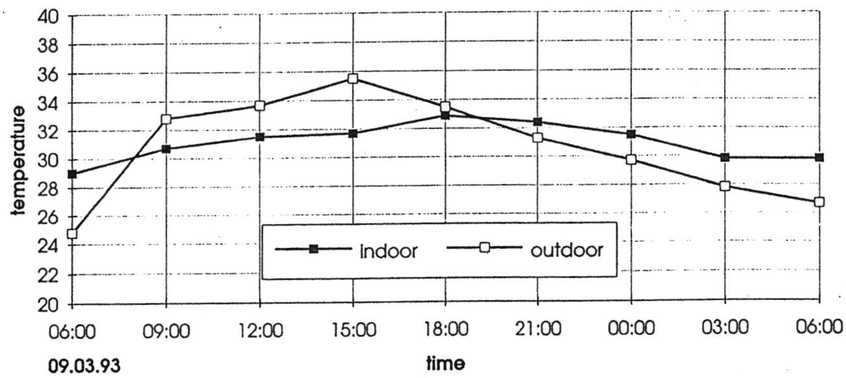
SCALE : 0 2.5 5 M



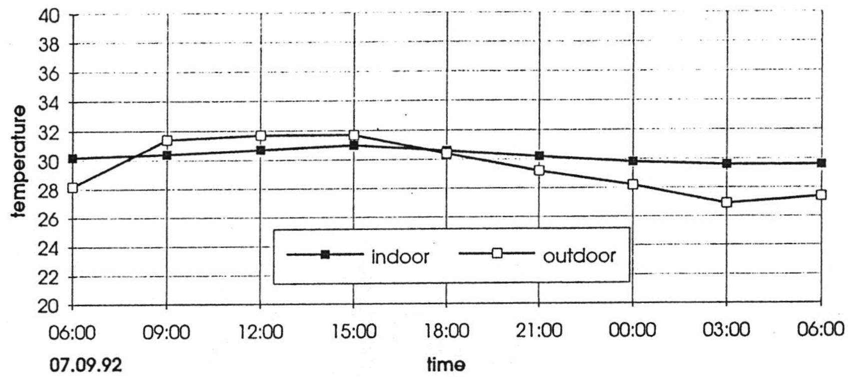
Exterior Wall Details.

SCALE : 0 1 2 4

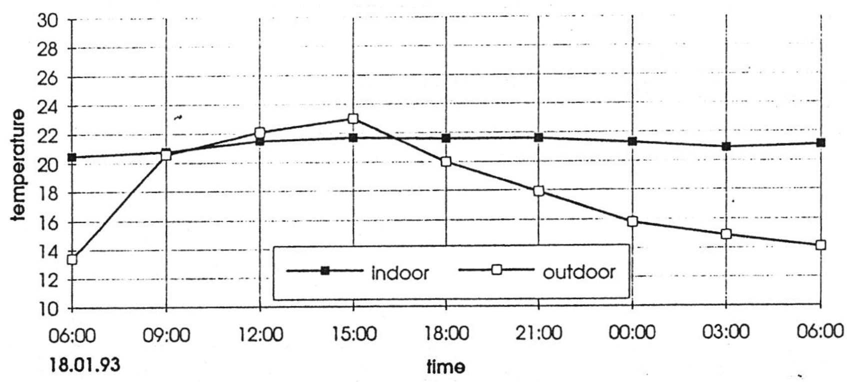
Case 10 (April)



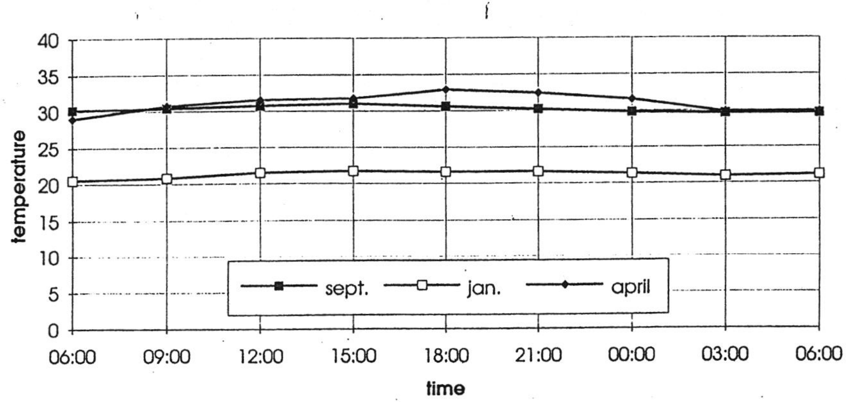
Case 10 (September)



Case 10 (January)



Case 10 (all year)



Temperature graphs for Case 10

TEMPERATURE DATA FOR ALL CASE STUDIES IN THE THREE MEASUREMENT DAYS

	time	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00
Case 1										
April	indoor temp.	27.2	31.3	32	32.4	33.2	31.8	29.7	28.3	27.8
	outdoor temp	24.2	32.7	34	35.9	33.4	32.2	28.7	26.5	25.4
Sept.	indoor temp.	30.6	30.2	31.1	31.4	30.6	29.9	29.6	29.1	28.8
	outdoor temp	28.2	30.5	32	31.8	29.9	28.8	28.2	27.5	27.2
Jan.	indoor temp.	19.6	20	21.7	22.6	21.9	20.9	20.3	20	20.3
	outdoor temp	15.3	22.4	25.6	26.3	20.9	20.1	17.8	14.7	15.3
Case 2										
April	indoor temp.	28	29.8	32.9	33	32.5	31.8	31	30.8	29.2
	outdoor temp	25.6	29.8	34.2	33.5	32.3	31.6	30.8	28.8	27
Sept.	indoor temp.	29.9	30.1	31.2	31.2	31	30.6	30	29.6	28.8
	outdoor temp	28.4	30.4	31.2	30.8	30.6	29.5	28.6	27.5	27.2
Jan.	indoor temp.	19.2	19.5	21.6	22.9	22.6	22.4	21.9	18.7	19.5
	outdoor temp	16.8	18.7	22.6	23.7	22.2	21.8	19.1	16	17.6
Case 3										
April	indoor temp.	29.3	33.8	34.9	35.9	35.9	33.8	32.4	32.1	32
	outdoor temp	24.8	34.1	36	36.1	33.7	30.3	29.1	28.7	26.4
Sept.	indoor temp.	30	31.2	32.8	33.2	32.8	31.3	30.4	29.5	29.7
	outdoor temp	27.5	31.6	34.1	33.5	29.9	28.4	27.9	27.4	27.7
Jan.	indoor temp.	19.2	19.3	21	23	22.9	22.4	21.5	20.2	19.7
	outdoor temp	14.1	18.9	25	25.8	20.6	18.8	16.8	14.9	14.5
Case 4										
April	indoor temp.	26.8	32.8	31.4	32	31.9	30.8	29.6	25.3	23.9
	outdoor temp	26.3	32.1	32.1	33.5	32	30.5	27.4	25.2	27.5
Sept.	indoor temp.	30.5	32.3	31	31.9	31.1	31	29	29.2	29
	outdoor temp	27.2	32.5	31.2	31.4	29.8	28.6	27.5	25.7	27
Jan.	indoor temp.	19.8	22.4	22.4	24.1	22.4	22.2	20.5	20.4	20.8
	outdoor temp	14.8	23	24.5	24.2	21.1	19	16.8	14.2	16.5
Case 5										
April	indoor temp.	30.8	30.2	32.2	35.4	36.5	35.2	33.4	31.6	31.2
	outdoor temp	24.3	28.8	33.2	35	34.5	32.8	27.8	26.7	26.1
Sept.	indoor temp.	32.3	31.6	32.6	33	33.3	32.9	32.6	31.4	31.9
	outdoor temp	28.4	30.6	32.8	31.6	31	30	29	26.9	28.3
Jan.	indoor temp.	19.4	18.4	18.6	20	20.7	20.7	20.1	17.6	18
	outdoor temp	13.5	15.8	19.2	19.7	17.8	15.7	14.6	12.3	12.5

	time	06:00	09:00	12:00	15:00	18:00	21:00	00:00	03:00	06:00

Case 6

April	indoor temp.	31.2	30.9	32.7	33.7	33.8	32.5	31.9	29.5	31.8
	outdoor temp	26.7	34.1	37.1	36.8	35.7	31.8	29.5	26.2	27.3
Sept.	indoor temp.	31.7	31.1	31.6	32.1	31.7	31.4	31.3	29.6	31.2
	outdoor temp	28.1	32.4	32.6	32.4	30.7	29.4	28.4	27	27.6
Jan.	indoor temp.	19.5	21.8	23.5	23.7	23.7	23.3	22.9	24	22.2
	outdoor temp	15	23.3	25.9	27.1	21.8	20.4	19.8	15.2	15.7

Case 7

April	indoor temp.	29.6	30.4	31.1	31.5	31	31	30.8	29.3	30.1
	outdoor temp	25.8	32.4	36.9	36	33.8	31.2	30.3	27.2	26.3
Sept.	indoor temp.	30.2	30.7	31.1	31.4	31	30.7	30.8	31	30.1
	outdoor temp	28.4	29.6	31.9	32.3	29.8	28.4	27.8	27.6	27
Jan.	indoor temp.	20.4	19.5	20.1	20.6	20	20.5	20.6	19	20.1
	outdoor temp	12	15.7	19.4	23.4	19.6	14.9	14	11.1	12.8

Case 8

April	indoor temp.	29.4	29.1	30	30.8	31.1	31.8	30.2	28.7	30.1
	outdoor temp	24.8	28.3	32.7	36.8	33.8	31.6	28.9	26.8	25.7
Sept.	indoor temp.	30.2	30.4	30.4	30.7	30.5	29.6	29.5	29	29.6
	outdoor temp	28.2	31.3	31.7	32.3	30.7	29.5	28.6	27.1	27.4
Jan.	indoor temp.	21	21.4	21.5	21.4	21.4	21.5	21.7	20.6	21.1
	outdoor temp	14	19.5	25.2	26.3	21.5	19.3	17.4	14.4	14.7

Case 9

April	indoor temp.	26.7	28.5	29.9	30.3	31.2	31	30.6	27.8	27.3
	outdoor temp	24.8	30.5	33.8	34.7	33.6	33.6	31.4	29.5	26.2
Sept.	indoor temp.	28.9	29.4	30.2	31.8	31	30.5	29.3	27.6	27.7
	outdoor temp	28.2	31.3	31.7	32.3	30.7	29.3	28.6	27.1	27.4
Jan.	indoor temp.	21.2	21.3	22.5	23.6	23.5	23.3	22.7	21.1	21.5
	outdoor temp	16.3	21.9	26.5	25.2	21.9	20.5	18.5	15.6	16

Case 10

April	indoor temp.	29	30.7	31.5	31.7	32.9	32.4	31.5	29.8	29.8
	outdoor temp	24.8	32.8	33.7	35.5	33.5	31.3	29.7	27.8	26.7
Sept.	indoor temp.	30.2	30.4	30.7	31	30.6	30.2	29.8	29.6	29.6
	outdoor temp	28.2	31.4	31.7	31.7	30.4	29.2	28.2	26.9	27.4
Jan.	indoor temp.	20.5	20.8	21.5	21.7	21.6	21.6	21.3	20.9	21.1
	outdoor temp	13.4	20.6	22.1	23	20	17.9	15.8	14.9	14.1

1. Alternative Roof Insulation Possibilities for Modern Urban Structures in Bangladesh
   Proceedings of Third European Conference on Architecture,.Florence, Italy. May 1993

2. Environmental Performance of Urban Housing Typologies in Bangladesh
   PLEA 94 Conference: Architecture of the Extremes, Israel, July 1994 (in publication)

3. Thermal Comfort in Tropical Climates: an investigation of comfort criteria for Bangladeshi subjects
   PLEA 94 Conference: Architecture of the Extremes, Israel, July 1994 (in publication)

ALTERNATIVE ROOF INSULATION POSSIBILITIES FOR MODERN URBAN STRUCTURES IN BANGLADESH

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ABSTRACT: Modern construction in the urban areas of Bangladesh usually have flat concrete roofs in most cases without proper insulation. Solar radiation contributes to the heat gain of the upper floors of these buildings and internal temperatures in the summer months is way above comfort levels. This paper investigates the potential of using ordinary earthen pots laid over concrete roofs as a alternative insulation possibility. An experiment was conducted on the roof of a top floor flat in Dhaka where such a method was used. Temperature readings for an insulated room were compared with that of an uninsulated one. The cooling potential was found to be significant and this method is proposed as a thermally and economically viable alternative for roof insulation. This method if made popular can help revive the pottery craft which is in danger of being taken over by environmentally harmful plastics.

1. INTRODUCTION

Along with high outdoor temperatures solar radiation is an important source of heat gain for buildings in Bangladesh. This is particularly true for urban areas where the nature of building construction and use is different from the rural areas. Rural houses consist of a number of one storied single cell units around a courtyard. Materials are mud, bamboo, thatch etc. These houses are extensively protected by trees which produce its own micro climate and protect the buildings from solar radiation (1). Most activities take place outdoors during the daytime hours and indoor comfort is only important at night. In the cities, however, life is different and a lot of activities take place indoors in "modern" buildings made of brick and concrete, closely packed together and without the benefit of trees to provide protection. The problem is intensified in the top floors of such buildings where the flat concrete roof is exposed to direct radiation. Mechanical cooling is a very expensive option and the commonly used ceiling fans do little to improve comfort in high temperatures. The need to develop passive means of solar control is important for comfortable living and higher productivity. Given the constraints of resources this has to take into consideration the use of local technologies, materials and skills.

2. THE CLIMATE.

Bangladesh has a hot humid climate and other than the period from November to February daytime maximum temperatures are above 30°C. During the pre monsoon period (March-May) this is highest. This period also has the highest solar radiation intensity (fig. 1.). The monsoon period has slightly lower temperatures but very high humidity. It is only during the cool period (November-February) that conditions are more or less comfortable.

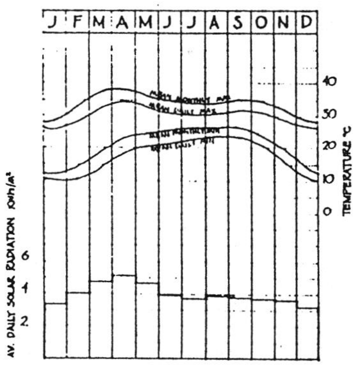

Fig. 1: Temperature and solar radiation for Dhaka(23.7'N)

3. CLIMATE RESPONSIVENESS AND MODERN URBAN BUILDINGS.

Modern construction in the urban areas is characterised by the use of brick and concrete.(fig. 2.) To accommodate the ever increasing population building heights are higher and it is common to find 4/5 storied houses but high rise blocks are yet to become popular.

For the hot humid climate air flow is as important consideration but due to heavy concentration of buildings this is not always successfully achieved. From the point of view of protection from solar radiation, walls in closely placed buildings have an advantage because of shading provided by other buildings. The roofs are exposed to direct solar radiation from the high summer sun causing heating up of the upper floors and there is little scope for trees to provide any extra protection beyond two storey heights. In a recent study of 10 houses in Dhaka, conducted by the author top floors were found to have temperatures of above 36°C as compared to ground floor rooms where temperatures were about 4°C lower in the hottest period. of the year. The roof construction was standard 125mm R.C.C. slabs without insulation. Recent developments in high strength deformed steel bars make it possible to have thinner slabs which makes the problem worse.

Fig. 2: Modern buildings in Dhaka

4. INSULATION PRACTICES

There are no standards for roof insulation in the building codes but there are some practices. Because flat concrete roofs as cast are not graded properly for water run off during the rains some roofs have a 75mm layer of lime terracing to grade it. This offers a certain degree of insulation. In the previously mentioned study by the author temperature differences between top floor rooms with and without insulation were found to be between 1 and 2°C. It was also noticed that in some cases the lime terracing deteriorates substantially after a number of years thus reducing its insulating properties. The cost of lime terracing is also going up and the process is time consuming.

Some attempts are made at roof gardening but exposure of the plants to high intensity radiation require that the plants themselves be protected

There are one or two examples of double roofs in Dhaka and they are quite effective. The cost of a double roof is substantially higher and very few can afford it.

Recently some buildings in Dhaka have made the use of hollow blocks plastered over concrete roofs to improve insulation. A study by Imamuddin and others at the Bangladesh University of Engineering and Technology has found differences of about 4– 5°C between the ceiling surfaces of such an insulated slab as compared to a standard concrete slab for flat roofs. The difference was more for inclined roofs (2). The difference in room temperature was, however, lesser, a maximum of 2°C.

5. USE OF EARTHEN POTS FOR INSULATION.

No known examples of the use of hollow earthen pots for insulation exist in Bangladesh but some references can be found in historical novels. They were known to be used in buildings in northern India which has a hot dry climate. Recently a modern building in Delhi has made of it with appreciable effects (3). The air gap created by the inverted pots insulates the roof and the covering over them adds thermal inertia to the slab as a whole.

Earthen pots are manufactured manually in Bangladesh by potters on the wheel and used for keeping food (fig 3). With the advent of plastic containers their use is less common, but they still continue to be manufactured in small quantities

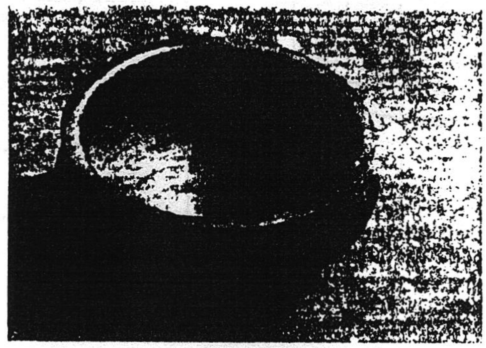

Fig. 3: Earthen pot

6. STUDY OF THE EFFECT OF EARTHEN POT INSULATION.

An experiment was carried out at the top floor flat of a three storied house in Dhaka. Two adjoining rooms of almost similar sizes both having 125mm concrete roofs, one with earthen pot insulation the other without were observed and the results compared.

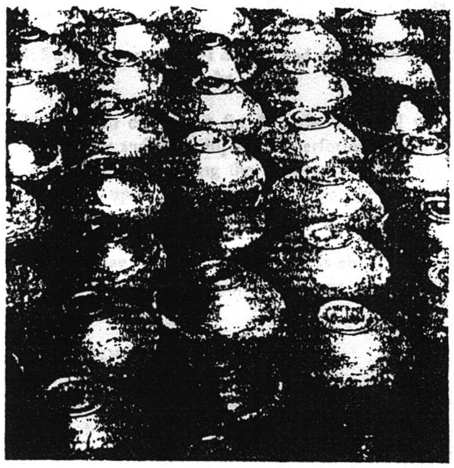

Fig. 4: Inverted pots laid over the roof

The roof of one of the rooms (3.8m x 4.5m) was covered by inverted earthen pots each measuring 225mm in diameter and 150mm in height (fig. 4). The gaps left as a result of the roundish conical shape of the pots were then filled with sand to bring the surface to a level. A cement concrete layer of average thickness 50mm was laid on top to create a slope for water run off (fig. 5). The pots were bought off a traditional potter's shop. The whole process took two masons and five helpers one whole day to complete.

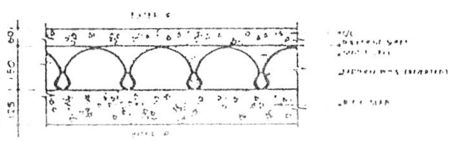

Fig. 5: Detail of insulation layer

Simultaneous measurements of temperature were made in the two rooms to compare the effect of insulated roof with the ordinary concrete roof. Readings were taken of the top surface, middle section and the ceiling for the insulated roof and only the top surface and ceiling for the uninsulated one as well as for the room temperature of both situations (figs.6,7). Outside air temperature was also recorded. The readings were taken on a hourly basis over a twenty four hour period in early October using ordinary digital thermometers. Ventilation of the interior was not considered and the windows were kept closed for the duration of readings.

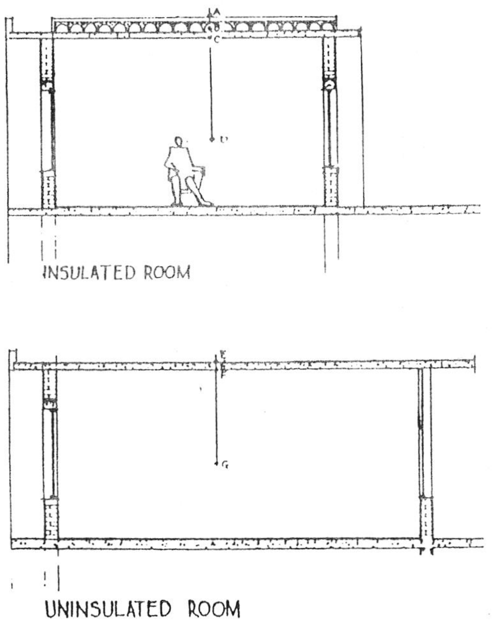

Fig.6: Temperature reference points for the two rooms

7. OBSERVATIONS AND RESULTS

The temperatures of the two rooms vary significantly in the afternoon hours (12 noon to 6 p.m.) and the difference is between 2.5°C to 3.4°C and at around 3 p.m. this is maximum. The outside temperature is highest at this time and it only .3°C higher than the temperature of the uninsulated room (fig.7). The difference of the ceiling temperature of the two rooms at the peak afternoon hours is above 10°C (fig.8).

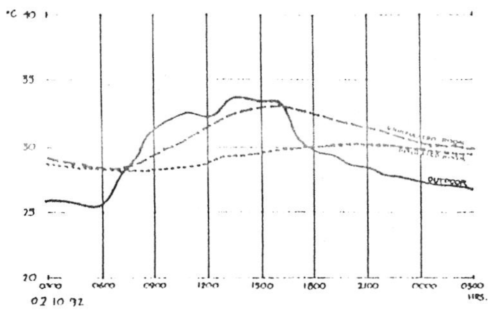

Fig. 7: Comparison of indoor temperatures for both rooms with outdoor conditions

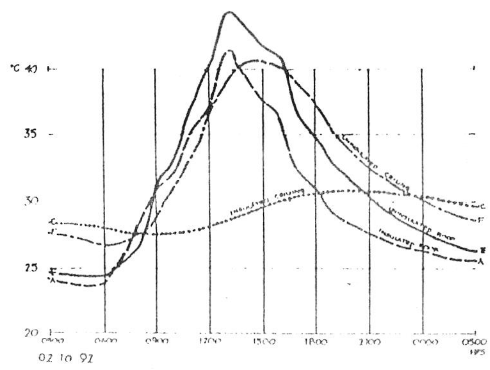

Fig. 8: Surface temperatures of roof and ceiling for both slabs

The overall conditions for the whole period were plotted in graphs and the comparative performance shows maximum differences during the afternoon hours. After midnight and upto the early mornings the interior conditions in both rooms are comparable when temperatures are below 30°C.

The time lag for the insulated slab is about 7 hours as compared to 1.5 hours for uninsulated one.

8. CONCLUSIONS

Insulation with earthen pots is a viable method for concrete roof slabs in Bangladesh as an alternative to commonly used lime terracing both from the point of view of performance and costs. Costs are less than conventional lime terracing given the fact that these pots were bought at retail prices and at a relatively small scale. The manufacturers are willing to reduce prices substantially for bulk purchases which would be the quantity for the whole roof of a standard house.

The pots are ordinarily used for keeping food and are of sufficient strength to allow the use of the rooftop for human activity as is common in Bangladesh.

The design of the pots may be modified to suit the purpose and to increase efficiency. An improved design may lead to the reduction in the quantity of sand needed to fill the gaps between them thus reducing costs.

With the increasing popularity of plastic containers the craftsmen who make these pots are gradually going out of business. The widespread use of this method will help to revive their trade, boost the local economy and hopefully protect the environment by preventing the future use of polystyrene as an insulating material.

Fig. 9: The completed insulation layer

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ENVIRONMENTAL PERFORMANCE OF URBAN HOUSING TYPOLOGIES IN BANGLADESH

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ABSTRACT. Indoor tempertaures and their relationship to comfort temperatures determine the comfort habitabilty of houses. Given the unpredictibilty of air flow in urban environments this is of particular importance. Within the range of housing typologies in the urban areas of Bangladesh and the variations in construction types behavior patterns are different in terms of indoor temperatures and its swing. Relationships between indoor and outdoor temperature swings and the corresponding decrement factors can be used as basis for evaluating the relative environmnetal performence of the housing typologies.

1 INTRODUCTION

Given the absense of air conditioning the thermal conditions in urban houses in Bangladesh are largely determined by design and construction as it interacts with the climatic context of the urban environment. Thermal interactions are largely determined by the nature of construction which relies heavily on the use of brick,cement and concrete. Temperatures indoor and resultant comfort conditions are determined, amongst other things, by wall and roof materials which offer some variation in thicknesses hence capacity to store heat. In dense building environments, air flow for thermal comfort is not always reliable and temperature is often the determinant for comfort. The following discussion attempt to evaluate the environmental potential of various housing types in terms of comfort on the basis of measured temperature data.

2 HOUSING TYPOLOGIES AND MEASUREMENT PERIODS

10 different houses with variations in construction, orientation, location (height from ground) and site characteristics were measured for indoor and outdoor temperatures during three periods to get a thermal profile for the whole year. A cold day in the cool period, a hot day in the hot dry period and a average day in the hot humid period, in January, April and September. The outdoor temperature was measured seperately for all cases and the measurements are

simultenous i.e. all houses were measured in the same days.The houses are representative of the main variation in housing typologies that occur in the urban areas. Their main characteristics are given in Table 1. The mass of a building is determined by the wall thickness, 125mm being light, 250mm medium and 375mm, heavy construction.

Case ref:	Site density	Orientations	Room	Construction	
				walls	roof / ceiling
1	open	south	2nd floor bedroom	250 mm brick exposed	150 mm r.c.c. +75mm lime
2	dense	north	gr. floor bedroom	125 mm brick plastered	corrugated iron/bamboo mat
3	dense	south	1st floor bedroom	125 mm brick plastered	150 mm r.c.c exposed
4	moderate	east north	2nd floor bedroom	125 mm brick plastered	150 mm r.c.c. floor above
5	dense	south	1st floor bedroom	125 mmbrick plastered	150 mm r.c.c. exposed
6	moderate	south west	2nd floor bedroom	125 mm brick exposed	125 mm r.c.c floor above
7	moderate	west south (partial)	gr. floor bedroom	375 mm brick plastered	150 mm r.c.c. floor above
8	moderate	south east (partial)	gr. floor bedroom	375 mm brick plastered	150 mm r.c.c floor above
9	moderate	south	5th floor bedroom	125 mm brick plastered	150 mm r.c.c + 75 mm lime
10	moderate	south east	gr. floor bedroom	250 mm brick plastered	115 mm r.c.c floor above

Table 1 Description of Case Studies.

3. INDOOR AND OUTDOOR TEMPERATURES.

The indoor temperatures as a rule have lower temperature swings than the outdoors in all three measurement periods. The indoor temperature range is contained within the outdoor range i.e. the maximum indoor temperature is lower and the minimum temperature higher than corresponding outdoor temperatures with the exception of one particular case (no.5) where the indoor maximum is higher than the outdoor maximum in all three instances.

The indoor temperature swing can be expressed as a ratio of the outdoor swing for the different cases the resultant fraction is called the dampening effect of the outdoor swing:

D.E. (dampening effect) = Indoor temperature swing/Outdoor temperature swing

The nature of this ratio is related to the nature of the building construction and the value varies from season to season as shown in fig 1.

The decrement factor gives the ratio of the maximum indoor temperature to the maximum outdoor temperature and expresses the ability of the particular indoor environment to moderate the outdoor temperature.

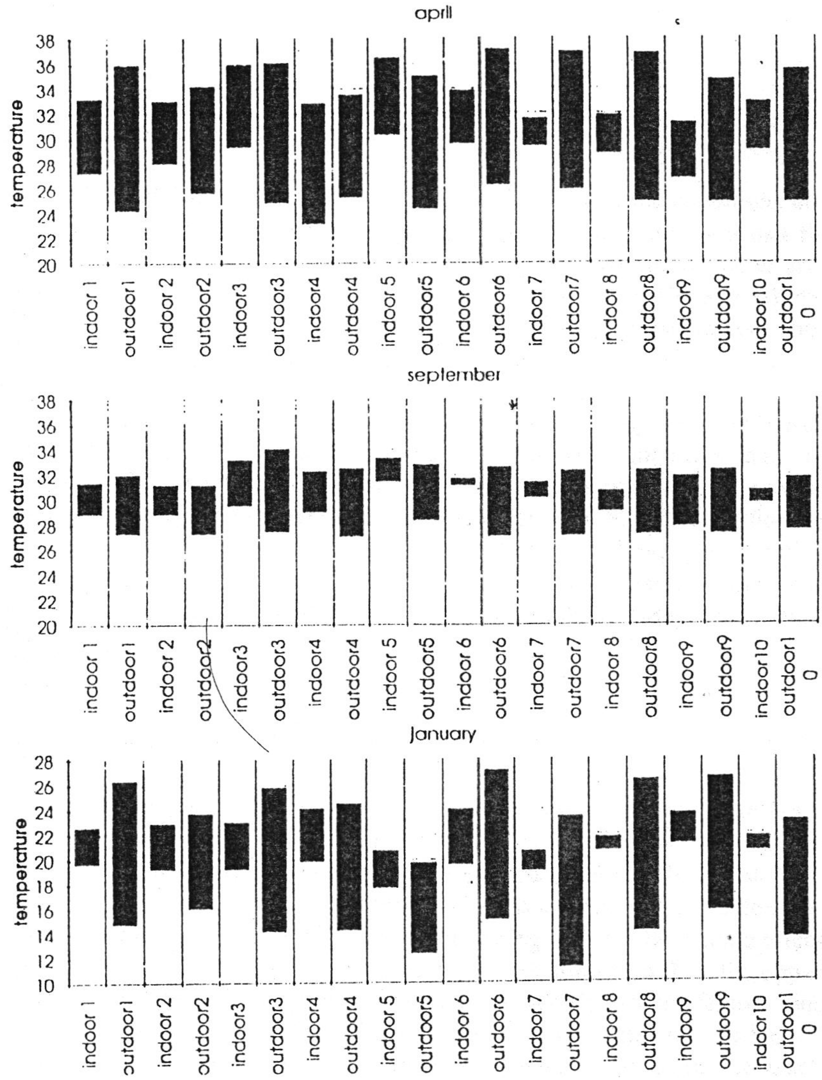

Fig 1. Indoor and outdoor temperature ranges for the three periods.

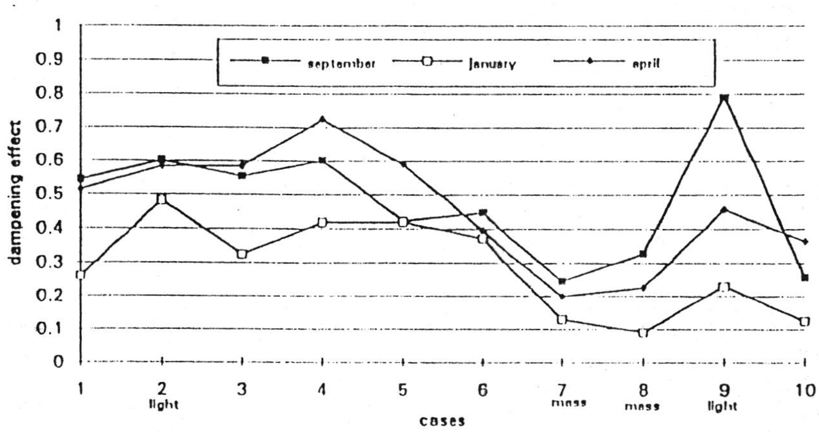

Fig 2. Values of dampening effect for the 10 cases in the three measurement periods.

4 EVALUATION OF COMFORT PERFORMANCE

4.1. Comfort temperatures for Bangladesh

There are certain established ranges of temperatures which define the conditions in which human beings feel comfortable (Olgyay, 1958; Fanger 1970 etc.). It is recongised that that the values that define this range depend on the location or that people in warmer climates are likely to feel comfortable in higher temperatures than their counterparts in colder climates.(Humphreys, 1978; Givoni, 1992) The comfort temperatures are also related to personal factors such as clothing and activity ranges.

An evaluation of comfort criteria for occupants of urban housing were made from volunteers from Dhaka with 400 individual recording of comfort conditions and corresponding temperature, humidity and other environmental and personal variables. The results indicate a marked tolerance for higher temperatures and humidities. For still air conditions or with slight air movement for people wearing ordinary summer clothing and engaged in sedentary or light activity, the range of temperature where people feel comfortably warm, comfortable or comfortably cool was found to be between 24°C-32°C.(Mallick, 1994) This is the basis for the evaluation of comfort performance of the case studies

4.2. Criteria for Comfort Evaluation

For any given outdoor temperature swing the preferable indoor swing is the range of comfort temperatures which in this case is 8. Within the comfort range lower value of the swing indicates lesser variation of comfort temperatures hence lesser need for people to adjust to temperature fluctuations. Therefore low values of dampening effect is a preferable condition for buildings. If the indoor temperature is to be constant value, both swing and the dampening effects are 0. The dampening effect alone cannot be used as a comfort evaluation tool. For the upper limit of the indoor swing to be defined it is necessary to compare the decrement factor. Since the upper comfort temperature in this case is 32°C for maximum outdoor temperatures higher than 32°C a decrement factor lower than 1 is desirable, the extent of which depends on the exact value of the outdoor maximum temperature. It is more preferable to have the indoor maximum temperature to be lower than the maximum comfort temperature. For warm days low value is preffered. For cold days when outdoor maximum is lower than the maximum comfort temperature the value should be more than 1. A more precise defination of the preffered decrement factor is given by:

$$\frac{28+\text{Indoor swing}/2}{\text{Maximum outdoor temperature}}$$

where 28°C is the mean comfort temperature. At the same time the lower comfort temperature should not be less than 24°C, to avoid feeling cold.

5 COMPARISON OF COMFORT PERFORMANCE OF THE CASE STUDIES.

The comfort performance of the case studies can be evaluated on the basis of the dampening effects and decrement factors for each situation. The comparison is made for the hot and the cold day. The dampening effect and the corresponding decrement factors are plotted in the charts in fig 3. The basis for comparison are the solid lines, all the points on which relate to conditions that should ideally occur in a comfortable interior. The top most point in the line correspond to values which relates to an interior temperature range equal to the comfort range and the lowest point to a constant temperature equal to the mean comfort temperature. The outdoor temperature range for the hot day is taken as 26°C to 36°C and 14°C to 26°C for cold day being the average maximum and minimum outdoor temperatures for all cases combined. The deviations from these ideal conditions line indicate the relative performance of each case.

Cases		April		January	
	building envelope	D.E	D.F	D.E.	D.F.
1	medium	.51	.92	.25	.86
2	light	.58	.96	.48	.93
3	medium	.58	.99	.32	.89
4	medium	.72	.98	.41	.98
5	medium	.58	1.04	.41	1.05
6	medium	.39	.91	.37	.93
7	mass	.19	.85	.13	.88
8	mass	.25	.86	.08	.83
9	light	.45	.9	.22	.89
10	medium	.36	.93	.12	.94

Table 2 Dampening Effects and Decrement Factors for the Hot and Cold Days.

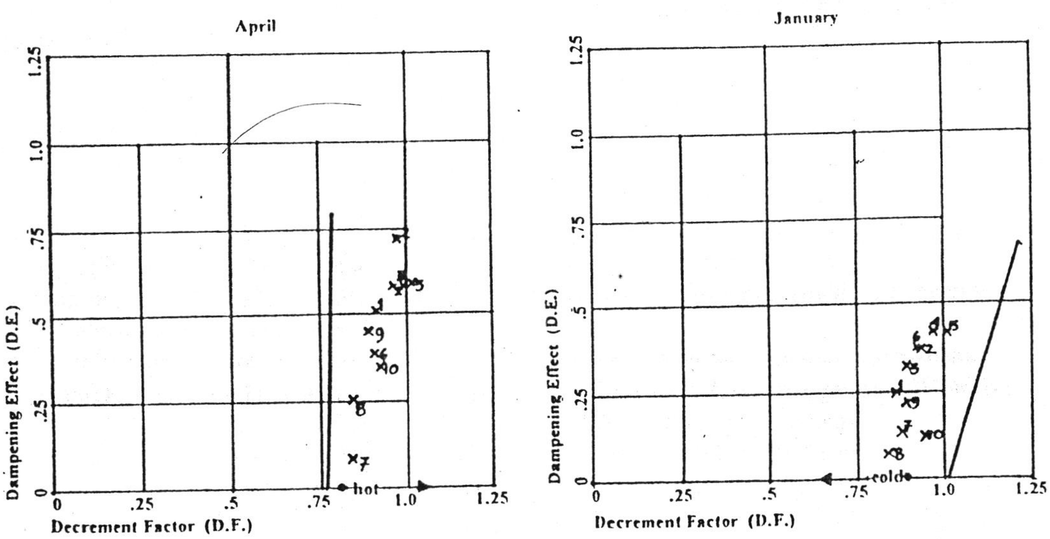

Fig 3. Performence of the case studies compared with ideal comfort situation (solid lines)

6 CONCLUSIONS

In the urban context natural air flow is not a reliable means for achieving indoor comfort. The air flow is unpredictable because of surrounding buildings specially for ground floor houses. In the event that there is outdoor air flow, it is not always able to reach indoors because for reasons of privacy and security the windows remain closed. If the windows are kept open, the air flow is greatly reduced by security grills and fly netting.(Koenigsberger, 1973). In such situation the ceiling fan is able to provide air movement and the indoor temperature conditions are important for providing comfort.

For the hot day the heavier buildings have the lower maximum indoor temperatures as well as lower swings. Indoor comfort conditions are fairly steady and there is better potential for comfort with the use of a ceilng fan. Conditions in the light structure (9) are also comparable and although indoor maximum temperatures are higher the swing is large to accomodate lower temperatures. The conditions in medium constructions are varied and in one particular case the indoor maximum temperatures exceed that of the outdoors (5).

In the cold day the interiors in the heavier buildings are colder and lighter buildings are warmer but also have a wider indoor swing to accomodate comfort temperatures. In all other buildings the higher indoor temperatures are just above minimum comfort temperatures. In Buildings with larger swings (2,3,4,5,6,) the indoor temperature falls below the comfort limits.

Since for a major part of the year outdoor conditions are warm, heavier buildings offer better possibilities for comfort the year round from two points of view, temperatures indoors are lower as well as the indoor swing and people do not need to adjust to fluctuations of temperatures. Higher indoor temperatures in light buildings can be tolerated because larger indoor swings makes it possible to have lower temperatures at times. The issue of comfort between the two is balanced between the reliability of warmer comfort conditions in heavy buildings and the occurances, at particular times, of cooler temperatures in the light buildings.

Between all buildings, differences in dampening effects are more prominent than differences in decrement factors, hence the swing of indoor temperatures is a major consideration for comfort performance.

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THERMAL COMFORT IN TROPICAL CLIMATES: AN INVESTIGATION OF COMFORT CRITERIA FOR BANGLADESHI SUBJECTS

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ABSTRACT. For people living in warm humid climates the perception of comfort is influenced by long term conditioning to high temperatures and humidity. Clothing and personal habits are influenced by exterior conditions as are expectations of comfort. A study of occupants of urban housing in Bangladesh indicates tolerance to high temperatures and very high humidities for comfort. Given the climate of the region and little experience of air conditioning this is not unexpected. Simple means such as cool surfaces and ceiling fans are able to provide comfort.

1 THERMAL COMFORT.

The existence of a comfortable living environment is necessary for a healthy and productive life. The state of comfort depends on a wide range of factors some of which, are not quantifiable such as psychological well being. In quantifiable terms thermal comfort is related to a set of environmental conditions such as air temperature, radiant temperature humidity, air movement etc. which are in turn dependant on personal variables such as clothing and activity. Experimental evidence have yielded certain values for the conditions (Olgyay, 1958; Fanger, 1970; Givoni, 1976 etc.) which are used in building design practices as guidelines towards achieving comfortable building environments.

2 LOCATION, CLIMATE AND COMFORT.

Comfort preferences are subjective but certain ranges of conditions accommodate the comfort sensations of a majority of people subject to a similar environment (Fanger 1970) Comfort preferences of people in different locations vary in terms of acclimatisation to a particular climate. The long term experience of a warmer climate may result in people of that environment having a tolerance to higher temperatures as compared to people in colder regions.(Givoni, 1992; Humphreys, 1978; Sharma and Ali,1986) Changes in behavioural patterns clothing and activity between locations have an effect on comfort preferences.

3 THERMAL COMFORT CRITERIA FOR BANGLADESH

Given the high temperatures and humidities that prevail for most of the year in Bangladesh and the adjustment of the people to the same creates the need for evaluating comfort criteria which are adjusted to local needs. The study focuses on the comfort requirements of occupants of urban housing in Dhaka. Assessments were made involving students of Architecture from whom around 400 recorded observations of comfort conditions could be gathered.

4 CONDITIONS OBSERVED

Assessments were made on the basis of the seven point Bedford scale of thermal sensations(Bedford,1936). Recordings of air temperature, humidity, globe temperature, air movement and in some cases external temperatures were made as the main environmental variables. Personal variables relating to age, sex, occupation, location, clothing and activity were also recorded. Observations were made in the homes of the people as they went about their daily lives over a number of days. The period of observations were between February and September which covered the short hot and dry period and the hot humid period. Ceiling fans are a common element in most urban houses and the effect of air movement was evaluated using air speed data for various speed settings. The identification of comfortable situations relate to the three central votes comfortably cool, comfortable and comfortably warm.

5 ACTIVITY AND CLOTHING RANGES.

The study considered normal conditions of clothing and activity as would take place in ordinary domestic situations. Activities as domestic functions included casual work mostly ranging in values between .8 to 1.2 met. There were no instances of work exceeding 2 met. The choice of clothing in warm situations were restricted to light clothes not exceeding an insulation value of .5 clo. Clothing styles in Bangladesh are adapted to comfort in their lightness and the way they are worn. In most cases they are loose and allow air movement within the body. Even the female preference of the saree which is a six meter long piece of fabric worn wrapped around the body is loose in its disposition and leaves areas exposed to air movement. Estimations of clo values were made with these considerations.

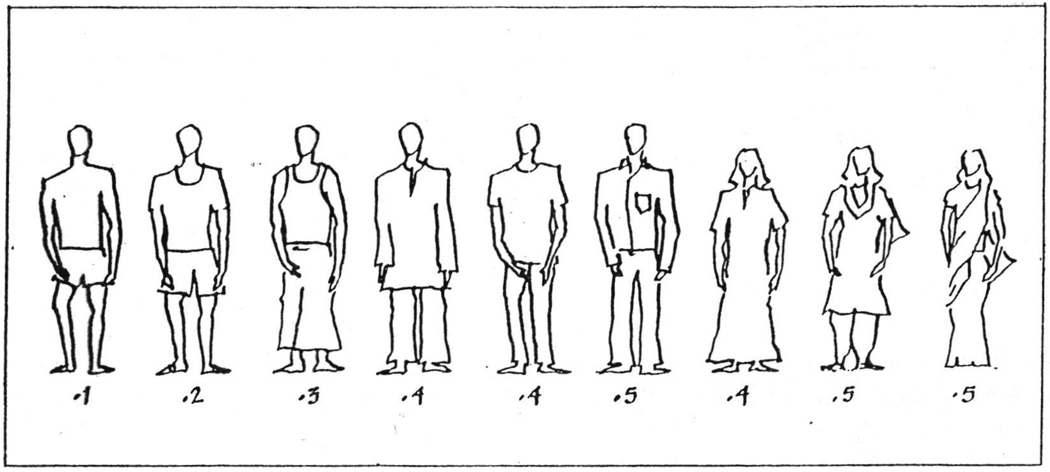


Fig 1. Clo values for typical summer clothing

6 COMFORT CONDITIONS

6.1. Air temperature and air movement

Under still air conditions comfort temperature ranges for people engaged in a range of household activities wearing ordinary clothing were found to be between 24°C and 33°C. Narrowing it down to sedentary activity only and clothing values of .5 clo the range is narrower between 24°C and 32°C.

The comfort temperatures increase with air movement but only for certain values. For air movement upto .15m/s generated by the slow setting of the ceiling fan there is no appreciable change in the range of comfort temperatures. For air flow of .3m/s there is a rise in the lower and upper limits of temperatures by 2.4°C and 2.2°C respectively. For higher air flow of .45m/s the change in both limits are less than 1°C.

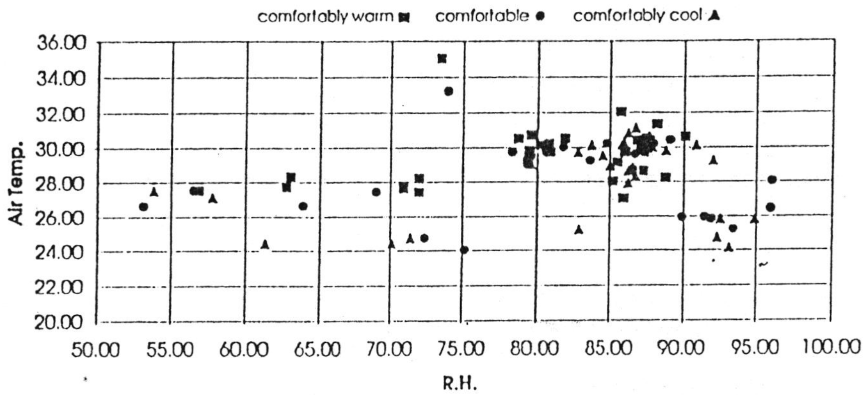


Fig 2. Comfort Conditions with no air movement

Fan speed setting	Air movement	Comfort range	Mean Comfort Temperature
none	0	24°C - 33°C	28.9°C
slow	.15m/s	24°C - 33°C	29.5°C
medium	.3m/s	26.4°C - 35.2°C	30.9°C
fast	.45m/s	27°C - 35.8°C	31.6°C

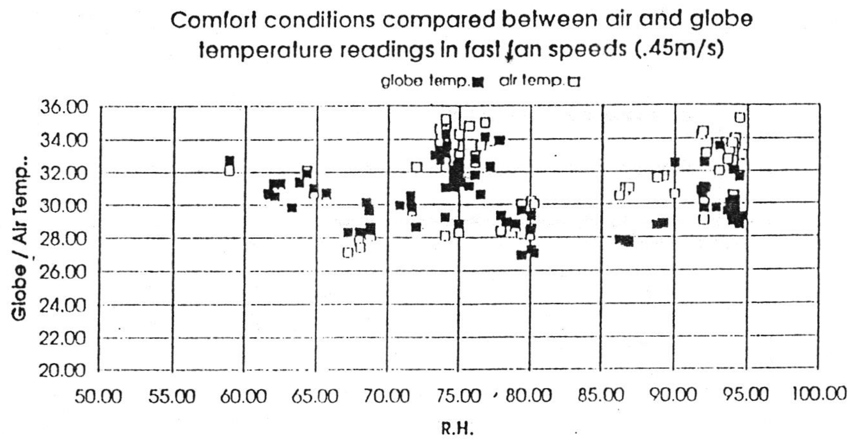
Table 1. Comfort temperatures for different air velocities

6.2. Humidity.

The results show a tolerance for high humidity conditions. There are instances where people have reported to be comfortable in humidities above 95%. The range is slightly more for conditions with no or slow air movement and decreases with higher air speeds. Lower limit of humidity is around 50%. The reaction to humidities below this could not be ascertained as such conditions did not occur during the period of observations. There was no apparent effect of humidity on changes in comfort sensations.

6.3. Radiant temperature

Globe temperature as an indicator of the mean radiant temperature was noted for all observations. As a general trend globe temperature is lower than air temperature. The walls in most houses are of masonry and floors are concrete with smooth finishes. In comparing both globe and air temperature for similar comfort conditions at different air speeds the difference between air and globe temperature readings diminsh with higher air speeds. Globe temperatures are always lower than external temperatures wherever recorded reinforcing the notion that nature of building construction has a direct bearing on comfort.



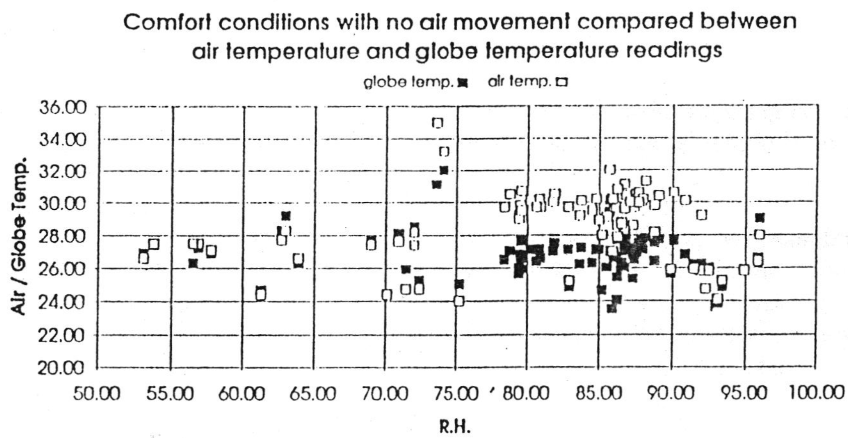


Fig 3. Globe and air temperature readings for comfort conditions at different air velocities

As a variable against comfort votes globe temperature values show the best relationship as opposed to air temperature and relative humidity. Regression analysis of votes and globe temperature yields a value of $r^2 = .25$. This is acceptable as a good correlation because of the nature of variation i.e. the votes only have values corresponding to absolute numbers. Subsequent calculations of comfort votes from the equation of the regression line and comparison with actual votes show an agreement with 44% of the actual votes in the three central categories and more than 60% in the case of the 0 (neutral) vote.

The equation for calculation of globe temperature from regression is given by:

$$C.V. = T_g * .18 - 5.11$$

C.V. is the value of the vote and T_g is the corresponding globe temperature. Subsequent calculation show a neutral radiant temperature of 28.3°C and a range of 22.8°C to 33.9°C for all three comfort sensations. Comparing the real data the neutral globe temperature seems to be accurate while the lower and upper limits are further away then what would seen to be reasonable deviation.

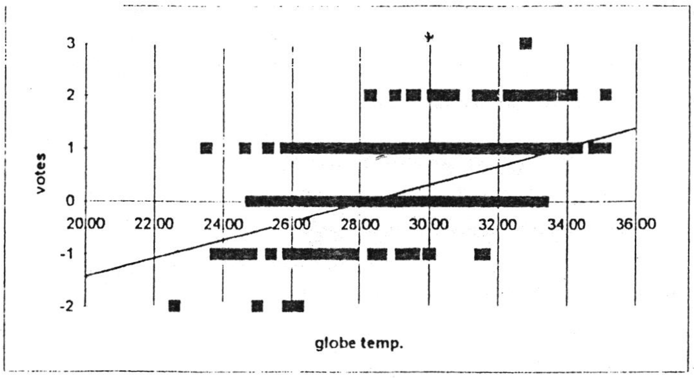


Fig 4. Regression line for comfort votes and globe temperatures

7. CONCLUSIONS

An air temperature range of 24°C to 32°C along with relative humidity values of between 50 and 90% can be said to be range in which people feel comfortable without or in little air movement.

The acceptance of high humidities as normal is more because of long term conditioning and higher threshold of tolerance to such situations and probably not by choice. There is little experience of lower humidities in that climate and very few instances of buildings where the humidity is artificially controlled. It may argued that people may actually feel uncomfortable at lower humidities. There is no decrease in comfort temperatures at higher humidities.

Radiant temperature is the decisive determinant for comfort and even if air temperature is high lower radiant temperatures can induce feeling of comfort. Building design has an important role to play in this respect. Buildings with heavier construction have lower radiant temperatures and are better in terms of comfort. Behavioural patterns such as walking bare foot over cool floors contribute to comfort.

Air flow can provide comfort at higher temperatures beyond velocities of .3m/s lower velocities can only contribute to health ventilation. In dense urban situations where air flow through open windows cannot always be depended upon, the ceiling fan is a reliable source for cooling but only at settings of medium speed and beyond.

During the cold period there is likely to be little adjustment to daytime comfort temperatures because the conditions are not cold enough to make a major difference in clothing. During particularly cold days and nights clothing insulation values may rise to 1 clo with subsequent lowering of comfort temperatures by 1-2°C. This is more valid for the colder north of the country than the milder coastal areas.

The study is limited to the urban population who are aware of the benefits to comfort provided by active means as the ceiling fan. For the rural population who lack these means and not aware of the benefits expectations of comfort hence tolerance levels may be higher.

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