

THE APPLICATION OF PASSIVE TECHNIQUES IN HOUSING DESIGN
IN HOT AND DRY CLIMATES; WITH SPECIAL EMPHASIS
ON INDIA

By

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B. Arch., Punjab University, India, 1982

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ADVANCED STUDIES IN
ARCHITECTURE

in

THE FACULTY OF GRADUATE STUDIES
School of Architecture

We accept this thesis as confirming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

August, 1988

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Abstract

This research focussed on the identification, evaluation and recommendation of passive design strategies suitable for housing design in hot and dry climates in India. The term 'passive' refers to those design techniques which, in order to enhance thermal comfort, utilize the favourable and minimize the unfavourable elements of the local climate. The objective of the research was to determine means by which reliance on mechanical means of achieving comfort and associated socio-economic costs can be minimized.

The thesis is divided into two parts. The first part identifies and evaluates the passive design techniques used in the dwellings of pre-industrial and post-industrial cities located in hot and dry region in India. Climate, environmental problems (primarily cooling), and indoor comfort criteria were analysed to establish preliminary criteria for evaluating the thermal performance of design techniques. The main objective was to enable designers to identify those techniques which can be used in contemporary dwelling designs.

The second part proposes strategies to incorporate passive techniques in contemporary housing design. General strategies recommended at various levels of design include the following:

- minimize solar gain
- minimize conductive heat flow
- promote ventilation
- minimize internal heat gains
- promote radiant cooling
- delay periodic heat flow
- promote evaporative cooling

- control high velocity wind
- control glare

These strategies, which recognize the comfort-related needs of dwelling occupants, promote the use of local construction practices.

The application of passive techniques presents architects with a considerable scope for creativity in housing design. However, at the outset, it is necessary to define priorities in the selection of design strategies, and to ensure these priorities are addressed through each level of design. The strategies selected in this thesis emphasize the need for minimizing heat gain during day time, and maximizing heat loss at night.

It is concluded from this research that the application of passive techniques in contemporary housing design allows for maintenance of most thermal comfort needs, thereby reducing reliance on mechanical means of control. At the same time, the use of passive techniques provides a potential for the housing designs to respond effectively to certain socio-cultural needs of the occupants.

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ACKNOWLEDGEMENT

I wish to express my gratitude to Raymond J. Cole for his superb guidance. As my advisor he also deserves the highest credit for motivating me and giving me helpful criticisms at various stages of this study.

I also wish to thank Bud Wood for his continuous support and patience. Without his support, especially at the initial stages, this endeavour would never have reached its destination.

I sincerely appreciate the efforts of David Rousseau and Gorden Brown in improving the English of this text, for it is in English where I need most help.

There are no words to express my deepest gratitude to my parents who provided emotional and financial support for my education in Canada. I owe more to them than to anyone else.

Last but not the least, as a close friend and now as a life partner, my husband Vinay deserves the most credit for giving me enough strength and intellectual support in writing and finishing this work.

INTRODUCTION

- 1. COMFORT AND DWELLINGS**
- 2. OBJECTIVES OF THE PROPOSED RESEARCH**
- 3. THE RESEARCH METHODOLOGY**
- 4. THESIS LAYOUT**

1. COMFORT AND DWELLINGS

The primary purpose of dwellings has always been the provision and maintenance of human comfort. Various methods of achieving comfort in dwellings have been devised by different societies according to their needs, resources and available technology.

The methods for achieving comfort have gradually changed over time. Before the industrial revolution, comfort in dwellings was achieved almost exclusively by the use of natural elements like sun and wind which were controlled through dwelling form and design*. During the industrial age new sources of fuel were discovered and mechanical heating and cooling devices were invented. Where this technology could be afforded, this permitted a change in the house form and in the life style of people.

The 1970's brought a temporary shortage of fossil fuels, and societies all over the world became concerned about the rising cost and limited supply of energy. Although developing societies like India consume less per capita energy than industrialized societies, the cost of energy which was already an issue in the developing world, became a critical development factor.

Inspite of the high cost of energy, cooling, lighting and

*Dwelling form, as observed by many architects (Anderson, 1968), is an expression of the interaction of the primary climatic, social cultural and economic needs whereas design is an expression of the interaction of building programme and site conditions.

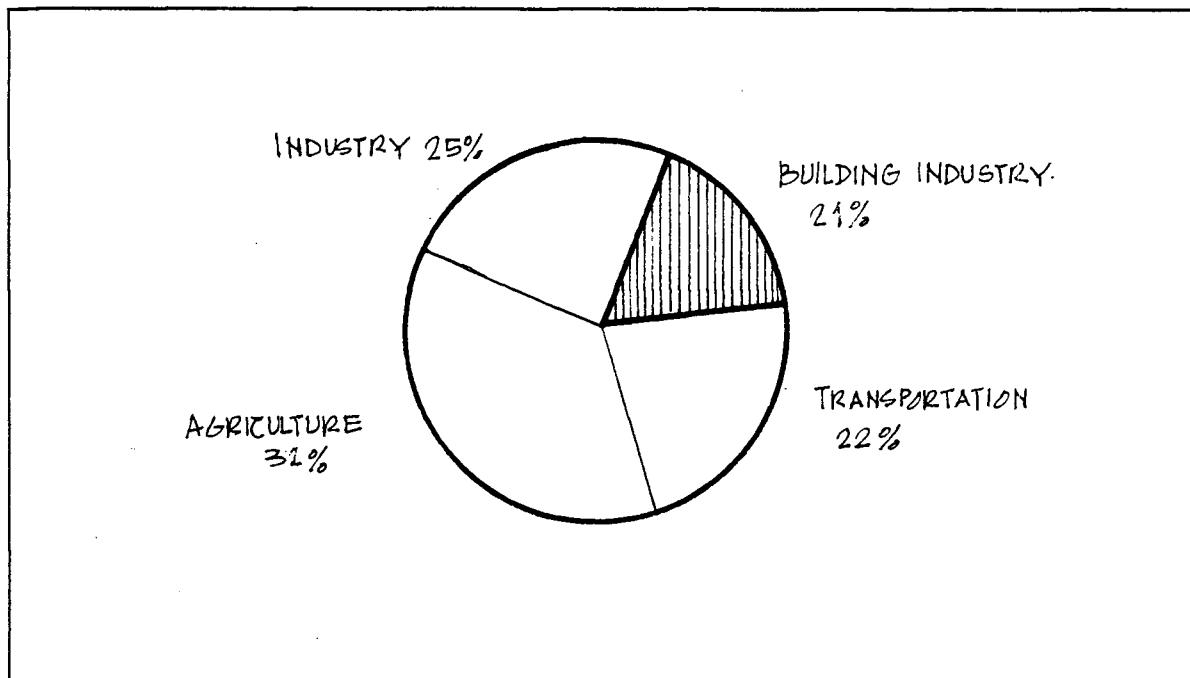


Fig.1. Commercial Energy Consumed for Achieving Comfort in Buildings in India.
Source: Parikh, 1976.

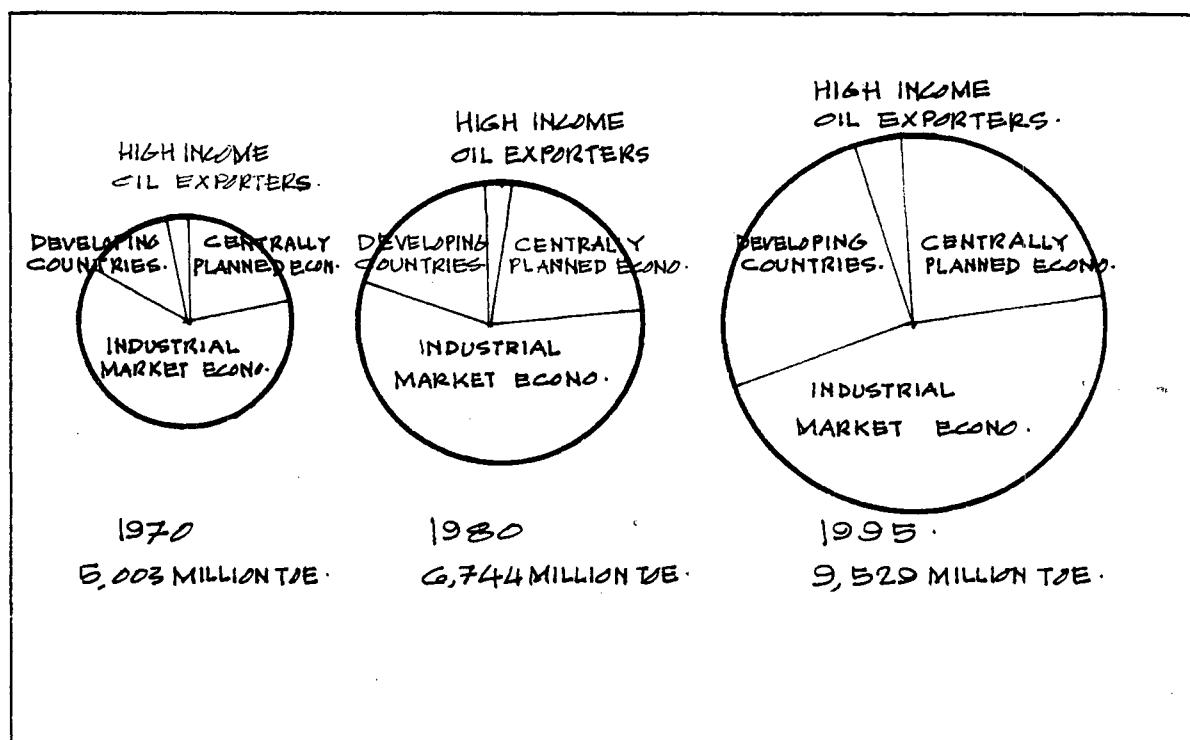


Fig.2. Shares of Country Groups in World Commercial Energy Consumption, 1970-95.
Source: Falvin, 1980.

heating of buildings in India, of which residential buildings form a large part, now consume nearly one quarter of the total energy supplies of the nation (Fig.1). The rate of growth of total energy consumption in India and other developing countries is expected to average 2.3% per year during the period 1980-1995 (Fig.2). It is certain from the estimated dwelling units (4.5 million) required to meet the growing demand for housing in India over the next 20 years (Manchanda, 1986) that use of mechanical means of achieving comfort in these buildings will contribute significantly to the projected growth in energy consumption.

While the recent reduction of oil prices has, temporarily at least, reduced the burden of energy imports, a most fundamental issue confronting developing nations like India remains unchanged: sustained development is dependent upon minimizing reliance on potentially high cost energy.

An awareness is growing that all buildings can be designed to minimize dependence on costly non-renewable energy sources. Planners and architects, who contribute the most towards making decisions regarding the use of energy for achieving comfort in buildings, are becoming aware of the need for energy-efficient designs. In architect Charles Correa's words:

"In a third world country like India, we simply can't afford to squander the kind of energy required to construct and air condition a glass tower in a tropical climate - and this of course is an advantage; for it means that the building must itself, through its very form, create the "controls" which the user needs. Such a response necessitates much more than just sun angles and louvers:

it must involve the section, the plan, the shape, in short: the very heart of the building.

To cross a desert and enter a house around a courtyard is a pleasure beyond mere photogenic making, it is the quality of light, and the ambience of moving air, that forms the essence of our experience. Architecture as a mechanism for dealing with the elements (truly, a machine for living!). This is the great challenge and opportunity of our third world."

(in Cantacuzino, 1984)

Utilization of natural energy sources, by means of the proper design of dwellings is not only beneficial and cost-effective, but is psychologically appealing. This realization has revived interest in traditional architecture* among many architects in developing societies. Traditional architecture offers several techniques of use in minimizing reliance on mechanical means. Poor societies, which have an abundance of knowledge based on traditional methods of building, fail to realize that they were once the most sophisticated of their time. The techniques employed by them for achieving comfort were superior to the techniques used by the industrialized societies of today because they responded effectively to the local climatic, economic, cultural, social and technological constraints.

This knowledge can still be of great value, either in its original form or as a basis for renewed design interpretation. On the other hand, however, many of the conditions (for example social, cultural economic and technological context)

*traditional Architecture refers to those structures and settlement patterns in which there had been no professional architectural and engineering involvement.

under which traditional techniques were effective have changed to the point where the original techniques are no longer immediately appropriate. Furthermore, the materials utilized for traditional techniques may no longer easily meet contemporary comfort expectations. These are perhaps a few of the reasons why these techniques are largely abandoned. But, it is also true that certain techniques introduced by architects in third world countries are inappropriate for local conditions. Therefore, as architect Hassan Fathy (1986) correctly points out that "we must determine what is basic and constant and thus worth keeping no matter what time period it evolved in".

Inspired by the above thought, this thesis is an attempt to understand, share and propose an application of traditional methods of achieving comfort in the dwellings of India, so that reliance on costly mechanical means of achieving comfort can be minimized.

2. OBJECTIVES OF THE THESIS

The main objective of this thesis is to examine ways to minimize reliance on mechanical means of achieving thermal comfort in residential buildings in hot and dry region* (Fig.3) in India. To achieve this goal, the following specific topics will be addressed:

a. Methods of achieving comfort in residential buildings in India through various periods of history. This will be accomplished:

- By identifying the design techniques which helped in achieving thermal comfort, and
- By evaluating and ordering the design techniques on the basis of their effectiveness in achieving thermal comfort.

b. Housing design strategies for achieving thermal comfort in hot and dry region of India with a minimum reliance on mechanical means. This will be accomplished by emphasizing:

- The use of local materials and building construction techniques available in the specific region, and
- The cultural and behavioral requirements of the users of the dwellings.

It should be recognized that although the proposed design strategies will emphasize non-mechanical means of achieving comfort, the aim here is not to eliminate the power driven

* Defined as a zone in which hot and dry climate predominates for a large time of the year.

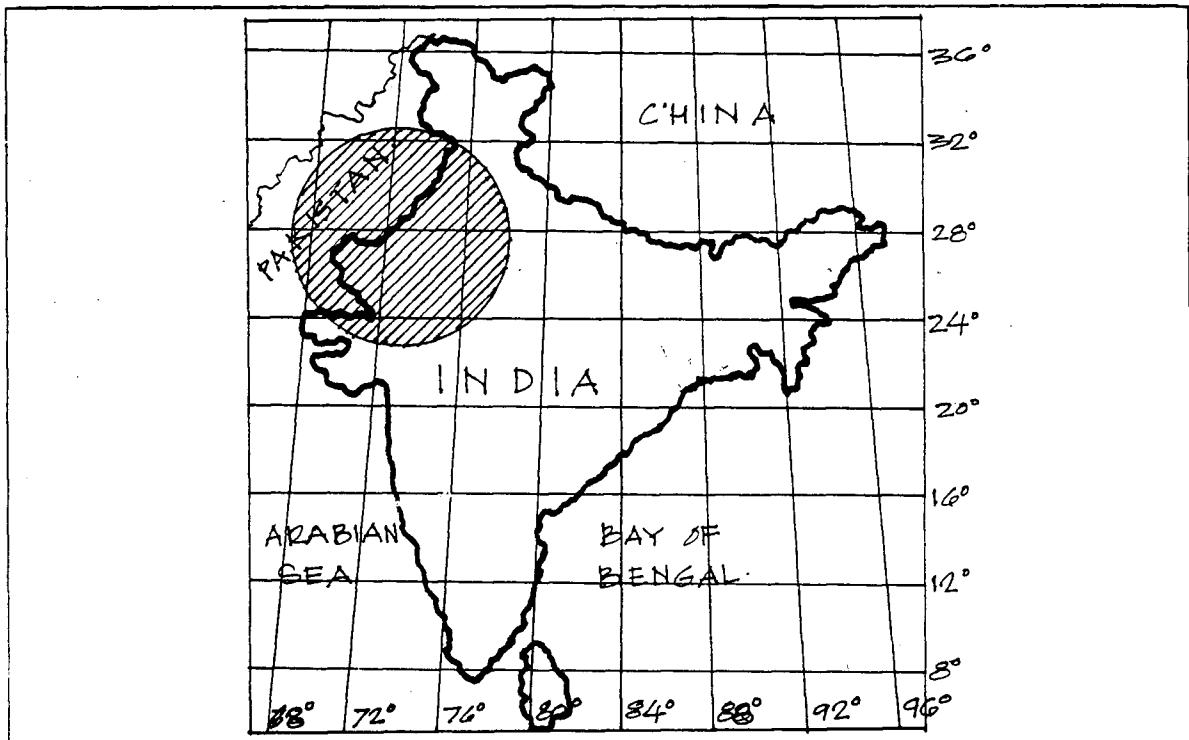


Fig. 3. Location of Hot and Dry Climatic Zone in India.

environmental control systems. Incorporating 'modern conveniences', and meeting comfort expectations in a dwelling, require that mechanical means cannot be ignored altogether.

3. THE RESEARCH METHODOLOGY

The evaluation of various design techniques in this thesis is based on their effectiveness in bringing the indoor thermal conditions within the desired comfort range.

With the increased availability of computer modelling techniques, it is now possible to predict, reasonably accurately, the thermal performance of a structure built with materials of known thermo-physical properties under given climatic conditions. However, the accuracy of prediction is limited, not by the model, which can be refined to almost any extent, but by the fact that the outdoor climatic conditions and the thermal characteristics of building envelope in-use can be predicted only with a limited degree of accuracy.

In air-conditioned or heated buildings where the internal thermal conditions are assumed to be maintained at a constant level with thermostatic control, the task is usually that of determining the amount of auxiliary heating or cooling that will be needed (Watson, 1973) to maintain that level over a given period of time. This is a relatively easy task. However, in the case of non air-conditioned buildings, as in this thesis, where natural energies are being used to achieve and maintain thermal comfort, predicting the precise degree of thermal comfort performance that the building will provide is a difficult task. In addition to the unpredictability of climatic conditions, the varied activities and responses of

building occupants make prediction more complex. Mathematical models are not very accurate in assessing the human response to varying thermal conditions, particularly when people may be changing some of the assumed building characteristics by opening or closing doors and windows. However, computer programmes and mathematical models are useful for the building designer to understand the quantitative performance of building fabric leading to the appropriate choice between different alternatives (Gupta, 1984).

The research in this thesis is based largely on literature review, as well as application of specific mathematical models and computer programmes. The emphasis is on understanding the theory and the principles involved in assessing the thermal performance of various design techniques, rather than the quantitative results.

4. THESIS LAYOUT

The thesis is divided into two parts. Part One presents a brief history of the means by which human comfort in domestic buildings has been achieved in hot and dry climatic region in India, in the pre-historic, Medieval and modern industrial periods.

Part Two focuses on developing contemporary design strategies. There are various levels of design at which decisions regarding the use of applied energy are made by architects. These are: site selection; site planning; form design; and fabric design. Strategies for minimizing the use of applied energy are discussed for each one of these levels. A general design principle applied in each of these sections is to minimize or modify the adverse effects of external climate while utilizing the favourable ones.

The relationship of existing topography and climate to the proposed buildings is considered in the section on site selection.

The site planning discussion considers the potential for creating an effective microclimate through street layout, design of open spaces and landscaping.

The form design section involves the role of building volume, shape and configuration in minimizing the adverse effect of climate.

The final section, involving the fabric design level,

considers the role of windows, walls and roof, and the materials for their construction, in modifying the undesirable and utilizing the favourable effects of exterior climate.

PART ONE: A HISTORICAL REVIEW OF METHODS FOR ACHIEVING COMFORT
IN HOUSING IN HOT AND DRY CLIMATES IN INDIA

INTRODUCTION

SECTION I: PRE-HISTORIC PERIOD

SECTION II: MEDIEVAL PERIOD

SECTION III: MODERN INDUSTRIAL PERIOD

SECTION IV: CONCLUSIONS AND CONTEMPORARY ISSUES

INTRODUCTION

Part one of this thesis presents a brief history of the techniques by which human comfort in domestic buildings has been achieved in India. The main objective is to identify the potential applications of these historical methods on contemporary domestic architecture. Climatic factors that influence comfort in residential buildings, comfort criteria, various environmental problems and, most importantly, the performance of building design techniques used in solving these problems are examined for typical examples of housing in the Pre-historic, Medieval and Modern Industrial periods. Part one concludes with outlining the techniques which can be effectively used to enhance and maintain thermal comfort in contemporary dwellings.

SECTION I: PRE-HISTORIC PERIOD

1. INTRODUCTION

The most significant examples of civilization in India from pre-historic times are found in the towns of Mohanjodaro, Harappa and Taxila, located in the hot and dry climatic zone. These towns developed during the 'Calcolithic' age, i.e. the period of transition from use of stone to bronze as the material for tools, which implies that the knowledge of building construction technology, the means of transport, the urban economy and hence the means of achieving comfort, were limited. As a result of less diversified knowledge of construction technology, these towns were similar in their layout and house design (Schoenauer, 1981). This section will examine the methods of achieving comfort in the residential buildings of Mohanjodaro.

2. HOUSING IN MOHANJODARO

2.1. Introduction

The archeological research by Marshal and Wheeler (Schoenauer, 1981) revealed that the city of Mohanjodaro existed for 500 years, from 3250 B.C. to 2750 B.C. Mohanjodaro, now located in Pakistan, is to the north-west of India (Fig.1.1). The river Indus and its many tributaries in this region irrigated the surrounding land and were a source of occasional floods*.

*The river Indus has almost dried and this area is a virtual desert now.

2.2. Location and Climate

Mohanjodaro is located at $27^{\circ} 55'N$ latitude and $69^{\circ}E$ longitude (Fig.1.1) and is 1.7m above mean sea level. The seasons which predominated in this area (it is assumed) were summer and winter. During summer the maximum and minimum temperature varied between $25^{\circ}C$ and $45^{\circ}C$. In winter the temperature varied between $5^{\circ}C$ and $25^{\circ}C$. The diurnal range of temperatures was between $15^{\circ}C$ and $20^{\circ}C$ (Fig.1.2) in both seasons. The sky was mostly clear and direct solar radiation was intense throughout the year. As the soil in this area was fertile during the period under discussion, the trees and shrubs grew throughout the year and the ground reflected solar radiation was not very intense. Wind velocity in this area was usually high during the months of May and June and the annual rainfall varied between 250 and 500 mm. Maximum relative humidity in summer could be as low as 30%.

2.3. Indoor Comfort Criteria

The two important factors influencing comfort in buildings are indoor environmental conditions, and the life style of the occupants. The way these factors influenced comfort criteria in the dwellings of Mohanjodaro are described below.

Indoor Environmental Conditions

The thermal conditions in a building are the result of the extent to which the building modifies air temperature, relative humidity, solar radiation and air movement (Givoni, 1969). The resulting conditions are experienced by the occupants.

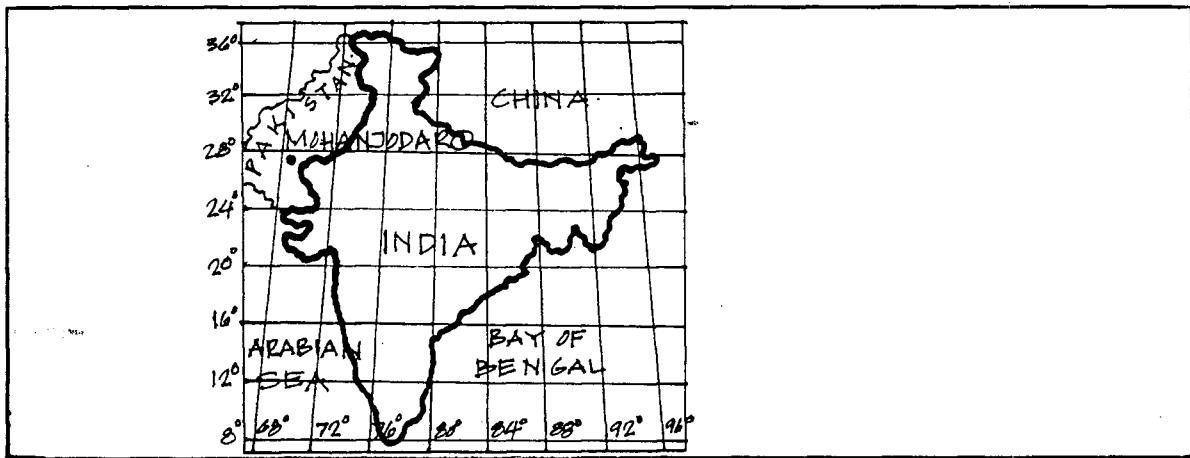


Fig.1.1. Map of India showing Location of Mohanjodaro.

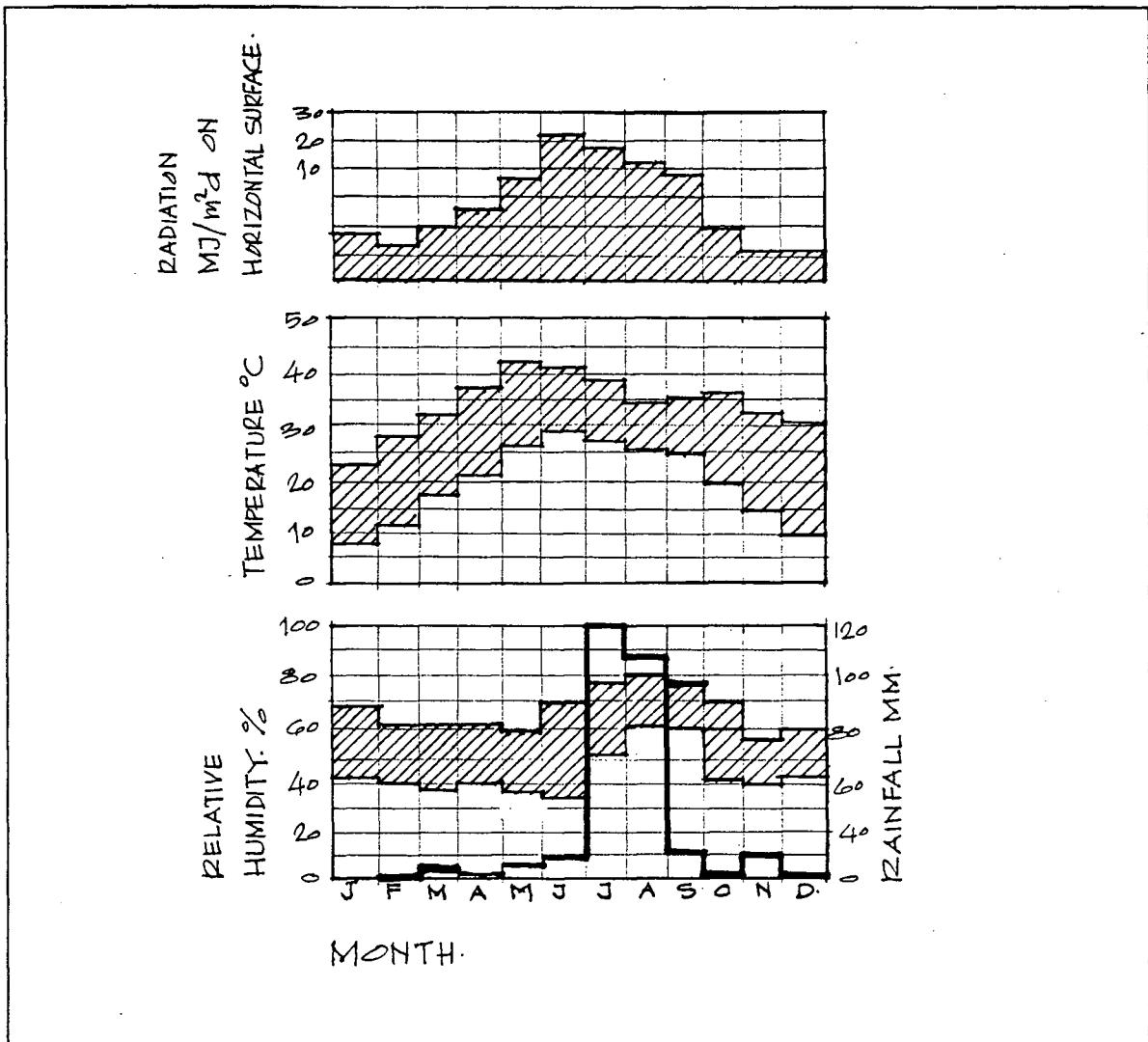


Fig.1.2. Climatic Data of Mohanjodaro (Monthly Means).
Assumed to be similar for the period under discussion.

For physiological comfort in a hot and dry climate, the air temperature required in a building should be between 27°C and 29°C during the day and 29°C to 32°C at night (Givoni, 1969). The air temperature in Mohanjodaro during the summer days was much higher than what is desired. Therefore, reducing the indoor air temperature to a comfortable level was critical. During the day, the entry of outside air was not desirable because of its high temperature which prevents convective heat loss from the body even when the air speed is high (Olgyay, 1963). Therefore, air movement was not a desirable solution for cooling for such a temperature range. The sweat evaporation rate from the body was high even in still air because of the low humidity. In addition to the high air temperature during summer, solar radiation was also intense which meant that the walls and the roof of buildings must minimize solar heat gain. The diurnal range of temperatures was also high which suggested that the building structure should have a high heat storage capacity with a time lag of 12-15hrs. for achieving comfortable internal temperatures. Direct penetration of sunlight into buildings was not desirable both for thermal reasons and to reduce glare.

Life Style

In addition to internal conditions, the life style of people, the way they use the building and how they dress determines the comfort expectations and influences the comfort criteria in buildings.

Given the limited technology, it can be assumed that buildings of Mohanjodaro were expected to provide comfort in

terms of basic protection from extreme climatic factors like high summer and low winter temperatures, as well as privacy and safe storage of goods.

Of all the areas within the house, the courtyard was most extensively used for various activities like cooking, sitting outside and sleeping. The front part of the house was not used extensively for reasons of privacy.

Spinning and weaving were widely practiced during this period and it is known that cotton was used exclusively for textiles in India. The clothes worn during this period were generally made of cotton which, because of its inherent material properties, protects the body from high summer temperature and is effective for evaporative cooling.

2.4. Environmental Problems

The most important environmental problem in the dwellings of Mohanjodaro was cooling. Other than cooling, the buildings also needed protection from direct penetration of light and occasional floods. The sections below will examine the building design features with a particular emphasis on cooling.

2.5. Building Design Techniques

Town Layout

Archeological excavations reveal that the streets of Mohanjodaro were planned on a grid pattern (Fig.1.3). Main streets had a north-south orientation, which is diagonal to the predominant wind direction, and were about 10 m wide. They were lined with shops on both sides (Schoenauer, 1981).

The other parallel streets were much narrower, though rarely less than 3m. in width, which allowed a cart to pass through them. Narrow lanes, varying from about 1 to 2 m in width, linked the primary and secondary streets. These lanes did not necessarily run in straight lines from one street to another because they were mainly used by pedestrians. The level of these lanes was considerably higher than those of main and secondary streets, presumably in response to the frequent floods. The residential buildings were of unequal heights.

House Form

Most of the excavated areas of Mohanjodaro appear to have been residential. The size of buildings ranged from humble two room dwellings to large multi-room houses that could be ranked as palaces. The typical dwelling unit of Mohanjodaro was an inward looking courtyard house (Fig.1.4). The smaller homes had only one courtyard, while the larger ones had several for the purposes of light and ventilation. As a result of the compact layout of Mohanjodaro, the width of the courtyard, usually square in shape, never exceeded the height of surrounding blocks. Residential units had no windows towards the subsidiary walkways for reasons of privacy (Grover, 1980). The windows towards the courtyard were small and decorated with intricate lattice work.

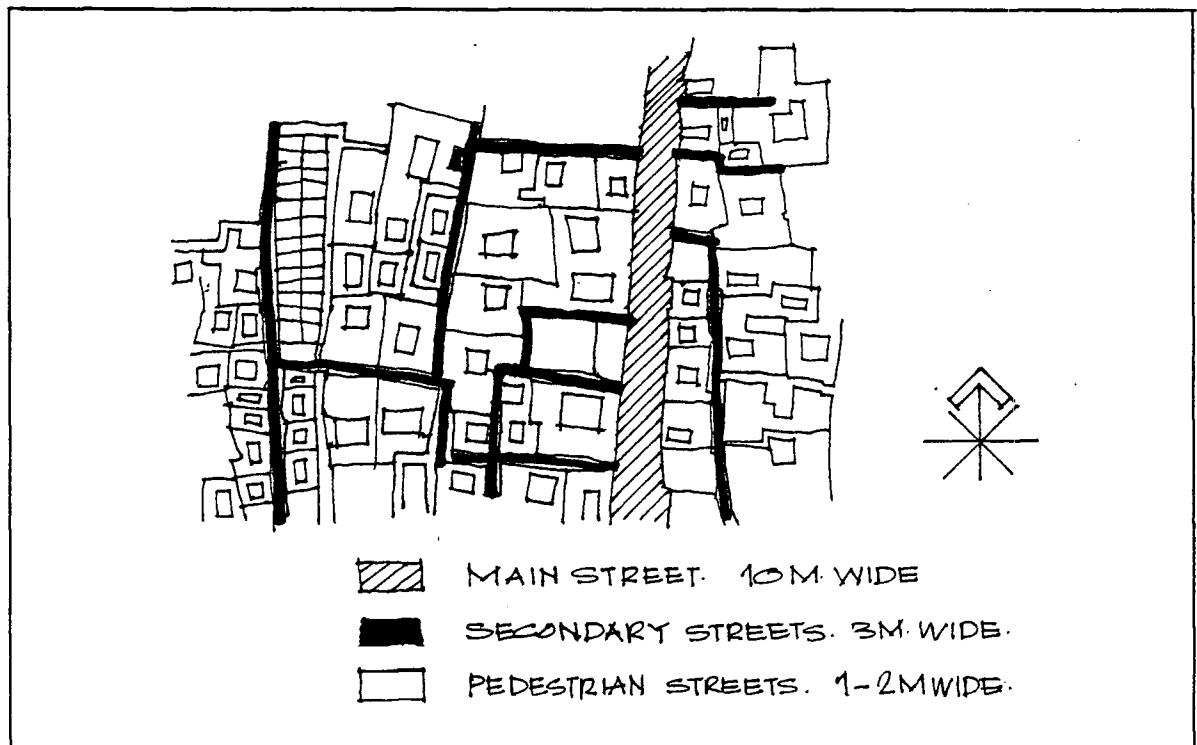


Fig.1.3. Street Layout of Mohanjodaro.
Source: Grover, 1980.

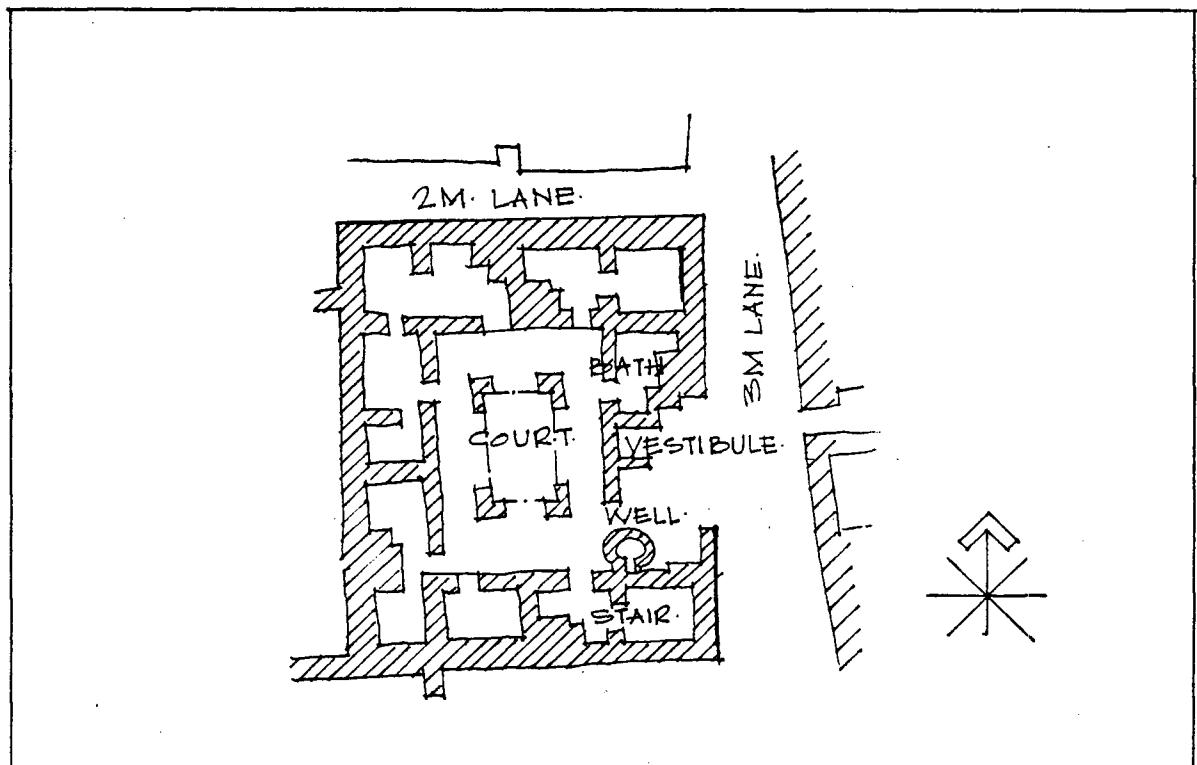


Fig.1.4. Plan of Typical Dwelling Unit in Mohanjodaro.
Source: Grover, 1980.

Building Construction and Services

The residential buildings were constructed with 45cm. or thicker brick walls and were roofed by brick tiles laid over timber rafters with a depth of 30cm. The total thickness of the roof was approximately 45cm. Water supply to the buildings was through the wells shared by three or four houses. The entire city was served by an extensive system of drainage. The bathrooms were connected to drains running under the walkways which in turn were connected to large sewers laid out under the main street. Manholes were located at regular intervals along the main sewer for inspection and cleaning of the drains. Smaller drains were covered with brick slabs and the larger main sewers were spanned by corbelled brick arches (Grover, 1980).

From the above description of buildings in the town of Mohanjodaro, it appears that the design of extensive drainage system, raising the plinth of buildings and use of ground floor for shops on main streets was a response to frequent floods. Cooling of the indoor environment was achieved by the use of the following building design features:

- Dense clustering of buildings,
- Sun control through orientation,
- Massive construction of roofs and walls,
- Courtyards,
- Small openings, and
- Use of lattice work for windows.

The following section will analyse the performance of these features in moderating the thermal environment.

2.5. Performance of Design techniques

Dense clustering of buildings / Sun control through orientation

In Mohanjodaro, layout of the town was the first level of modification of a harsh summer climate. All the houses were built wall to wall with central courtyards. This meant that only two sides of the buildings were exposed to the sun. The secondary and main streets in the town ran N-S and were 3 to 10m. wide so that the residences facing these streets had either an east or a west facade exposed to the sun. The summer sun would shine on the east facade until 11.30 a.m. and the west facade after 12.30 p.m. The altitude of sun during these periods varies from 0° to 80° (Fig.1.5) so that the facade facing the secondary street was exposed to the sun for no more than 2-3 hours. As shown in Figure 1.4, this was the entrance facade and did not have any windows opening towards the street. The only door which opened on the street had an entry with a vestibule which gave the front facade full protection from direct penetration of sunlight. The front part of dwellings was not extensively used for living purposes. The bathing area, garbage chutes and wells, which require less consideration of comfort conditions, were placed there.

The eastern facade facing a narrow street was shaded before 10.30 a.m. and after 1.30 p.m. as a result of the lower altitude of the sun (Fig.1.5). Thus the solar radiation on this facade was effective for no more than an hour and this was protected by the massive brick wall construction which

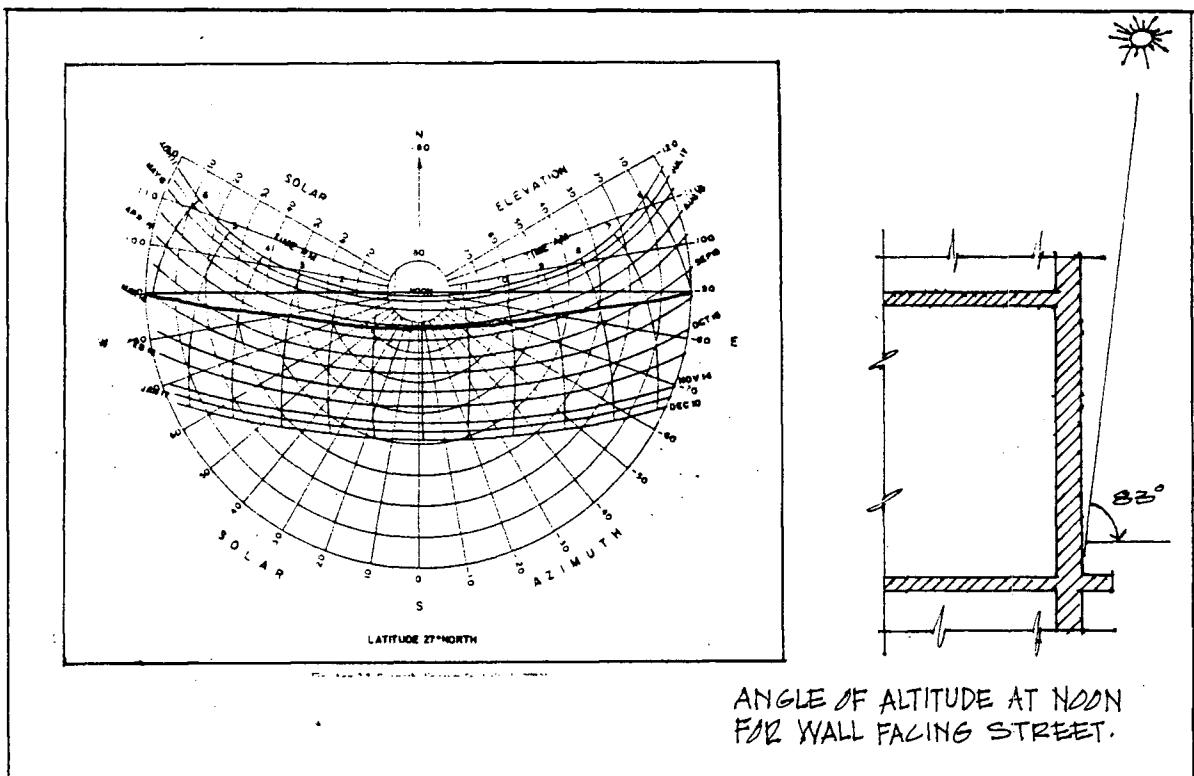


Fig.1.5. Summer Shading Mask for an Eastern Wall in a Narrow Street. (Shading Mask for Western Wall is Similar).

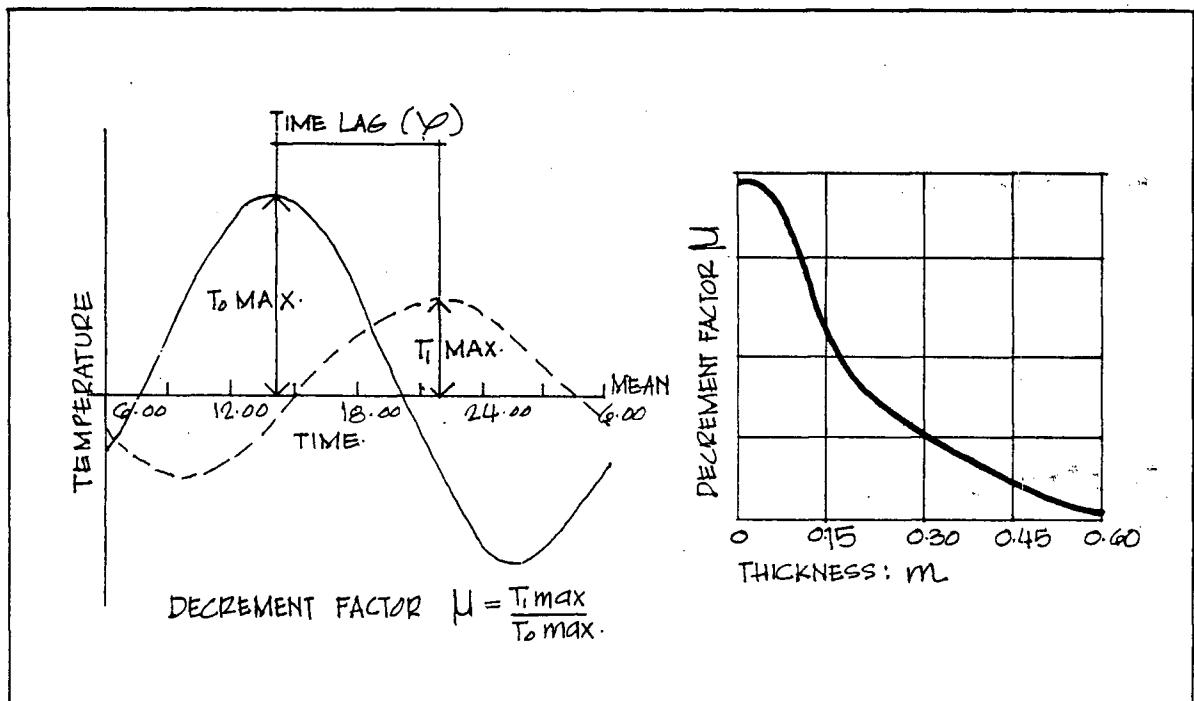


Fig.1.6. Time Lag and Decrement Factor for Thick Walls.
Source: Koenigsberger, 1973.

ensured high heat storage capacity and time lag of 10-15 hrs (Givoni, 1969). The walls facing the courtyard, in the same orientation, remained in shade for most of the day as the width of courtyard was less than its height. These walls received solar radiation between 11.30a.m. and 12.30p.m. when the altitude of sun is close to 80° . The incident solar radiation on the vertical surface is less intense however due to the steep angle.

Massive construction of roofs and walls

Because the walls were protected from solar radiation to a large extent, the main area of solar heat gain was the roof. Roof construction of about 45cm. in thickness, made from wood and brick materials ensured a time lag of 12-15 hrs (Givoni, 1969) and were effective in reducing heat gain. This implies that by the time the internal roof surface reached its highest temperature, it was already night and the effect of mean radiant temperature could be offset by the lower temperature of ventilation air (Fig.1.6).

Courtyards

At temperatures below 35°C , thermal comfort can be provided by ensuring adequate air movement in the built space. Natural air movement in buildings can result from wind or temperature differences between interior and exterior. As high temperature wind was not desirable during the day time, air movement was achieved by temperature differences (Koenigsberger, 1971). The courtyards in the houses were effective in cooling the interior spaces through air movement (Fig.1.7). The courtyard was shaded during the day and

retained the pool of cool night air (below 35°C). Because the cool air is heavier than the surrounding warm air (above 40°C), in the day time when the walls towards the street received intense solar radiation and the internal temperature began to rise, the cool air flowed in from the courtyard and replaced the warm air rising through the interior. Although wind velocity in summer was high, the cool air in the courtyard was left undisturbed because of the courtyard's small size in comparison to its height. The cooler air, cooler surfaces and the earth beneath the courtyard draw heat from the surrounding areas and re-radiate it to the open sky during the night.

Small openings / Use of latticework for windows

The luminance of the sky near the horizon is greater than at the zenith under clear sky conditions and can be a source of glare. In addition, buildings surrounding the dwellings in Mohanjodaro were of a light color and were a source of glare in strong sunlight. On the one hand the small windows helped in reducing solar radiation, but they could also be a source of glare because of their small size which created a dramatic contrast between the dark interior and the bright sky outdoors. To protect the interior from these sources of glare, the windows at eye level in the houses of Mohanjodaro had intricate lattice work which excluded glare while bringing diffused light in to the interiors.

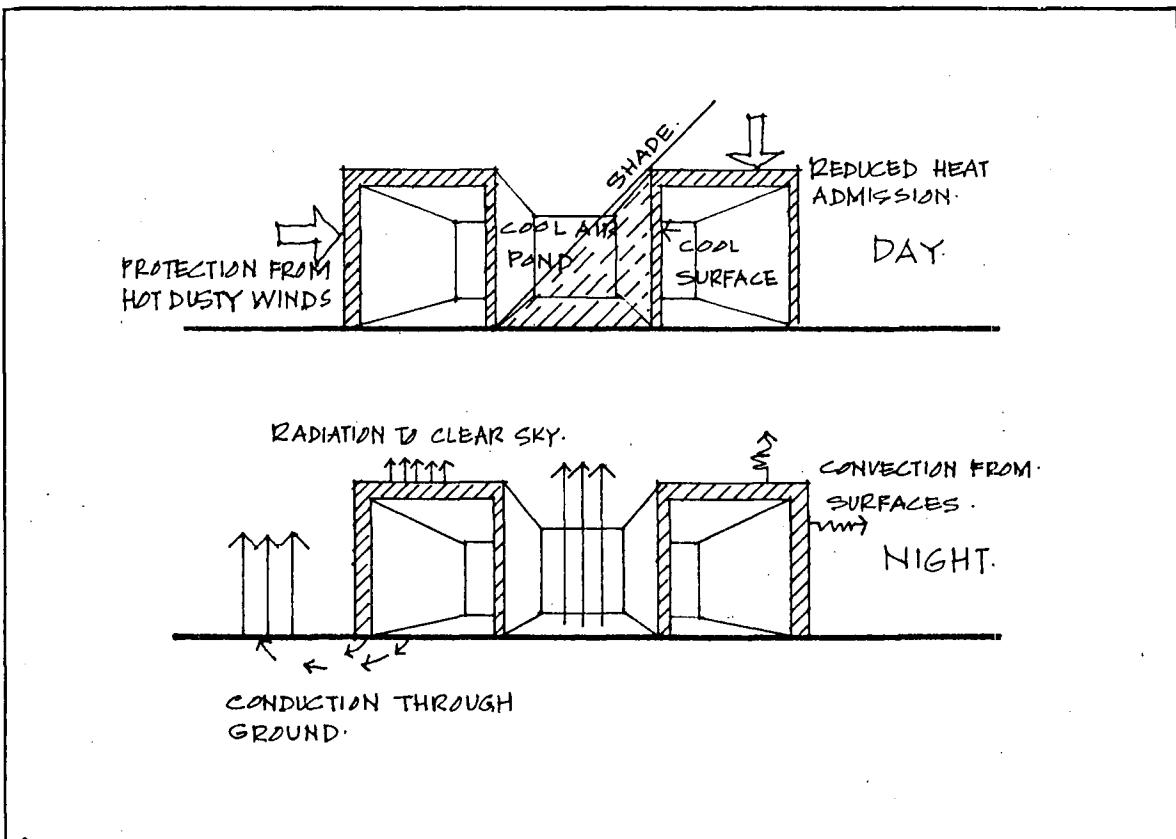


Fig.1.7. Thermal System of a Courtyard House in Mohanjodaro.

In summary, thermal comfort in the houses of Mohanjodaro was achieved by minimizing the impact of the unfavourable climate and by improving the micro-climatic conditions with the help of town layout, housing form, and construction of various components like walls, roofs, windows. These are termed "passive" design techniques. In addition, personal adaptations were made by people through clothing and the use of various areas of the house such as courtyards where conditions were moderated.

SECTION II: MEDIEVAL PERIOD

1. INTRODUCTION

The most important Indian cities which developed in hot and dry climate zone during the early part of the medieval period between 1000A.D.-1800A.D. were old Delhi, Ahmedabad, Udaipur, Jaisalmer and Jaipur (Fig.1.8). The medieval period in India was marked by many invasions. Most cities in this region were therefore built for defence purposes and were similar in layout and house form. The city of Jaisalmer is used here to demonstrate methods of maintaining comfort in houses of the hot and dry climatic zone during the medieval period.

2. HOUSING IN JAISALMER

2.1. Introduction

The town of Jaisalmer was founded in 1156 A.D. as a military fort and trading post for the east-west caravan route crossing the Thar desert. The expansion of the town outside the fort started in 1725 A.D. (Agarwal, 1979) with the influx of population from surrounding areas. During the years 1750-1850 A.D. additions to the town included fortifications around the town and construction of many larger residential buildings called "Havelis". Jaisalmer is famous for the richly carved facades of the havelis and other residential buildings.

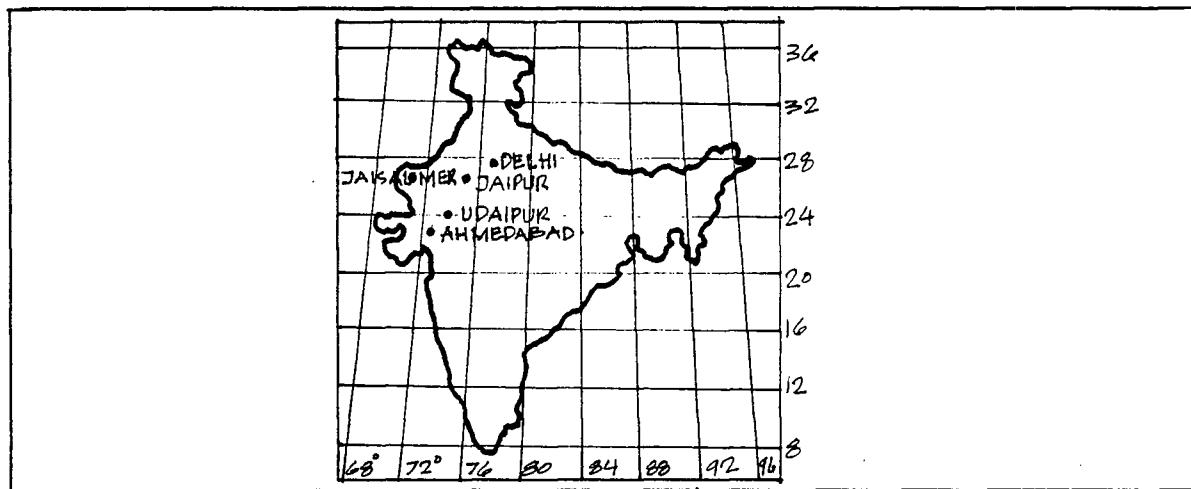


Fig.1.8. Location of the Cities Developed during Medieval Period in India.

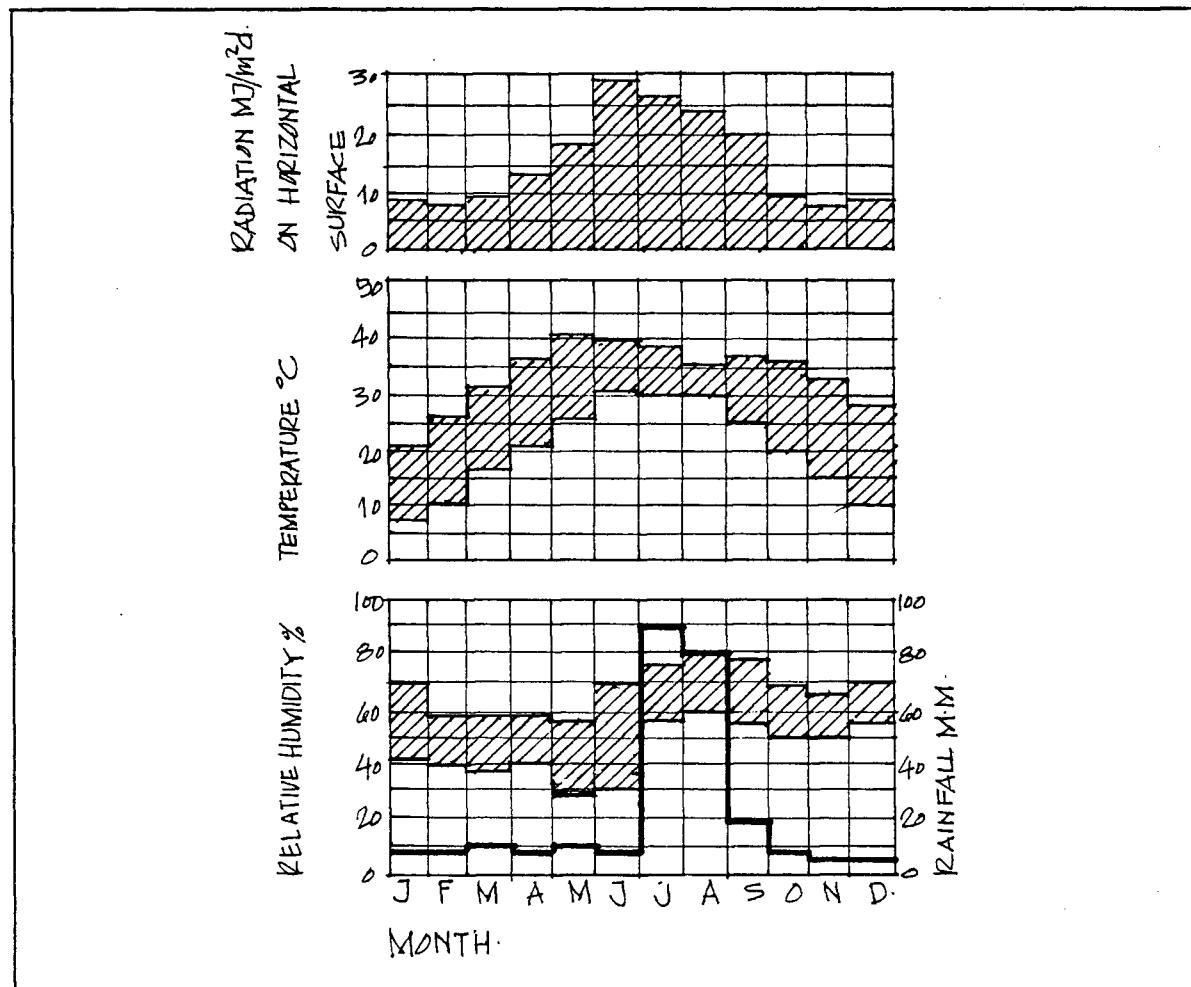


Fig.1.9. Climatic Data of Jaisalmer (Monthly means).
Source: Mani, 1982

2.2. Location and Climate

The town of Jaisalmer is situated at $26^{\circ}55'N$ latitude and $75^{\circ}55'E$ longitude (Fig.1.8) and is 1.7m above mean sea level. The climate of Jaisalmer is typical of the extreme hot and dry region. Although the summer and winter temperatures are like the town of Mohanjodaro, i.e., between $25^{\circ}C$ and $45^{\circ}C$ during summer and between $5^{\circ}C$ and $25^{\circ}C$ during winter, the relative humidity in the month of May and June is occasionally less than 30% (Fig.1.9). The average annual rainfall in this area is less than 25cm and direct and ground reflected solar radiation is intense for the whole year. In June, which is the hottest month, the average solar radiation on a horizontal surface is 27.2 MJ/m^2 a day. Wind velocity is usually high, it often exceeds 4.8 m/sec, and there are severe dust storms during the months of May and June.

The landscape of the surrounding region is flat, rocky and barren. There are shifting sand dunes in the areas around Jaisalmer. Several kinds of light coloured limestones and sandstones are available as building material.

2.3. Indoor Comfort Criteria

Indoor Environmental Conditions

Being in a hot and dry climatic zone, the indoor thermal conditions for buildings in Jaisalmer are similar to Mohanjodaro. However in Jaisalmer, an additional consideration for human comfort is protection from the dust-laden wind.

Life Style

The life style of the people of Jaisalmer was similar to

other medieval cities in this climatic zone in India (schoenauer,1981). Given their technological limitations, the people of Jaisalmer had to live with a scarcity of water and the severe climatic conditions. People made personal adaptations in their daily indoor and outdoor activities to achieve thermal comfort. For example, during the hot summer day, cooking, sleeping and other household activities were limited to the indoors whereas in the cooler evenings or at night, terraces and outdoor spaces were used for these activities. As the use of most spaces in the house changed diurnally and seasonally, with the exception of a few service areas, the various rooms of the house were rarely designed for a single activity. Most areas of the house were washed and cleaned everyday and walls were whitewashed annually by the residents.

Clothes worn by people in Jaisalmer were made of thick cotton. People wore loose garments, and covered their heads for cultural reasons, which also gave them protection from the strong sun and wind blown dust outside. Cotton, as already stated, is more effective for evaporative cooling than other clothing materials.

2.4. Environmental problems

The basic environmental problem in the buildings of Jaisalmer is cooling, in addition to which the buildings need protection from dust storms.

2.5. Building Design Techniques

The Town Layout

The town of Jaisalmer has an irregular polygon shape and is

surrounded by a 6m. high wall. Various gates called the 'Poles' define the entry points to the town while the fort, which is within the town, is located on a hill surrounded by a second wall for defensive purposes (Fig.1.10). The area within the fort is triangular in shape and contains the royal palace in addition to numerous common dwellings. Unlike other Indian forts, which are characterised by strong rectilinear geometry and open spaces, the fort in Jaisalmer has a winding street network, possibly for security reasons, and has few community open spaces.

The major streets in the town outside the fort have a general E-W orientation with minor streets at right angles to these. The "havelis", with richly carved fronts, are located on the E-W streets which are wider than other streets (Schonauer, 1981). The height of buildings in general is one to two times the width of streets, the buildings are of unequal heights, and the facade abutting the street has richly carved balconies and fins projecting at the upper level.

For various socio-economic reasons, the town plan of Jaisalmer developed in the form of 'Padas' (residential districts) based on the caste or profession of the residents.

The House Form

The residential buildings were constructed with mutual help by using locally available materials and construction technology. The involvement of occupants with building construction and their struggle with climatic technical, political and economic constraints made them develop a keen design sense which is evident in the buildings of Jaisalmer. The dwellings of

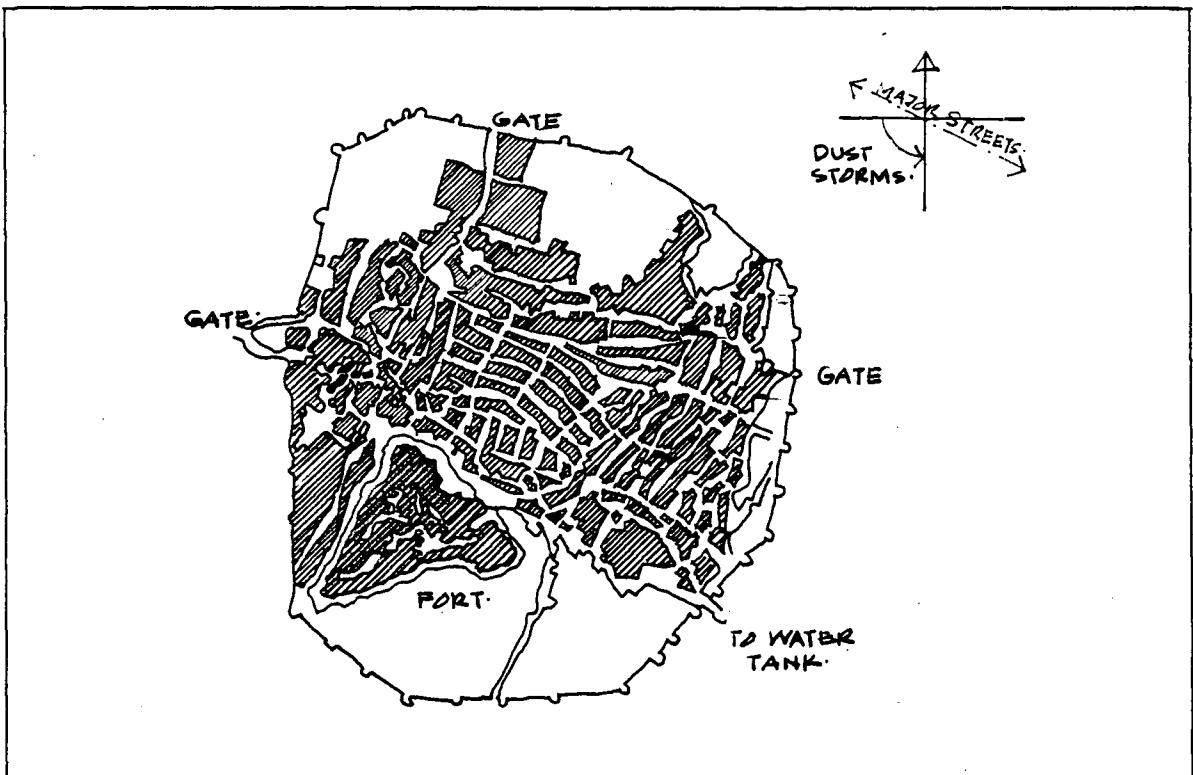


Fig.1.10. Town Layout of Jaisalmer.
Source: Schoenauer, 1981

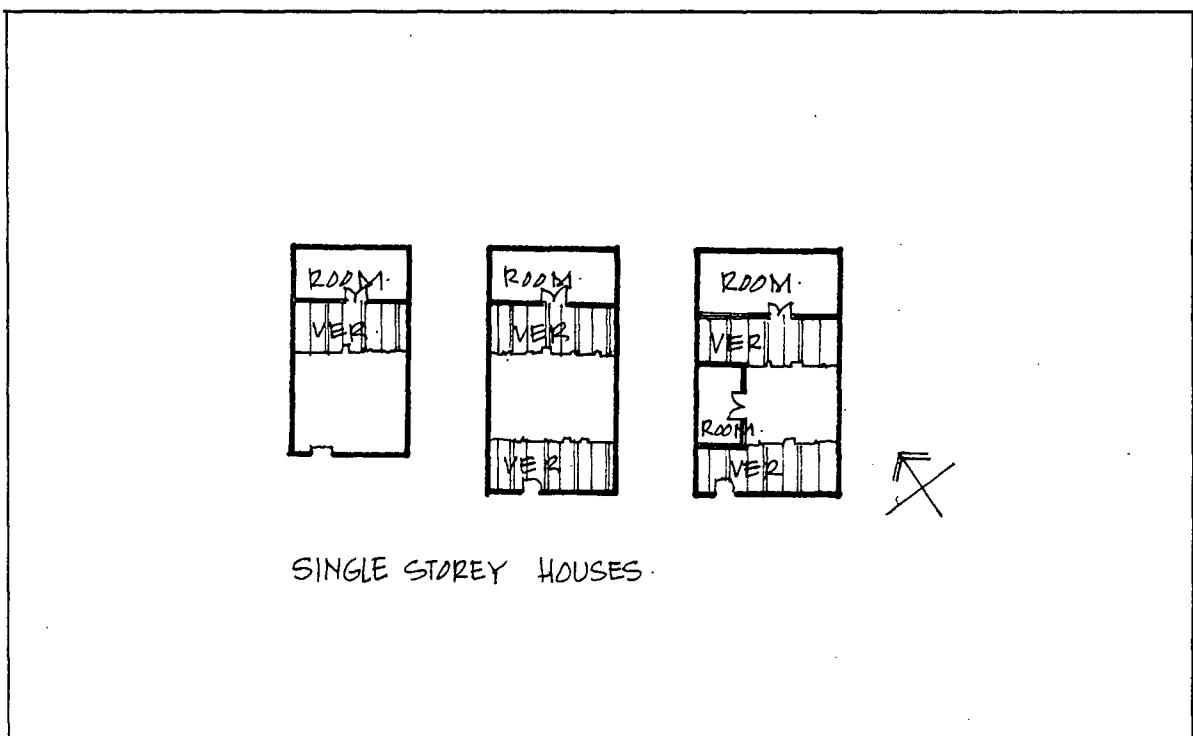


Fig.1.11. Plan of a Small House In Jaisalmer.
Source: Schoenauer, 1981

Jaisalmer are real evidence of the sophisticated interaction between the above constraints, and a manifestation of an expressive type of architecture. The houses belonging to all socio-economic groups were primarily designed to provide protection from extreme climatic conditions with additional considerations for privacy and the safe storage of possessions. However, the financial status of the occupant dictated the luxury of the building in terms of its ornamentation and vastness of spaces.

There are three types of houses in Jaisalmer each belonging to a different socio-economic group:

- a. The first type consisted of a single room, a verandah and a courtyard (Fig.1.11). Larger houses of this type had another verandah over the entrance and some had an additional room on one side of the courtyard. These houses were owned by the poorest people and were built in the peripheral areas of the town.
- b. The second type can be termed the "typical" house of Jaisalmer and belonged to middle-income people (Fig.1.12). The design and configuration of this house was similar to the first type, but with additional rooms and small enclosed terraces located on the upper floors. The front of the first floor had balconies projecting over the street. The typical house of Jaisalmer was attached to other houses on its side and at the back, leaving only a narrow facade with small openings exposed to the street.
- c. The third and most complex type, were the "havelis" (Fig.1.13), owned by rich merchants and were located

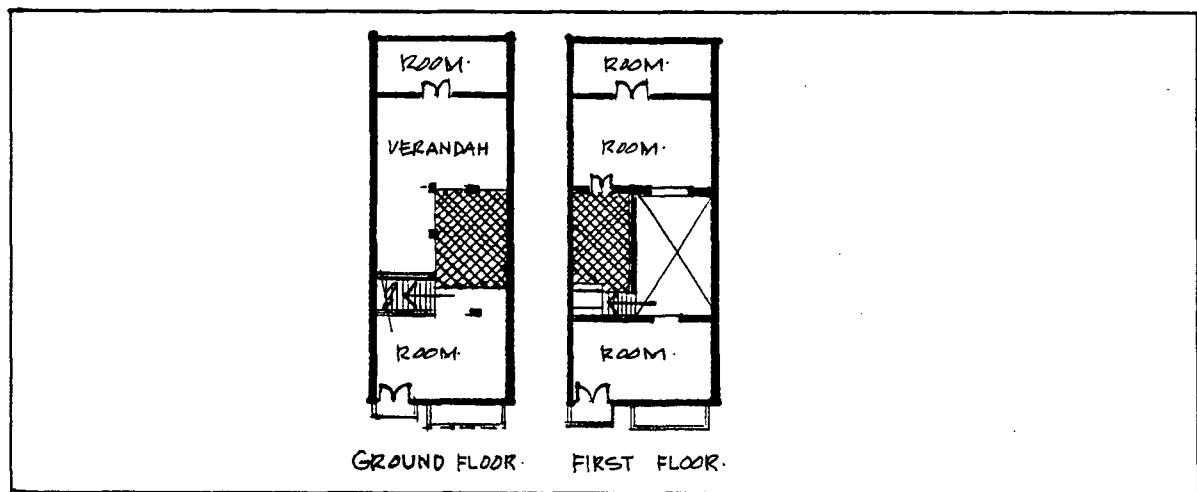


Fig.1.12. Plan of a Middle Income House in Jaisalmer.
Source: Gupta, 1985

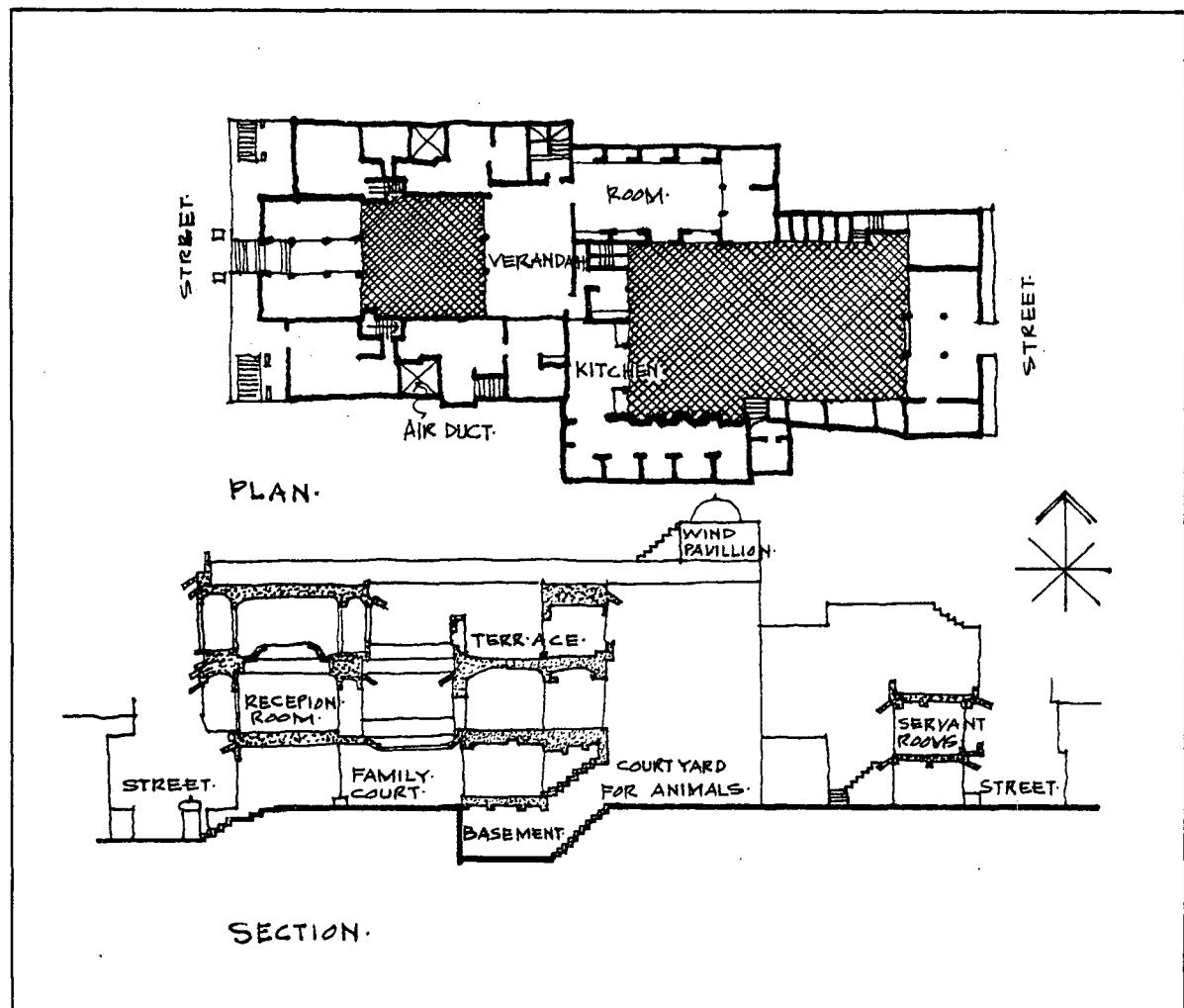


Fig.1.13. Plan and Section of a Haveli.
Source: Gupta, 1985

inside the fort. In these four or five storied houses, the courtyard was surrounded by rooms or verandahs on all sides. There were also underground rooms, sometimes on two levels, one below the other. The uppermost storey was comprised of terraces enclosed by wind pavillions and high parapet walls. In some cases, the house was built around two courts. In addition to courtyards, air ducts were sometimes used for ventilation.

Building Construction

The most common building materials used in Jaisalmer were light yellowish sandstone and limestone. The sandstone was used for walls which were 0.45m or more in thickness. In better quality construction the stone was dressed and joints were made accurately without any mortar. The individual stones were held together by stone keys cut into the blocks themselves, or by iron clamps. In the smaller houses the stone was undressed and the walls were built in mud mortar and finished with mud plaster.

On the upper floor levels of the "havelis", where the building facade projected out, 50mm thick panels of limestone projected from the wall as fins. These were deeply carved in various geometrical patterns. Both the limestone used for carving, and the sandstone used for masonry were light in colour and provided a permanent finish.

Roofs and floors were built with timber beams placed on the walls, spaced closely, and covered with a thick layer of grass matting and a thick layer (0.45 to 0.60m) of earth on top (Fig.1.14). Because of the limited availability of timber

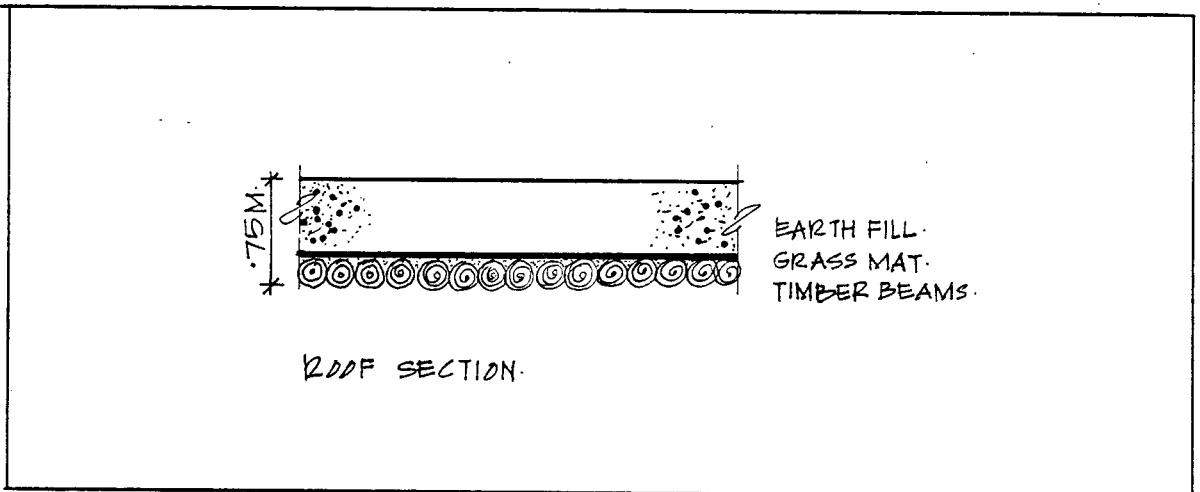


Fig.1.14. Construction of the roof of a Haveli.
Source: Gupta, 1985

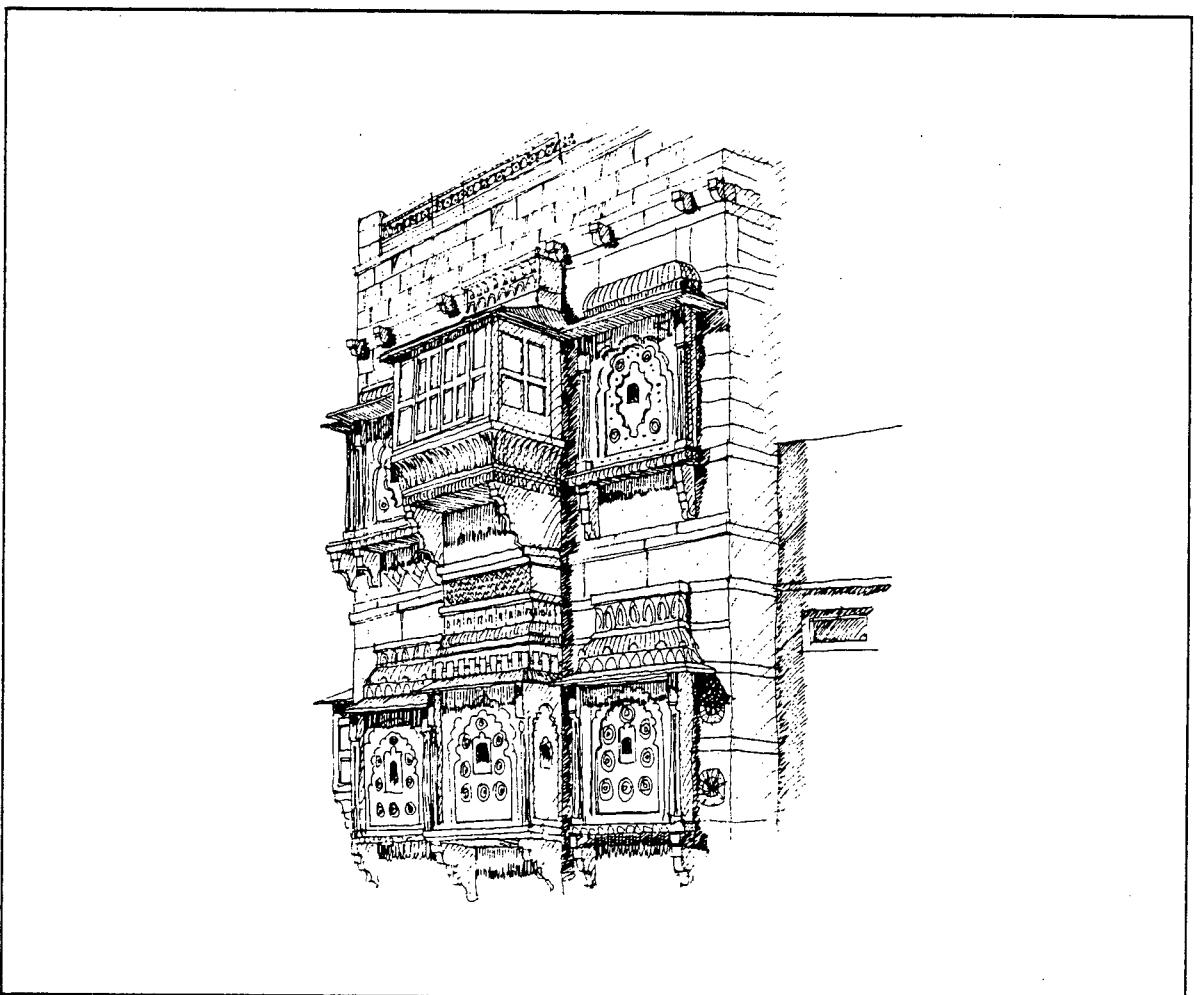


Fig.1.15. Structural Projections and Fins on the Upper Level Facade of a Haveli.
Source: Schoenauer, 1981

in the desert, in some houses the timber beams were replaced by stone slabs (this did not present a problem of water seepage as there was little rainfall).

Windows were generally small and fitted with solid timber shutters. Because of the need for privacy, the use of windows was limited to upper floors only. Doors were built with stone frames and also fitted with thick timber shutters.

In the houses described above, some of the design features to achieve cooling were the same as those discussed in the houses of Mohanjodaro; dense clustering of buildings, sun control through orientation, massive construction of walls and roofs, and the use of courtyards. However, additional design features introduced here to enhance cooling included:

- the use of structural projections to control sun,
- unequal building heights,
- cooling of sunlit surfaces by the use of fins and carving,
- air ducts for ventilation,
- basement living spaces.

2.6. Performance of Building Design Techniques

As the basic environmental problem in both Mohanjodaro and Jaisalmer was cooling, the thermal performance of common design techniques such as dense clustering of buildings, sun control through orientation, massive construction of roof and walls, and courtyards can be assumed to have been equally effective for both. Therefore, only the additional design features of Jaisalmer are examined in detail for their thermal performance and protection from wind and dust.

Use of Structural Projections, Unequal Heights, and Fins for Cooling

The structural projections and fins, unequal heights of

buildings, and carving on the front facade provided combined thermal protection to the buildings at three different levels:

- a. The unequal building heights, wind pavillions, and high parapet walls created an uneven skyline, and shaded each other in the process.
- b. The structural projections and fins shaded the upper level facade (Fig.1.15), which would otherwise receive intense solar radiation.
- c. Parts of the building facade and structural projections were deeply carved. When the solar radiation was intense, and the surface temperature was high, the convective heat transfer to the air from the carved surface was more than the flat surface due to a greater surface to volume ratio. This enabled the carved surfaces to cool down quickly when the ambient air temperature was low during the evenings (Gupta, V., 1985).

In Jaisalmer, carved surfaces were used at the upper level where wall thickness was between 5-15cm., whereas the ground floors had flat surfaces and wall thickness of greater than 45 cm. The ground floor walls were in shade during the day - time because of the narrow width of the streets in relation to the high buildings. The carved surfaces were useful only in thin walls as the thicker walls were capable of reducing heat gain even without texture because of their inherent thermal moderating characteristics.

In addition to carvings, the light colour of the stones absorbed less radiant heat (Markus and Morris, 1980) and therefore maintained the external surface temperature closer

to that of the outdoor air, which in turn reduced the heat flow through the relatively thin walls.

Air Ducts for Ventilation

When buildings are tightly clustered together it is generally difficult to let wind into the house through windows and doors, and air movement due to temperature differentials is usually too sluggish to improve comfort unless it is augmented by additional design features. In addition, there were two more important problems related to ventilation in Jaisalmer:

- a. The temperature of the outside air needed to be reduced before it entered any living space, or else its cooling effect on human skin was nullified due to its high temperature.
- b. Due to the dust storms in summer, the air had to be pre-treated to reduce its dust particle content.

In Jaisalmer air ducts were used as a special feature for ventilation in addition to the courtyards. The air ducts, built with massive stone walls, temper the air before it entered the living space and also reduced the amount of dust in it (Fig.1.16).

The operation of these air ducts was similar to that of the wind towers used in hot and arid regions like Iran (Bahadori, 1979). Figure 1.16 shows the cross section of a typical air duct. The circulation of air through night and day, and the reduction of dust particles in the air ducts took place in the following way:

Night Operation

When there was no wind blowing at night, the air ducts acted

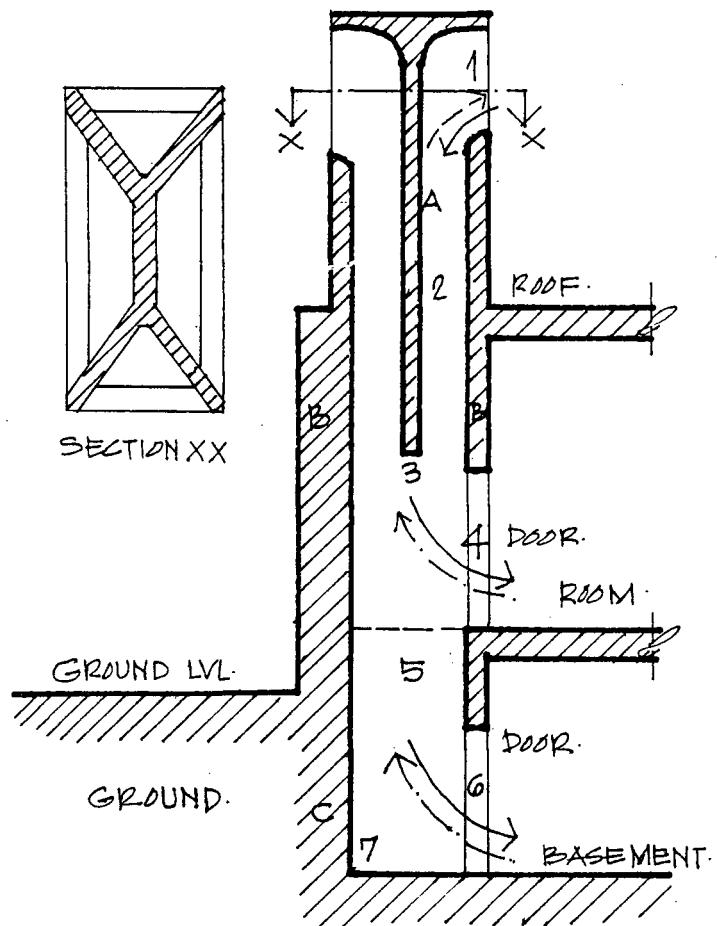


Fig.1.16. Operation of a Wind Tower in Summer. Air Flow during the Day, → ; Air Flow during the Night with no Wind, ←—.

Source: Bahadori, 1979.

as a chimney. The walls of the duct that were heated during the day transferred heat to the cool night air. The heated air was then exhausted at the openings (Fig.1.16). This chimney action maintained circulation of the ambient air throughout the building, and cooled the structure of the building as well as that of the air duct.

When there was a wind blowing during the night, the air circulation was in the direction opposite to that described, but the walls of the tower were cooled, and some cooling of the rooms might have resulted.

Day Operation

When there was no wind blowing during the day, the duct operated as a reverse chimney. The hot outside air in contact with cold walls (A) and (B) (cooled during the previous night) was cooled and sank down through passages (2) and (3). This air may be let out through door (4) or door (6) the dust particles of which have been left in area (7).

When there was a wind, the air circulation and the rate of cooling were increased and the cool air could reach further inside the house. When air went through section (5) and when wall (C) was moist, the air was further cooled by evaporation. The psychrometric chart presentation of ordinary and evaporative cooling processes through air ducts is shown in Figure 1.17.

Basement Living Spaces

Almost all houses in Jaisalmer had basements as living spaces. The temperature underground remained almost constant throughout the year due to the absence of any heat load, and

due to rapid decay of the ambient temperature wave in soil. Therefore, the rooms in the basement stayed much cooler than the upper floors of the buildings during summer.

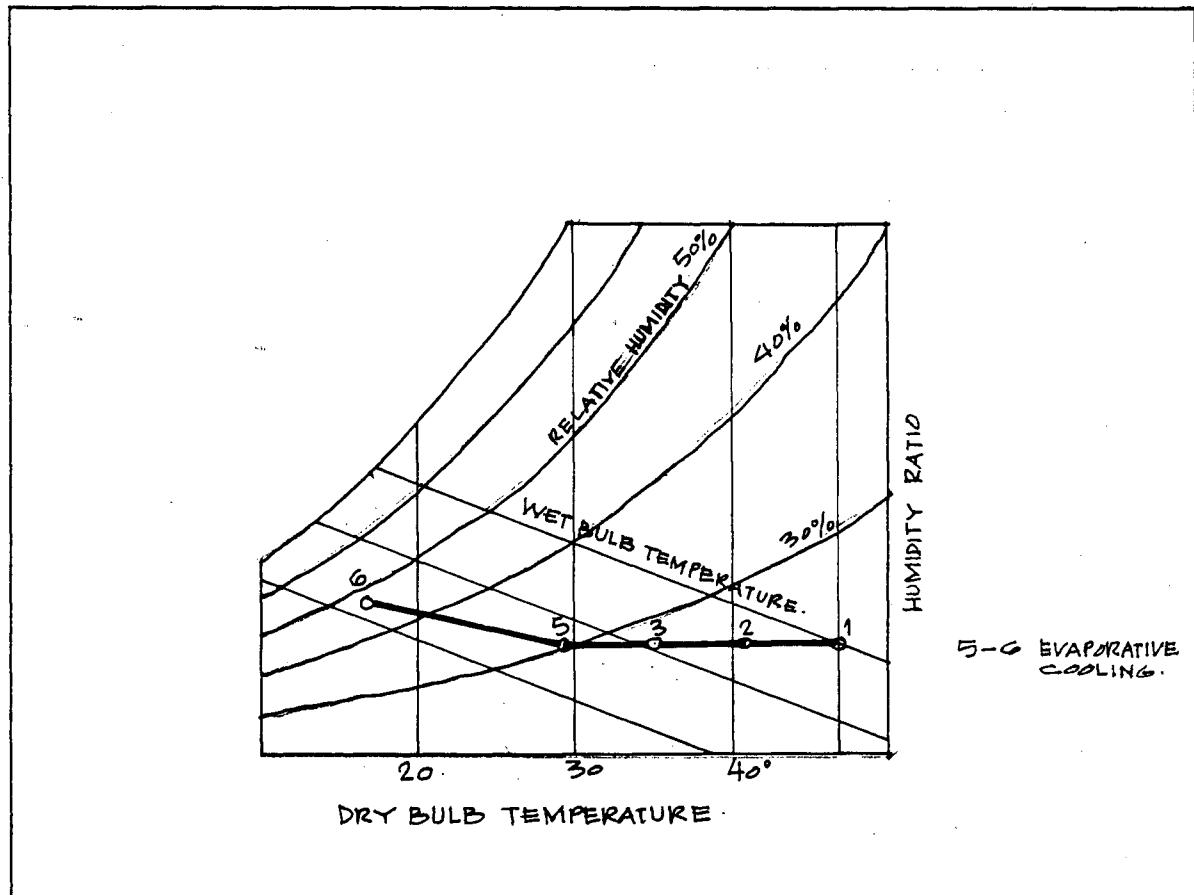


Fig.1.17. The Psychrometric Presentation of Cooling Process Through the Wind Tower. (Ref. Fig.1.16 for 1,2,3,5,6, locations).

Source: Bahadori, 1979

SECTION III: MODERN INDUSTRIAL PERIOD

1. INTRODUCTION

In India after World War II, the introduction of rapid transportation systems, the availability of building construction materials like concrete and steel, and the widespread use of electricity and fossil fuels brought about a significant change in the housing design and construction methods. The servicing of houses also changed dramatically with the introduction of electric lighting and modern cooling and heating systems. Following India's independence in 1947, political stability and rapid economic development resulted in significant urban sprawl and unlimited horizontal expansion of towns and residential neighbourhoods. This also brought an abundance of people to the urban areas requiring new planning criteria to solve the problem of housing. New and experimental cities like Chandigarh, Rourkela, Bhilai and Gandhinagar were designed and developed with 'modern' design principles and construction methods. The city of Chandigarh, located in the hot and dry zone, is discussed in the following sections to demonstrate the methods of achieving human comfort in dwellings during the modern industrial period.

2. HOUSING IN CHANDIGARH

2.1. Introduction

Chandigarh was built since 1951 as a capital city for the state of Punjab (Sarin, 1982), which lost its capital during the partition of India in 1947. The city was designed by a team of foreign architects headed by the French architect Le Corbusier.

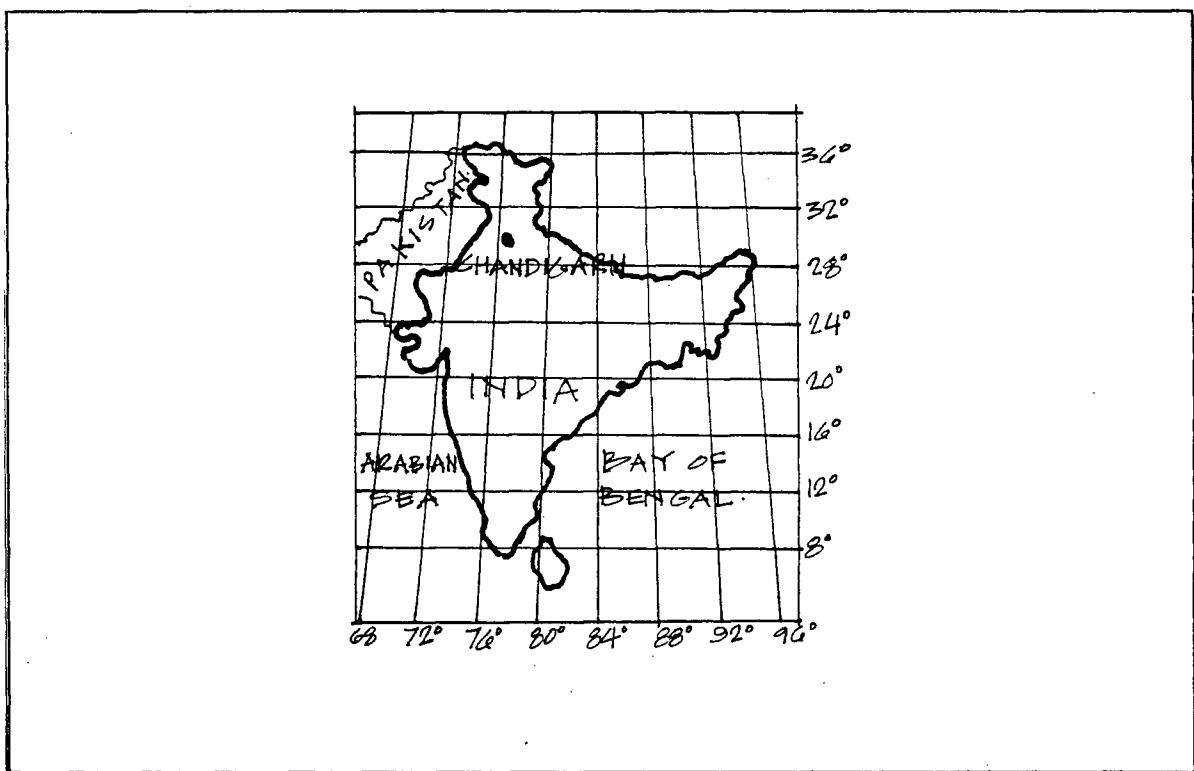


Fig.1.18. Location of Chandigarh.

2.2. Location and Climate

The city is located at $30^{\circ}43'N$ latitude and $76^{\circ}47'E$ longitude (Fig.1.18). The monthly air temperature, relative humidity and solar radiation on a horizontal surface (Fig.1.19) in Chandigarh are typical of the hot and dry zones.

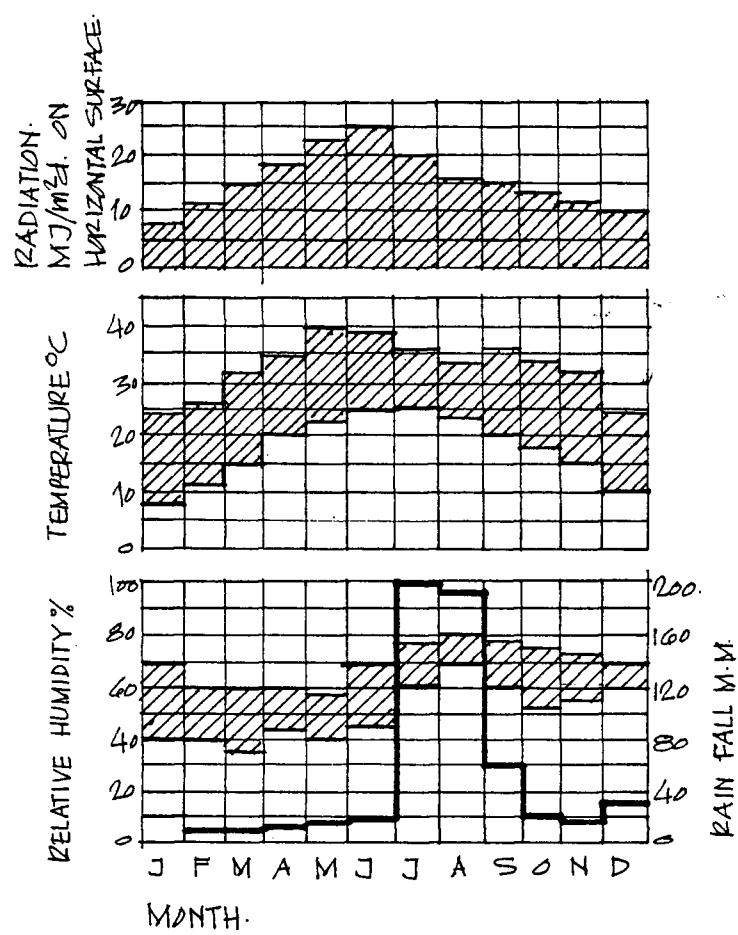


Fig.1.19. Climatic Data of Chandigarh (Monthly Means).
Source: Mani, 1982

The landscape of the surrounding area is flat towards the southwest with occasional trees and bushes. Hills and seasonal rivers form the northeast and southwest boundaries. The soil is clay and suitable for making bricks.

2.3. Indoor Comfort Criteria and Environmental Problems

Indoor Environmental Conditions

For the buildings of Chandigarh, the indoor thermal conditions and the need for cooling are similar to those in other hot dry climatic zones like Mohanjodaro or Jaisalmer as discussed in the previous sections.

Life Style

Chandigarh was designed after independence when India was beginning to go through social, technical and economic changes (Bhattacharya, 1979). The city was envisaged as a new experiment against the wide context of traditional city planning and house design in India. The inhabitants of the city were expected to adapt to a new 'urban' way of life. The house, as a part of a neighbourhood, was expected to provide a sense of the new social identity based upon the general similarity of income of the occupants rather than the traditional concept based on caste, language and religion (Evenson, 1966). The function of the house for providing shelter, protection from the extremes of climate, safe storage of goods and provision of privacy, was not envisaged in the traditional sense. Instead it was argued by the designers that the house should be a 'living machine' (Evenson, 1966) where all activities like cooking, eating and sleeping would take place in a efficient and systematic way.

The functional aspects of the house design were given more importance than the traditional socio-cultural needs for comfort. It was expected by the designers that the increasing use of energy intensive services like artificial lighting and cooling would help people in achieving required environmental conditions, therefore, all houses were provided with an electricity supply. The widespread use of electricity in Chandigarh houses has created new habits and comfort expectations. The occupants, instead of adapting their behavior to achieve comfort, now expect mechanical means to provide their comfort requirements.

Since the time when Chandigarh was built, various clothing styles and new cloth materials have developed in India and they change every year with new trends in fashion. The most popular cloth material worn by the middle class in Chandigarh is a blend of cotton and synthetic called 'tericot' which is relatively inexpensive, durable and can be worn without ironing, but inhibits evaporative cooling.

As the need for privacy was not emphasised in the housing design, thick curtains are used on window and door openings for the purpose of privacy. Although wooden doors and windows are provided in all rooms, they are not frequently operated by most people (Brolin, 1976). Terraces and verandahs are used for sleeping outdoors during summer. As expected by the planners, fans and other mechanical means are consistently used for cooling inside the house.

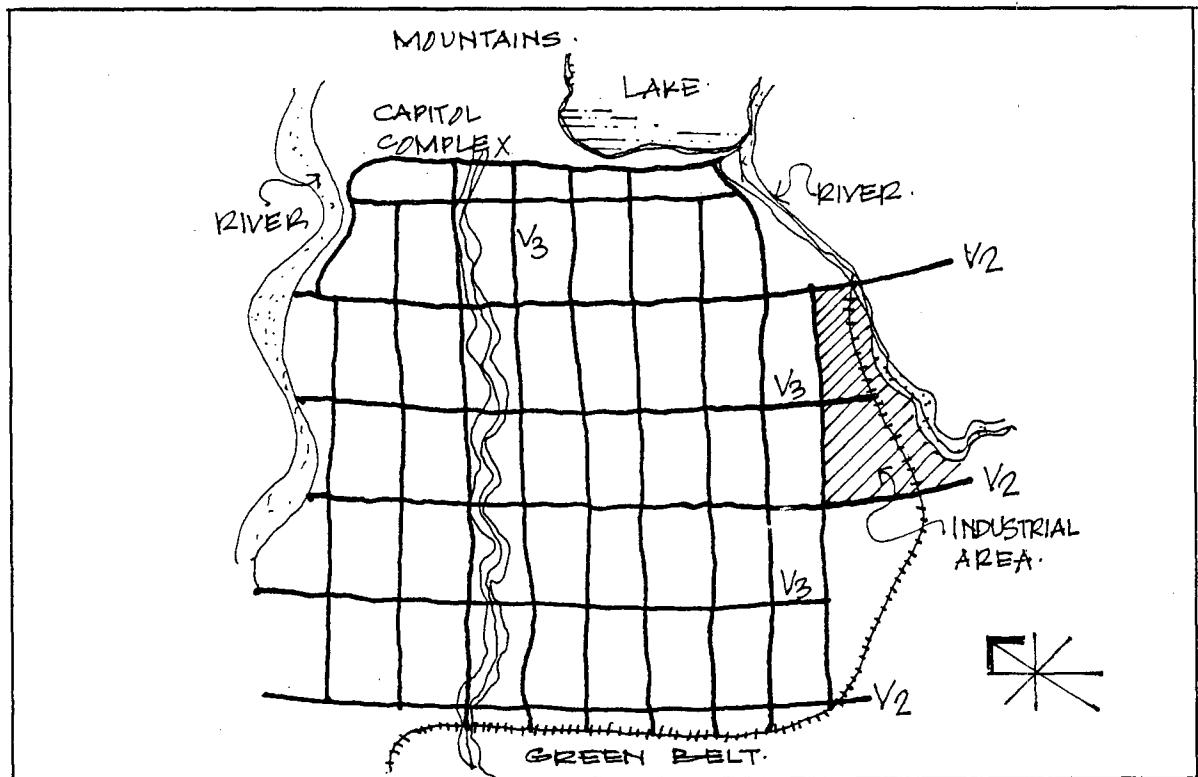


Fig.1.20. Layout of Roads in Chandigarh.
Source: Evenson, 1966

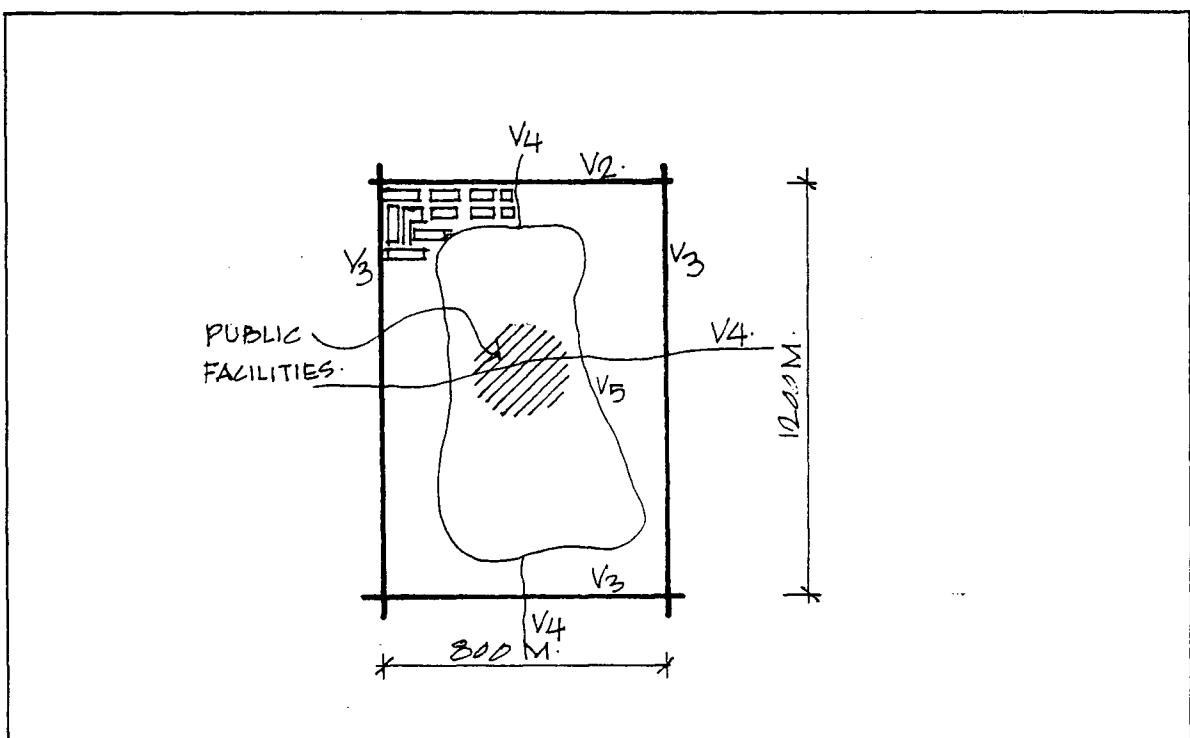


Fig.1.21. The Sector Layout.
Source: Evenson, 1966

2.4. Building Design Techniques

The City Layout

The City of Chandigarh is planned on a uniform grid pattern (Fig.1.20). All major streets called V2's run SE-NW to protect the vehicle drivers against direct sun, and secondary streets (V3's) run perpendicular to them. The total width of the V2 and V3 roads is 80 m and 60 m respectively with 9 m of road surface. The city is divided into various neighbourhoods called 'sectors' (Fig.1.21) each of which is 800x1200 m, and is surrounded by V2 and V3 roads. Each sector is subdivided by V4 roads into four parts with centrally placed shopping, community and recreational facilities. A 40 m wide loop road (V5) connects all parts of the sector. The houses face 30 m wide V6 roads and are oriented SE-NW or NE-SW. The height of residential blocks does not exceed three storeys (10 m) for structural reasons.

All sectors have a similar housing layout pattern. The zoning regulations and architectural controls prepared by planners and architects for standardization of construction and uniformity of residential expression, specify the size of projections on the facade for shading, the size of window and door openings, the size of back and front yards, the height of compound walls and the height of residential blocks.

The House Form

There are two categories of house owners in Chandigarh (Evenson, 1966):

- a. Government agencies (used by their employees)

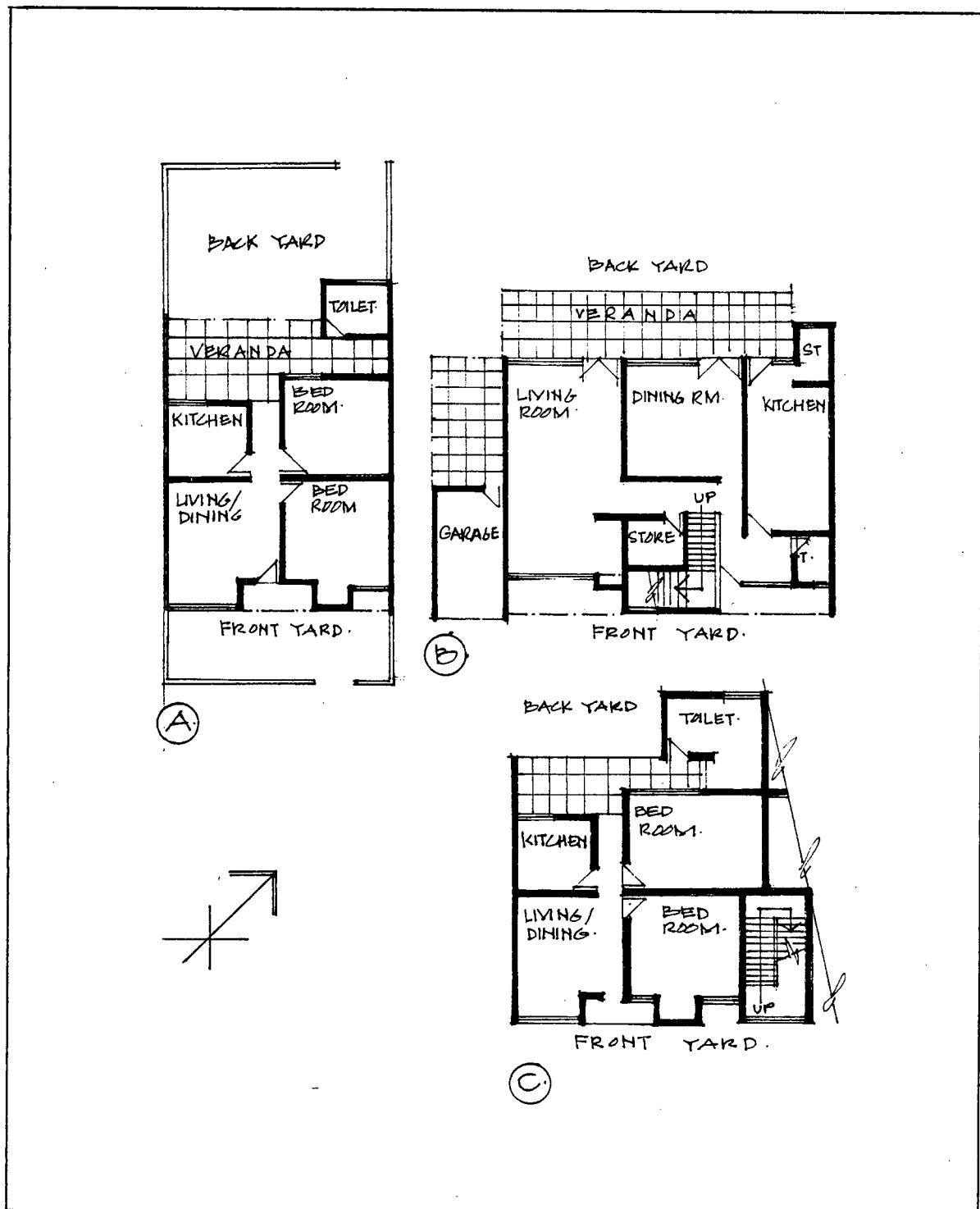


Fig.1.22. Government Housing in Chandigarh.

- Ground Floor Plan of Single Family Attached House.
 - Ground Floor Plan of Single Family Detached House.
 - Ground Floor Plan of Multiple Family Attached House.
- Source: Evenson, 1966

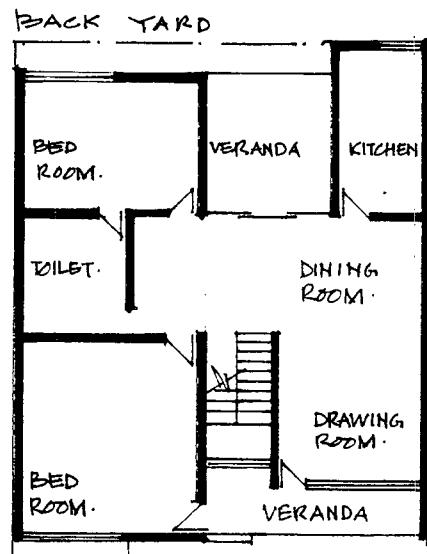
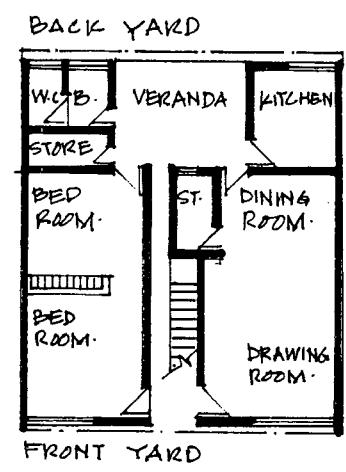


Fig.1.23. Private Housing in Chandigarh.

- a. Ground Floor Plan of a Single Family Attached House
- b. Ground Floor Plan of a Single Family Detached House.

Source: Evenson, 1966

b. Private homeowners.

Each category has two different types of houses (single family attached and single family detached) which are used by people of different income levels (Fig.1.22, 1.23).

The typical form of the single family detached houses (Fig.1.22b, 1.23b) is the 'bungalow' type. These houses are surrounded by open space on all sides and have window openings on two sides. The glazed window openings, as specified in the architectural controls, are 1/6th of the total area of the room and are protected by a brise soleil or deep veranda. Provision for terraces is made in all single family detached houses.

The single family attached houses (1.22a,c and 1.23a) share side walls and have yards in front and back. The compound wall in the rear yard is 2 m high for the purpose of privacy, and is .75 m high at the front. One bedroom and the livingroom face the front yard, and the kitchen, the toilet and bathrooms are kept at the rear for ease of connection to the main sewer lines. In some cases the toilets are attached to bedrooms and ventilated by ducts. All houses have flat roofs which are accessible for use as terraces.

Building Construction and Services

As brick was made locally, it became the principal material for construction of all houses in Chandigarh. The walls are constructed with 20x10x7.5 cm bricks and cement mortar. The external load bearing walls are 30 cm thick and are plastered and whitewashed on the inside. The internal load bearing

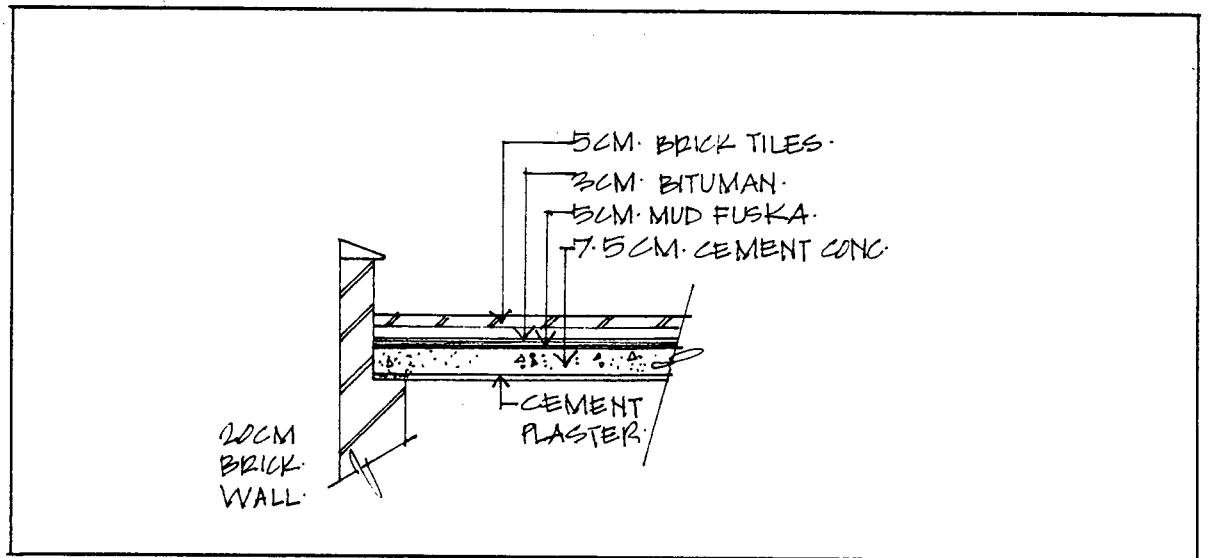


Fig.1.24. Typical Roof Section.

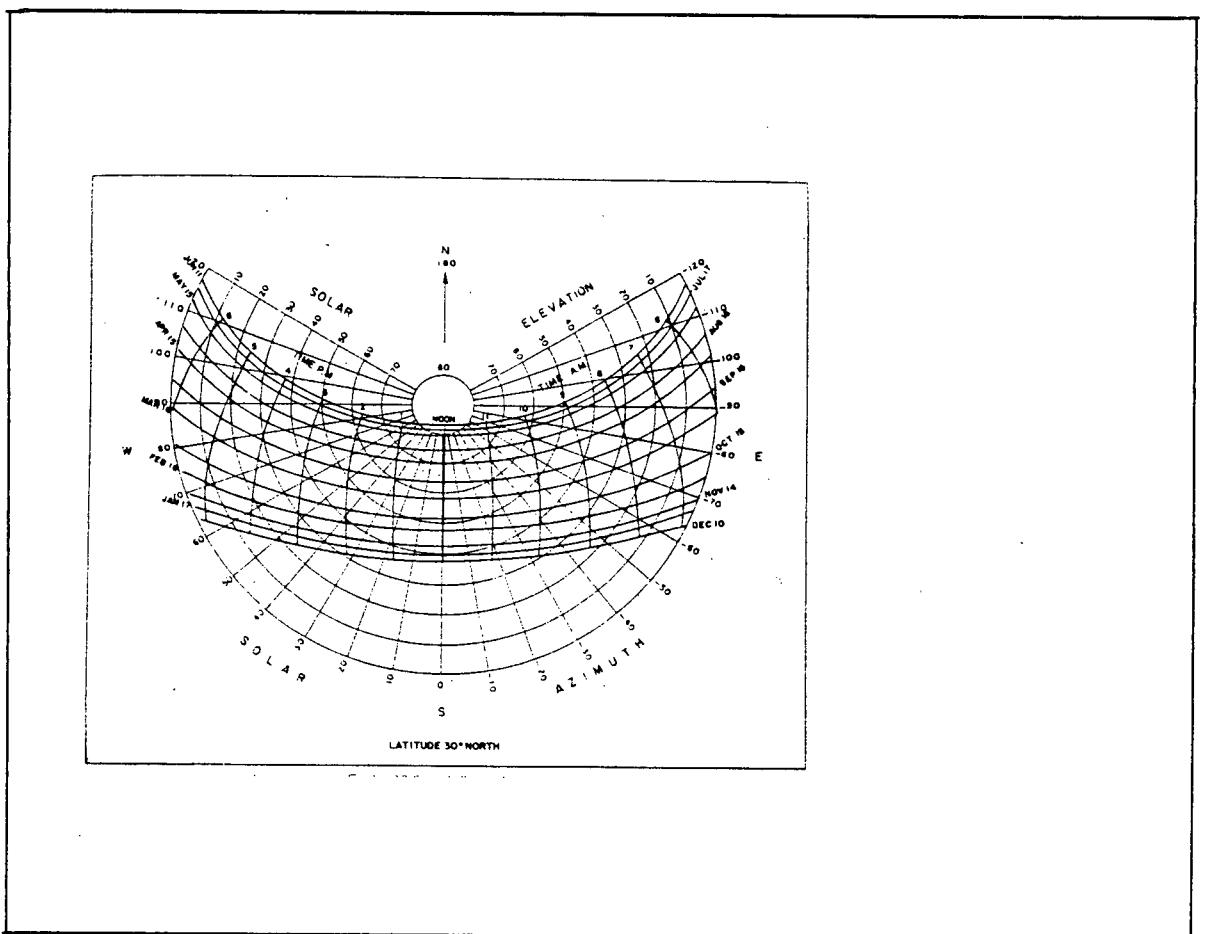


Fig.1.25. Sun Path Diagram for SE Facade.
Source: Mani, 1982

walls are 20cm. thick and are plastered and white washed on both sides. For roof construction (Fig.1.24), brick tiles of 20x10x5 cm are laid over 10 cm thick concrete, 5 cm mud fuska (mud and hay) and a 3 cm layer of bitumen. The thickness of the roof seldom exceeds 25 cm and is supported on the brick walls.

The door and window jambs are made out of locally available wood, and are fitted with openable, fixed glass and wiremesh panes. Fixed grills are added to all windows for the purpose of security. Shading devices like projections and brises soleil are of reinforced concrete.

The building features designed to provide cooling are:

- orientation,
- brise soleil and verandahs,
- roof construction with special materials.

In addition, artificial cooling devices like fans and evaporative coolers are commonly used.

2.5. Performance of Building Design techniques

Orientation/Use of brises-soleil and verandas

In the planning of Chandigarh, the orientation of dwellings combined with the use of a brise-soleil is the primary design feature through which some control over the sun is achieved. All the houses are oriented SE-NW or NE-SW. In a single family attached house (Fig.1.22a & 1.23a) oriented SE-NW, areas like the living room and bed room face SE and only two walls are exposed. The altitude of the sun in the summer months varies between 0° and 80° (Fig.1.25) so that the windows facing SE get solar radiation between 9 a.m. and 12

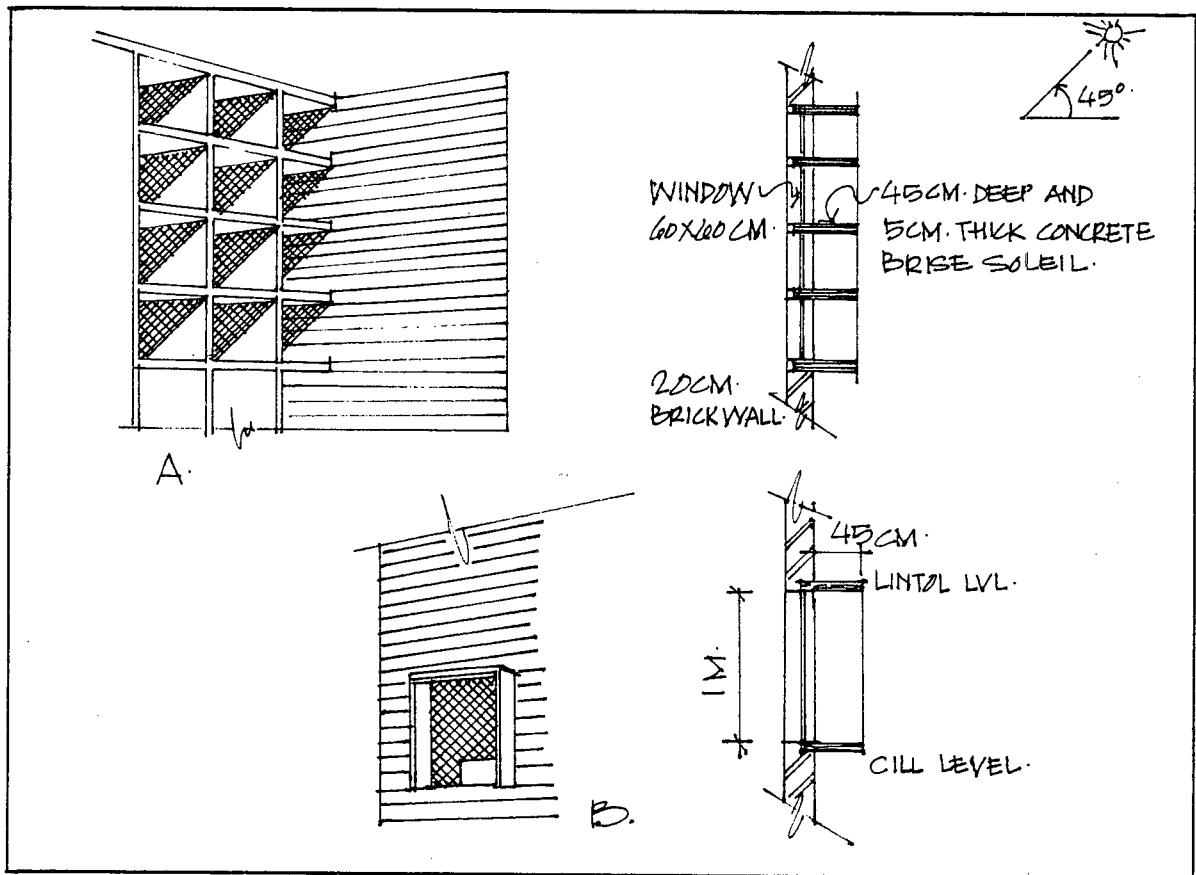


Fig.1.26. Shading Devices for Chandigarh Houses.

- Brise Soleil for SE and SW Facades in the Earlier Houses in Chandigarh.
- Horizontal and Vertical Projections for Solar Protection.

Source: Evenson, 1966

p.m. For this reason, all windows facing SE in the earlier houses of Chandigarh are kept small (45cmx45cm) and are protected with 45 cm deep brise soleil (Fig.1.26a). In the later houses the brise soleil is replaced, for the purpose of economy and unwanted obstruction of view, with one horizontal projection at the lintel level combined with vertical projections on both sides of the comparatively larger window openings (Fig.1.26b). This provides protection from the sun between 10 a.m. and 12 p.m. when the altitude angle varies between 60° and 80° and the solar intensity is high.

In addition, thick curtains are used for windows and doors to obstruct direct solar radiation. However, curtains are not effective ways of solar control as they absorb the solar heat and dissipate it to the interior by convection and radiation. Half of this re-radiation is outwards, but as it is of long-wavelength, it is stopped by the window glass and the narrow space between the window and the curtain is substantially overheated.

The sun penetrates the NW facade after 2.30 p.m. when its altitude is below 45° . Solar heat gain on this side is particularly uncomfortable as its maximum intensity coincides with the hottest part of the day. To prevent the sun from penetrating inside, very deep horizontal projections are required for the windows. Therefore a 3 m deep veranda is provided in front of the bed rooms in this orientation.

Roof Construction with Special Materials

The use of special materials like bitumen and mud-fuska,

because of their thermo-physical properties, provides thermal insulation for the roof. Mud-fuska and bitumen are placed above the structural concrete layer (Ref. Fig.1.24) which reduces the amount of heat penetration into this layer during the daytime. The heat which does penetrate is absorbed in the 10 cm mass of concrete and the resulting increase in internal temperature is small.

In addition to the special materials, the terraces are used frequently during summer and are washed or sprayed with water almost every day which helps in reducing the external surface temperature well below the air temperature through evaporative cooling.

Use of mechanical cooling

Inspite of the climate responsive performance of some building design features, there are various factors which necessitate the mechanical control of thermal conditions inside the dwellings in Chandigarh:

- a. Planning the city of Chandigarh with standardized facades, building heights and wide roads was detrimental with respect to natural cooling. Standardization created equal building heights in residential sectors and regular facades which, combined with wide roads, did not take advantage of mutual shading for cooling as used in the cities in pre-historic and medieval times
- b. Selective ventilation (i.e. ventilation only during the cooler periods of the day), if used, can help in lowering the indoor temperature during the day in summer. However, the windows in Chandigarh houses are normally open

throughout the day, with the result that the internal air temperature rises considerably.

- c. Heat generated by certain appliances and the occupants themselves raises the indoor air temperature.
- d. Personal adaptations to thermal comfort through clothing are also not very effective because of the material properties of the popular cotton/synthetic blends.

To achieve thermal comfort under these conditions, the use of evaporative coolers and air circulating fans is necessary.

It was observed in Chandigarh that simple and cheap air circulating fans are acceptable during the periods when the air temperature is below 32°C. At higher temperatures the use of fans enhances overheating due to circulation of warm air.

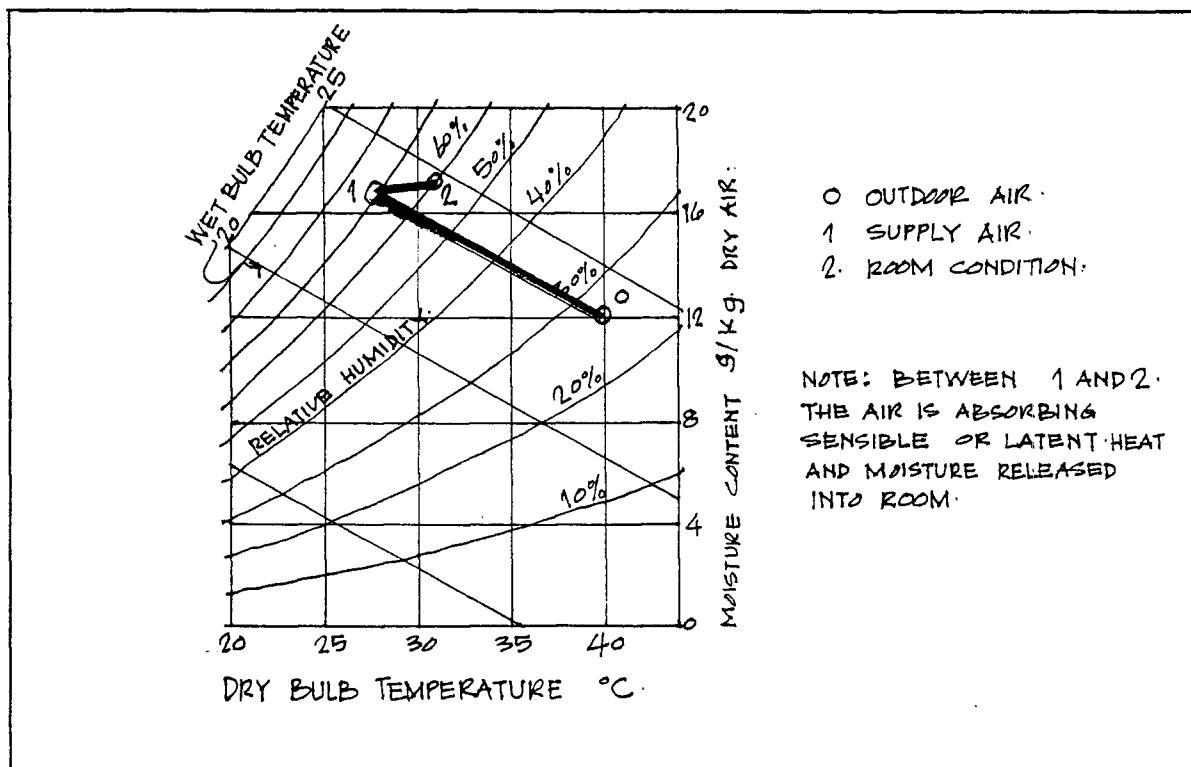


Fig.1.27. The Psychrometric Presentation of Cooling Through Evaporative Coolers.

Evaporative coolers with a blower, although relatively expensive, both cool the air and provide a desired level of relative humidity, thus contributing considerably to physical comfort in hot, dry weather (Fig.1.27).

In recent times, however, sporadic electricity shortages and high energy costs have discouraged the reliance on and use of these mechanical methods.

Unfortunately, inspite of these sorts of unforeseen problems, the Chandigarh example was used extensively as a model for future housing developments in India. Akhtar Chauhan (1986) points out the many negative repercussions that resulted from the extensive use of Chandigarh planning:

"The tragedy of Chandigarh was that instead of evaluating it as an experiment, our technocrats and bureaucrats accepted it as a prototype for future developments. Le Corbusier himself was a great student of vernacular architecture and he did a lot to develop a scientific and artistic approach to the housing problem. But in our rush to cope with the fast growth of cities, most of us blindly accepted the forms of European functional architecture. This resulted in the mushrooming of boxes, piled up vertically and horizontally as answers to the housing crisis. This approach produced dwellings which were expensive to construct, consumed more energy, were indifferent to climate and non-responsive to user needs."

SECTION IV: CONCLUSIONS AND CONTEMPORARY ISSUES

Prior to the introduction of mechanical means, comfort in domestic buildings was achieved by climate responsive or "passive" design techniques.

They were not based on a deliberate pre-planned concept or a scientific knowledge of the behavior of climate, building materials and building components. Instead they were a result of hundreds of years of actual experimentation within the harsh physical context of limited natural resources and economic, political, cultural and physical constraints. This is the reason why they performed effectively in providing comfort and were repeatedly used.

The passive design techniques, through which thermal comfort in domestic buildings were achieved, were a combination of layout, form, orientation, openings, walls, roof and landscaping. This design oriented technology was effective in bringing the internal thermal conditions within the comfort range by shaping the building to modify or utilize the climatic conditions. For example, building form minimized the exposure of wall surfaces and windows to sun and reduced solar heat gain. The courtyards acted as thermal modulators, wind towers enhanced the movement of air indoors and the massive brick walls were a good example of structures which moderated outdoor temperature into reasonable indoor temperatures. In addition to thermal comfort, the passive techniques also

provided many other social, economic and architectural benefits which can be of particular interest to the architects designing housing in a contemporary context. For example, the compact layout of dwellings in hot and dry climates allowed a high density which is necessary in India today (Sengupta, 1986).

Furthermore, the use of indigenous materials and a simple construction technology developed by the local people themselves ensured minimal material and labour costs. Additionally, the houses required minimal maintenance, other than whitewashing of the interiors once or twice a year. The end of this type of construction occurred as a result of the availability of high technology alternatives triggered by sudden industrialization. The use of expensive materials like concrete and steel in building construction now requires specialized labour, advanced construction methods and additional transportation which have resulted in a high cost of construction. The use of elaborate mechanical systems to cool the spaces also requires an additional maintenance and repair cost and specialized technicians.

In addition, the traditional dwellings were very well suited to the user's physical and psychological needs due to participation of the user in design and construction. This participation process has declined in contemporary dwellings, especially in mass scale housing projects developed by private and government agencies. The houses are designed and constructed by a single owner and then bought or occupied by

the users. Many times this practice results in a design which is ill-suited to user needs.

Finally, the use of passive design technology and the life style of the occupants, formed traditional behavioral habits in the people. For example, activity occurred outdoors in the evening, where the temperature is cooler and comfort is provided by the natural breeze. Natural fibres in clothing were used to enhance thermal comfort.

The minimum reliance on passive design technology, coupled with a changing lifestyle of people has contributed to exclusion of these adaptations. In addition to the basic comfort requirements, occupants now desire their dwellings to have thermal controls which can be regulated by them.

Although the mechanical controls help in finetuning the occupant comfort and electricity is a widely available item, the sporadic electricity shortages during the peak hours of summer days depreciate the benefits of mechanical cooling systems.

All these architectural, economic and social ill-effects associated with mechanical systems, in addition to the cost of energy and its limited supply, suggest that their widespread use is unsuitable, expensive and unreliable in countries like India. The mechanical means have therefore become a liability rather than an asset.

In conclusion, a simple and most effective way of reducing the ill-effects of reliance on mechanical devices is to minimize their use by incorporating passive design

technology in dwellings. This does not imply that mechanical cooling or heating should be eliminated, however less reliance on it will be necessary if more emphasis is placed on passive design technology.

The remainder part of this thesis explores ways of systematically and consciously incorporating tried and tested passive design techniques in contemporary dwellings.

PART TWO: HOUSING DESIGN STRATEGIES

INTRODUCTION

SECTION I: SITE SELECTION STRATEGIES

SECTION II: SITE PLANNING STRATEGIES

SECTION III: FORM DESIGN STRATEGIES

SECTION IV: FABRIC DESIGN STRATEGIES

INTRODUCTION

Part two of this thesis focuses on developing passive design strategies for housing in the hot and dry regions of India. These strategies can be used for a contemporary housing settlement, involving larger site development, or for a single dwelling on an isolated lot within or outside the inhabited area.

The most important objectives underlying these strategies are;

- a. to achieve thermal comfort inside the dwellings with the application of passive design techniques and,
- b. to incorporate, wherever possible, traditional passive techniques into a contemporary context. This does not mean a literal translation but an interpretation of basic principles.

These objectives will be accomplished with;

- a. an emphasis on the application of local construction practices, materials and techniques,
- b. the incorporation of cultural and behavioral aspects of occupants, and
- c. the integration of artificial systems to finetune occupant comfort.

As observed in dwellings in various periods of history, passive means are most accepted and economical if local building construction practices, materials and techniques are

used. The incorporation of the cultural and behavioral aspects of people is particularly important in the design of dwellings in hot and dry regions. As the climate is harsh, the occupants spend a substantial part of day "trapped" inside the dwelling and any failure of the house to meet social and cultural needs is felt more significantly. To enhance occupant comfort and to meet modern standards of livability including convenience and health, the inclusion of artificial systems is inevitable. However, in order to use artificial systems beneficially, an understanding of their design and installation in the building system is required by the architects.

The general strategies selected for achieving thermal comfort with the help of passive techniques in the hot and dry climate are:

- Minimize solar gain,
- Minimize conductive heat flow,
- Promote ventilation,
- Minimize internal heat gains,
- Promote radiant cooling,
- Delay periodic heat flow,
- Promote evaporative cooling,
- Control high velocity wind and dust and,
- Control glare.

These strategies are examined in detail in the following specific levels of design:

1. The first level of the design strategies deals with site selection. Site climate is examined with the aim of utilizing the favourable and minimizing the unfavourable elements of climate on the future buildings on a selected site.

2. The next level of strategies is concerned with modifying the effect of undesirable external climatic elements with the help of site planning. The potential for street layout, open spaces and landscaping are examined in creating an effective microclimate.
3. The third level of design strategies is concerned with dwelling form. These emphasize the role of building volume, shape and configuration in modifying or selecting the elements of exterior climate.
4. The fourth and final level involves considering walls, windows, roof, building materials and their thermal properties in modifying the effect of external climate on the internal thermal conditions.

As the basic objective throughout is to assist in achieving thermal comfort, it should be understood that:

- a. the strategies at each level are inter-related and thus there may be an overlapping of strategies across different levels.
- b. to make maximum use of the strategies, a designer should be consistent in following them at each level of design. It is because if the strategies are not followed at any one level it would require an additional emphasis at the next level as a means of compensation.
- c. the strategies at various levels may become contradictory as design solutions. For example, a design solution for promoting air flow may contradict the control of solar heat gain. It is the responsibility of the architect to determine which strategy is more

important in this case and to emphasize and resolve them in that order.

d. the strategies are intended to be applied at the specific level of design and under the circumstances mentioned with them. For example, the strategies for reducing internal heat gain do not apply at the site planning level. Similarly the strategies at the site selection level can not be applied in the absence of specified topographical features.

Although developed specifically for the context of the hot and dry regions in India, the strategies for passive means of achieving thermal comfort should not be used as a simple set of rules or as a checklist. These strategies should be used instead as a set of basic principles.

In the process of housing design, an architect has to satisfy the social, functional and aesthetic needs of the occupants by dealing with many forces, both economic and technological, besides those of climate. In 'The Timeless way of Building' (1979), Christopher Alexander proposed that one of the central qualities of beautiful architecture is that all of these needs and forces are resolved. Therefore, the strategies presented in the following sections should be treated as a part of the wider context of housing design but not the complete design, with the understanding that their integration will produce a richer architecture.

SECTION I: SITE SELECTION STRATEGIES

1. INTRODUCTION
2. SITE CLIMATE
3. THERMAL COMFORT CRITERIA
4. MINIMIZE SOLAR GAIN
 - 4.1. Slope Orientation and Gradient
 - 4.2. Existing Vegetation and Topography
5. PROMOTE AIR FLOW
 - 5.1. Site Altitude
 - 5.2. Proximity to Water Bodies

1. INTRODUCTION

Although many factors usually dominate the choice of building site, to achieve thermal comfort, an important concern of designers is the immediate external climate which surrounds and penetrates the dwelling through openings, and by heat transfer through walls and roof (Fig.2.1). The internal thermal environment surrounding the occupants results from the immediate external climate (Markus & Morris, 1980). For occupant thermal comfort the impact of external climate on the internal environment can be both favourable and unfavourable depending upon the month and time of day. A

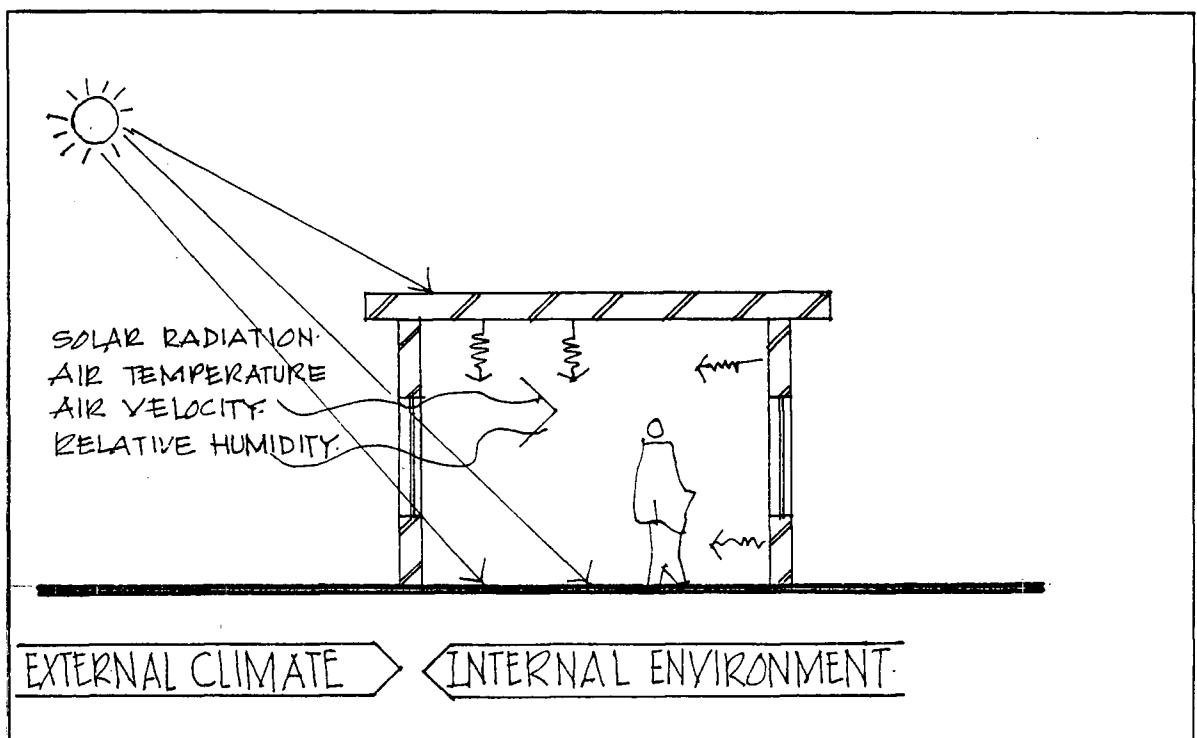


Fig.2.1. The elements of External Climate and the Resulting Internal Environment Influencing Occupant Thermal Comfort.

primary concern of designers, therefore, is to utilize the favourable and minimize the unfavourable impacts of external climate. In order to understand how the particulars of external climate will relate to the internal environment and building design, it is important to first understand the site climate and comfort criteria for the occupants.

2. SITE CLIMATE

The term site climate or microclimate is used here to denote the climate of the housing site. In order to understand the site climate, a designer must first obtain local climatic data.

Climatic information such as solar radiation, air temperature, wind velocity and precipitation for various locations in India is reported in Mani & Rangarajan (1982). Solar radiation data is published for 145 locations and consists of tables of global, diffuse and direct solar radiation on horizontal and sloped surfaces on mean monthly and hourly basis. It also includes sun path diagrams for latitudes 6°N to 36°N and a brief description of the cloud cover of India. Although a large part of the information in this work is on solar radiation, monthly and in some cases hourly mean values of other climatic characteristics for 105 locations in India have also been covered. This is the most extensive collection of compiled information on climatic characteristics at various locations in India to date.

Although the local climatic data provides information which may be a useful guide to the climate for that location, conditions can vary within a short distance, from one site to

another, or even within each site with differences in site altitude, slope, orientation, surrounding buildings and existing vegetation (Golany, 1980).

It is often not realistic for an architect to gather information about microclimate by direct measurement, especially on sites for smaller housing schemes. Even for larger projects an architect is seldom given an opportunity to carry out site observations and measurements for any length of time. A realistic approach in most projects is, therefore, to start with published local climate data on mean monthly or hourly basis and predict the likely deviations. A visual inspection of the site or use of survey maps can help in predicting the variation of climatic characteristics if the designer is aware of some general rules about their behaviour with the variation in topography (the one's applicable to hot and dry region are discussed in site selection strategies). This approach towards analyzing site climate is very crude, but in addition to the time constraint for architects, the collection and examination of extensive data on site climate will also tend to be confusing as the designer is only interested in climatic data useful for the particular project (Cole, 1979). A visual inspection or a site visit is beneficial in all cases as it gives the architect an opportunity to examine the relative importance and interplay of the climatic elements which may not be noticeable from the raw climatic data.

3. THERMAL COMFORT CRITERIA

The thermal comfort criteria is influenced by the internal thermal environment and the activity and clothing of occupants. The bio-climatic chart (Fig.2.2) shows an air temperature, humidity and air velocity range within which occupants with certain type of clothing and activity will feel comfortable. The fine tuning of comfort for each occupant can only be achieved by making personal adaptations of clothing and activity level or with the use of mechanical means. However, the climatic characteristics suggest that the most important general thermal comfort criteria for dwellings in hot and dry region require a reduction in heat gain and promotion of heat losses. This can be achieved by:

- minimizing solar gain,
- minimizing conductive heat flow,
- promoting ventilation,
- promoting radiant cooling,
- promoting evaporative cooling, and
- delaying periodic heat flow

With these general strategies in mind an architect can develop specific design strategies at each level.

The site selection strategies in the following sections are derived from general rules about the behaviour of climate in the presence of those topographical features which are commonly found in hot and dry regions. The extent of climatic deviations due to these features and their effect on site selection is explained in these strategies. The effect of site slope, altitude and waterbodies etc. on air temperature, humidity, wind speed and solar radiation is dealt with

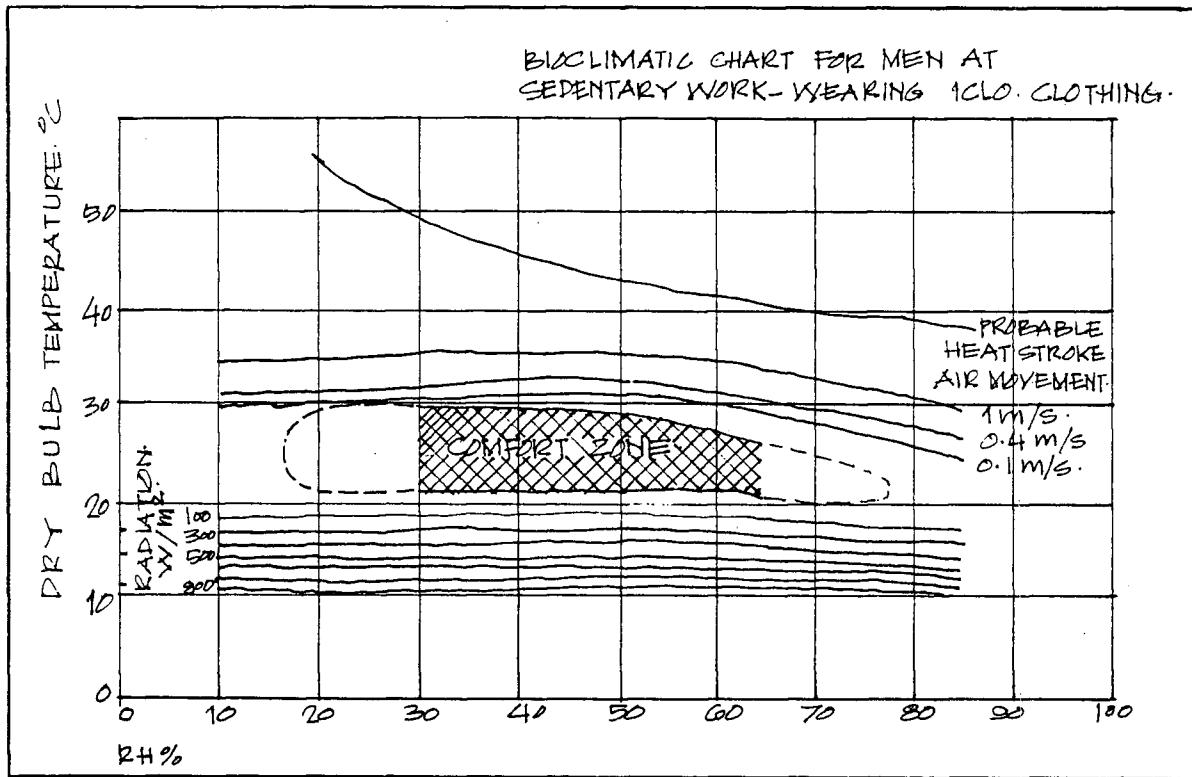


Fig.2.2. Bio-climatic Chart for Hot and Dry Climate.

Source: Koenigsberger, 1973

individually in the following sections as the aim here is to develop strategies which can be used in various situations. Therefore, the strategies discussed here are also presented in order of priority.

4. MINIMIZE SOLAR GAIN

4.1. Slope Orientation and Gradient

The direction and inclination of slope can influence the site climate significantly by regulating the amount of solar radiation received by the ground surface. This will increase or decrease the temperature of air coming in contact with the

ground. For instance, at latitude 25°N , in the months of May and June, the altitude of the sun varies between 0° to 80° from morning to noon and sun path from sunrise to sunset is a full 240° (Fig.2.3). The east, west, and north facing inclined surfaces receive more solar radiation than south. Therefore, to achieve maximum cooling in summer months, sites on northern, eastern and western slopes should be avoided. However, east facing slopes are better suited than west facing slopes, since the former tend to be cooler on summer evenings.

In order to evaluate the effect of site slopes on the mean monthly radiation, the degree of inclination of the slopes is an important factor (Mani & Rangarajan, 1982). A surface that is perpendicular to the direction of the sun (Fig.2.4) receives the maximum radiation. Therefore, given a choice of selecting a site on south oriented slopes with various inclinations, the slope inclination which faces sun at an obtuse angle rather than at right angle should be selected.

4.2. Existing Vegetation and Topography

A site with existing vegetation and topography will create shade and thus reduce solar radiation and air temperature. For instance, presence of a mound on the west side can block evening summer sun (Fig.2.5). Shade can reduce the air temperature by $8\text{-}10^{\circ}\text{C}$ (Watson, 1983) in summer.

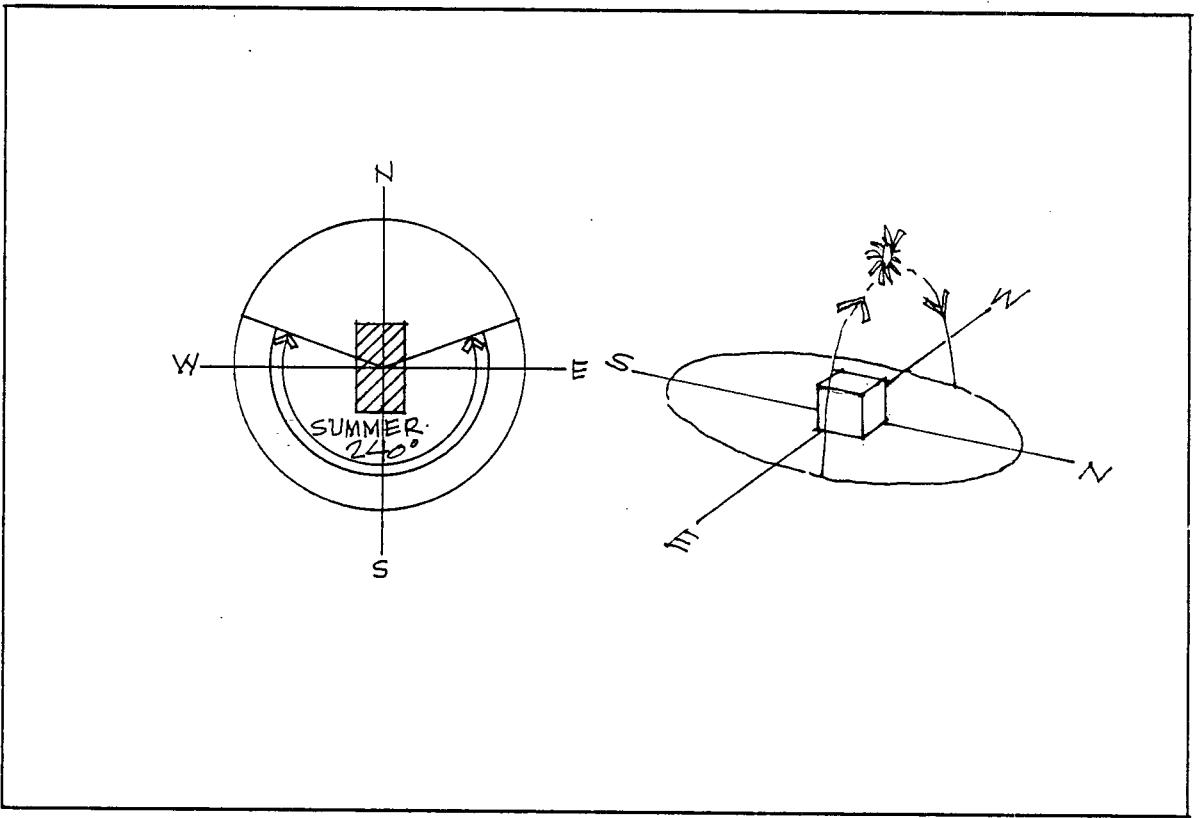


Fig.2.3. Summer Sun Path at Latitude 25°N

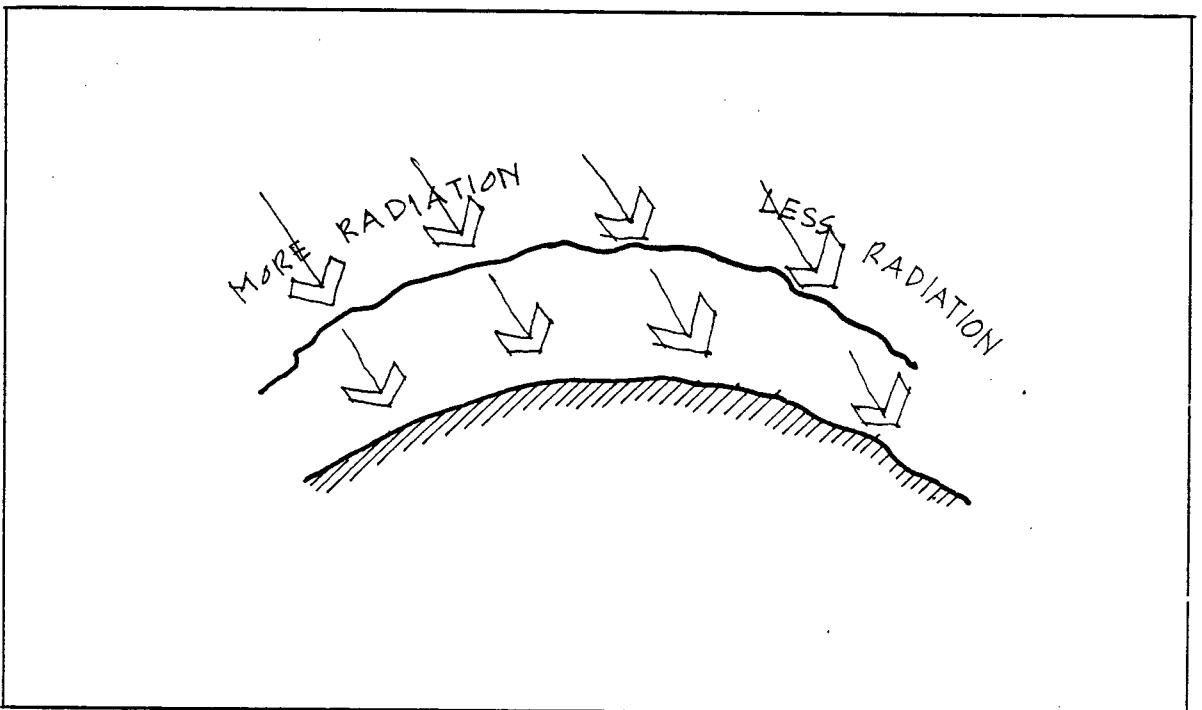


Fig.2.4. The Surfaces Perpendicular to the Direction of Sun Receive More Radiation.

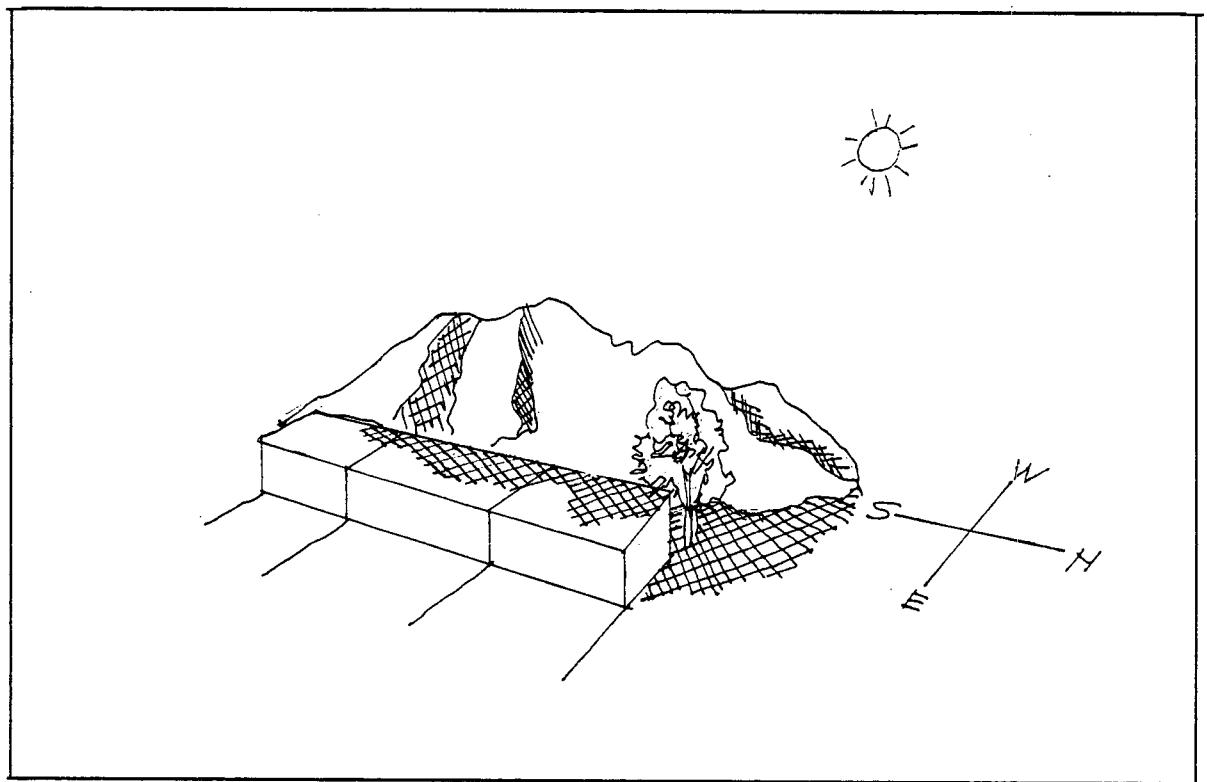


Fig.2.5. A Mound or Tree in the West will Reduce few Hours of Solar Radiation on the Dwelling Structure.

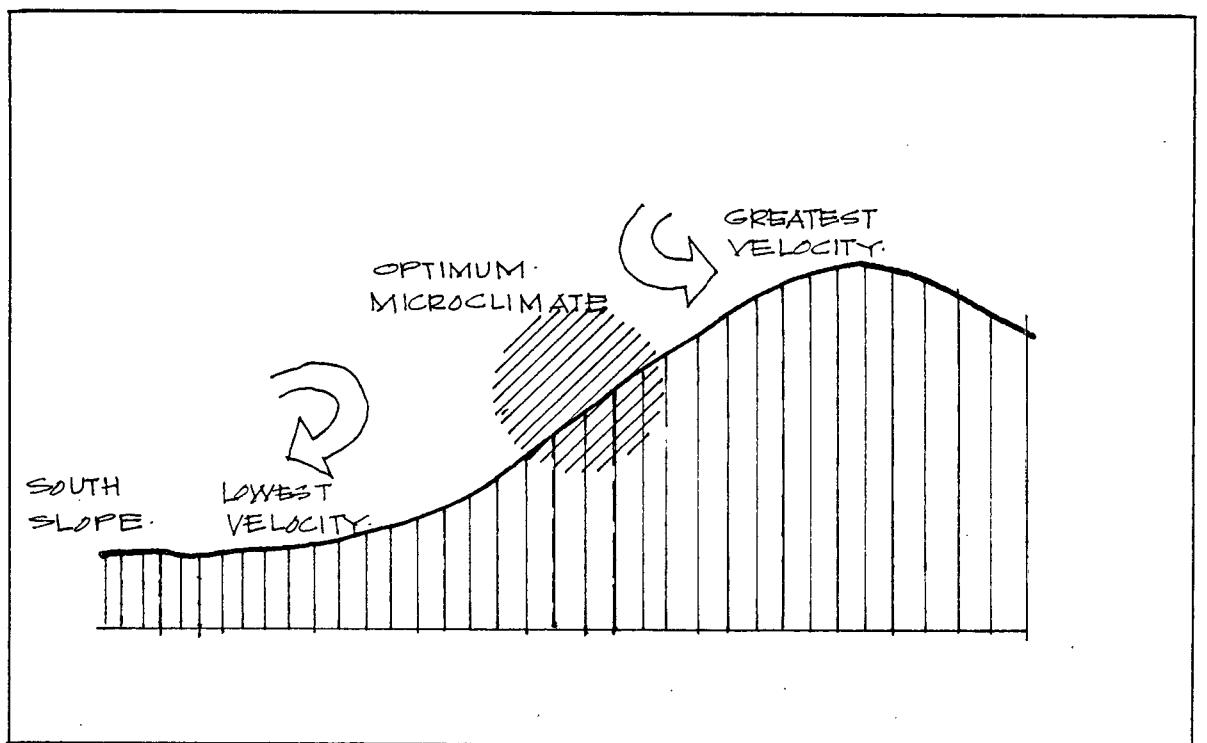


Fig.2.6. Suggested Location of Houses on a Sloped Site.

5. PROMOTE VENTILATION

5.1. Site Altitude

For promoting air flow in a building, site altitude is an important consideration as it affects summer air velocity and temperature. For every 100m of slope elevation, the wind increases or decreases the temperature by 1°C (Golany, 1980). The highest wind velocity on a hill is in the area just below the crest. The lowest velocity is at the bottom and in the wind shadow (Olgyay, 1963). Therefore, the optimum microclimate will usually be below the middle but above the foot of a slope. Sites selected in this area will benefit from cool air movements in early evening and warm air movements in early morning (Fig.2.6).

Valley bottoms experience the maximum temperatures on summer days (Geiger, 1950) while sites above the valley tend to be cooler. Thus, it is desirable to avoid the valley bottom sites and select the sites above (Fig.2.7).

A raised embankment, wall or impermeable hedge on the lower side of a sloped site can block the cooler air which flows slowly down the slope (Fig.2.8). It would, of course, be desirable to provide a gate or deciduous hedges so that the flow of air is maintained during the colder parts of the year (Konya, 1980).

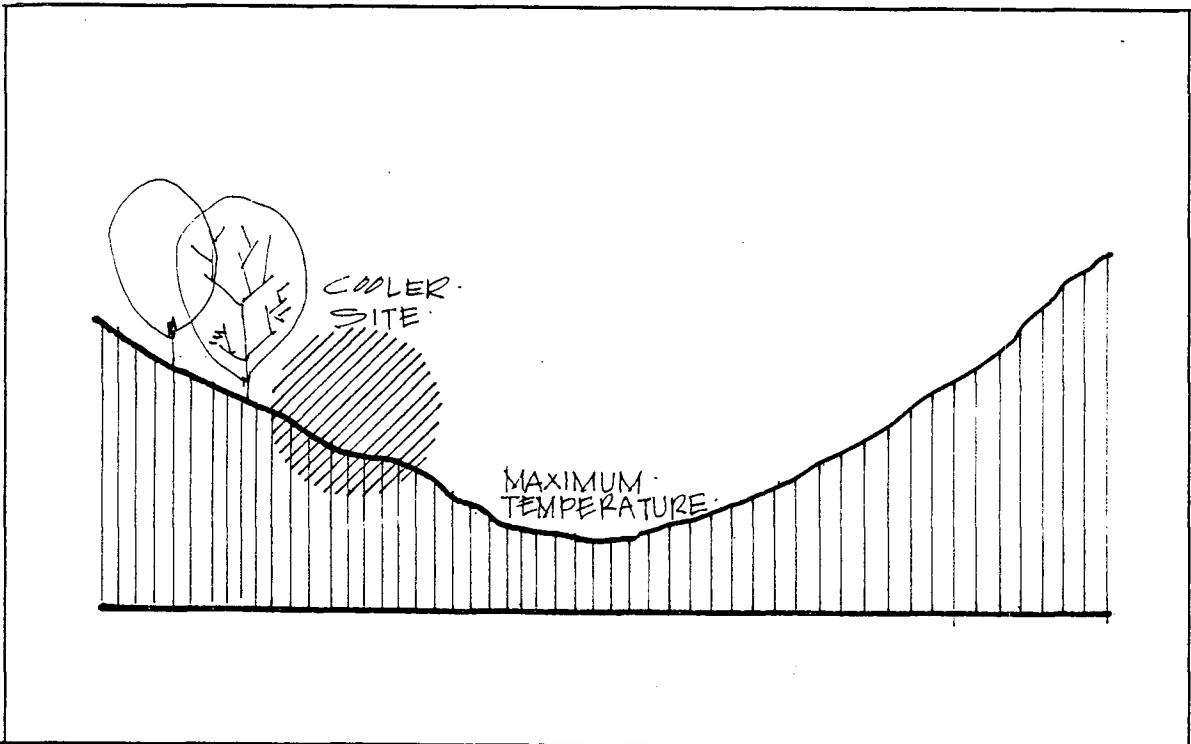


Fig.2.7. Site Selection in a Valley Situation.

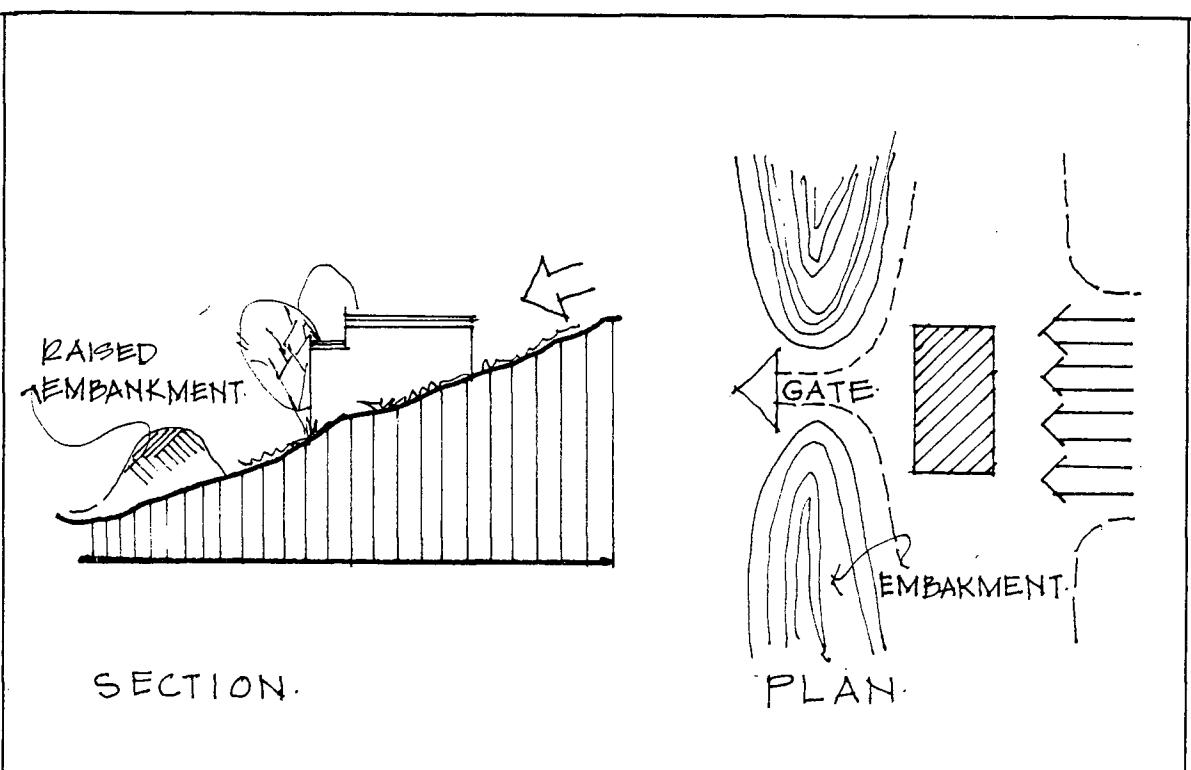


Fig.2.8. Raised Embankment to Enhance the cooling Effect of air.

5.2. Proximity to Water Bodies

Water bodies close to site can result in moderating the extreme day time air temperature and reducing variations in day and night temperatures during summer.

During the summer days, the land surface heats up more than the water. This causes the hot air over the land surface to rise and cooler air over the water flows to replace it. The shores of lakes, as a result, benefit from a daytime breeze blowing from water to land. This cooling effect can be noted between 400 and 800m inland. During the night the air over land cools faster than that over the water and this results in

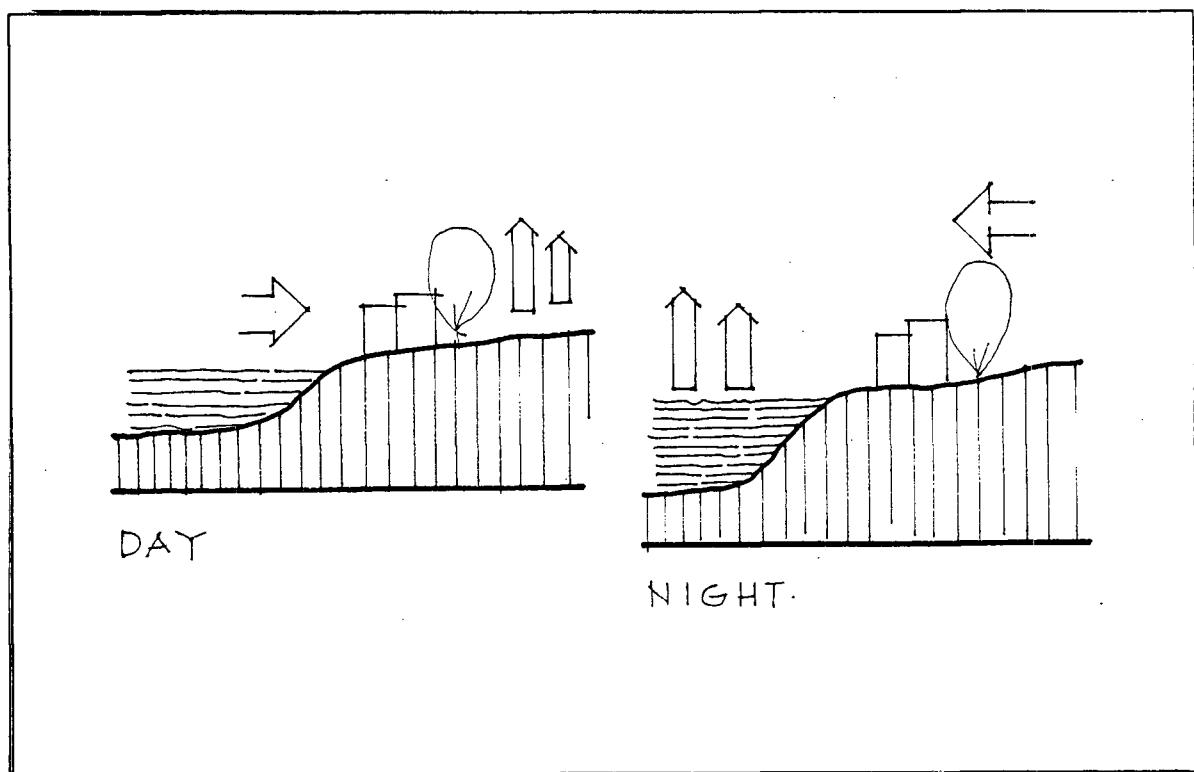


Fig.2.9. Cooling Process due to the Proximity of Water.
Source: Konya, 1980

reversing of the process, with the breeze blowing from land to water (Fig.2.9). The larger the body of water the greater its impact on the microclimate. Land surrounding a lake will also be warmer in winter (Robinette, 1983).

SECTION II: SITE PLANNING STRATEGIES

1. INTRODUCTION
2. MINIMIZE SOLAR GAIN
 - 2.1. Street Orientation
 - 2.2. Street Width
 - 2.3. Location and size of Open Spaces
 - 2.4. Landscaping
3. PROMOTE VENTILATION
 - 3.1. Distribution of Open Spaces
 - 3.2. Building Heights
4. PROTECTION FROM HIGH VELOCITY WIND AND DUST
 - 4.1. Shelterbelts

1. INTRODUCTION

Selecting a site with a desirable climate may not always be possible or be beyond the control of the architect. This is particularly the case for housing projects where a client or a housing agency approaches the architect with a preselected site. Under such circumstances modifying the unfavourable elements of the microclimate and optimizing the favourable ones through site planning, for example street layout, design of public spaces and landscaping, becomes the primary aim of the architect.

2. MINIMIZE SOLAR GAIN

Shading is an effective technique for reducing solar heat gain. The shadows created by buildings on site reduce the air temperature by about 25% in the summer months (Watson, 1983). In order to maximize the benefit of shading in the microclimate, the orientation and width of streets, the size and location of open spaces and landscaping are important considerations.

2.1. Street Orientation

Street orientation, if dwelling blocks are facing the street, affects the shadow length. For calculating shadow lengths, solar altitude and azimuth angles for different hours of the day can be taken from the sun path diagram for a particular latitude (Fig.2.10a), and can be translated into shadow length (Fig.2.10b).

East and west facing building blocks abutting the street cast larger shadows in the afternoons and mornings throughout the year. The length of the shadow cast by south facing blocks increases in summer (April-June) mornings and afternoons. Additionally, during this period, the sun shines for lesser hours on south facing blocks and at a much steeper angle than on east and west facing blocks. This implies that the layout of streets parallel to an east-west axis, which can maximize south facing blocks, will effectively (Fig.2.11) utilize shading by building blocks.

2.2. Street Width

Street width is another design factor which an architect can employ to modify excess solar radiation. Narrow streets with buildings on both sides will increase the shadows created by surrounding blocks.

The street width in housing design, according to zoning regulations (1984) in hot and dry regions in India, depends on two factors: the requirements for vehicular traffic, and the height of surrounding residential blocks. In general, streets for vehicular access have to be much wider than pedestrian streets. The summer solar altitude at latitude 25°N (Fig.2.10a) is high so that paved surface of vehicular streets (Fig.2.12a,b) running east-west remains unshaded for a significant amount of time and can raise the surrounding air temperature considerably.

One generally accepted method of reducing the width of streets carrying vehicular traffic is to remove the traffic from the

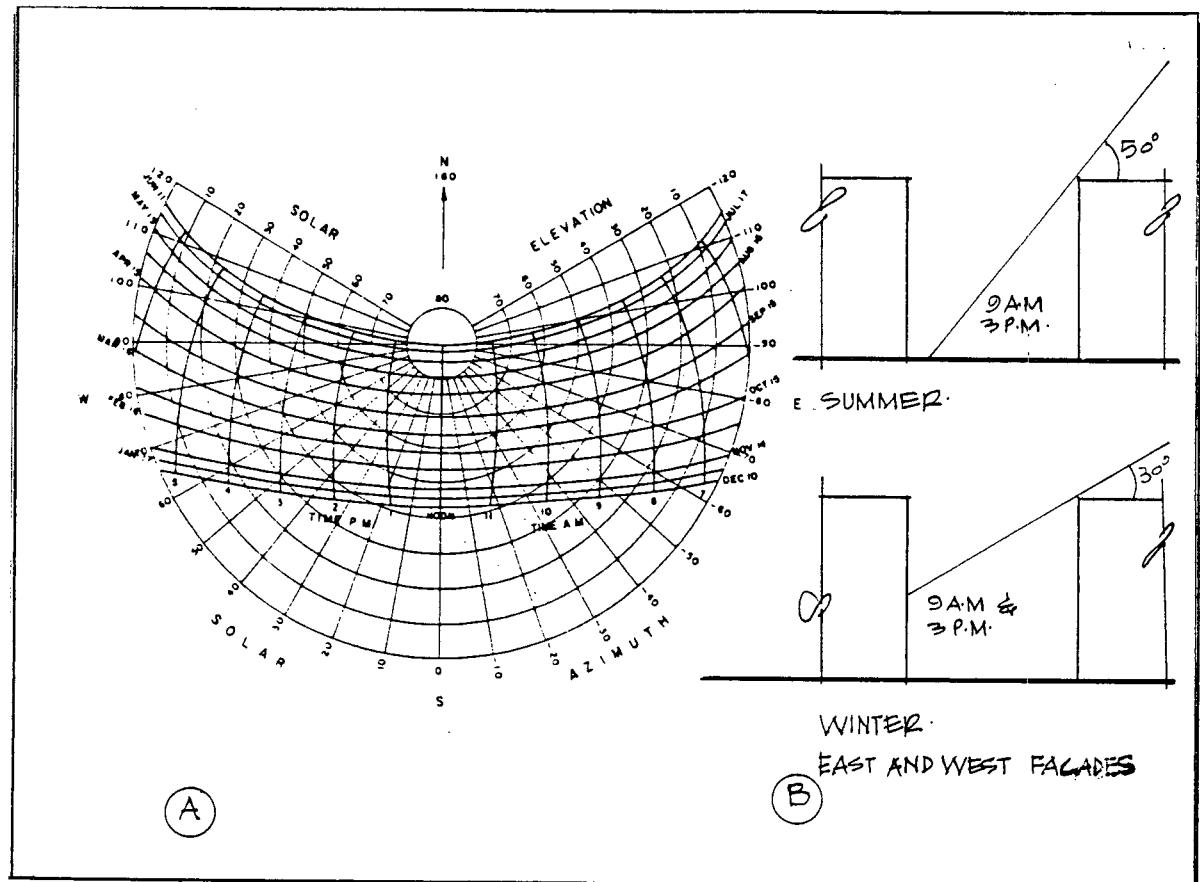


Fig.2.10. a. Sun Path Diagram for Latitude 25°N.
 b. Shadow Length for East and West Facing Dwelling Blocks.
 Source: Mani, 1982

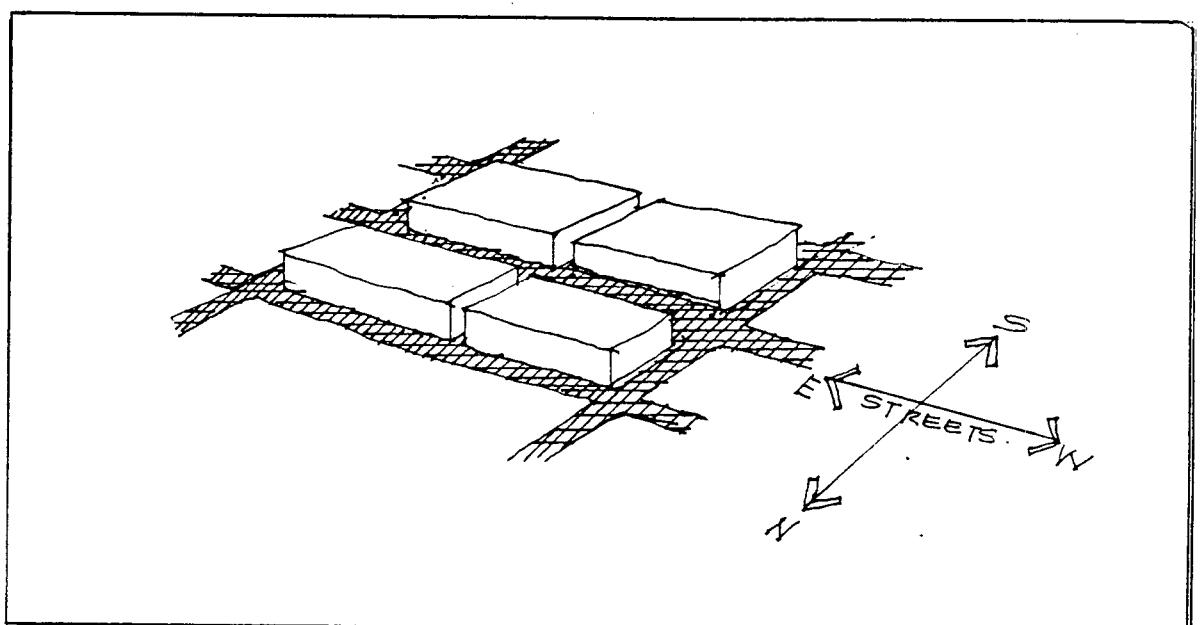


Fig.2.11. Streets running east-west with blocks facing south.

dwelling frontage. This is particularly advantageous for large housing projects where the whole scheme can be divided into smaller residential segments, each surrounded by peripheral parking and access roads (Fig.2.13). Within each segment, a network of narrow pedestrian streets is then created. Because of their close proximity, the building blocks can then shade from each other and the ground surface. In addition to maximizing the effect of shading, the narrow street width results in a compact housing layout, with shaded space through which people from various places within the residential and service unit can move on a human scale adapted to climate. A narrow street network also helps in achieving more ground coverage, higher densities, and reduces the utility networks (water supply, sewerage lines etc.), maintenance and energy consumption for street lighting.

The narrow street network, however, reduces privacy and individual residential identity and may increase noise pollution. Therefore, the street width should be kept to a minimum compatible with these problems or by taking additional measures to rectify them.

2.3. Size and Location of Open Spaces

In hot and dry climates, open spaces are used frequently and this is possible only when open spaces are shaded.

Isolated large open spaces which are not protected from solar radiation are uncomfortable. Instead of a few large open spaces, a number of small open spaces in the compact layout can benefit from shading by the surrounding residential

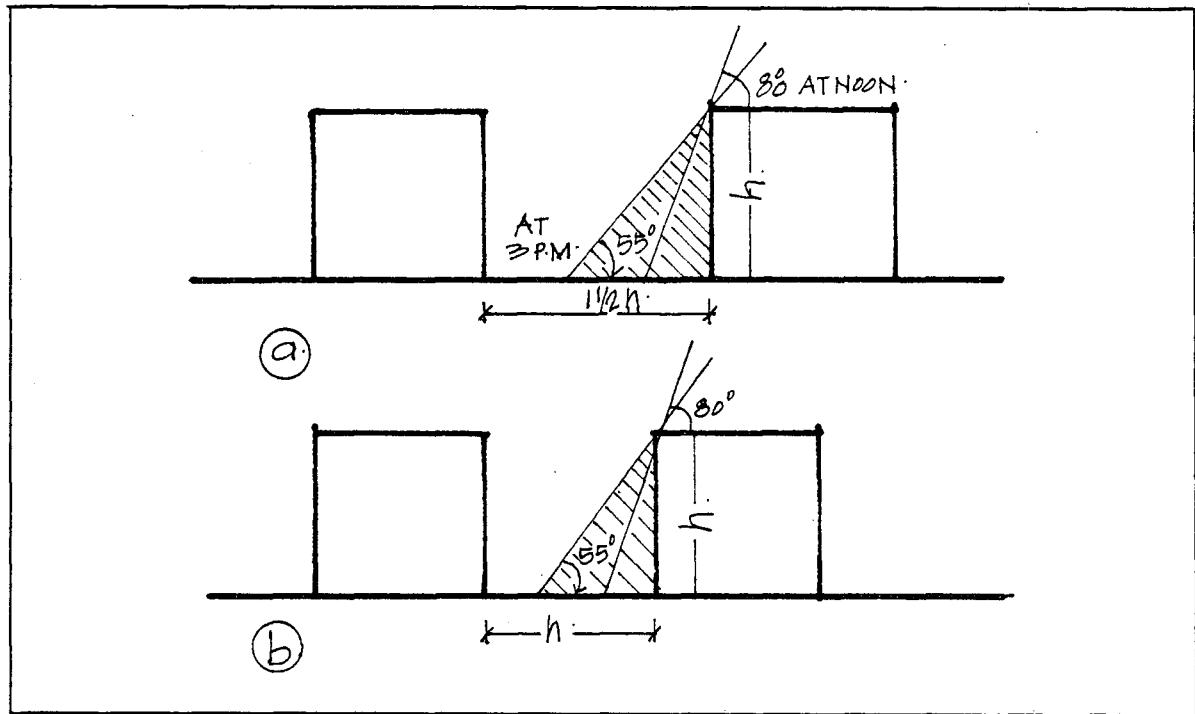


Fig.2.12. The Effect of Street Width and Block Height on Shading.

- a. Street Wider than Block Height.
- b. Street Width Equal to Block Height.

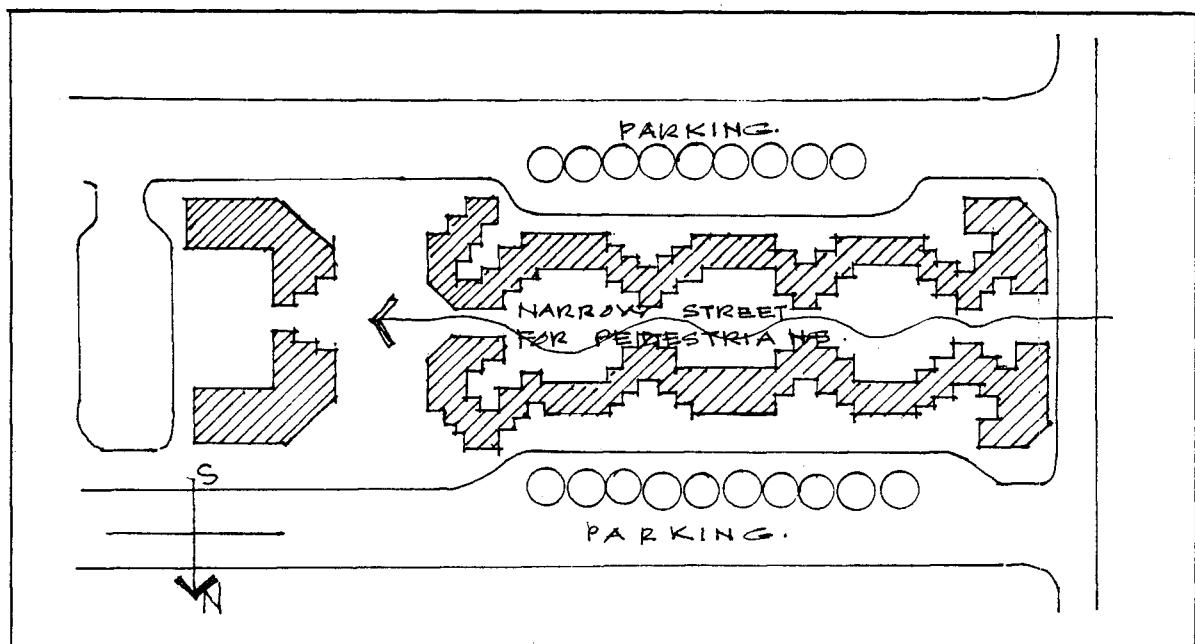


Fig.2.13. An Example of Achieving Narrow Street Width by Segregating Vehicles from Dwelling Front.
Source: Kessler, 1979.

blocks and can also improve wind movement around dwellings, similar to the courtyard effect.

Open spaces which are smaller in length and width than the height of surrounding blocks (Fig.2.14) will benefit from full or partial shading in summer in the morning and afternoon hours. Smaller open spaces distributed throughout the residential segments, in addition to reducing the effect of solar radiation, are easier to maintain.

Furthermore, location of open spaces towards south and south-east orientation is most effective as it can benefit from shade in the afternoon, the time when most outdoor activity in hot and dry climates generally takes place (Saini, 1980).

2.4. Landscaping

Vegetation can reduce the external air temperature by blocking direct solar radiation and by filtering and cooling the air (Davis & Schuburt, 1974). Trees can also speed up the cooling process in the evening by heat radiation to the open sky (Robinette, 1983). Passive cooling by the plants is in many ways superior to cooling with the help of building envelope or form. Bowen (1980) has characterized the alternatives:

"The most significant resulting difference between the cooling effects of plants and manmade structures is that the structure is made of non-living (concrete) or dead (lumber) materials and therefore offers limited cooling capabilities determined by the thermal performance of the materials; while a plant - which is a living organism will constantly position and arrange its canopy and leaves to take maximum advantage of the sun's rays, thus maximizing their cooling effects."

In addition plants filter pollutants from the air, reduce

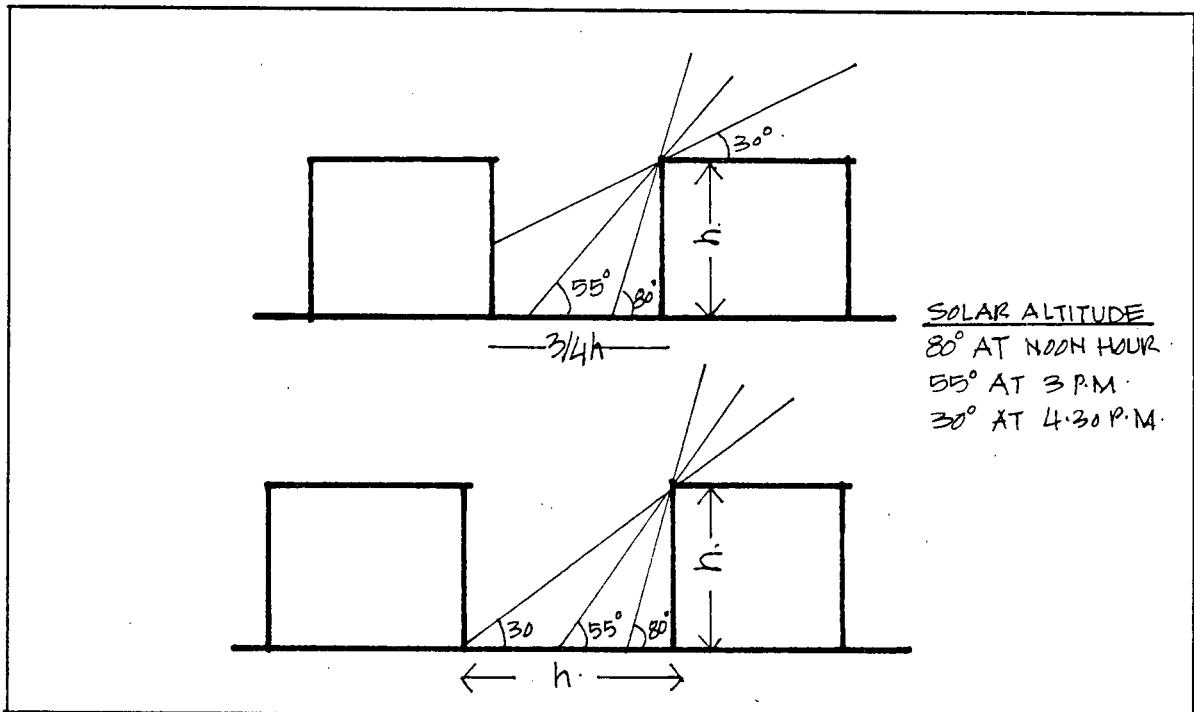


Fig.2.14. Shading in Open Spaces Smaller than Surrounding Blocks.

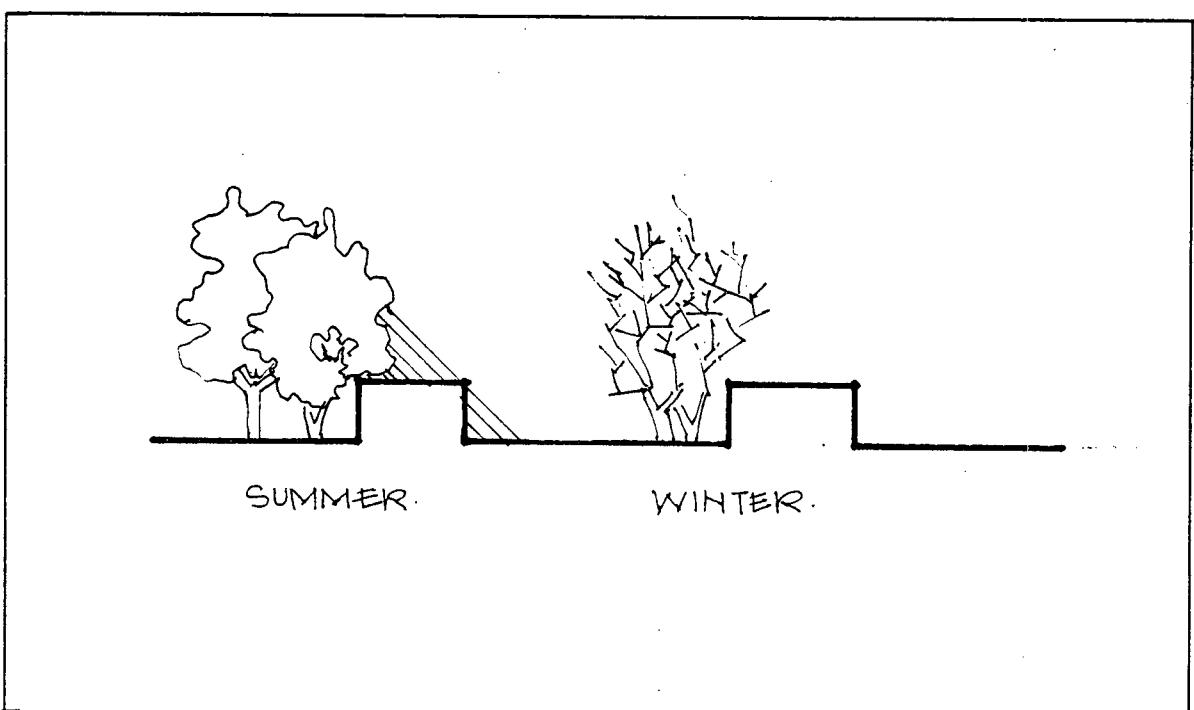


Fig.2.15. Deciduous Trees and Summer and Winter Solar Penetration.

noise levels and can also be used to direct air flow, reduce glare, screen undesirable sights and control circulation. They in real sense provide psychological and spiritual solace in addition to providing cooling. Therefore, they are nature's most attractive passive cooling device.

Deciduous Trees

Deciduous vegetation should be considered, not only where shade is required to avoid excessive heat gain during the overheated times of the year (May and June), but also when solar exposure is desired during the underheated periods (December and January). It is desirable to plant more trees towards the west so that they can provide shade during the afternoons when the maximum air temperature ($40-45^{\circ}\text{C}$) in summer coincides with the heat gain from solar radiation. Important measures of the cooling potentials of trees are their size and form and the shading density coefficients of their canopies. A design matrix for deciduous trees should also include their leaf out and full leaf drop dates. Because the leaf drop and refoliation of most native plants and trees in hot and dry regions corresponds very closely to the times of the year when solar exposure and shade, respectively, are needed, it is useful to take advantage of the natural rhythms of these plants (Fig.2.15).

Ground Cover and Shrubs Around the Dwelling

The solar radiation received by the ground surface (Fig.2.16) at latitude 25°N during the month of June is about twice that received by east or west walls. Therefore, the solar

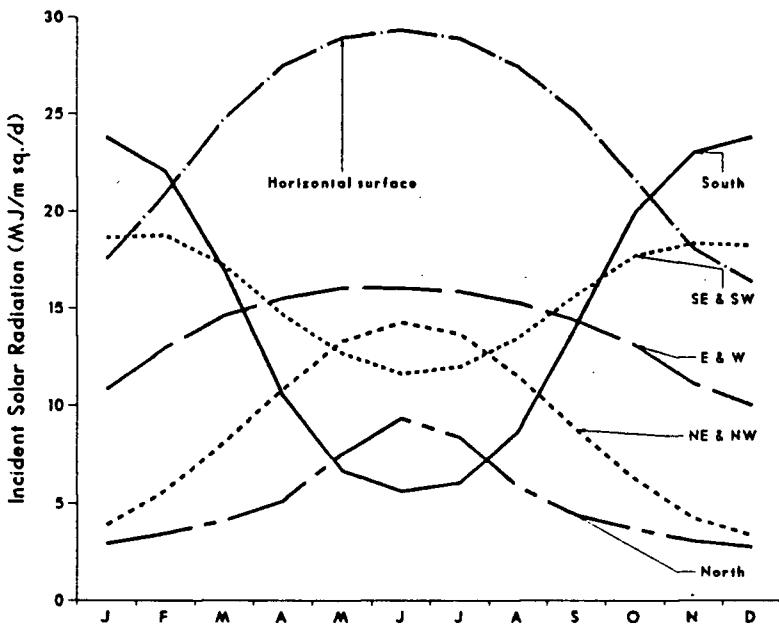


Fig. 2.16. Solar Radiation Incident Upon Ground Surface and Vertical Surfaces facing East, West, South and North at Latitude 25°N.

PERCENTAGE OF SOLAR RADIATION REFLECTED BY VARIOUS MATERIALS			
<u>BRICK:</u>			
LIGHT RED	45%	<u>GRASS GREEN</u>	33%
DARK RED	28%	<u>AFTER RAIN</u>	<u>PLASTER</u>
<u>LIMESTONE</u>			<u>WHITE</u>
LIGHT	65%	<u>GRASS DRY</u>	33 - 31%
DARK	50%	<u>GRASS FRESH</u>	25%
<u>MARBLE</u>		<u>DARK GREEN</u>	
REDDISH	45%	<u>BUSHES</u>	10 - 15%
WHITE	90%	<u>SAND DRY</u>	30%
<u>ASPHALT</u>		<u>SAND WET</u>	20%
<u>CONCRETE</u>	40%	<u>BARE GROUND</u>	
<u>DESERT GROUND</u>	25%	<u>DRY</u>	25%
<u>SURFACE</u>		<u>BARE GROUND</u>	
		<u>WET</u>	15%

Table I. Reflectance Values for various Surfaces.
Source: El Bannany, 1984

radiation reflected from the ground onto building facades will add significantly to the cooling requirements of the dwelling.

The reflectance values for paved surfaces are much higher than that of landscaped or green surfaces (Table I). Although asphalt surfaces for roads keep the reflected radiation at a minimum, the heat absorbed by them increases the surrounding air temperature (Geiger, 1969). Therefore, for summer cooling, it is desirable to minimize the paved surfaces around the dwellings and to replace them (wherever possible) with grass or vegetative ground cover.

Plants, shrubs, and vegetative ground cover around the dwellings also reduce the air temperature due to their absorption and evaporation. The measured summer cooling effect has shown 10-14°C cooler (Fig.2.17.) temperatures for grass surfaces as compared to paved or asphalt surfaces (Olgyay, 1963).

In addition to daytime cooling, plant cover will also reduce diurnal temperature fluctuations by trapping and reflecting thermal radiation from the ground at night (Miller, 1980).

3. PROMOTE VENTILATION

Wind velocity at the ground level is reduced considerably by dwellings or settlement clusters. Fig.2.18 shows that the wind velocity in a built up area at ground level is much lower than in open country (Koenigsberger, 1973). The most important design factors influencing the wind velocity in a built up area are: orientation and width of streets, distribution and

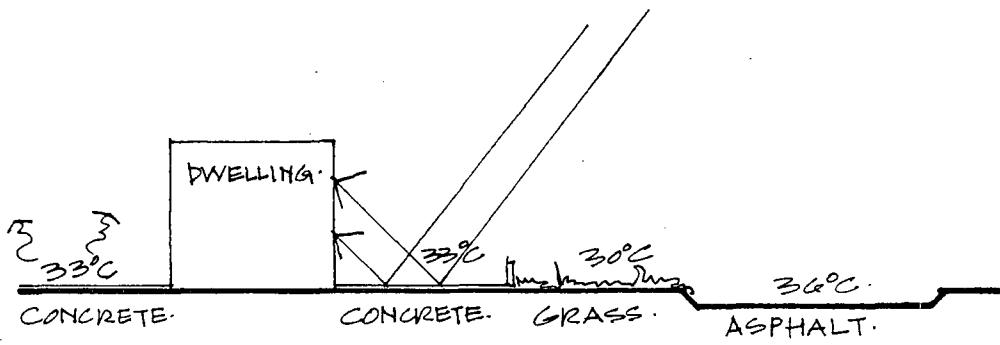


Fig.2.17. Air Temperature Above Various Surfaces.

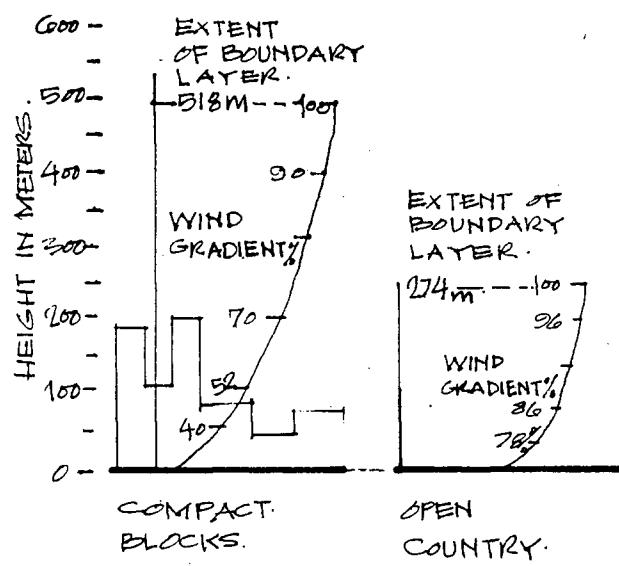


Fig.2.18. The Wind Velocity in Open Country and Built up Areas.
Source: Koenigsberger, 1973.

size of open spaces, and the size and height of surrounding buildings.

In determining the orientation and width of streets in hot and dry region, the considerations for minimizing solar radiation are more important than for air movement. The dilemma facing the designer in this region is, therefore, to minimize solar heat gain while still allowing adequate air movement.

3.1. Distribution and size of Open Spaces

The prevailing wind directions during the summer in India's hot and dry regions are from east and west. The orientation of streets in an east-west direction with the dwelling blocks facing south is the most desirable for maximizing summer shading. In a grid layout, however, this orientation also prevents wind movement through the blocks. A slight tilt of blocks towards the east will improve the wind movement in dwelling interiors, but this effect is partially offset due to the narrow width of streets, again desirable for minimizing solar gain. Therefore, the most effective way to improve wind movement in a block is with the provision of small open spaces distributed throughout the whole compact settlement.

The open spaces will provide wind movement as long as they are shaded (similar to courtyard effect) or at least six times larger than the height of surrounding buildings (Koenigsberger, 1973).

3.2. Building Heights

When the buildings in a compact settlement are approximately the same height, there is a separation between the free air flow above the buildings and that in the built up zone so that wind velocity near the ground is much lower. A single building projecting above the height of the neighbouring buildings in such cases can modify the pattern and velocity of the air flow near the ground. The air velocity at the ground level of a taller block is found to be much more than around blocks smaller in height (Koenigsberger, 1973). This can serve a useful purpose in a hot and dry climate, especially in the

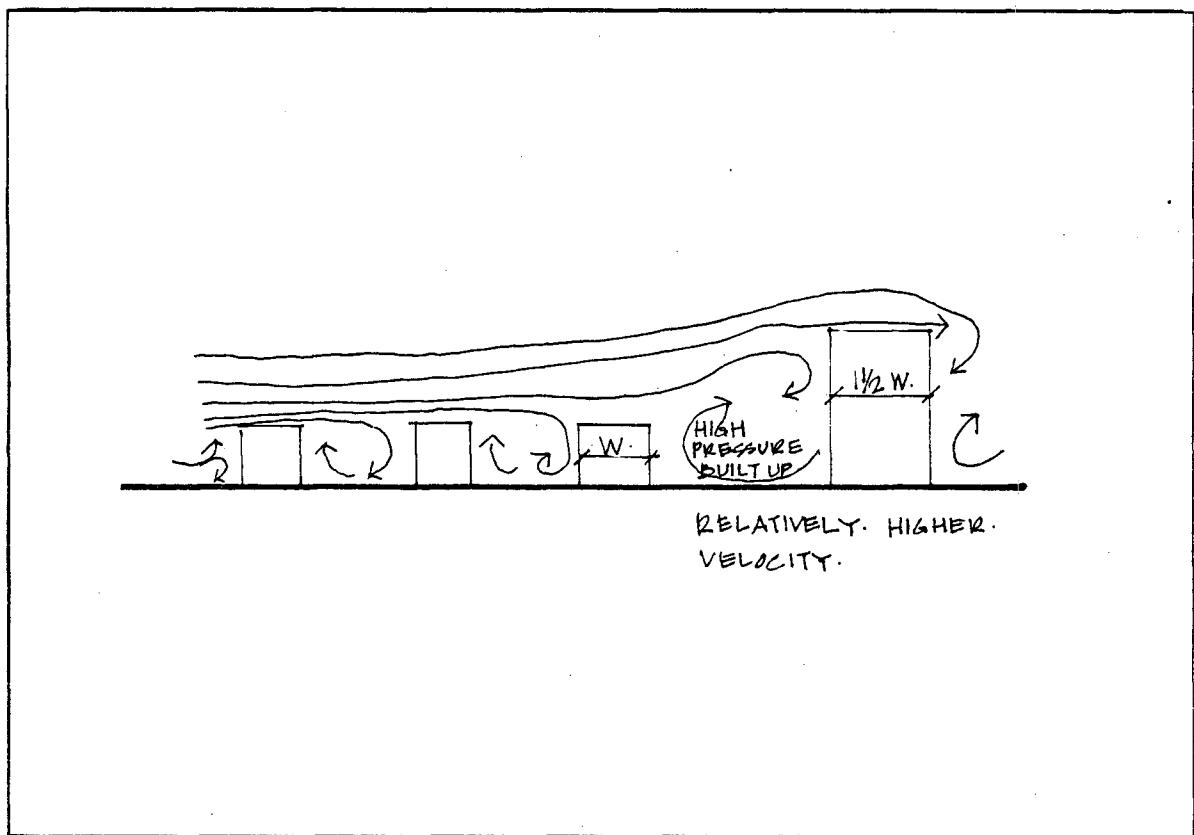


Fig.2.19. Air Velocity Near the Ground Around Taller Blocks is More Than Around Lower blocks.
Source: Koenigsberger, 1973

central part of a compact settlement where wind velocity at the ground level is found to be the lowest. A taller building located there will improve the air movement for the surrounding blocks as long as its horizontal dimensions are not much larger than those of the lower blocks (Fig.2.19).

4. PROVIDE PROTECTION FROM HIGH VELOCITY WIND AND DUST

4.1. Shelterbelts

In India's hot and dry regions, the afternoon wind, particularly in the months of May and June, can be troublesome for thermal comfort. The average wind velocity during this time of the day is high (above 4.8m/sec), and the air is generally dust laden. The larger public open spaces, periphery blocks and dwellings in open areas are more likely to be affected by dust and high winds and will need protection. Shelterbelts or plants in groups placed perpendicular to the wind direction are an effective way of controlling wind velocity in these areas.

The height of shelterbelts is the most important factor in determining the zones of protection behind them (Fig.2.20). The wind velocity on the leeward side of the shelterbelts may be reduced by as much as 30-50% (Melaragno, 1982) for a distance of 10-20 times the height of the barrier (Fig.2.21). The influence of a shelterbelt in reducing wind velocity may extend as far as 25-35 times its height depending on its penetrability and width.

Controlling dust with shelterbelts is not equally effective because dust particles can be lifted to a considerable height

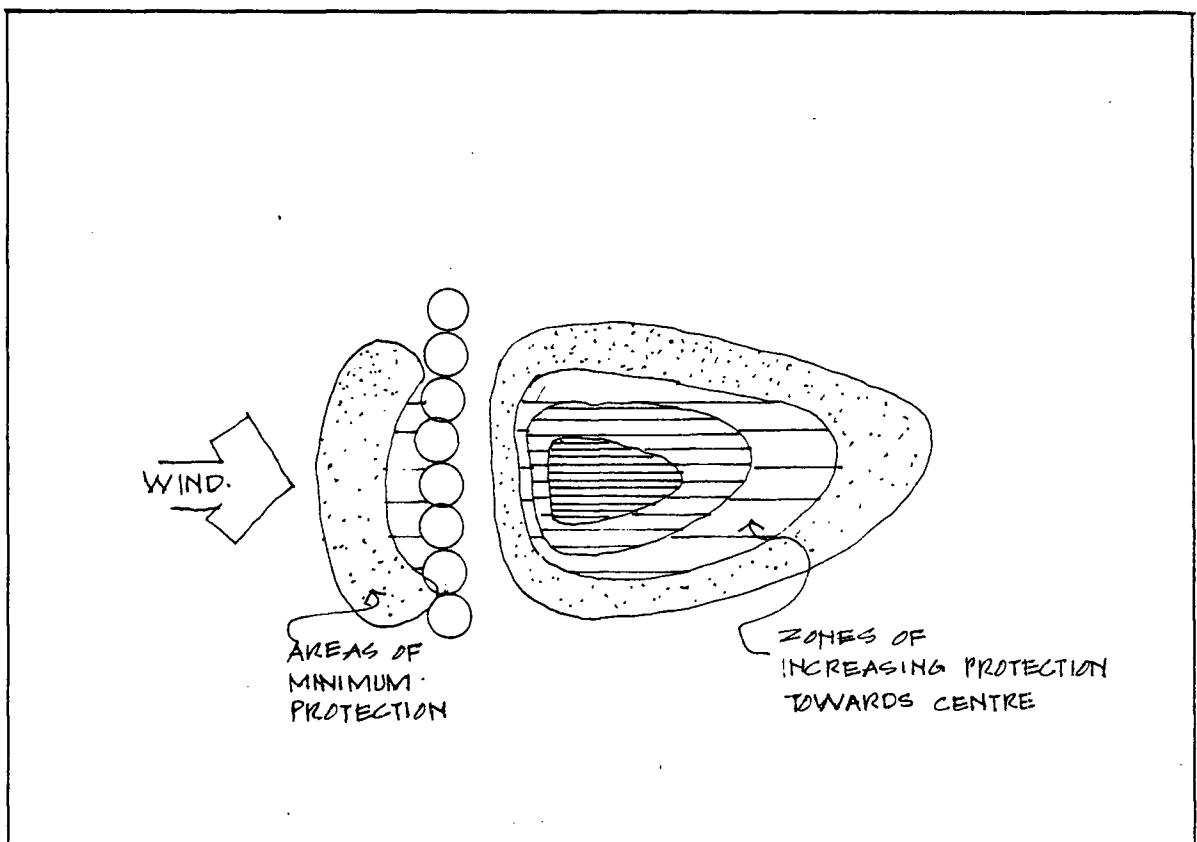


Fig.2.20. Use of Shelterbelts for Summer Wind protection. (Plan).

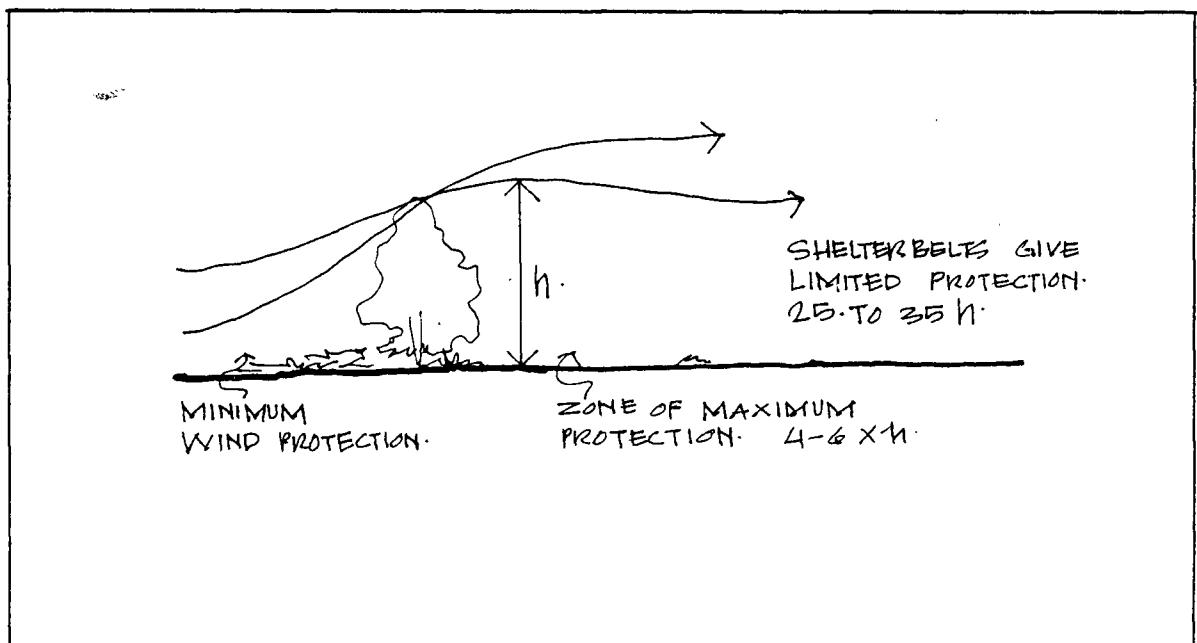


Fig.2.21. (Section).
Source: Melaragno, 1982

and are carried for long distances before returning to the ground (Saini, 1973). For maximum protection from dust in the building blocks the barriers need to be at least as high as the building itself and less than 2 m away from the facade, but this arrangement has the disadvantage of excluding the possibility of fully utilizing the cool evening breezes. Therefore, window shutters and other parts of the building fabric discussed in later sections can be used more effectively to control dust. Only sand, because of its tendency to bounce along the ground, can be stopped effectively by low vegetation of about 1.7 m in height (Saini, 1973).

Because of the need for conserving the water required to grow new plants in this region, existing vegetation, earthforms and waterbodies should be used as an integral part of site planning and not treated as an expendable element. As discussed in site selection, a particular effort should be made to use existing trees and mounds (if any) in the west or east orientation to provide protection from hot winds and solar radiation.

SECTION III: FORM DESIGN STRATEGIES

1. INTRODUCTION
2. REFERENCE BUILDINGS
3. MINIMIZE CONDUCTIVE HEAT FLOW
 - 3.1. Orientation
 - 3.2. Exposed Surface/Volume ratio
 - 3.3. Plan Shape
 - 3.4. Building Facade
 - 3.5. Thermal Zoning of various Spaces
 - 3.6. Living Areas Below Grade
4. REDUCE INTERNAL HEAT GAINS
 - 4.1. Heat Generating Areas
5. PROMOTE VENTILATION
 - 5.1. Interior Courts and Shafts
 - 5.2. Orientation
6. PROMOTE RADIANT COOLING
 - 6.1. Terraces

1. INTRODUCTION

The internal thermal environment in a dwelling is a result of the influence of external climate and the internal heat gains

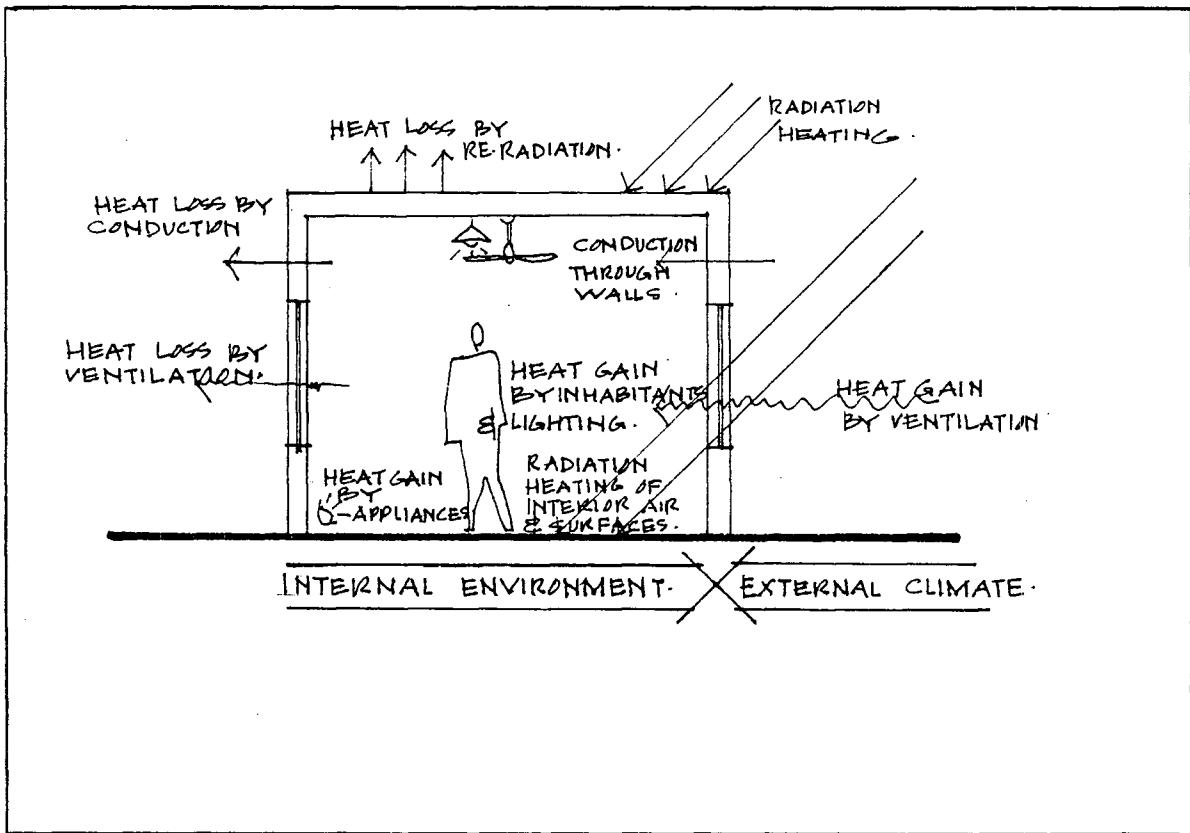


Fig.2.22. Modes of Heat exchange Inside the Dwelling.

(Fig.2.22). The more significant of these in domestic buildings is the external climate.

The main objective of form design in this thesis is to utilize the favourable and modify the unfavourable elements of external climatic through building shape, volume, configuration and orientation. The strategies followed at the

form design level are particularly important as any inappropriate decisions regarding orientation, building shape etc. are difficult to rectify and any effort to compensate for them at fabric design level will involve more design time and extra building materials. It is important, therefore, to follow these strategies critically.

2. THE REFERENCE BUILDINGS

For the purpose of heat gain analysis, four most commonly used forms for single and multiple family dwellings are examined (Fig.2.23). These are:

- Detached,
- Row Housing,
- High Rise and
- Cluster.

a. Detached

In this arrangement (Ia,Ib) the dwellings are separated from each other and are surrounded by open space. Single family dwellings in this arrangement are typically limited to three storeys. The side setbacks, according to building regulations, are kept equal to or more than the mean height of the structures for the reasons of privacy.

b. Row Housing

In this arrangement (IIa,IIb), the dwellings share common side walls and usually do not exceed three storeys in height. They do have front and back setbacks, however.

c. High Rise

The required setbacks between highrise buildings (III) vary according to their height. The height restrictions for multiple family highrise buildings vary from four to fifty or

Fig.2.23. The Dwelling Forms used for Analysis.

ITEMS.	HOUSING FORM.					
	LOT BY LOT		ROW AND CLUSTER.		HIGH RISE.	
IA	IB	IIA	IIB	III A	III B.	
LENGTH (M.)	12.16	7.6	12.16	7.6	12.16	12.16
WIDTH (M.)	7.6	6.8	7.6	6.8	7.6	7.6
HEIGHT (M.)	3.4	6.8	3.4	6.8	3.4	3.4
VOLUME (C.U.M.)	283	283	283	283	283	283
ROOF AREA (EXPOSED) (SQ.M.)	107.64	53.82	107.64	53.82	N.	N.
FLOOR AREA (SQ.M.)	107.64	107.64	107.64	107.64	107.64	107.64
EAST FAÇADE (SQ.M.)	26.9	43.05	N	N	26.9	N.
WEST FAÇADE (SQ.M.)	26.9	43.05	N.	N.	N.	26.9
SOUTH FAÇADE (SQ.M.)	43.05	53.82	26.9	43.05	43.05	N
NORTH FAÇADE (SQ.M.)	43.05	53.82	26.9	43.05	N.	43.05
SURFACE AREA (EXPOSED) SQ.M.	247.5	247.5	161.46	193.75	69.96	69.96
SURFACE/VOL.	.87	.83	.57	.33	.24	.24

more storeys, depending upon the zoning in the area.

d. Cluster Housing

Single or multiple family dwellings in hot and dry regions of India were arranged traditionally in small clusters, around common open spaces, for social and cultural reasons. The cluster form is similar to row housing (IIa, IIb), only the back and front yards of the dwellings are omitted and they are grouped closely around a common open space. This provides more flexibility in the orientation as compared with the row arrangement. The height of the dwellings can vary from one to three storeys.

Figure 2.23 gives the details on the forms used for analysis in this section. Each of the four dwelling forms has different heat transfer characteristics which are important to consider in climate responsive design.

Before discussing the form design strategies it is important to examine ways by which heat exchange in the dwelling takes place:

- through conduction/fabric
- solar radiation/windows and,
- ventilation/infiltration.

The rate at which heat is conducted through the opaque surfaces in a building is a function of:

- the temperature difference between inside and outside air.
- the exposed areas of building fabric.
- the insulating properties of the fabric (U-values)

The solar radiation incident upon exposed surfaces increases the air temperature surrounding the building. To calculate this increase in air temperature, the effect of solar

radiation incident on building surfaces can be combined with the outdoor air temperature and the fraction of heat absorbed by the surfaces, by using the sol-air temperature concept. This theoretical external air temperature can be used for calculating heat gain by conduction (Givoni, 1981).

For a constant U-value of building fabric and a given indoor air temperature, heat gain by conduction through opaque surfaces becomes a direct function of the area of exposed surfaces and their orientation. In terms of form design, this factor is described as the exposed surface/volume ratio. In general, a reduction in exposed surface/volume ratio will reduce the heat gain by conduction.

A greater source of heat gain inside buildings however is from the solar radiation entering through windows. Glass windows are transparent for the short wave radiation emitted by sun but are opaque for long wave radiation emitted by the objects in a room. As a result, solar heat heat, once it has entered through a window, is trapped inside the building. Therefore, the presence of windows in fabric can significantly influence the total heat gain inside a building and depends upon:

- the solar radiation incident upon the window,
- the Window area,
- shading devices and,
- glass type.

Heat gain by ventilation results from :

- the air exchange rate,
- the temperature difference between inside and outside air, and
- the specific heat of the air

Air exchange rate is a multiple of the number of air changes per hour in a particular volume of space. For a given

temperature difference and specific heat of the air, the heat gain by ventilation is mainly determined by the volume of space and the number of air changes per hour. As there is a limit to the allowable reduction of air exchange rate for health reasons, the volume of space becomes the most important factor which determines heat gain. A reduction in the volume will therefore reduce heat gain by ventilation. As ventilation rate in hot and dry climates is generally kept low during the day time, reducing heat gain by conduction becomes more critical at form design level.

3. MINIMIZE CONDUCTIVE HEAT FLOW

3.1. Orientation

Orientation is the most important factor in determining solar heat gain.

The following figures (Fig.2.24a,b) show the distribution of solar radiation on vertical surfaces in various orientations at latitude 25°N . The effect of orientation on form design, from these calculations, can be summarized as follows;

- a. During the summer months (April-July) nearly 50% of the total heat load from solar radiation is on the roof (Fig.2.24a). East and west facing surfaces receive a heat load of around 19-20% each, north facing surfaces 6-13% and south facing surfaces only 2%. This implies that optimum orientation for larger surfaces (opaque or glass) in any form is due south because the heat load due to solar radiation is minimum. However, figure 2.24b demonstrates that solar radiation incident upon

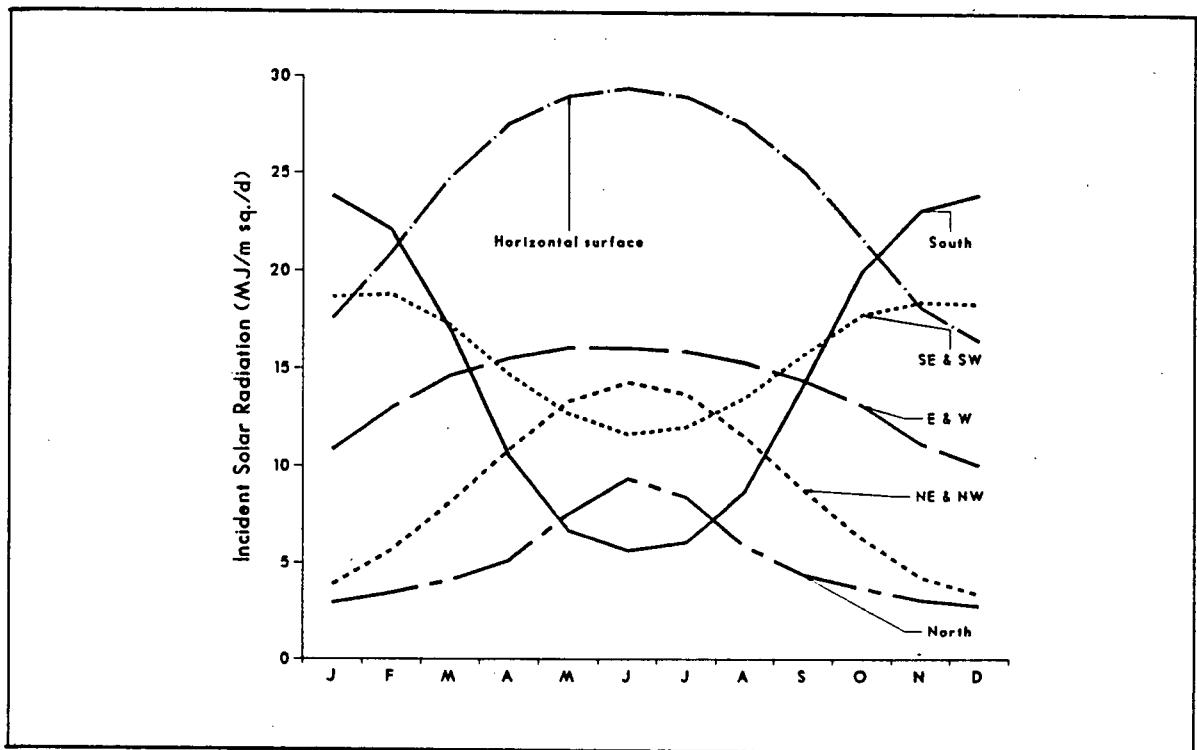


Fig.2.24a. Solar Radiation Incident upon Surfaces in Various Orientations at Latitude 25°N.

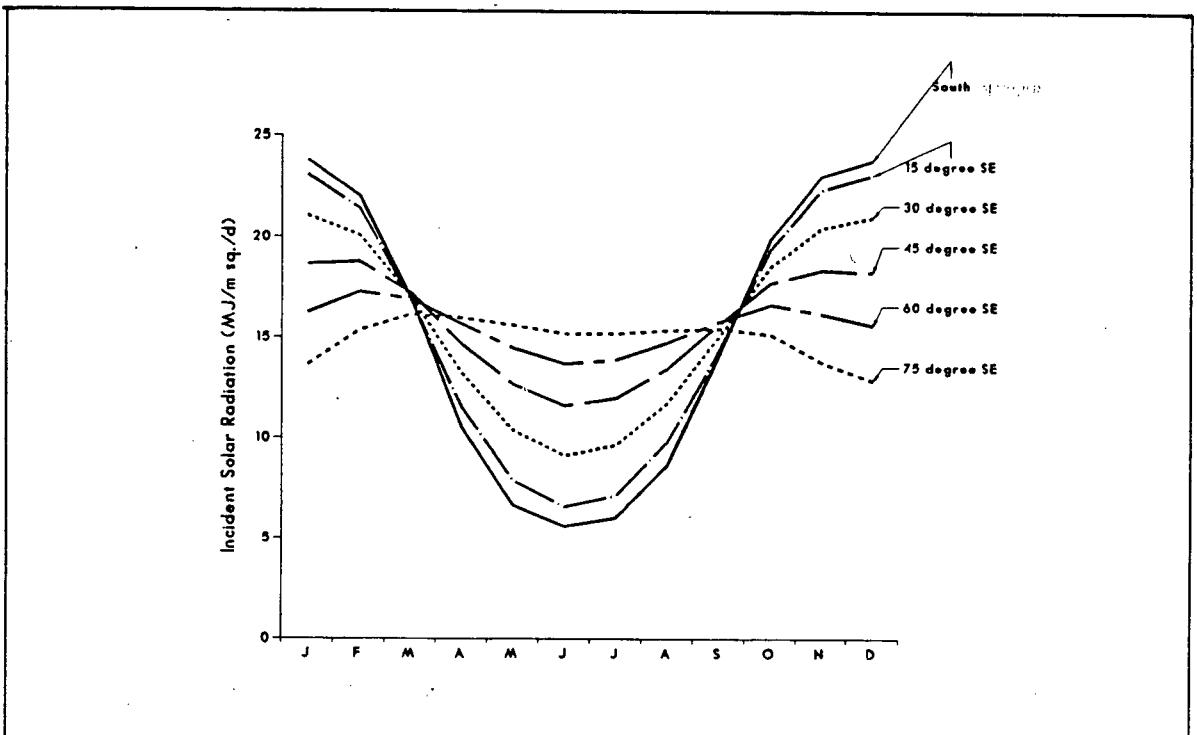
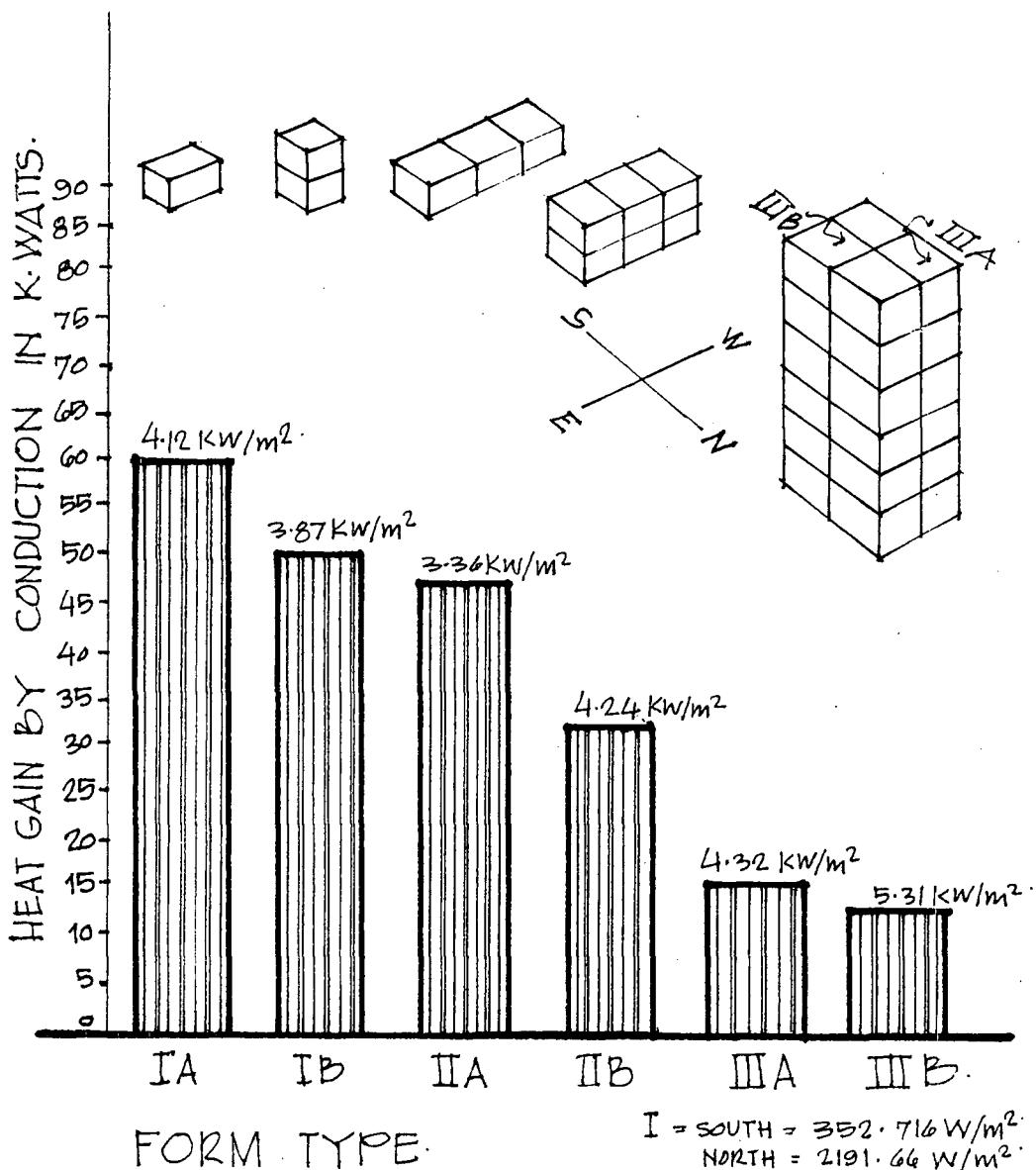


Fig.2.24b. Solar Radiation Incident upon South to South-east Facing Surfaces.

- surfaces facing up to 25° east of south does not rise significantly. This implies that a slight deviation of larger surfaces from south orientation does not increase the heat gain significantly. Consequently the exposure of larger surfaces in any building form upto 25° east of south is acceptable from the point of view of minimizing heat load. A major deviation from south orientation, however, will cause excessive heat gain.
- b. Both east and west facing surfaces receive maximum incident solar radiation during summer. However, larger glass and opaque surfaces (with time lag less than 2 hrs.) in east are more effective than in the west because they receive solar radiation in the morning when the air temperature is below comfort level.
 - c. Larger surfaces can also be oriented to the north where the heat load is less than east and west orientations. The problem with north orientation, however, is that surfaces receive minimum solar radiation in winter when some heating may be required.

3.2. Exposed Surface/ Volume Ratio

Heat gain by conduction takes place through the external walls and roof of dwellings. In the following example (Fig.2.25), heat gain by conduction is compared for the four different dwelling forms already introduced in this section. The dwellings of each form have the same floor area and volume, but exposed surface area in each case varies and consequently so does the exposed surface/volume ratio (Ref. Fig.2.23).



$$\begin{aligned}
 I &= \text{SOUTH} = 352.716 \text{ W/m}^2 \\
 &\text{NORTH} = 2191.66 \text{ W/m}^2 \\
 &\text{EAST} = 4047.22 \text{ W/m}^2 \\
 &\text{WEST} = \text{SAME.}
 \end{aligned}$$

$$\begin{aligned}
 q &= .80 \\
 f_o &= 30 \text{ W/m}^2 \\
 U &= 2.5 \\
 T_i &= 25^\circ\text{C} \\
 T_o &= 37^\circ\text{C}
 \end{aligned}$$

Fig.2.25. Heat gain by Conduction for Different Form Types.

The heat gain calculations in this example are for dwellings located at latitude 25°N in the month of June. The average daily outside air temperature (T_o) is 37°C and acceptable indoor air temperature (T_i) is assumed to be 25°C.

For the purpose of calculating sol-air temperature (T_s), mean daily radiation intensity (I) for surfaces facing various orientations has been taken from the available climatic data (Mani, 1981). The absorptance of the surface (a), surface conductance (f_o) and air to air transmittance (U -value) are those for 228mm brick walls (Koenigsberger, 1973), plastered on the inside only and subjected to a wind speed of 4m/s.

Heat gain by air exchange and solar radiation through the windows is not included in these calculations. The larger surfaces of each form are oriented towards the north-south. The following points regarding form design emerge from these calculations:

- a. Fig. 2.25 demonstrates that forms with lesser exposed surface have lesser heat gain. This implies that a compact form like a cube or dwellings arranged in row or multistorey, which share the side walls, are more effective in reducing heat gain in comparison with detached houses. However, these implications must be evaluated in conjunction with the ability of each form to increase heat loss through outgoing radiation at night and to provide ventilation cooling during the evening. Both functions are also important for thermal comfort at night and in the evening.

For instance, a compact form like the dwellings arranged in a multistorey (III) has the minimum exposed wall surface and thus the least heat gain. This applies in particular to internal units with adjoining neighbours on each side, above and below. In the above analysis, total heat gain by conduction in a multistorey dwelling (III) is 65% less than a two storey detached (Ib) house and 48% less than a two storey row (IIb) house. However, this form also has less potential for the use of natural energies, especially for summer cooling by outgoing longwave radiation and natural ventilation. The cooling of the interior in this form will be very slow in the evenings and at night. Therefore, although this form is useful for minimizing heat during the day, it will hardly achieve any comfort at night.

On the other hand, the heat gain in row and cluster houses (IIa,IIb) is only 21-40% less than detached houses (Ia,Ib). Evening and night time heat loss in a row house, although less than a detatched house, occurs through the exposed roof resulting in rapid cooling by re-radiation to the clear sky. Heat loss in this form can be further enhanced by the use of courtyards and shafts (the thermal behavior of courtyards has already been discussed). As a result, row and cluster houses benefit from both reduction in excessive day time heating and rapid night time cooling. This form, therefore, is relatively more effective in hot and dry climate.

Row and cluster form, as a general expression of an effective response to heat gain problem, can be further translated into various design solutions responding to desired arrangement of spaces and site climate of specific housing projects.

- b. Since the roof contributes to a large extent in heat exchange, the above analysis (Fig.2.25) also demonstrates that roof area is a critical part of form design. A comparison between two detached houses (Ia & Ib) shows that in a single storey detached house (Ia), only the roof contributes 55% of the total heat gain. In a two storey detached house (Ib), where the roof area is reduced by 50% for the same volume and floor area, the total heat gain of the building is reduced by 15%. Further, in row houses (IIa, IIb), where side walls are shared, the roof contributes to 70% of the total heat gain by conduction. If the roof area in this form is reduced by 50% (IIb), the total building heat gain decreases by 30%. This comparison suggests that two or three storey houses of the same floor area and volume are more effective in reducing heat gain by conduction than single storey houses because of lesser roof area.
- c. Although heat gain by conduction and solar radiation through windows is not included in the above calculations, it is important to mention here that even with a minimum exposed surface/volume ratio, the presence of windows can significantly contribute to the total heat gain by the form. Therefore, a reduction in exposed

surface/volume ratio will be effective only when the properties of fabric, most importantly the windows, have been designed for minimizing heat gain.

3.3. Plan Shape

In a single family detached house, where the side walls are not shared and the exposed surface/volume ratio is high, the plan shape becomes an important factor in reducing heat gain by conduction.

In the following calculations (Fig.2.26), heat gain by conduction in a square plan is compared with various other plan shapes. All these plan shapes have similar roof areas and volumes and their larger surfaces face north or south orientation. These calculations do not include heat gain by infiltration and solar radiation through windows. Sol-air temperatures for various orientations, inside air temperature and U-value are similar to the calculations in the previous section.

These calculations demonstrate that:

- a. A square plan may not minimize heat gain during summer even though it has the minimum exposed surface/volume ratio. The reason for this is the unequal distribution of solar radiation on various orientations.
- b. A reduction in east west facades reduces conductive heat gain, however, there is a limit at which it is no longer effective. Plans with a ratio between 1:1.6 to 1:2.5 are most effective in reducing conductive heat gain. The optimum shape is a 1:2 ratio of sides. An optimum plan shape, however, cannot be generalised for

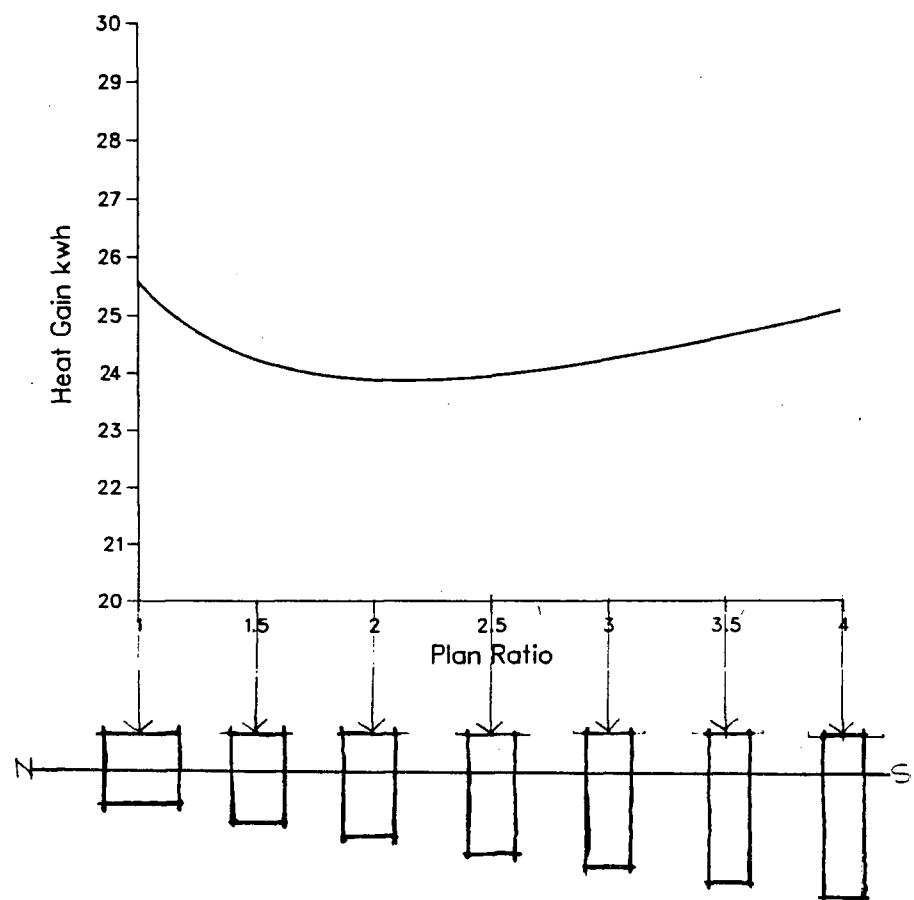


Fig.2.26. Heat Gain by Conduction in Various Plan Shapes as Compared with a Square Plan.

all locations because of the differences in the radiation intensity. In any case an optimum plan shape is not critical, and plans with 1:1.6 to 1:2.5 ratio of its sides will give acceptable performance.

3.4. Building Facade

Shading of the walls and surrounding spaces reduces the external air temperature by about 25%. Therefore, it is an effective and simple way of controlling heat gain to the dwelling interior.

In order to maximise the shade on building facade, orientation, and distance between building blocks are important factors. The effect of orientation on the shading of building facade is as follows:

- a. As sun path is northerly during summer and shines at higher altitudes for considerable time (Fig.2.27a), the south facade remains in shade for long part of the day. During mid day, when sun is at a steep angle to south walls, a slight projection of the building in horizontal direction creates an extensive shadow. As a result, in two or three storey dwellings, shade can be created by projecting or receding each floor (Fig.2.27b).*
- b. East and west facades each receive sun in the morning and in the afternoon for 4-5 hours. As the sun shines on these facades at a direct angle, they are difficult to shade with the variations in building facade. Therefore, the exposure of east and west facades should be avoided (wherever possible) by sharing the side walls or with landscaping.

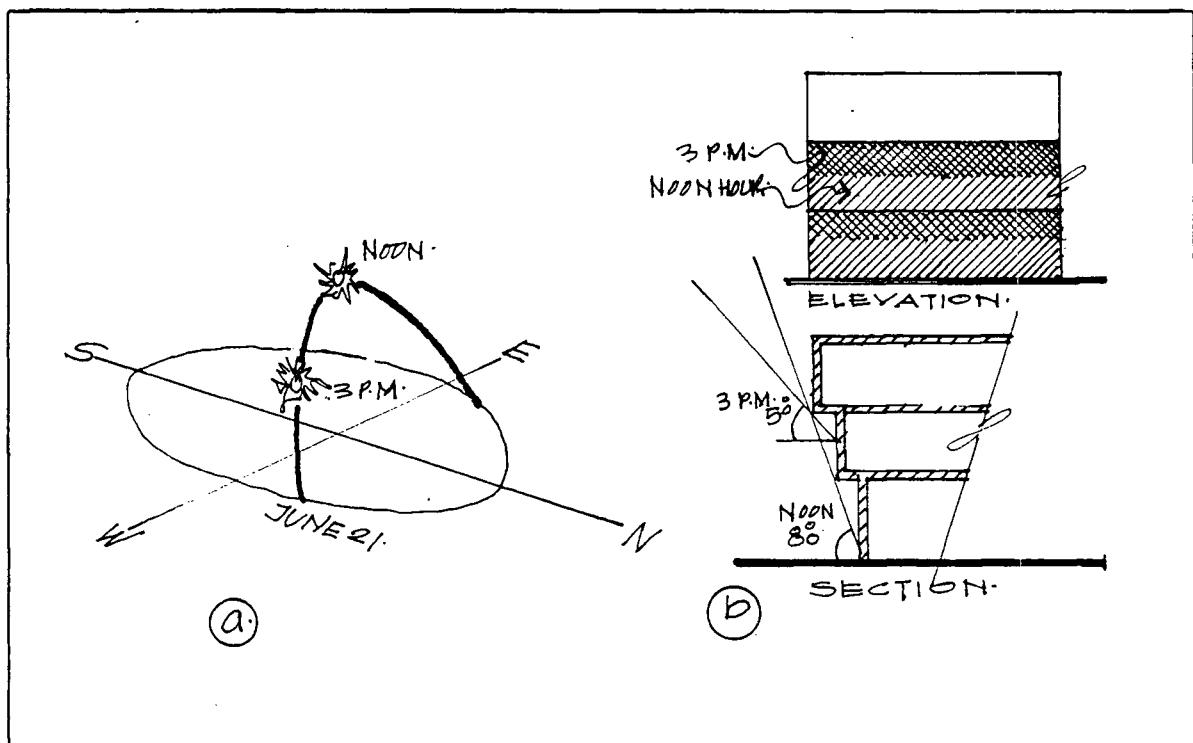


Fig.2.27. Solar Altitude and Shading of South facade
 a. Solar Altitude During Summer at Latitude 25° N.
 b. Shading of South Facing facade by projecting each floor.

The effect of distance between blocks on shading has been discussed under site planning strategies. This analysis suggests that compact forms like two to three storey housing blocks arranged in rows or clusters, with exposed surfaces facing north south orientation, benefit from maximum mutual shading if they are separated by distances less than their heights.

3.5. Thermal Zoning of various Spaces

Thermal zoning of various spaces according to their thermal comfort requirements using warm and cool areas in the dwelling is an effective way of enhancing thermal comfort.

Domestic buildings offer many possibilities for thermal zoning due to the varied use of spaces, and different time and frequency of use. As a result, with only a little effort by the designer, thermal comfort can be enhanced.

The main factors which should be considered in making decisions about thermal zoning (Cole, 1979) and the resulting allocation of spaces are showed in tables IIa and IIb. It is assumed that light weight cotton clothing is worn by the occupants.

Some important considerations regarding the thermal zoning of various spaces are:

a. In a hot and dry climate, because of afternoon rest periods especially during the peak summer months (May-July), bedrooms are used during the afternoon as well as at night. Therefore, maintaining cooler indoor temperatures for afternoon and night comfort is the prime concern in allocating bedrooms. The morning air temperature is below comfort range and penetration of sun at this time does not create as much discomfort as in the evenings.

Because of these considerations, a south or southeast orientation is most desirable for bedrooms. North or northeast orientation is also acceptable as it keeps the room cooler in the afternoon. In the forms like row houses which allow less flexibility in zoning spaces, preference should be given to locating the master bedroom in south or southeast and the remaining bedrooms in north or northeast. Split level planning in such cases

<u>ACTIVITY</u>	<u>THERMAL COMFORT CRITERIA</u>				
(SPACES)	TEMPERATURE CONDITION	VENTILATION	TIME OF USE	FREQUENCY	HEAT GENERATION
SLEEPING (BED ROOMS)	COOL	LOW	NIGHT/AFTERNON	CONTINUOUS	LOW
REST & LIGHT ACTIVITY (LIVING/DINING)	MODERATE	MED - LOW	DAY/EVENING	CONTINUOUS	LOW
FOOD PREPARATION (KITCHEN)	WARM	MED - HIGH	MORNING/EVENING	INTERMITTENT	HIGH
BATHING (TOILETS)	COOL	MED - HIGH		INTERMITTENT	LOW
STORING	COOL	MED - LOW		INTERMITTENT	LOW

Table IIa. Activity Analysis of Spaces in a Dwelling.

<u>ACTIVITY</u>	<u>ORIENTATION (ALLOCATION)</u>							
(SPACES)	N	NE	E	SE	S	SW	W	NW
SLEEPING (BED ROOMS)	✓	✓	✓	✓	✓			
REST & LIGHT ACTIVITY (LIVING/DIN)		✓	✓	✓	✓			
FOOD PREPARATION (KITCHEN)	✓	✓	✓	✓	✓			
BATHING (TOILETS)	✓	✓	✓	✓	✓	✓	✓	✓
STORING	✓	✓						

Table IIb. Allocation of Spaces with Respect to Orientation.

will achieve the best possible orientation for all the bedrooms.

- b. Living and dining spaces are used throughout the day and in the evening. As the evening activity in hot and dry climates is often outdoors, a livingroom abutting a terrace or an open space with a south or south-east orientation will be most desirable. Western exposures should be avoided for living rooms because of the evening over heating. In a compact layout where the side walls are shared. and the block is narrow, a split level planning will be useful. In split level houses, preference should be given to placing bedrooms on upper floors to improve comfort by rapid cooling at night.
- c. Toilets are separated from main living areas for hygenic purposes and moisture generation. This space is used intermittently and does not require thermal control. Only a higher ventilation rate and adequate lighting conditions are necessary. A west and southwest orientation will enable the toilet to act as a buffer zone for the living areas.
- d. Kitchen spaces generate heat and it is desirable to segregate them from the main living areas in order to reduce internal heat gain. The kitchen is used intermittently during the daytime but continuously in the morning and evening. A south-eastern exposure for a kitchen will provide cooler thermal conditions in the evening. The heat loss rate in the evening will also increase with the natural ventilation whereas, during

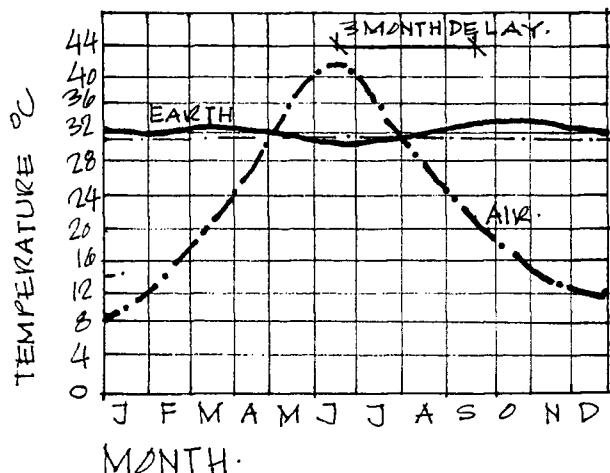
daytime, natural ventilation will increase the heat gain. A mechanical exhaust system can be used to augment or as a substitute for natural ventilation and to help control heat gain during day time.

- e. Many activities normally associated with indoor spaces in a cold climate are performed out of doors in a hot dry climate. This especially applies to activities like sleeping, washing, cooking, playing, eating etc. Therefore, the area adjoining the buildings becomes an extension of the indoor space and should be treated with equal care. For indoor spaces, passive means for thermal control are preferable to mechanical controls; for outdoor spaces this is the only form of control possible. Outdoor spaces like terraces, balconies, etc. are likely to be used in the evening or at night. A south or south-easterly exposure for these spaces will keep them cool for evening use.

3.6. Living Areas Below Grade

The soil can be used as a heat source in cold climate, a heat sink in hot climate or as insulation (Morelan, 1980). An approximate air temperature compared with earth temperature at a depth of 3m. in the hot and dry regions on a vegetated site in North America (Fig.2.28) illustrates that:

- a. The earth reaches a temperature of approximately 19°C (65°F) in summer and a high of 21°C (70°F) in winter, with an annual average of 20°C (66°F).
- b. The daily range of earth temperatures is much smaller than the daily range of air temperatures.



	AIR EXTREMES.	EARTH EXTREMES.
	COLDEST (JAN.)	HOTTEST. (JUNE)
AIR TEMPERATURE	8°C	42°C .
EARTH TEMPERATURE	BARTH AT AVERAGE OF 20°C DURING THESE PERIODS.	AIR AT AVERAGE OF 42°C AND 22°C DURING THESE PERIODS.
		30°C 34°C .

Fig.2.28. A Comparison Between Mean Monthly Air and Earth Temperatures.
Source: Moreland, 1980

Therefore, the soil surrounding a below grade space serves to radically reduce external climatic heating and cooling effects.

At the form design level, a designer can locate one or two living areas like bedrooms or living rooms in the basement. These areas will remain cooler than above grade spaces. The basement spaces, in addition to providing a comfortable thermal environment, increase the floor area of the house without adding to the ground coverage.

4. REDUCE INTERNAL HEAT GAINS

In residential buildings, the internal heat gains by body heat, appliances and electric lighting are not as significant as in commercial buildings. Thermal comfort in residential buildings is primarily climate related (Mara, 1984). However, in hot and dry regions, where external air temperature in summer is already 8-10°C above the comfort level, even a small amount of heat generated indoors will be undesirable for achieving and maintaining thermal comfort.

The amount of internal heat gains in a given area depends on the number and power of light bulbs, the heat generating capacity of appliances and the occupancy rate of the dwellings. Heat generated by the occupants depends upon their activity level.

Table III. shows the average heat gain from various sources in a dwelling with an occupancy rate of five.

4.1. Heat Generating Areas

The kitchen is the major area in residential buildings where a significant amount of heat is generated by cooking and the use of appliances.

Factors	Amount of Heat Gain
Human bodies	between 130-160 Watts for each body (Sedentary activity).
Lights	Incandescent 95% Of Wattage Fluorescent 79% of Wattage for each Lamp (when in use).
Appliances	Gas stove 1500-2000 Watts each Electric iron 500-1000Watts Washing machine 500-800Watts (when in use).

Table III. Internal Heat Gain from Various Sources.

Living rooms and study rooms require supplement lighting due to their continuous use and function. At the form design level, there are two ways of controlling internal heat gains in residential buildings;

1. By keeping heat generating areas like the kitchen and utility room etc. away from the areas of main use like livingrooms or bedrooms. A buffer space like a veranda, courtyard or passage can be placed in between.
2. By increasing the daylight potential of some spaces. This may be done by the provision of courtyards and light shafts in a compact layout.

The design of courtyards and shafts for ventilation, discussed in the following section, is equally effective for daylighting.

5. PROMOTE VENTILATION

Natural ventilation is most desirable during evenings when the outside air temperature is cooler than inside. Natural

ventilation contributes to thermal comfort inside the dwellings in two ways:

- a. By cooling the structure when the indoor temperature is above the outdoors. This may be termed as 'structural cooling'.
- b. By increasing heat loss from the body when the surrounding air is cooler than body temperature, and by evaporation of moisture from skin. This may be termed as 'comfort cooling'.

Structural cooling is a function of number of air changes per hour if the outdoor air temperature is cooler than indoor whereas Comfort cooling, for an air temperature lower than body (37°C), results from air movement and its adequate distribution in occupied zone. At the form design level natural ventilation for structural and comfort cooling may be enhanced by interior courts and shafts and by provision for cross ventilation.

5.1. Interior Courts and Shafts

In compact forms such as cluster or row housing, due to the proximity of surrounding buildings, the outside air velocity decreases before it enters the spaces inside the dwelling. As a result, the potential for both comfort and structural cooling by natural ventilation is reduced considerably. An improvement in air movement and exchange (Givoni, 1977) in such forms can be achieved by incorporating courtyards and shafts. The following factors are important for achieving structural and comfort cooling with courtyards and shafts:

- a. the temperature difference between inside and outside air, and
- b. the vertical distance between two openings.

The courtyards reduce the incoming air temperature by providing shade. This pool of cooler air stays in a courtyard because of being heavier than the surrounding warm air. For maximizing shading and resulting cooling of air, the length and width of a courtyard should be less than the height of surrounding structures.

When openings are provided at a higher and a lower level in a wall facing the courtyard (Fig.2.29), a convective loop is started with the cooler air coming in at the lower level and hot air rising and going out at the higher level. A minimum vertical distance of 2 m is required between openings to start and maintain this convective loop. A larger vertical distance between two openings will increase air movement desirable for comfort cooling, but will also involve more building material and additional cost. Therefore, courtyards may be more effective for providing structural rather than comfort cooling.

A higher air movement in a occupied zone within the dwelling can be achieved with cross ventilation. In the evening, when outside air is cooler than inside, air movement will be created by cross ventilation if windows of the room on both windward and leeward sides are opened. In order to achieve desired air movement and distribution in a room, the following factors are important:

- orientation of inlet and outlet windows with respect to wind direction and,
- their position and size.

Position and size of windows is considered at fabric design

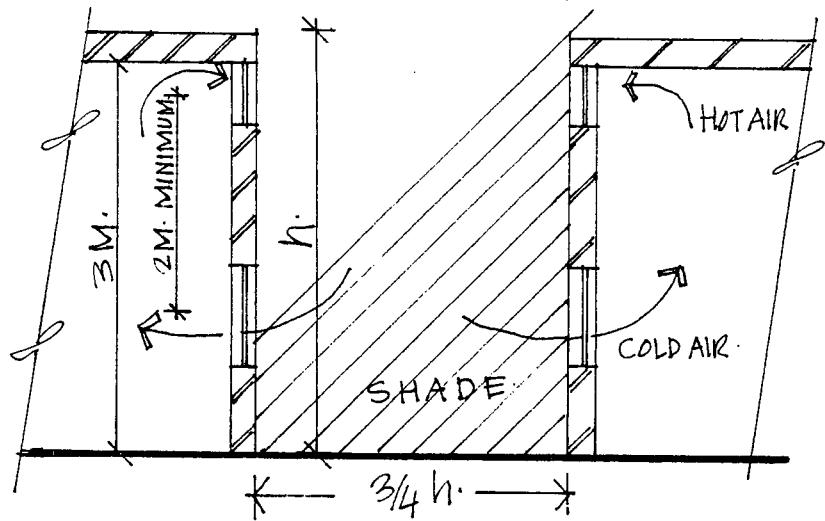


Fig.2.29. Size of Courtyard for Air Exchange due to Thermal Force.

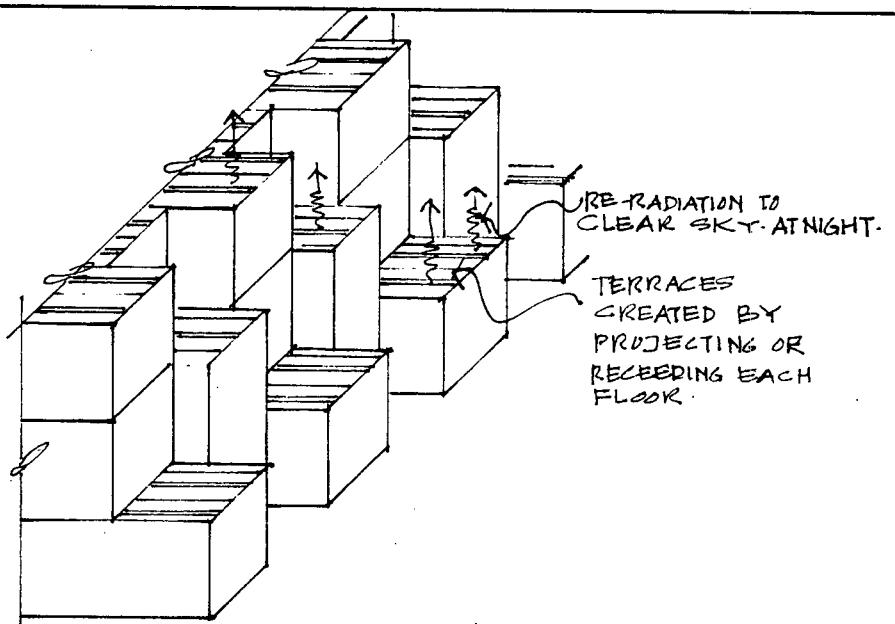


Fig.2.30. Terraces for Row Housing.

level whereas their orientation is decided at form design level.

5.2. Orientation

The wind movement in summer is from the east to west. Orienting windows towards the wind direction is not very effective because the air in this case will flow straight through the rooms, ventilating only a limited section (Givoni, 1981). On the other hand if the windows are oriented oblique to the wind direction, a larger indoor area will be affected by the air flow, and average velocities will be higher. Based on these considerations, a south to south-east orientation of form will fulfil required conditions for comfort cooling more effectively than east-west. In a hot and dry climate, where ambient temperature has a greater physiological influence than ventilation, the orientation of larger surfaces between 15 and 30° east of south will also minimize heat gain from solar radiation.

6. PROMOTE RADIANT COOLING

6.1. Terraces

At night, long wave re-radiation to the clear sky causes the temperature of horizontal surfaces to drop below ambient air temperature. This phenomenon can be used for cooling some spaces in dwellings at night with the help of an exposed roof surface (Givoni, 1981). In multiple storey row houses, where ground and middle floor roofs are not exposed, it is advantageous to have terraces on these levels (Fig.2.30). Terrace form housing, in addition to providing radiant cooling

for the spaces under terraces, also provides outdoor space suitable for use in the evening and at night.

Terraces, however, create the problem of heat gain during daytime. As a remedy to this problem various methods of shading the roof during the daytime can be considered. Some of these methods are:

- a. Use of movable shades made of canvas or some insulating material
- b. Fixed shades made of light weight materials
- c. Shading by deciduous creepers

Fixed shades are least effective because they obstruct radiant cooling at night. Movable shades made of canvas, timber and some insulating materials have maintenance problems and a short life span. Shading by deciduous creepers trained on to wiremesh, about 2 m above the roof surface is an effective method of controlling heat gain on the roof. The creepers do not interfere with radiant cooling as leaf temperatures are lower than the ambient temperature.

SECTION IV: FABRIC DESIGN STRATEGIES

1. INTRODUCTION
2. MINIMIZE SOLAR GAIN, PROMOTE VENTILATION,
CONTROL GLARE
 - 2.1. Windows: Introduction
 - 2.2. Window Orientation
 - 2.3. Exterior
 - 2.4. Exterior Accessories
 - 2.5. The Window
 - 2.6. Interior Accessories
 - 2.7. Interior
3. DELAY PERIODIC HEAT FLOW, MINIMIZE CONDUCTIVE
HEAT FLOW
 - 3.1. Roof and Walls: Thickness, Materials,
Colour

1. INTRODUCTION

The fabric of a dwelling comprises of windows, walls and roof, built with different building materials and thickness. Each of these elements acts as a filter that rejects, receives or moderates the external climate (Fig.2.31). At the fabric design level an architect can design various elements which can bring the internal thermal conditions to a desired level. However, the particular

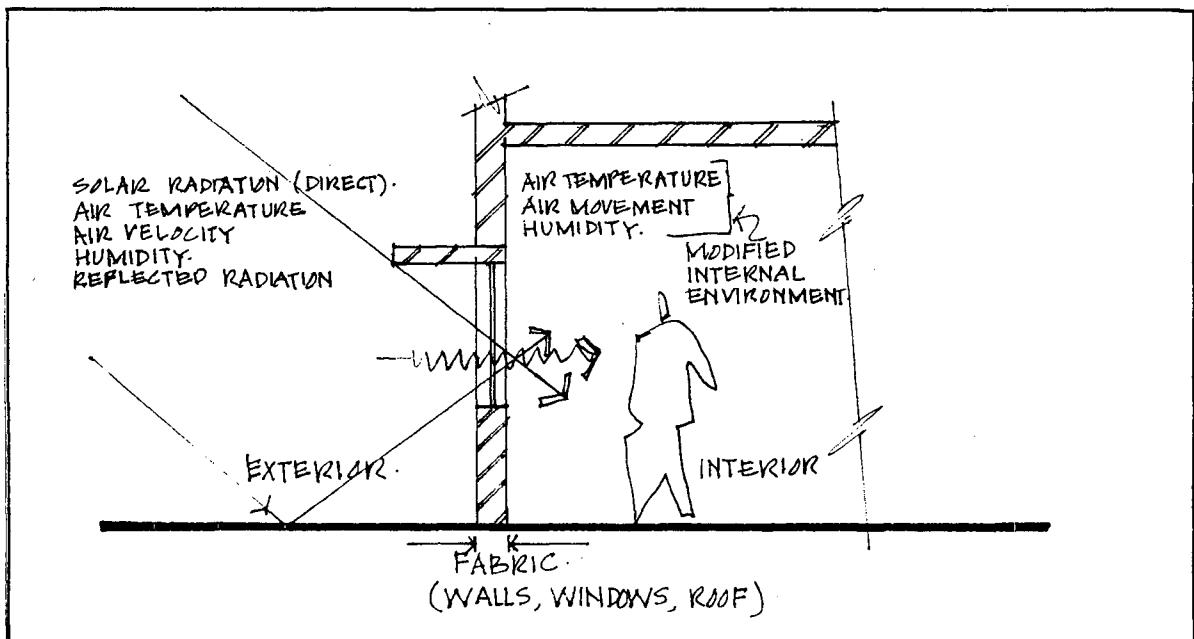


Fig.2.31. Fabric as a Filter of External Climate.

emphasis and design effort required for each element of the fabric is dependent on strategies followed at earlier levels of design.

The strategies for windows walls and roof design for enhancing thermal comfort are discussed in the following

sections.

2. MINIMIZE SOLAR GAIN, PROMOTE VENTILATION, CONTROL GLARE

2.1. Windows: Introduction

Traditional dwellings in the hot and dry regions in India were built with a minimum window area to reduce the adverse effect of extreme climate. A window, however, in a contemporary dwelling is expected to serve the following functions:

- a. to permit daylight,
- b. to promote ventilation for comfort and structural cooling,
- c. to provide view,
- d. to minimize solar gain in summer,
- e. to allow winter heat gain,
- f. to give protection from glare,
- g. to provide noise insulation, and
- h. to fulfill the aesthetics of facade.

Because of their ability to transmit solar radiation, windows permit several times greater heat gain than wall areas (Givoni, 1981,). However, the overall thermal performance of windows is not based only on heat gain by solar radiation. With respect to thermal comfort the important functions of windows are to provide protection from summer solar gain, glare, and to promote natural ventilation for comfort and structural cooling. Window design is a careful balancing of all these functions. For instance, the need to decrease heat gain in the room may lead to designing a small window which could, in turn, result in depriving the interior of ventilation for comfort cooling. Therefore, all functions important for achieving thermal comfort must be considered collectively so that the emphasis on one function does not

result in depriving the occupants of the others. The window design becomes even more complicated when addition functions such as providing view are also considered.

The solar gain, ventilation and glare permitted by windows are regulated by several design factors which are within the control of a designer. The most significant of these are the window area, its orientation, its vertical and horizontal positioning and the glazing materials. However, the contradictory functions of windows make it difficult to achieve desirable thermal performance with only these factors and require additional parts and window accessories to improve each function separately. Therfore, the design of window accessories such as shading projections, canopies and landscaping around the window becomes equally important. On account of the contradictory functions and several design factors, window design is the most complex part of the fabric design. In order to simplify the complexity of the overall window system, it is useful to differentiate it in terms of exterior parts identified with exterior climate, and interior parts identified with interior environment (Leu, 1980): The hierarchy of parts in the overall window system is as follows:

- a. Exterior
- b. Exterior Accessories
- c. The Window
- d. Interior Accessories
- e. Interior

Each of these parts of the window system can help in modifying the influence of exterior climate on internal thermal conditions. The specific architectural design of these parts is dependent on the elements of external climate, the time of the day and the month. A general introduction of all these parts is given below.

a. Exterior

The exterior of the window system constitutes the surrounding surfaces, vegetation, screens etc. The exterior elements are the first factors in window design by which the adverse effects of climate can be reduced.

b. Exterior Accessories

These constitute shading devices, roller blinds, exterior shutters, awnings, and screens, all of which are partly or fully attached to windows. The basic purpose of exterior accessories is to control solar gain and to modify wind movement.

c. The Window

The window itself is an important part of overall window system as it influences the internal thermal conditions by permitting heat gain and ventilation. The window area, its position, and the type of window material used are the most important design factors.

d. Interior accessories

Interior accessories such as drapes, blinds and shutters. provide control over the solar radiation that is permitted through the window. Although they are not effective for

reducing heat gain, they can reduce glare.

e. Interior

The colours and material of the walls can be used to supplement the thermal performance of windows. This is especially useful for reducing glare which can be accomplished with careful selection of color.

2.2. Window Orientation

An important consideration in window design is its orientation because it dictates the design of both the exterior and interior parts of the overall window system.

Figure 2.32 shows the solar heat gain permitted by a 1mx1m window in various orientations. The window is without any shading devices and is unventilated. The effect of orientation on heat gain and its implications on window system design are summarized below:

- a. The heat gain through windows facing south to 30° east of south is lower than other orientations during summer. This orientation also allows wind movement in the evening as the direction of wind flow is east-west. Therefore, larger window area in this orientation will benefit from both minimum heat gain and comfort ventilation. In addition, due to a higher altitude of sun in south during summer it is easier to provide effective shading with less complicated shading devices.
- b. Heat gain through east and west facing windows is the maximum, hence relatively smaller and fewer windows

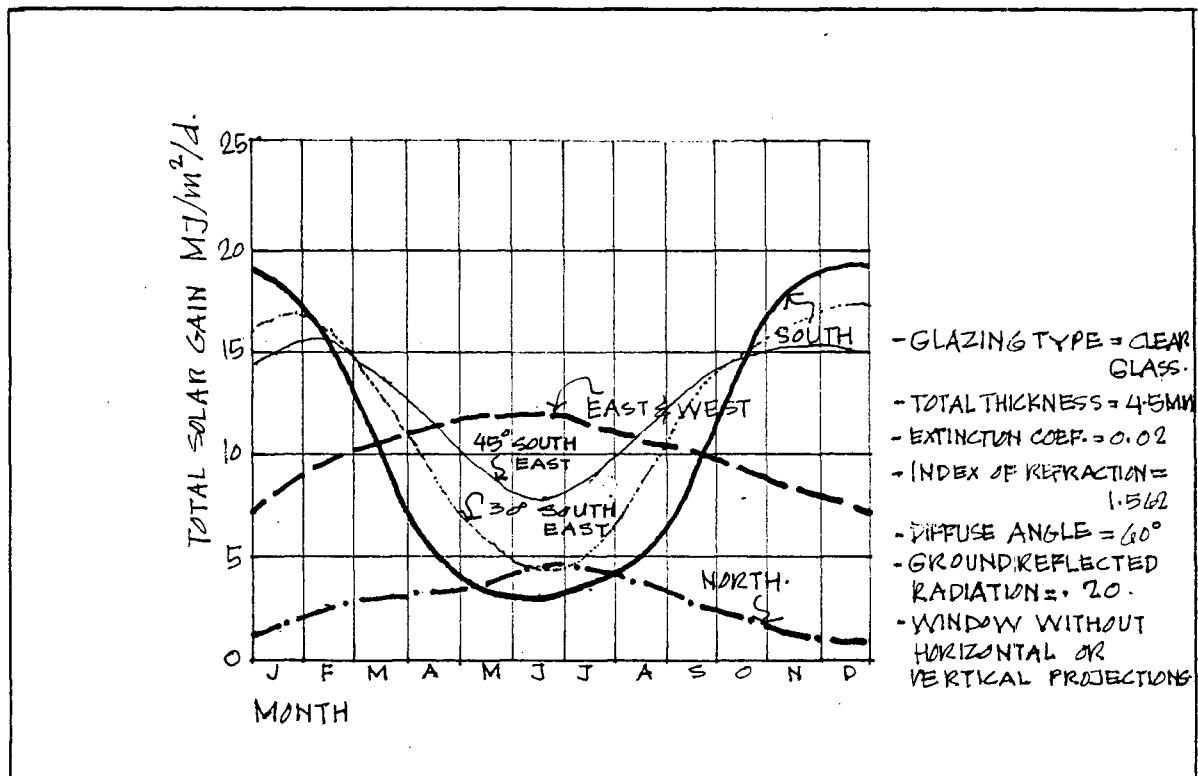


Fig.2.32. Solar Heat Gain Permitted by a 1mx1m Window in Various Orientations.

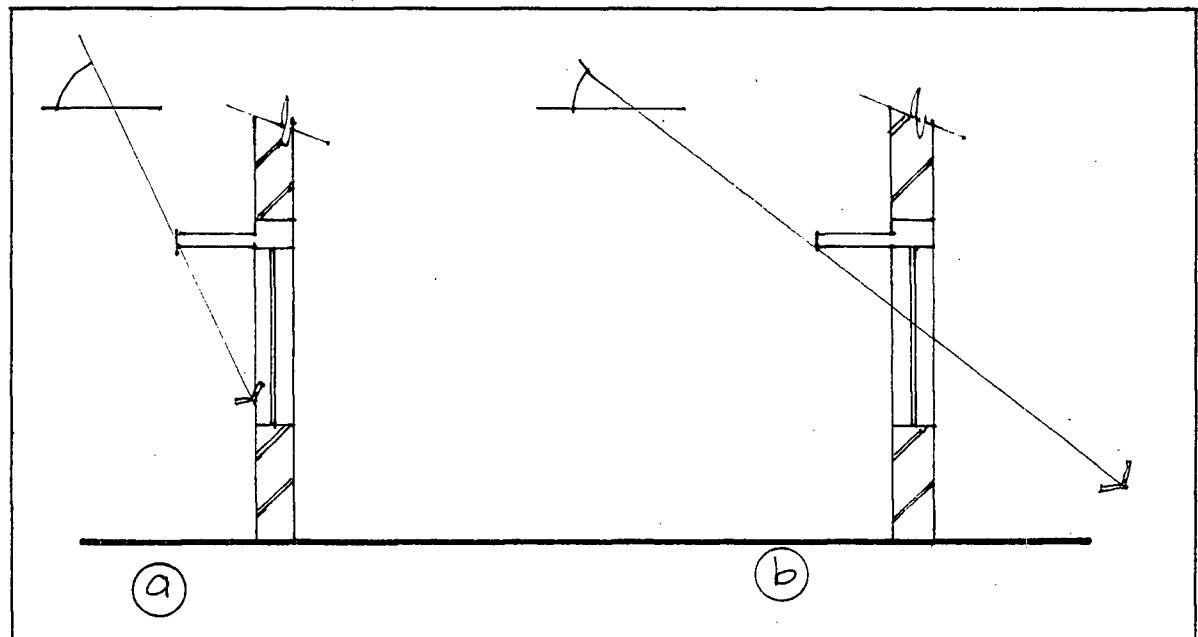


Fig.2.33. Solar Altitude and Windows in various Orientations.

a. Solar Altitude during Summer and Windows in South

b. Solar Altitude during Summer and Windows in East and West.

- should be placed in these facades. In addition, the design of fixed shading is most critical in these orientations. Windows facing east or west receive summer sun for more hours and at a more direct angle than southern exposures (Fig.2.33a,b). Therefore, these windows are more difficult to shade and require more complicated horizontal and vertical overhangs.
- c. East facing windows are better than west facing ones for thermal comfort, since the former receive summer sun in the evening when the air temperature is maximum. This implies that the window area in the east can be larger than the west.
 - d. North facing windows allow less heat gain than east and west. Larger window area in north is beneficial in summer but can cause some discomfort during winter due to the absence of direct sun.

Heat gain in various orientations can be altered, however, with the degree and efficiency of shading devices and with the presence of ventilation conditions (Givoni 1981).

2.3. Exterior

In addition to direct radiation, the buildings receive diffuse and reflected radiation. Figure 2.34 shows the relative proportion of these components upon a south facing window at latitude 25°N . The reflected radiation incident upon a window varies with the reflectance value of surface materials surrounding the window and its orientation.

With the lower altitude of the sun, such as in east and west

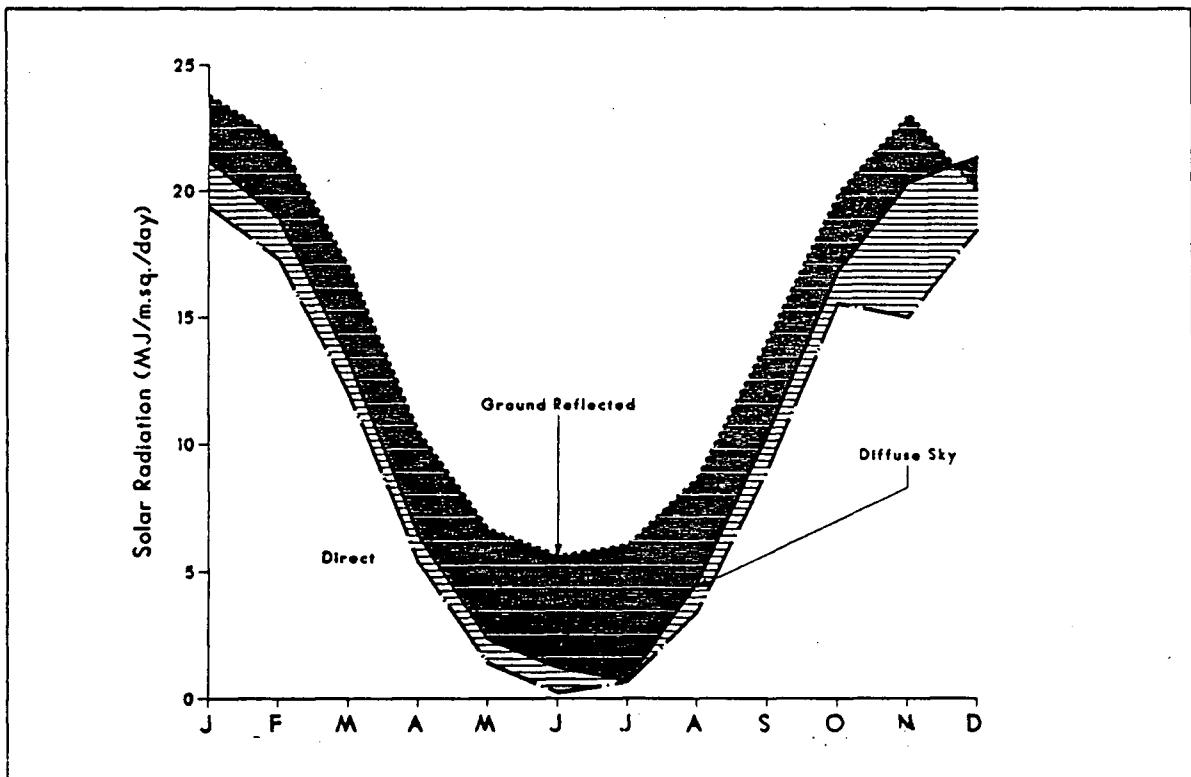


Fig.2.34. Relative Proportion of Ground Reflected, Direct and Diffused Solar Radiation Incident upon a South facing Window at Latitude 25°N

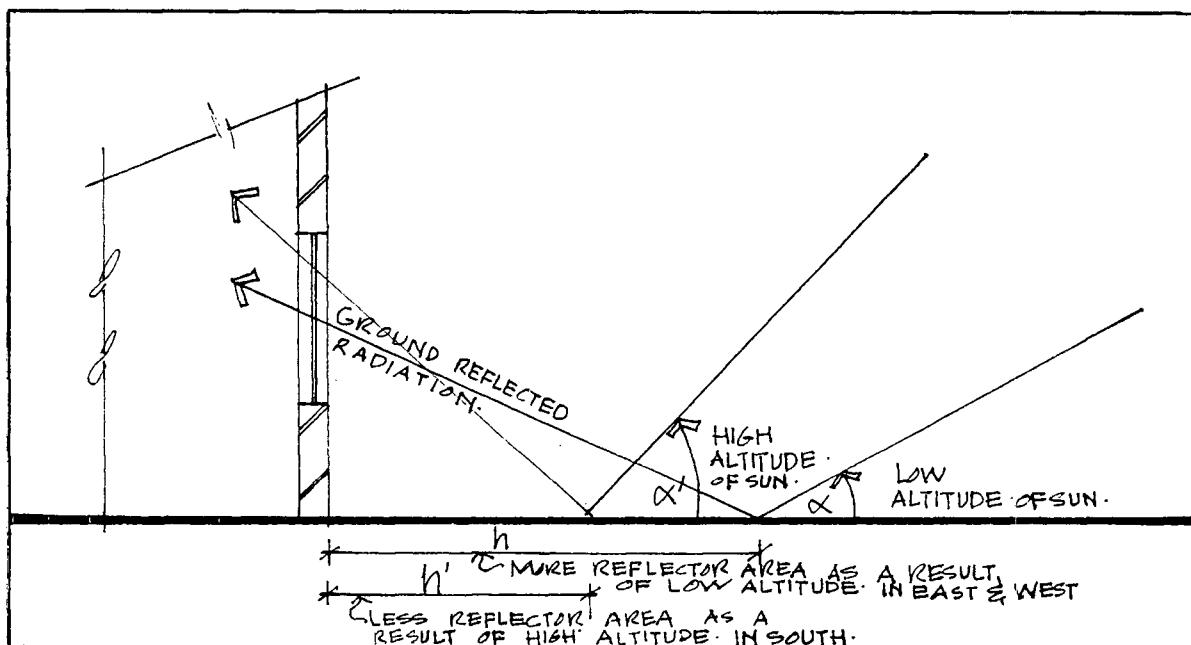


Fig.2.35. Solar Altitude and Reflector Area in East, West and South Orientations.

orientations, the reflector area surrounding the window increases (Fig.2.35) which in turn increases the solar radiation incident upon the window. The greatest concern in these orientations is the material used for the reflector area surrounding the window. The use of landscaping outside the window will be effective in reducing the reflected radiation. Landscaping will also reduce the temperature of incoming air if the windows are open. The shrubs, hedges and plants, however, should be lower than the window sill so that they do not deflect desired air movement.

2.4. Exterior Accessories

The basic purpose of exterior accessories is to control solar heat gain during the summer and to permit it in winter. Another function of exterior accessories is to promote ventilation to enhance thermal comfort. The accessories designed for solar control and comfort ventilation, however, also affect daylight, glare, and view.

Accessories for solar control

There are two types of exterior accessories for solar control: fixed and adjustable shading devices. The fixed shading devices include horizontal, vertical and eggcrate projections whereas the adjustable devices include wood shutters and a variety of louvers: vertical, horizontal and combinations of both. The adjustable shading devices can be moved at will to fulfill changing requirements, but fixed devices exert their effect in a predetermined fashion.

In order to design fixed shading devices the architect must first know the solar altitude and the solar azimuth angles. Both can be found, for any date of the year and any hour of the day, by using the sun-path diagram for the particular latitude. Fig.2.36a shows the sun path diagram for 25°N latitude.

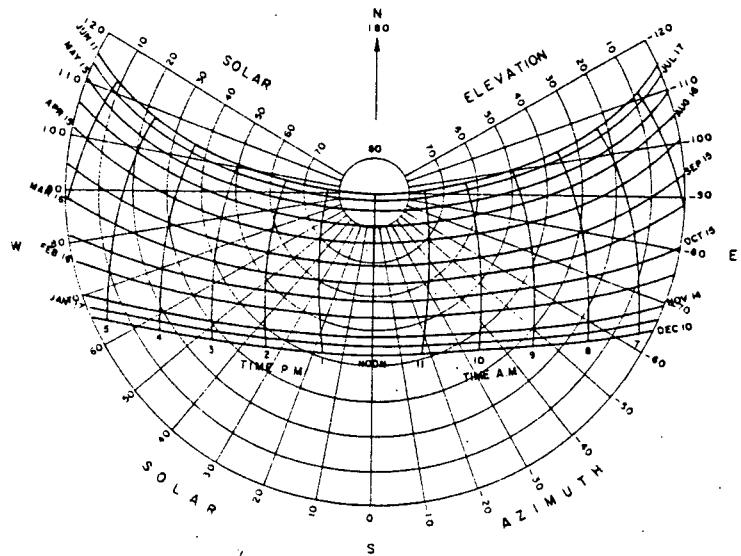
The next step is to define and mark the overheated period on the sun path diagram. Using the mean hourly temperatures for each month, the overheated period can be defined and marked on the sun path diagram (Fig.2.36b).

Once the overheated period is determined, with a solar shading mask placed on the sun path diagram, vertical and horizontal shadow angles can be found. With this information the depth and shape of vertical and horizontal projections can be determined for any orientation.

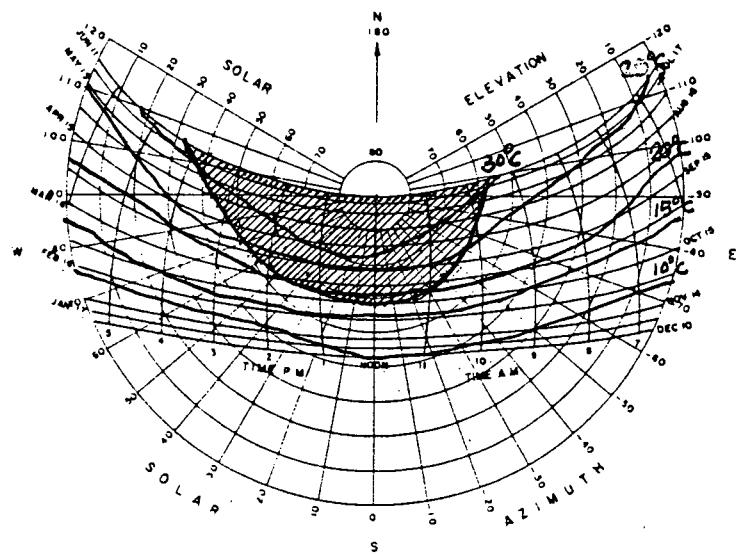
Due to different solar altitude and azimuth, the shape and size of solar control devices may be different for various orientations. Therefore, solar controls, in addition to providing protection from sun can give a strong architectural character to a facade. An architect can utilize this aesthetic potential in a positive way by giving an individual character to each facade.

The fixed shading devices are also easy to integrate into the conventional building construction methods in India. The simplicity of their integration makes them an attractive option, especially for south facing windows.

On the negative side, the performance of fixed shading devices,



(A)



(B)

Fig.2.36. a. Sun Path Diagram for Latitude 25°N
 b. Overheated Period for Latitude 25°N

designed to control solar gain during the periods with maximum temperature, may not be as effective as desired. This is illustrated by Givoni (1981):

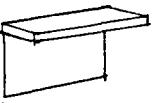
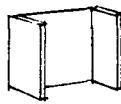
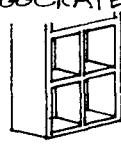
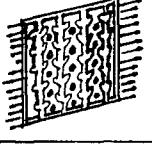
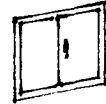
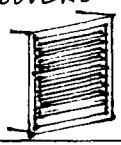
"The functional requirements for solar control differ widely with regional climates and, within each region, with seasonal climatic variations. This problem is further complicated because of the different yearly patterns of temperature and solar radiation. While the intensity of solar radiation (in the northern hemisphere) has its maximum on June 22nd and its minimum on December 22nd, the temperature yearly wave is delayed on account of the heat capacity of the earth's surface and reaches its maximum in July-August and its minimum in January-February. Therefore when the sun is excluded in the hot late summer by some fixed arrangement it will be excluded too in the cool spring, so that some compromise is required in this case."

In addition, fixed shading devices, due to the use of materials like steel and concrete for their construction, are an expensive solution to the problem of heat gain.

For such conditions, adjustable shading devices will provide more satisfactory performance and will be relatively inexpensive to construct. With adjustable shading devices like wooden shutters and louvers, it is possible to eliminate upto 90% of the heating effect by solar radiation during the periods with maximum temperature in summer.

Table IV lists the thermal performance of some commonly used exterior shading devices in hot and dry climates. The influence of these devices on daylight, glare and view is also included in this table. It is indicated in this table that horizontal projections in south orientation are more effective than vertical to control solar radiation. Vertical projections on the east and west are effective in

IV. Performance of Exterior Shading Devices.

EXTERIOR SHADING DEVICES	THERMAL PERFORMANCE	OTHER FACTORS
FIXED.		
HORIZONTAL PROJECTIONS.	<ul style="list-style-type: none"> - REDUCE SOLAR GAIN EFFECTIVELY IN S, SW, SE. - REDUCE GLARE. - DEFLECT WIND ADVANTAGEOUSLY. - LEAST EFFECTIVE ON E & W FACADES. 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT POTENTIAL. - DO NOT BLOCK VIEW - COLLECT DUST.
VERTICAL PROJECTIONS.	<ul style="list-style-type: none"> - NOT VERY EFFECTIVE IN REDUCING SOLAR GAIN IN ANY ORIENTATION. - IMPROVE WIND VELOCITY & DISTRIBUTION IN INTERIOR. - REDUCE GLARE. 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT POTENTIAL. - BLOCK VIEW PARTIALLY.
EGGCRATE	<ul style="list-style-type: none"> - PARTICULARLY EFFECTIVE IN SE AND SW ORIENTATIONS FOR REDUCING SOLAR GAIN. - REDUCE VENTILATION CAPABILITIES. - INCREASE GLARE 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT POTENTIAL SUBSTANTIALLY. - EXPENSIVE SOLUTION TO SOLAR CONTROL PROBLEM. - BLOCK VIEW PARTIALLY.
LATTICE (JALI)	<ul style="list-style-type: none"> - REDUCE SOLAR GAIN - REDUCE WIND VELOCITY BUT ALLOW VENTILATION. - REDUCE GLARE. - REDUCE DUST. 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT POTENTIAL. - AESTHETICALLY PLEASING. - BLOCK VIEW PARTIALLY.
VERTICAL PROJECTIONS AT 45° ANGLE.	<ul style="list-style-type: none"> - REDUCE SOLAR GAIN IN E, W. ORIENTATIONS - BLOCK WIND SUBSTANTIALLY. - REDUCE GLARE. 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT POTENTIAL SUBSTANTIALLY. - BLOCK VIEW TO A LARGE EXTENT.
MOVEABLE		
WOOD SHUTTERS (CLOSED)	<ul style="list-style-type: none"> - REDUCE SOLAR GAIN SUBSTANTIALLY. - BLOCK WIND SUBSTANTIALLY. - REDUCE GLARE. - REDUCE DUST. 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT SUBSTANTIALLY. - BLOCK VIEW SUBSTANTIALLY.
HORIZONTAL LOUVERS	<ul style="list-style-type: none"> - EFFECTIVELY REDUCE SOLAR GAIN IN ALL ORIENTATIONS. - POSITION TO REDUCE SOLAR GAIN MAY CONFLICT WITH WIND MOVEMENT. - REDUCE GLARE. 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT POTENTIAL. - BLOCK VIEW PARTIALLY.
VERTICAL LOUVERS	<ul style="list-style-type: none"> - EFFECTIVELY REDUCE SOLAR GAIN IN ALL ORIENTATIONS. - DIRECT WIND MOVEMENT IN THE DIRECTION POSITIONED TO CONTROL SOLAR GAIN. - REDUCE GLARE. 	<ul style="list-style-type: none"> - REDUCE DAYLIGHT POTENTIAL. - BLOCK VIEW PARTIALLY.

providing adequate shading only if they are tilted at 45° to the south. This position, however, eliminates comfort ventilation.

The thermal performance of both fixed and adjustable external shading devices improves if they are of darker colours and the room is unventilated (Givoni, 1981). This is because darker colours reflect lesser solar radiation towards the interior and an increase in external air temperature, from the heat absorbed by shading devices, does not elevate the air temperature of the unventilated room.

Accessories to promote ventilation

The accessories designed for controlling solar radiation may also promote ventilation. In row houses or other compact forms, where only two facades are exposed, it is not always possible to provide cross ventilation by keeping windows in both windward and leeward direction. The exterior accessories are advantageous for such cases as they accelerate the wind velocity and enhance comfort cooling particularly in rooms with windows only in windward direction. Figure 2.37 illustrates this:

- a. A room with one window in windward direction has a much lower wind velocity than a cross ventilated room (Fig.2.37a,b). This is because the internal external pressure gradient across the opening is very small (Melaragno, 1983).
- b. By providing two windows (with a total area equal to the single window in first case) in windward direction (Fig.2.37c) the wind velocity in the same room improves,

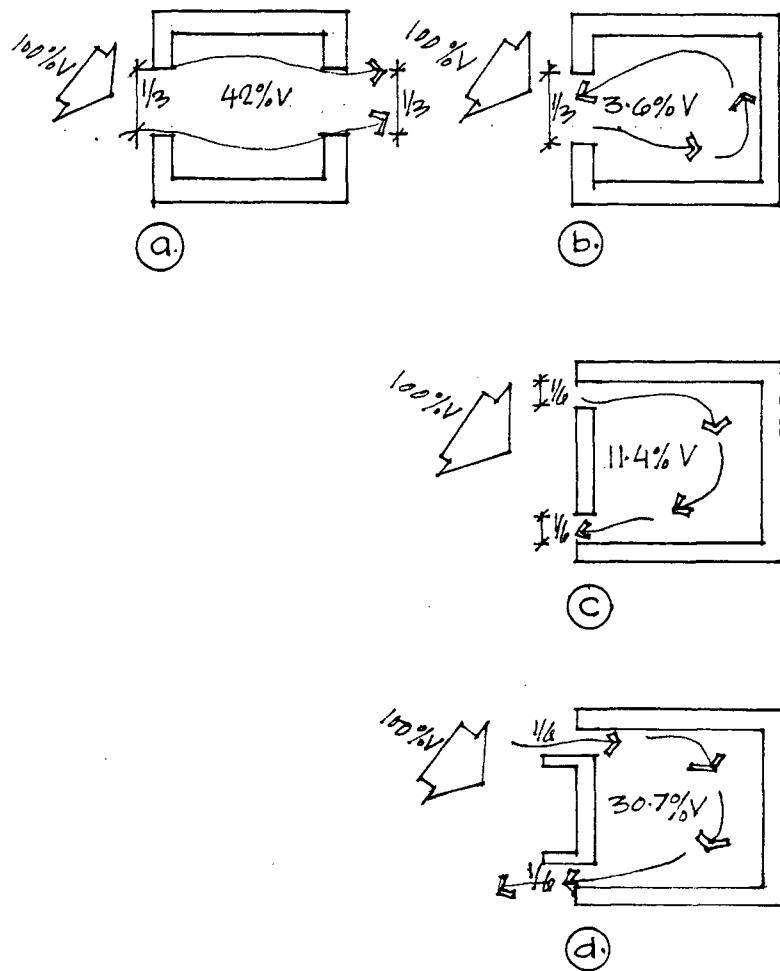


Fig.2.37. Vertical Projections and Wind Velocity in a Room.

- Wind Velocity in a Cross Ventilated Room.
- Wind Velocity in a Room with One Window.
- Wind Velocity in a Room with Two Windows on the Same Wall
- Wind Velocity with the Addition of Vertical Projections.

Sources: Chandra, Subrato, 1983. Melaragno, 1982

but only moderately as the pressure gradient is still small.

c. However, when vertical projections are added to these windows (Fig.2.37d) the wind velocity in the same room increases dramatically. The interior wind velocity in this case increases almost three times the first case but only if the wind direction is oblique to the inlet windows. This improvement in wind velocity is achieved because, with the addition of vertical projections, a pressure region is formed in front of the inlet window and a suction at the outlet window resulting in improved cross ventilation.

The depth of vertical projections is not an important factor for improving ventilation conditions (Givoni, 1981). However, if vertical projections are provided for windows of 2-3 rooms in the same orientation, the depth of projections should not be more than one half the distance between two openings. The projections larger than this may obstruct the wind movement in the adjacent room.

Horizontal projections do not influence the velocity of air, but have significant impact on the air flow pattern in a room. For instance, fixed horizontal projections eliminate the effect of pressure build-up above the window, thus the pressure below the window directs the air flow upwards leaving the occupied zone without airflow (Fig.2.38a). A gap between the horizontal projection and the building face can ensure a downward pressure.

There may be a conflict between desirable air flow pattern and

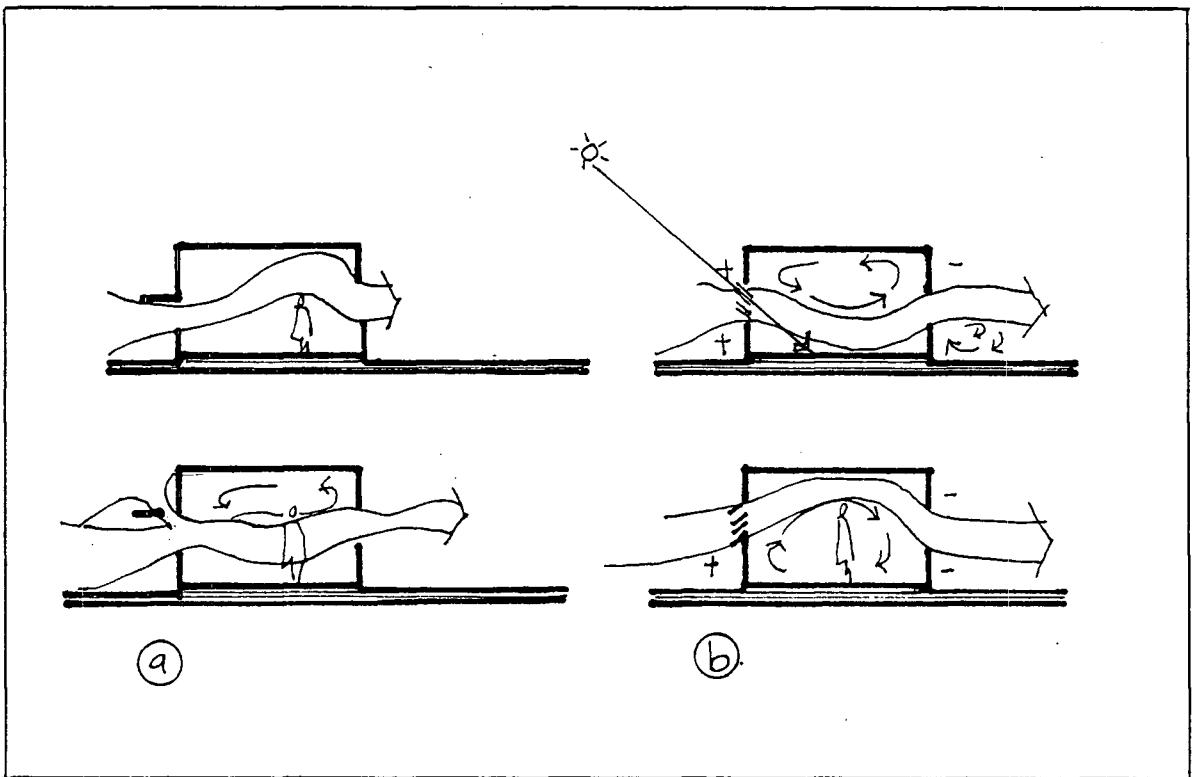


Fig.2.38. a. Fixed Horizontal Projections and Air Flow.
b. Adjustable Horizontal Louvers and air Flow.
Source: Fathy, 1986

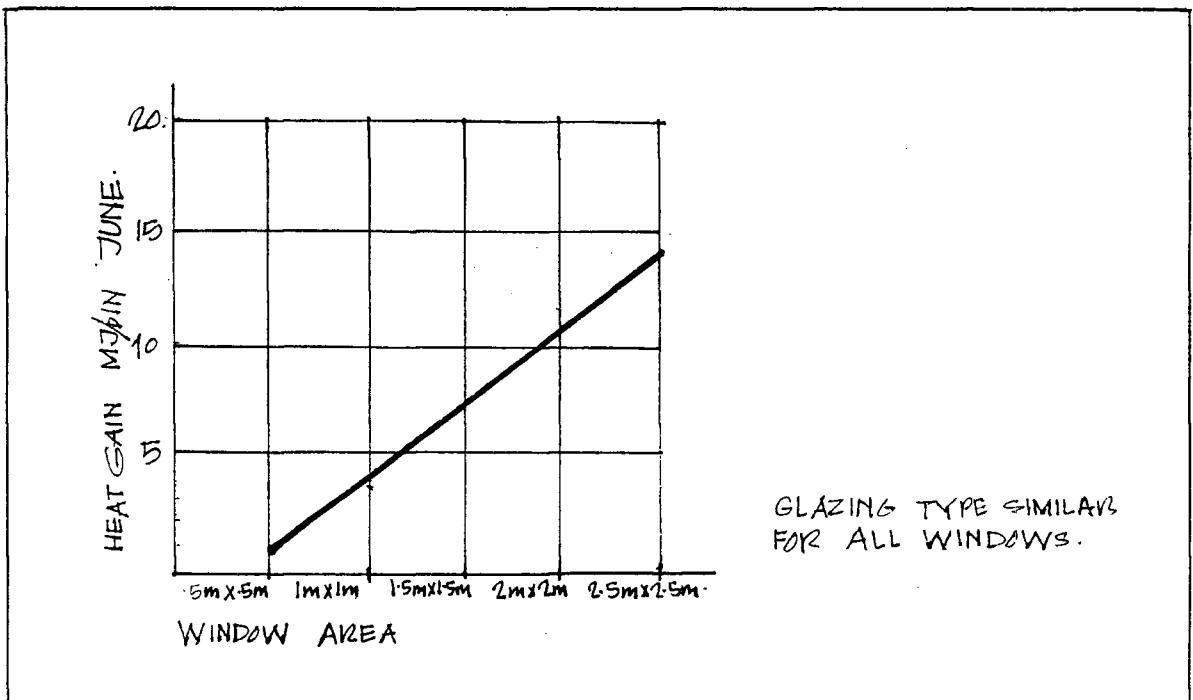


Fig.2.39. Heat gain Through Windows of Different Areas in South Orientation.

control of solar radiation in positioning adjustable horizontal louvers. For instance, louvers angled downward will direct the air flow into the occupied zone (Fig.2.38b) in a room, but will not prevent the sun to penetrate.

2.5. The Window

Window Area

A significant amount of heat gain through the closed glass windows takes place by solar radiation. For a constant radiation heat flow and solar gain factor of the window glass, window area is the most important consideration in determining heat gain by solar radiation (Fig.2.39).

Window area is also an important consideration for structural and comfort cooling as it determines the air exchange rate (m^3/h) and wind velocity in a space, when the windows are opened in the evening. For a given outdoor wind velocity, the air exchange rate in a space increases proportionately with the window area.

Whereas, from the point of view of reducing heat gain, a minimum area of window is desirable even in south orientation, a considerable decrease in window area will also reduce comfort and structural cooling in the evening resulting in an increased dependence on mechanical cooling. Therefore, window area should be kept to a minimum compatible with adequate comfort and structural cooling requirements.

When the window area is 25-30% of the corresponding wall area in north and south orientations, and is designed with proper shading and minimum ventilation, the room air temperature and

requirements for mechanical cooling are minimum during the day time in summer (Shrifteiliq, 1980). In the evening and at night (between 9 p.m. to 7 a.m.), if the windows are open and the room has between 12-30 air changes per hour, the indoor air temperature drops within the comfort range ($22-30^{\circ}\text{C}$). A high air change rate during the night, achieved by 25-30% window area, also improves the room air temperature during the day due to structural cooling and keeps it within an acceptable range of thermal comfort (Golneshan, 1985). Window area is an important factor for determining air velocity for comfort cooling in a space.

In a room with one window the influence of window area on air velocity is appreciable (Fig.2.40), especially when direction of air flow is oblique to the window. The wind velocity in this case increases proportionately with window area and also is distributed over a larger space (Givoni, 1981).

If a room is cross ventilated, an increase in the size of windows has a greater effect on internal air velocity, but only when the inlet and outlet openings are increased simultaneously. When a room has unequal openings, and the outlet is larger than the inlet, higher average speeds and much higher maximum velocities are obtained (Fig.2.41). However, a combination of a small inlet with larger outlet produces a concentrated airflow, limited to a small section of the room. Such an arrangement is desirable when the air stream is to be directed at a given part of the room. On the other hand, when the inlet is larger than the outlet, maximum velocities are much lower but the average indoor velocity is

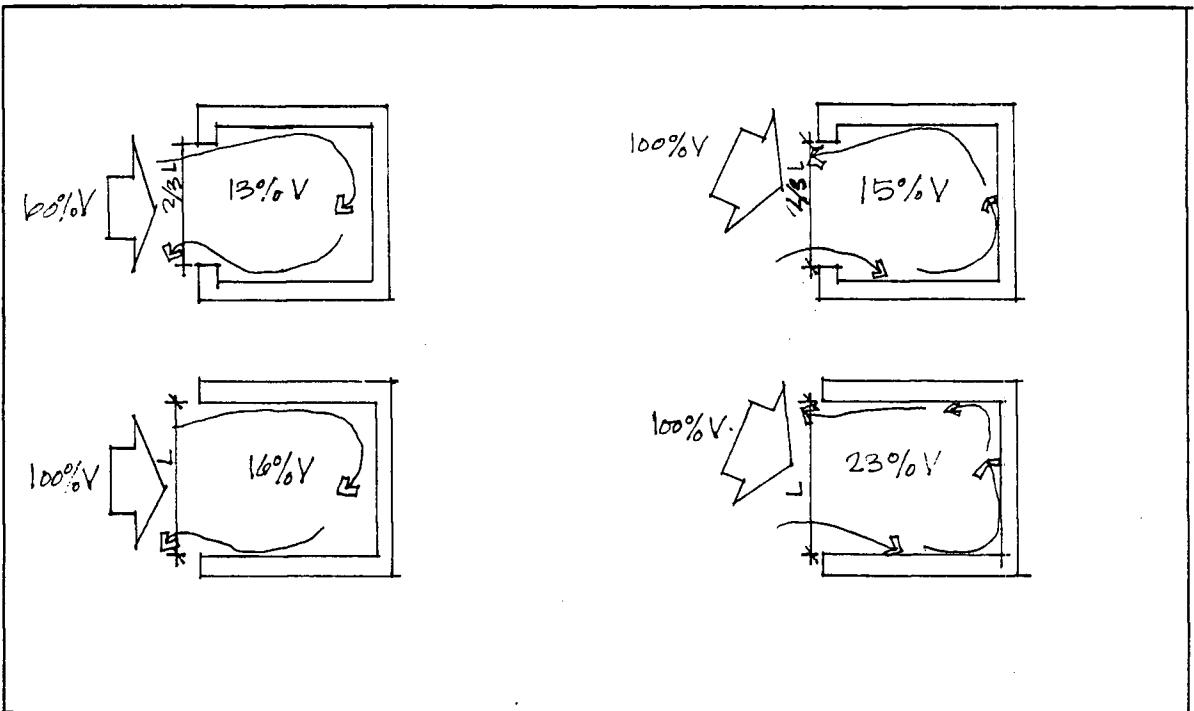


Fig.2.40. A Larger Window Area Increases Wind Velocity in a Room with One Window Especially When Wind is Oblique to the Window.

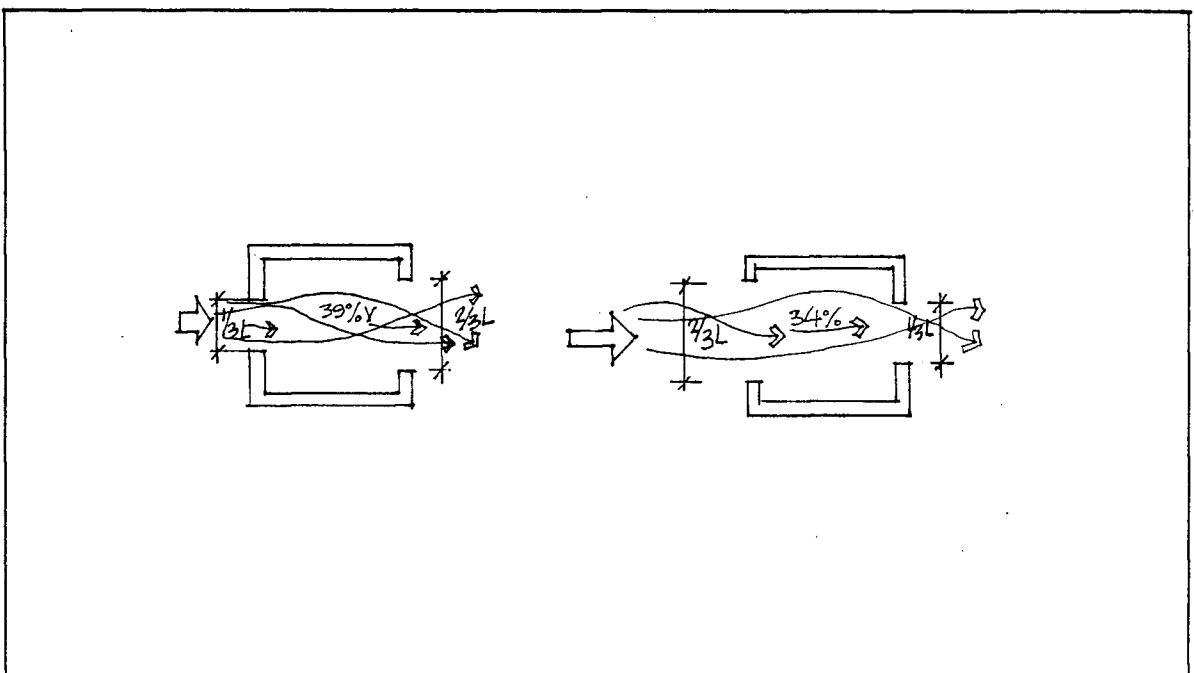


Fig.2.41. Higher Wind Velocity Inside a Cross ventilated Room Can be Achieved When it Has Unequal Openings and the Outlet is Larger than the Inlet.
Source: Givoni, 1981

not affected much. When air flow through the whole space is required, a large inlet opening will be desirable.

Window positioning

A significant effect of window position is on air distribution and velocity in a space.

The vertical position of a window, with respect to the air distribution, varies with space usage in a dwelling. For instance in the living room, where most of the area is occupied by seated people, the main air flow will be desired at the head and shoulder height (70 to 120cm.) of the seated people (Givoni, 1969). In bedrooms the main airflow in the evening should be at a height a little above bed level (50 to 80cm.). Windows kept below these levels will not be effective in providing comfort cooling in these rooms and will only increase the heat gain.

In the kitchen space, requirement for adequate air changes is more important than proper air distribution and velocity due to cooking odours and moisture. Air changes in kitchen are best achieved through windows placed closer to the ceiling. A light breeze in kitchen may be required below the counter top level, whereas air distribution above or at the work top level will be disruptive to cooking activity. However, windows above the counter top level are required for daylighting in kitchen.

If the room is cross ventilated, the height of the outlet window has a small effect on the distribution and velocity of the air, but there is an abrupt drop in air velocity below the sill level of an inlet window. This implies that a proper

vertical position of an inlet window is more important than the outlet window in a cross ventilated space.

In addition to air distribution and velocity, window position also affects glare. Glare is a function of the contrast between the window and window wall (Fig.2.42a). A room with windows on one wall only will always have this problem. However, such problem can be rectified by positioning windows on opposite or adjacent walls (Fig.2.42b). The glare can also be reduced by positioning windows with the sill above eye level which also concentrates ground reflected light on to the ceiling. A light colour ceiling can in this way ensure adequate and well diffused interior lighting, through a comparatively small window (Fig.2.42c). Low level windows will be glare free if they open into a shaded and planted courtyard. Vertical strip-windows placed in the corners of room will also be effective in reducing glare if the adjacent wall is painted a light colour (Fig.2.42d). This will throw light onto the wall surface thus providing a larger apparent source of a lesser luminance.

Window materials

The choice of appropriate material for a window is important in minimizing heat gain and promoting ventilation through a window. Wood and glass are the two most commonly used materials for windows in India. Wooden shutters, used before glass became popular, were effective in controlling heat gain for the closed windows during the daytime. However, the closed wooden shutters also obstruct daylight and view completely.

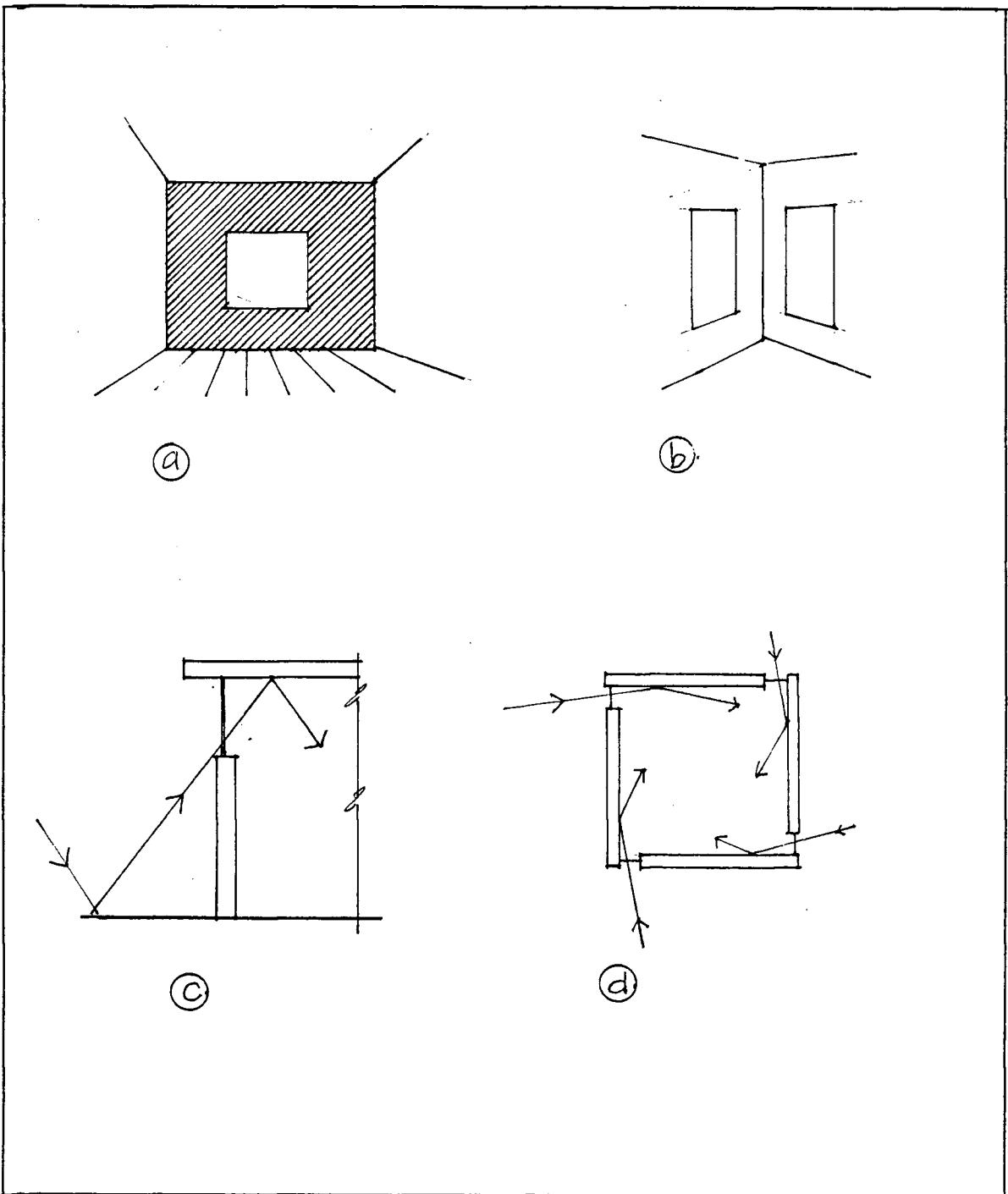


Fig.2.42. Glare From Windows.

- Glare due to Contrast between Window and Window Wall.
- Reduced Glare by Positioning Windows on Adjacent Walls.
- A high Level Window with Light Colour Ceiling Reduces Glare.
- Corner windows Reduce Glare.

Source: Gupta, 1984

Windows fitted with wooden louvers perform better than wooden shutters, since they not only provide control over heat gain but also allow for light penetration. However, as discussed earlier (section 2.4.), the position of louvers with respect to the air flow pattern may conflict with control of solar radiation.

A window fitted with a wooden lattice (Fig.2.43) is the most effective solution in terms of the thermal performance of a window if wood is to be used as window material. An intricately woven wood lattice (jali), in addition to providing protection from direct sun, also provides air flow and glarefree light in a single architectural solution (Fathy, 1986). With landscaping around the jali, the incoming air can be cooled and humidified during the daytime.

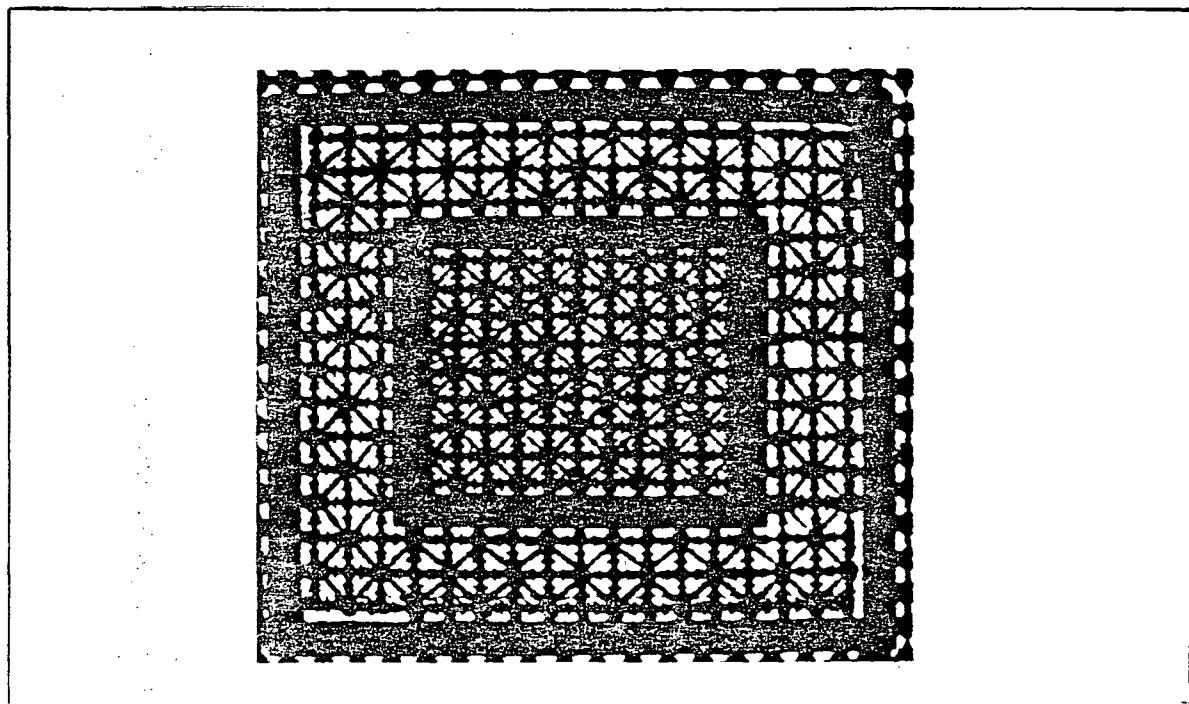


Fig.2.43. Intricately Woven Wood Jali as Window Material.
Source: Fathy, 1986

Although clear glass, as a window material, has the advantage of providing maximum light and view, it also admits solar radiation. The heat gain through a window can be reduced with the help of interior and exterior shading devices and replacing clear glass with solar absorbing glass, but all these require additional cost. A 4mm clear glass window with shading devices admits 1/3 of impinging radiation in a south orientation (Straaten, 1967). Therefore, if clear glass is to be used as window material, an emphasis should be placed on adequate design of shading devices.

2.6. Interior Accessories

The purpose of interior accessories is to regulate solar radiation and to provide protection from glare. Although interior accessories obstruct solar radiation, external shading devices are more effective in providing protection from solar heat gain. The reason for this is that part of heat absorbed by internal devices is dissipated towards the interior which adds to internal heat gain. The colour of interior accessories is an important factor. The light colour accessories will absorb less heat and also reduce glare.

2.7. Interior

The windows in hot and dry climates need to be smaller and fewer in number, with the result the interior lighting level will be low. The use of a light colour on the walls increases the reflection of daylight and the overall brightness in a room. This in turn reduces the contrast between the window and the window wall, which in turn reduces glare.

3. DELAY PERIODIC HEAT FLOW, MINIMIZE CONDUCTIVE HEAT FLOW

3.1. Roof and Walls: Thickness, Materials and Colour

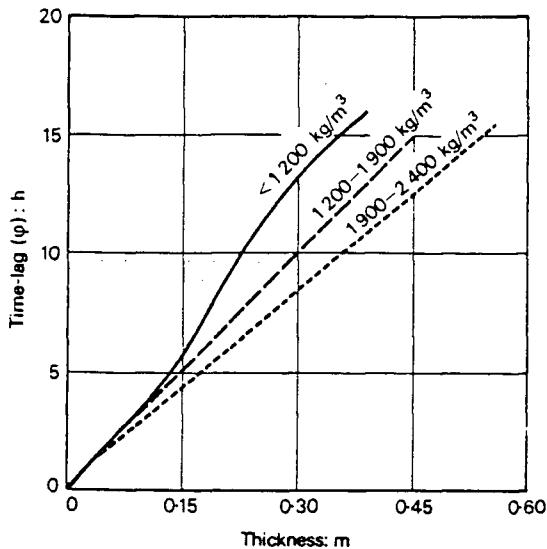
Hot and dry climates potentially have a high diurnal range, normally between 10 and 15°C. This temperature fluctuation causes discomfort during various times of day and night. External walls and the roof should therefore have properties which moderate this high external temperature range and minimize conductive heat flow.

Roof and walls with high thermal capacity and resistance will reduce this external temperature range by delaying the periodic heat flow to the interior (Givoni, 1981). This delay in periodic heat flow is associated with an advantageous time lag. The time lag for an exposed roof should be at least 12 to 15 hours so that the release of heat to the interior, which is absorbed during the day, is delayed until the cooler hours of the night.

The required time lag for walls depends upon their orientation. For instance, east facing walls require a time lag of 12 to 14 hours as they receive their maximum heating between 10 and 11a.m. A time lag of only 10 hours for east walls will allow the inside surface temperature to reach its maximum at 8p.m., when the ambient air temperature is still likely to be above the comfort level.

West facing walls require a relatively smaller time lag, normally 8 to 10 hours, as they receive their maximum heating between 3 and 4 p.m. South and north facing walls do not require a large time lag, because their total maximum heating in summer is much lower.

in order to achieve a greater time lag and low thermal conductivity, the thickness and thermal properties (density and specific heat) of roof and walls are important criteria (Givoni, 1981). The total thickness of roof and walls is a combination of layers of various materials including exterior and interior finishes, each layer of which contributes in modifying and delaying the heat conduction from external to internal surface. One of the reasons for combining various materials in roof and wall construction is to reduce the structural load and material cost. As roof construction in hot and dry regions in India is usually done with concrete, a slab of 300 mm (Table V) would be required to achieve a time lag of 12 hours. This is unlikely to be economical, since not only is the volume of material excessive, but also the weight would require larger structural members to support it. Use of an insulating layer on the outside of a thinner concrete slab can provide the same time lag (Koenigsberger, 1973) without increasing the weight of the total structure. Earth pots with an air gap (Fig. 2.44), foam concrete, or expanded polystyrene are some of the recommended insulating materials (Sodha and Bansal, 1984). Inverted, closely packed earthen pots on a roof, in addition to providing a time lag of above 12 hours and low thermal conductivity, provide increased surface area for radiation emission to the clear sky at night, and cool faster than a flat roof. However, this kind of roof is not suitable for frequent occupancy. Foam concrete or polystyrene



MATERIAL	DENSITY Kg/m ³	CONDUC- TIVI- TY/W/m degC
EXPANDED EBONITE	64	0.029
GLASSWOOL	24	0.042
FOAMED SLAB CONC.	1280	0.338
STEEL	7800	58
ALUMINIUM	2700	229

Table V. Time Lag Provided by the Materials of Various Thermal Properties and Thickness.
Source: El Bannany, 1984

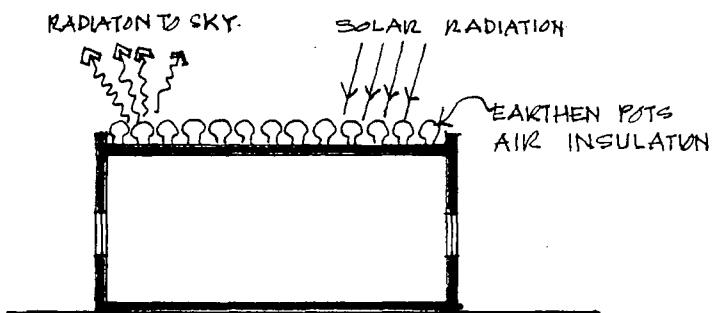


Fig.2.44. Roof Finished with Earthen Pots.
Source: Sodha and Bansal, 1984

finished with brick tiles are, therefore, more suitable for a roof which is frequently used. These materials, however, are more expensive than the cheap earthen pots.

The walls in hot and dry climates are built with bricks as they are locally available. The thickness of walls depends upon the available size of the bricks. For further reduction of conductive heat flow and a larger time lag, double walls can be built with a air gap in between.

As discussed earlier, the thickness of walls in various orientations should be different depending upon the time lag required. For east orientations, where the maximum time lag is required, the external walls should not be less than 300 mm. and should preferably have a cavity. For west orientations 300 mm thick walls without a cavity will provide the required time lag. For north and south orientations, 220 mm thick walls would be sufficient, but the building codes in India specify that all external walls must be 300 mm thick to prevent the seepage of moisture during the rainy season and for structural reasons. The wall thicknesses mentioned here do not include the exterior and interior finishes. The periodic heat flow and conductive heat gain through walls will be further affected by exterior finishes and their colour. If the external colour of the walls is white, that is with an absorptivity of less than 0.4, the flow of heat will decrease further but, only if walls are less than 220 mm thick (Givoni, 1981). The influence of exterior colour in reducing conductive heat flow through thicker walls (above 220 mm) is not critical.

SUMMARY AND CONCLUSIONS

This research set out to identify, evaluate and recommend passive design strategies suitable for housing design in hot and dry region of India. Passive design strategies were investigated because they allow effective thermal control within residences with the minimal use of modern mechanical cooling devices. Passive design strategies additionally provide the potential to create a residential environment which is visually and psychologically more appealing than that associated with modern, mechanically-controlled residences. A qualitative analysis of the thermal performance of various passive design techniques used in traditional dwellings in Part One demonstrates that, in addition to providing thermal comfort, passive techniques responded effectively to the cultural, economic and technological constraints under which people designed and constructed their dwellings. On the other hand, mechanical cooling devices widely used in the contemporary dwellings, although effective in providing thermal comfort, are expensive to use, unreliable as a long term solution to the cooling problem and encourage dwelling designs which are ill-suited to user needs. This analysis, in addition to sharing the knowledge and providing a rational basis for the use of passive design techniques, enables architects to critically select those techniques which are useful in the contemporary context.

In Part Two, a conceptual framework for incorporating passive techniques at various levels of design has been presented. Various climate-responsive strategies are selected at a

general level by considering local climate and comfort criteria and then translated into the specifics of site selection, site planning, form and fabric design. A general objective of the strategies at all levels is to minimize the adverse effects of climate and maximize its benefits. Table VI presents all these strategies in the order of their priority in application. In hot and dry climates the need for reducing heat gain during daytime and promoting heat loss at night overrides other comfort requirements and becomes a decisive factor at various levels of design.

This thesis also shows that inclusion of passive design techniques into the wider context of housing design does not restrict the architects from evolving diverse design solutions. In fact, strategies at each level give architects a considerable scope for creativity. As site conditions and programming requirements for each project are distinct, each strategy which addresses a particular thermal comfort problem will respond differently to the needs of each project, and can be translated into diverse design solutions and architectural expressions. However, a designer should clearly define the problem and be consistent in following it at each level of design.

The use of passive techniques provides thermal comfort and various other benefits to all types of dwellings and these benefits can be substantial when applied in mass scale developments like multi family housing. According to the current housing trends in India, the great bulk of new dwelling units are multi-family structures created by

Table VI

MINIMIZE HEAT GAIN.					
PRIORITY INDEX	SITE SELECTION	SITE PLANNING	FORM DESIGN	FABRIC DESIGN	
1	<ul style="list-style-type: none"> SELECT SOUTH OR EAST FACING INCLINED SURFACES PREFER 15-30° INCLINATION OF SLOPE. AVOID VALLEY BOTTOMS AND SELECT SITES ABOVE UTILIZE EXISTING VEGETATION 	<p>MINIMIZE SOLAR GAIN.</p> <ul style="list-style-type: none"> MAXIMIZE NORTH AND SOUTH FACING BLOCKS WITH STREETS RUNNING EAST WEST. MINIMIZE STREET WIDTH. LOCATE OPEN SPACES IN SOUTH OR SOUTHEAST. KEEP OPEN SPACES SMALLER THAN THE HEIGHT OF SURROUNDING BLOCKS. USE DECIDUOUS TREES. USE GROUND COVER, FOLIAGE 	<ul style="list-style-type: none"> ORIENT LARGER SURFACES IN S-30° SE. MAXIMIZE ROW OR CLUSTER FORM. CONSIDER PLAN RATIO IN D/W DETACHED DWELLINGS. USE UNEVEN FORM TO SHADE FACADE IN SOUTH. PROVIDE BUFFER SPACES IN WEST. PROVIDE LIVING SPACES BELOW GRADE 	<ul style="list-style-type: none"> ORIENT LARGER WINDOWS IN S-30° SE. MINIMIZE PAVED SURFACE AROUND WINDOWS IN EAST & WEST. KEEP WINDOW AREA MAXIMUM 25-30% OF WALL AREA IN SOUTH. UTILIZE HORIZONTAL OVER-HANGS IN SOUTH. USE WOODEN LATTICE FOR WINDOW. USE ADJUSTABLE LOUVERS IN E-W 	<ul style="list-style-type: none"> USE INSULATING MATERIALS FOR ROOF. USE CAVITY WALLS IN EAST & WEST USE LIGHT COLOUR EXTERIOR WALL FINISHES.
2				<ul style="list-style-type: none"> SEGREGATE HEAT GENERATING AREAS FROM LIVING SPACES. PROVIDE LIGHT SHAFTS. 	<ul style="list-style-type: none"> KEEP WALLS 30CM THICK IN EAST AND WEST. USE AIR GAP TO INCREASE TIME LAG.
3					<ul style="list-style-type: none"> CONSIDER WINDOW POSITION. USE LIGHT COLOUR INTERIORS. [contd]
4	DELTAE	REDUCE INTERNAL HEAT GAIN	LOW CONDUCTIVE FLOW.		
5	GLARE	PERIODIC FLOW			

Table VI (continued..)

PRIORITY INDEX.	SITE SELECTION	SITE PLANNING	FORM DESIGN	FABRIC DESIGN
1	<ul style="list-style-type: none"> SELECT SITE TOWARDS THE MIDDLE OF SLOPE. SELECT SITE WITHIN 400M DISTANCE FROM EXISTING WATER BODIES. ORIENT DWELLING BLOCKS 30° EAST OF SOUTH. DESIGN SMALL SEMI ENCLOSED OPEN SPACES. KEEP HIGHER BUILDINGS TOWARDS THE INNER PART OF SETTLEMENT. 	<ul style="list-style-type: none"> CONSIDER WIND ORIENTATION BETWEEN 15-30° EAST OF SOUTH. PROVIDE CROSS VENTILATION. PROVIDE INTERIOR COURTS & SHAFTS.  	<ul style="list-style-type: none"> PROVIDE OPERABLE GLASS WINDOWS. USE VERTICAL PROJECTIONS. CONSIDER WINDOW POSITION. CONSIDER RENATIVE SIZE OF INLET & OUTLET WINDOWS. USE WOOD LATTICE. 	
2	PROMOTE VENTILATION.	PROMOTE RADIANT COOLING.	<ul style="list-style-type: none"> PROVIDE TERRACES & COURTS. 	
3	PROMOTE HEAT LOSS.	PROMOTE HIGH VELOCITY WIND & DUST PROTECTION.	<ul style="list-style-type: none"> USE SHELTER BELTS. USE HEDGES & SCREENS. 	

government or private bureaucracies (Chauhan, 1986). This centralization of dwelling developments is compatible with mass scale application of passive techniques and brings the benefits of climate responsive design to a larger number of people at a low per unit cost.

Given the estimated dwelling units required to meet the growing demand for housing in India, it is absolutely essential that housing designs based on passive techniques are implemented, widely used and accepted by the dwelling occupants.

In order to implement the housing designs based on passive techniques, it is imperative for the government policies and housing regulations to reflect their objectives. The climate responsiveness of dwellings should, therefore, form an important basis for housing regulations and government policies, especially in regions with extreme climates.

Finally, passive design techniques can be successful and beneficial only when they are widely used and accepted by dwelling occupants. In a rapidly industrializing country such as India, the use of mechanical cooling in residences is considered by many to be a modern necessity ensuring maximum comfort in contemporary dwellings. Besides changing attitudes like this, it will be necessary to convince opinion leaders, in particular contemporary architects, about the benefits of passive design technology. An emphasis on the research and development of passive techniques, and making this knowledge widely available are the two extremely important initial steps which can be instrumental in

encouraging use and acceptance of housing designs based on passive techniques.

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