PATTERNS OF BIOCLIMATIC DESIGN IN RESIDENTIAL ARCHITECTURE OF CHARLES CORREA IN THE HOT-HUMID REGION IN WESTERN INDIA

by

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ABSTRACT

Energy efficiency is one of the most crucial factors for building design in the modern times of energy crisis. This can be achieved by a realm of architecture called bioclimatic architecture, which takes advantage of climatic and environmental conditions so as to achieve thermal comfort inside. More and more architects are adopting the idea of bioclimatic architecture as a means to create a new style of "regional modernism". The regionalist concepts of bioclimatic architecture are the basis for Charles Correa's designs. Correa has been a pioneer for such work in India and abroad.

This research studies the works of architect Charles Correa in order to discover recurrent design concepts based on specific regional climatic conditions in India. The suitability of the architecture to the context will be analyzed by measuring bioclimatic descriptors against individual case study buildings in the form of a template. The descriptors will be selected based on bioclimatic design principles. The results will be presented in terms of recurrent patterns of the case study buildings that give evidence of bioclimatic design for housing in the Mumbai region of India.

Correa's works attempt to explore a local vernacular within a modern environment. This is emphasized by his recognition of the intelligent climatic problem solving strategies used in the old colonial bungalows. His usage and modification of these strategies is based on the suitability to the context, which is the main focus of this research. The research setting is the residential architecture of Correa in Mumbai and surroundings, located in the hot and humid region in Western India. The selection of this region is based on two factors. One is feasibility; the purpose of the study of bioclimatic descriptors will be justified if the setting is limited to one particular climate. The second is the scale. Residential buildings are the most impacted by natural energy and lifestyle relationships. The scale factor of a residence makes the study more holistic because it captures the relationship between the habitat as a form and the living patterns of the residents. The research analyses four examples of Correa's residential buildings and one example of a generic model of a Bungalow that represents the traditional architecture of the local setting.

This research brings out the commonalities between Correa's design strategies and the vernacular strategies in the bioclimatic perspective. This is done through comparisons of his buildings with the traditional bungalow. The hypothesis on which this study is based is that there will be many of these commonalities, and these will form the basis for recurrent design patterns that will be identified. These identified patterns form the conclusions of the research. There are many commonalities between Correa's design strategies and vernacular example. Correa has also modified some strategies according to the modern context out of which some have been successful and some unsuccessful.

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Dedicated to my brother…

CHAPTER 1:INTRODUCTION

Introduction and Background

Charles Correa has been practicing for fifty-five years in India. In a country like India, where the climate is warm and the economy is "developing", Correa's architecture is a response to the climate and to the situation where mechanical ventilation and air-conditioning are not viable and affordable for most of the population. This research would benefit people from different realms in different ways. The significance of this research can be explained in two different areas:

Bioclimatic Perspective

Bioclimatic architecture takes advantage of climate and environmental conditions so as to achieve a situation of thermal comfort. It deals with design and architectural elements, with no need of complex mechanical systems. In times of energy crisis and depletion of non-renewable resources, it is all the more important for us to look to energy efficiency by way of design of buildings. Due to ever-increasing energy prices and the global warming, more and more clients are aware of the necessity to reduce the energy consumption in their buildings. More and more architects are adopting the idea of bioclimatic architecture as a means to create a new style of "regional modernism". The main objective of this research is to bring out the importance of this new style by analyzing Correa's work, because he has been a pioneer for such work in India and abroad.

Architecture for Developing Countries

Another significant aspect of this research is to bring out the aspects of Charles Correa's architecture that are applicable to developing countries. Many times the International and modern styles do not apply very suitably towards developing countries. Developing countries have a very characteristic set of problems that have to be catered to in diverse ways. Principle practitioners have established a foundation for research in this area with different perspectives. The research tries to analyze the effectiveness of the architectural strategies used by Correa in India by taking a particular region and his buildings in that region as case studies. The conclusions will help to see how far these strategies are successful in a country where air-conditioned mechanical ventilation is not feasible.

Regionalism and Vernacular Architecture:

Architecture of the House

Humans have been involved in dwelling activity from the earliest times. Dwelling is the process of living at a location and it is the physical expression of doing so.[1] It was essentially started when a human being wanted protection from the forces of nature. It is only natural for different parts of the world to have diverse built forms because of difference in climate and materials. Different parts of the world have shaped their built forms indigenously according to their climate. For example in Egypt, Iraq, and Pakistan, deep loggias, projecting balconies, and overhangs casting long shadows on the walls of buildings are found to protect the people from the extreme heat. Wooden or marble lattices fill large openings to subdue the glare of the sun while permitting the breeze to pass through. Such arrangements characterize the architecture of different regions, and evoke comfort as well as aesthetic satisfaction with the visible endeavors of people to protect them against the climate.

Although traditional architecture has evolved intuitively and experimentally over long periods, research shows that it can be confirmed by scientifically valid concepts. Also, these traditional solutions have been found to be much more in harmony with the human physiological functions at the regional level. In countries like India where mechanical means of ventilation are still not affordable by common people, along with the consideration of climate there are other factors that have to be taken into account like building materials, surface textures and colors of exposed surfaces of the buildings, and the design of open spaces, such as streets, courtyards, gardens, and squares.

"All houses are dwellings; but all dwellings are not houses.... It is this double significance of dwelling as the activity of living or residing, and dwelling as the place or structure which is the focus of residence-which encompasses the manifold cultural and material aspects of domestic habitation."[2]. The primitive man had essentially developed a built form to protect himself. It took a considerable amount of time for these built forms to be differentiated according to their function into various types. A house is the earliest

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[1] Oliver, Paul. *Dwellings: The house across the world.* (Oxford: Phaidon Press Ltd., 1987), 7.
[2] Ibid.

and the most common form that can be compared across the whole world. According to Rapoport, these houses are the direct expression of changing values, images, perceptions, and ways of life[3]. The importance of studying the residential architecture is found in the way it is integrated with the culture and climate of the region under study. The design of a house is a continuing process since its first inception as a temporary structure made of leaves or rocks by the prehistoric man. The design has been advanced in various ways over time and in different climatic regions of the world.

Another important factor for the study of residential architecture is the duration of time spent by a person in his/her house. Considering the modern times and the most common work cultures around the world, more than half of the time in a day is spent within the house. The various activities performed during this time require the environment to be thermally comfortable. This research is an endeavor to study the factors influencing the thermal comfort within the paradigm of a house.

Vernacular Architecture as a Premise:

Every society has gone through a natural progression in the field of architecture for centuries now. Vernacular architecture is the living proof of this progression. The arguments about the differentiation between vernacular, primitive, traditional and indigenous architectures are continual to date amongst people. The basis for the argument lies in the fact that primitive is imprecise in the sense of its implication to primitive origin or the people who built them. According to Oliver[4], it is a term embracing an immense range of building types, forms, traditions, uses and contexts. For the purpose of this study, vernacular architecture will refer to structures built of local materials in a functional style devised to meet the needs of common people in their time and place. The structures, forms, materials, the cultural and physical forces involved and the ingenious ways these buildings meet the climatic requirements are all evidences of an organic genesis. This genesis has been natural and indigenous. People who lived in these structures for years have made changes in them to adapt to their needs and requirements.

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[3] Rapoport, Amos. *House Form and Culture.* (New Jersey: Prentice-Hall, Inc., 1969), 12.
[4] Oliver, 9.

The importance of vernacular architecture to this study is established by discussing the significance of this premise. The definition of vernacular architecture discussed above emphasizes the relation the structures have with the 'context'. Vernacular dwellings are an expression of the context or the locale they are set in. The question whether vernacular architecture is a response to environment, social or cultural factors is yet to be answered. Considering all these three factors to be responsible for the evolving of the present day house in the context of a particular region and culture, a commonality in time of the context would still be the climate as socio-cultural factors keep varying in time. Hence the significance of the study of a house in both a vernacular and a modern context with the same parameters of climate of that particular region is justified.

Establishing a case for Regionalism

As said by Corbusier and cited by Olgyay:

> "The symphony of climate…has not been understood… The sun differs along the curvature of the meridian; its intensity varies on the crust of the earth according to its incidence… In this play many conditions are created which await adequate solutions. It is at this point that an authentic regionalism has its rightful place"[5].

In countries with strong cultural and social backgrounds, modern architecture has established itself by taking out the roots of the culture. Rapoport says that in modern times, the clear hierarchy of primitive and vernacular settlement is lost, reflecting the general loss of hierarchies within society. This is when regionalism comes in the picture. "Regionalism attempts to put back into architecture what orthodox Modernism conspicuously took out, namely, continuity in a given place between past and present forms of building."[6]

Regionalism has gained a strong momentum throughout the world in the recent times. But developing countries where modernism has brought about drastic changes

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[5] Olgyay. Olgyay, Aladar. *Design with Climate: Bioclimatic Approach to Architectural Regionalism.* (New Jersey: Princeton University Press, 1963), 13.

[6] Abel, Chris. *Architecture and Identity: Towards a global eco-culture.* (Boston: Architectural Press, 1997), 167.

have adopted Regionalism by way of their 'search for identity'. A realm of contemporary architects like Ken Yeang, Hassan Fathy and Correa practice architecture with an emphasis on regionalism. Bioclimatic design has been a conscious movement in developing countries that are trying to come out of the influences of colonial architects. To go further into establishing a case for regionalism, it is important to discuss some interpretations of Regionalism.

> "... Regionalism is committed to finding unique responses to particular places, cultures and climates... At its best regionalism penetrates to the generating principle and symbolic substructures of the past, and then transforms these into forms that are right for the changing social order of the present". (Curtis, 1986, p. 24)[7]

Regionalism is also viewed as a 'continuity' with local tradition and culture. The buildings in a place should not be out of context in the sense of the surrounding buildings, and with regards to the aesthetic and cultural values of the people living there. As cited by Jadhav in his thesis report[8], Wayne Attoe developed a way of classifying regionalism into three different ways:

1) **Physical**: This approach is based upon the built characteristics of a region, which are, in turn, based upon the sun, heat, cold, local materials, vegetation and historic precedents- basically the physicality of the region. These characteristics may include architectural elements like arcades, colonnades, courtyards, shaded passages, local vegetation, plazas, regional materials, color play, use of light, and so on, which are appropriate to the local climate of a region and which may have been used before in that region.

This approach is very much applicable to this research and to establish a case for the basis of this research.

2) **Interpretive:** The 'interpretation' is associated with imageability. It has more to do with the topography or history. One example is that of recessed windows in a

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[7] Curtis, William J.R. *Towards an authentic regionalism.* Database on-line. Available from http://archnet.org/library/downloader/document/4558/dpt0500.pdf . Accessed October 18, 2002.

[8] Jadhav, R. "Eastern Regionalism and Indian Identity: A Case Study of Charles Correa's 'Inter-University Center for Astronomy and Astrophysics' & Raj Rewal's 'Central Institute of Educational technology'" M.Arch. Thesis, Kansas State University, 1998.

blank façade as is often used in a desert climate. This window design gives the impression that the walls are thick and the glass is recessed-an appropriate response to a desert climate.

3) **Social**: This is related to the present social values of the people. This approach of regionalism is not to be confused with cultural values. While cultural values may be considered, addressing social content and values means drawing peoples to a building so that they may use it meaningfully.

These three approaches by Attoe are more specifically related to Phoenix, Arizona. But the regionalism related to the local climate is a commonality considering any region or country. The climate of a region can be considered a constant regional determinant during any 'time' or 'culture'. Architectural regionalism is about creating harmony between the energy of a natural environment and a man-made environment. Climate, viewed in the overall perspective of human history and built settlements, is the single most constant factor in our landscape, apart from its basic geological structure. While socio-economic and political conditions may change almost unrecognizably over a period of, say, one hundred years, as may visual taste and aesthetic sensibility, climate remains more or less unchanged in its cyclical course.

CHAPTER II: METHODOLOGY

Design of the Study:

> "Qualitative research is an inquiry process of understanding based on distinctive methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyzes words, reports detailed views of informants, and conducts the study in a natural setting."[1]

The approach of this study is qualitative in nature. The various stages involved in the research are designed based on the question of inquiry. All the stages suggest a qualitative method. In his book, Creswell describes in a short list the characteristics of a 'good' qualitative study. Based on the list, the following paragraphs of the design of the study reflect the nature of the study and give a description of the method and the questions involved:

Rigorous data collection procedures: Various data are collected for the analysis process from books, the architect's interview, online and journal publications, and the numerous plans, sections, sketches and photographs of each setting.

Based on assumptions: The study is based on some basic assumptions. A quintessential assumption is that Correa's architectural designs are based on the climatic setting and the traditional architecture. But apart from the basic assumption, other characteristics of qualitative method including presentation of multiple realities, and the researcher as an instrument of data collection are present in this study.

Begins with a single focus: The single focus of the study is described in the above paragraph. It does not start with any causal relationship of variables but eventually depends on variables while the basic assumption is being studied.

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[1] Creswell, John W. *Qualitative Inquiry and Research Design: Choosing Among Five Traditions.* (California: Sage Publications, 1998), 15.

Verisimilitude: The study involves persuasive writing of the theories and comparisons to give the readers a feeling of 'being there'. This also helps to be more substantial about the theory being studied.

Multiple levels of abstraction: The application of the same template to all the case studies and the repeated nature of analysis, incorporate the study with multiple levels of abstraction sometimes from particular to general levels and vice versa. This strengthens the conclusions.

There are five traditions of inquiry for the qualitative research methodology. The tradition of inquiry used for this study is the Grounded Theory. According to Glaser and Strauss "...the investigator as the primary instrument of data collection and analysis assumes an inductive stance and strives to derive meaning from the data. The end result of this type of qualitative research is a theory that emerges from, or is 'grounded' in, the data..."[2] The grounded theory study is mainly based on the data analysis scheme. The data analysis could be done using the standard format that is divided into three progressive stages discussed in the following paragraphs.

Open Coding:

This is the initial stage of data analysis in which the data is segregated and grouped in a general way into categories. Within these categories, sub categories are formed according to properties of the data. The main purpose of this is to 'dimensionalize'[3] the data in some manner.

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[2]Glaser, G. Barney, and Strauss, L. Anselm. *The Discovery of Grounded Theory.* (Chicago: Aldine Publishing Company,1967), 15.
[3] Ibid., 57.

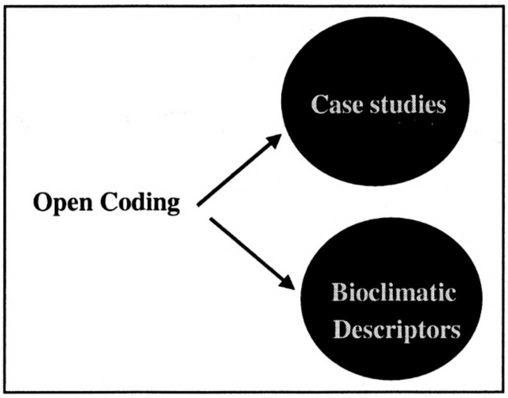

Fig.1.1: Open Coding

Figure 1.1 explains the process of open coding with regards to two sets of data that are the case studies and the bioclimatic descriptors. The data in these two sets is categorized generally into various sub categories.

Axial Coding:

After the initial stages of open coding, the data is analyzed again in axial coding. In this step, the central phenomenon, causal conditions, and strategies are identified in a more specific way. Connections are made in the data towards more specific goals. The template creation and inputting data into the template is a part of this process. Figure 1.2 shows the basic process.

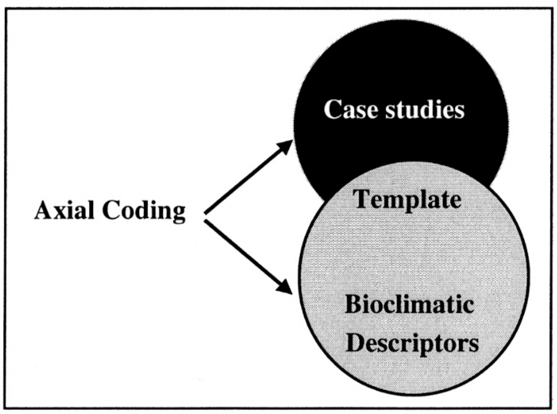

Fig.1.2 : Axial Coding

Selective Coding:

In this process, the researcher identifies specific patterns and writes conclusions that integrate the categories so far established. The hypothesis is referred to again and conclusions are based on the patterns identified in the other two stages of coding. Patterns are the recurrences of combinations of descriptors within the case studies. In this research, the template is the tool used for pattern identification.

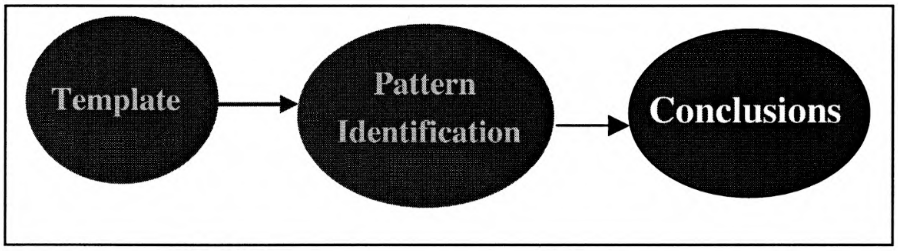

Fig.1.3: Selective Coding

The template is repetitively analyzed for patterns. Conclusions are formed based on the patterns identified in the final step of selective coding.

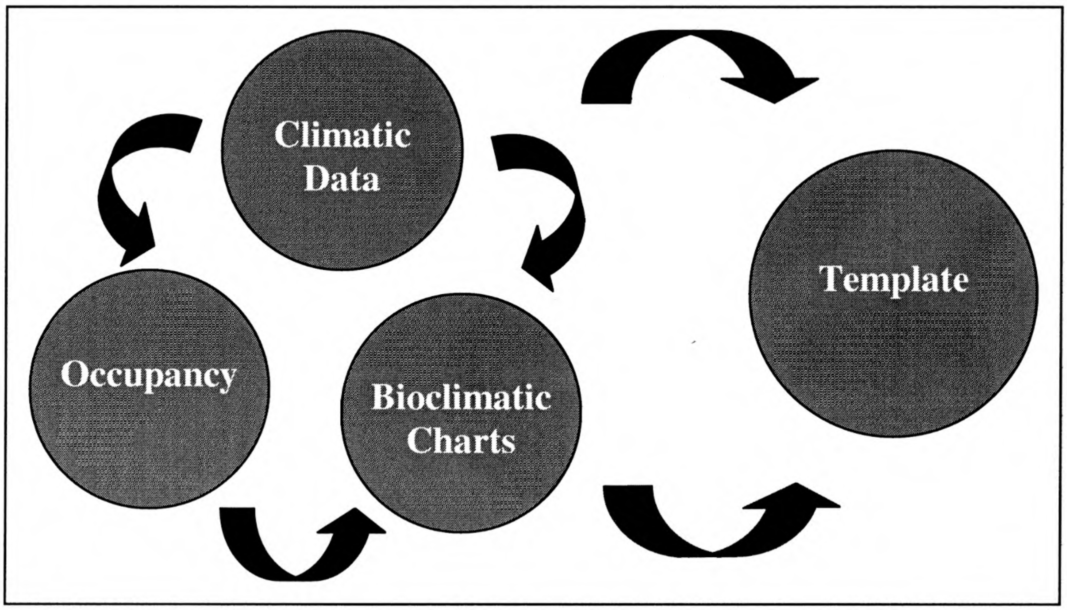

Fig.1.4: Cyclical Process

The methodology is a cyclical process as shown in figure 1.4. The three categories- the climatic data, occupancy and the bioclimatic charts are studied for each case study in an integrated manner. The observations are then entered in the template from which the conclusions are drawn.

Research Methodology

The study is initiated by establishing a case of regionalism in India by understanding the basic concepts of Vernacular Architecture, Regionalism and climate. The case is established by identifying the importance of bio-climatic architecture and addressing Correa' architecture in this context.

The next step involves data collection of climatic data of hot-humid region of Mumbai. With this climatic data, bioclimatic charts for optimum thermal conditions for comfortable living of residents are plotted and studied. A selection of four days of four typical months of the year is made, that represent the four seasons.

The case studies are identified in and around Mumbai. The selection of case studies is based on the following criteria:

- Residential building.
- Scale of building.
- Same region.

After the case studies for Correa's designs are identified, a generic three-dimensional model of a traditional bungalow as an example of vernacular architecture is developed using software, which would be treated as one of the case studies. This model follows the design guidelines of a traditional bungalow according to Anthony King in his book about the bungalow[4]. The contemporary examples selected will be studied in comparison with this vernacular model.

For the purpose of comparison, a set of bioclimatic descriptors is identified to analyze case studies. Conditions for each descriptor for this region for the particular times are listed. The case studies are analyzed for comfort based on the optimum conditions for each descriptor. The following graphs and models are plotted and developed for analysis:

- Bioclimatic charts for four months based on climatic data.
- 3-D models of the case studies for analysis based on available information.
- Occupancy charts according to time for each case study.

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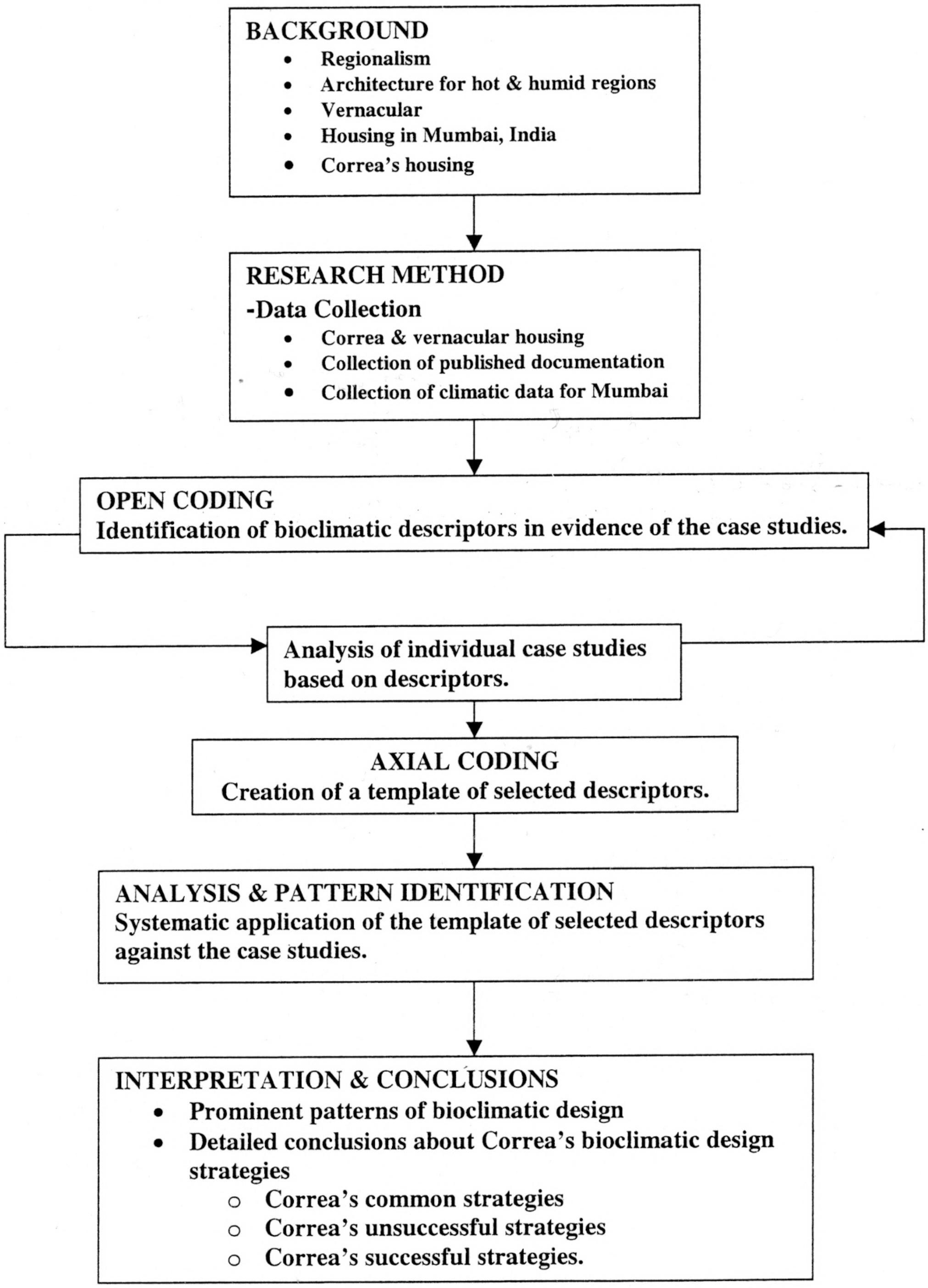
[4] King, Anthony D. *The Bungalow: The Production of a Global Culture.* (New York: Oxford University Press, 1995).

The next stage is the most important and crucial stage of the study. A template or a two dimensional matrix of the descriptors against each case study and entering the analysis data into this matrix is developed. The data for the descriptors is put in this matrix. This matrix will help in listing bioclimatic strategies used commonly amongst all the case studies and also in comparison with the traditional bungalow.

The observations noted from the template will form the conclusions of the commonalties, the unsuccessful and the successful strategies used by Correa in the case studies. These conclusions interpret the regionalistic ideologies behind each design. The strategies used by Correa can be seen in the light of responses to the climate and culture of the context.

Research Design Diagram



CHAPTER III: CHARLES CORREA

Life Sketch and Ideology

Charles Correa is one of the pioneer architects of contemporary Indian architecture and a major figure in contemporary architecture worldwide. He is an architect, planner, activist and a theoretician. He was born in Secunderabad, India, on September 1, 1930. His initial schooling was done in Mumbai, and then he continued his architectural education at the University of Michigan where he did his undergraduate studies. He pursued his masters' degree in architecture later at the Massachusetts Institute of Technology until 1955. He worked for a few years in the United States before he started a full-fledged practice in 1958 in India.

The core of his architectural education was under the influence of great architects from the west like Le Corbusier. He also taught design in the two universities he studied in and gives lectures every year in the United States. He currently practices in Mumbai, India. The most prominent characteristics of his design have always been his utilitarian concepts that are well suited to the context in which the design is set. He is believed to have mastered the art of applying principles based on the local setting in his designs. His understanding of the culture, society, economy and traditional architecture has been the driving force in his designs. This understanding with respect to India is discussed in the following paragraphs.

Living Patterns and Energy Passive Buildings:

> "In a warm climate, people have a very different relationship to built form. One needs but a minimal amount of protection, such as a *chatri* (i.e. an overhead canopy), during the day; in the early morning and at night, the best place to be of course is outdoors, under the open sky".[1]

Correa believes in design that is integrated both functionally and culturally with the people in a particular region. He believes that understanding of traditional architecture and the local culture is required in order to design for a context. Rather than using it as a pastiche, it is very important to intelligently apply this understanding in new

[1]Correa, Charles. *Quest for Identity.* Database on-line. Available from http://archnet.org/library/pubdownloader/pdf/2651/doc/DPC0265.pdf. Accessed November 22, 2002.

designs. Traditional architecture has evolved with people. It is a reflection of their culture and socio-economic conditions over time. The relationship between the traditional architecture and climate is organic in nature. This relationship has to be maintained in order to design habitats in an area for a community. In India, the functionality of the open and semi-open spaces or what Correa calls 'open-to-sky' spaces is very high because of the warm climate. "...under Indian conditions courtyards have a usability coefficient of about half that of a room and verandahs about three-quarters"[2].

To design for such a warm climate, Correa utilizes various concepts to achieve functionality. An important issue in a third world country is that of low resources. People cannot afford to depend on mechanical ventilation most of the times. In such a country, Correa suggests designing buildings such that "the building must itself, through its very form, create the 'controls', which the user needs", in other words, these maybe called passive energy buildings. For example the usage of verandahs a traditional feature of the colonial bungalows provides the building's interior with two lines of defense at the exterior level.[3] A very effective method, the design of cross section of a building to control air is another characteristic feature. In such designs, the prevailing breeze that enters from one end of the apartment is vented throughout the house with the help of large, open volumes inside; hence the section acts as a strategy to control the microclimate. In this way, Correa uses some new and some culturally and traditionally embedded strategies to design an environment.

Nature of Change and Continuity:

> "To find how, where, and when he can be useful is the only way the architect can stretch the boundaries of his vision beyond the succession of middle and upper income commissions that encapsulate the profession in Asia"[4]

Correa believes in the attitude of basing designs to cater to the people in an effective manner by stretching the norms and vision of an architect. Asia consists of developing countries like India, which have low financial resources. The income levels of

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[2] Cantacuzino, Sherban in Correa, Charles. *Charles Correa: With an essay by Sherban Cantacuzino.* (Singapore: Concept Media Pvt. Ltd., 1984), 11.
[3] Ibid., 12.
[4] Correa, Charles. "Transfers and transformations" from Khan, Hassan-Uddin. *Charles Correa.* (Singapore: Concept Media Pvt. Ltd., 1987), 171.

people dominate the type of architecture prevailing in the country. In such a country, where architects are restricted to low project budgets, the concern of the architect towards the people he or she is designing for can also be restricted. Correa believes that it is all the more essential to design for people with such constraints in a creative manner that provides them with maximum amenities with low construction costs. This creativity has to come within the architect, which comes by envisioning new ideas.

To envision new ideas, Correa tries to bring about the concept of 'continuity' and 'change'. He advocates the ideology that architects should bring about change in not only the design aspects but also in the norms and ethos that are being blindly followed by people with the concept of 'continuity' in mind. According to Correa, achieving continuity should not be analogous to copying the past. Instead change should be brought "by understanding the past, how it was done and then inventing it again"[5]

Urbanization:

His ideas of architects having to 'stretch the boundaries of their vision' are related to urbanization also. In 1985, the government of India appointed Charles Correa as the chairperson for the National Commission on Urbanization. He believes that cities can generate skills and that they are centers for hope and engines of economic growth. These beliefs have guided his urban design skills in the growth of New Bombay. Bombay was a city of hope for everybody who came in trying to secure a job there and establish their home in the city, which led to overpopulation and slums throughout the city. Correa was the master planner for the new urban design and restructuring of old centers to redirect the incoming population towards New Bombay and to develop job opportunities and new businesses there.

Space as a Resource:

Another ideology recognized by Correa was that in a country like India, the space itself should be treated as a resource. By this he means that the space available for people should be designed to provide maximum functionality. This is seen in the low income

[5] Correa, Charles. *Professional Approaches to Continuity and Change*. Database online. Available from: http://archnet.org/library/documents/one-document.tcl?document_id=3821. Accessed January 20, 2004.

housing developed in Belapur, designed by Correa. The housing was constructed from locally available low cost material and by local masons. The design is very simple and was easily expandable by the residents themselves. The system of spaces provided by Correa in this housing expresses his sensitivity towards the usage of spaces by people. The hierarchy of spaces was based on the utility for example the hierarchy of the courtyard, doorstep, water tap and the community center.

To summarize Correa's ideologies, for him, people and context determine the process called architecture. He 'believes' in architecture. According to one of the interviews he gave[6], Correa believes that four forces act upon architecture in a society. These are culture, aspirations of that society, technology of the time and place, and the climate of the region. These four forces interact with each other to create a 'perfect' piece of architecture for that society at that time. But it is seen in his architecture that apart from these four forces that he believes in, the past or the traditional architecture has a tremendous influence on his design strategies.

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[6]Jadhav, 109.

Role of house and Housing in Correa's Architectural Career

Contemporary housing in Indian architecture has come a long way since the origin of the Regionalistic school of thought. The Indian contemporary housing is a tangent of global architectural activity in the late twentieth century. It brings out many aspects of architecture in the developing countries and is the product of the problem solving techniques in these countries. India is the second most populated country in the world. The limitations in a developing country like the urban land resource problems, the economy, low income rates, over-population and many other concerns have given the scope for architects and planners to be more creative rather than being inhibitive on architectural innovation in the country. It is this innovation that is the basic approach for Correa's housing designs. He believes that housing is the built expression of the socio-economic condition and the acute sense of place and past of India.[7].

Correa has more than 40 years of experience in housing design. He is regarded internationally as an expert on housing in developing countries. His expertise in housing lies in the range of low cost, low-rise buildings to high rises in high-density contexts, and even complete townships. His experience in both planning and architecture acts as an advantage, because for him, housing design starts at addressing the issues or problems of the context in the developing countries.

> "It is indeed an absurd situation-as if in times of famine housewives needed to run around writing cook books so that people could start eating. People starve not because they don't know how to cook-but because they are denied the necessary ingredients."[8]

His philosophy for housing in the developing countries is to understand what is lacking in the system and try to set it right by way of suitable solutions instead of just constructing buildings and providing people with housing. His solutions for urbanization and mass housing in Mumbai are based on such understanding.

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[7] Correa, Charles. *Form Follows Climate* [Audio Cassette and slides]. World Microfilms. 1980.
[8] Correa, Charles. *Housing and Urbanization*. (London: Thames and Hudson, 2000), 108.

At the onset of his career, Correa specialized in housing for the first twenty years. He invented new forms of design based on the importance of the climate. He followed two strategies based on the climate of the region, the 'open-to-sky space' and 'the tube dwelling'. The first strategy is a common feature of his housing projects in the parts of the country where there is extensive use of outdoor spaces. He also uses it as a symbolic public space based on traditional architecture. According to him, an optimal pattern of housing can be achieved at the point of trade-off between the production costs of a room and the courtyard. The housing could have more open-to-sky spaces and less fully enclosed spaces resulting in more usable spaces, and hence be a better solution to the problem of low-cost housing that just caters to provide only built up structures *'i.e., boxes'*[9].

His first tube house (Fig. 1.1), a narrow twelve feet wide building was based on a strategy totally opposite to the 'open-to-sky' spaces. In this tube house the emphasis was on shielding the interior space because of the hot and dry climates. This tube structure protects the interiors from the sun and the overlapping pitched roof of the house facilitates ventilation and exhaustion of hot air by virtue of the Venturi effect.

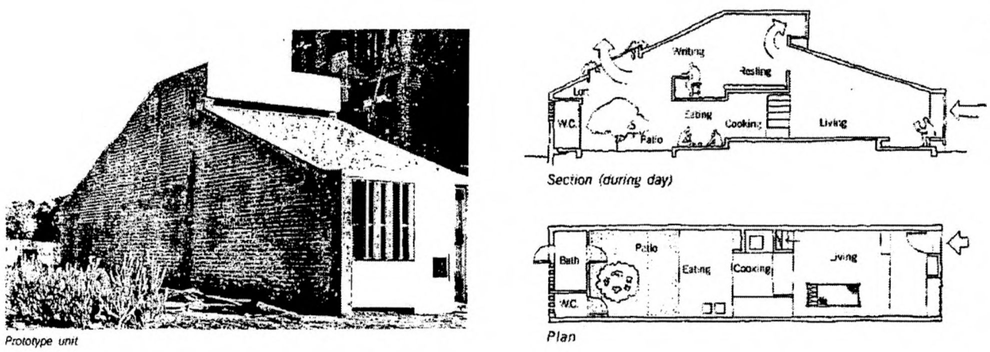

Fig. 3.1 Tube House, 1961-62, Ahmedabad.

[9] Ibid., 107.

Correa makes use of these two strategies in many of his housing examples based on climate. The strategies are incorporated in residences of varied scales and proportion over the years. At places where the house was very large, he broke the design into two structures and used the concept independently for the two structures. One of the popular implementations involving both these strategies in one building is the Ramakrishna House in Ahmedabad. In this design, the house was distributed into two parts. One part of the house was usable during summer and the other during the winter. This concept is very common for vernacular housing in many cultures.

Correa's belief in the working strategies of the traditional architecture motivated him to incorporate them in the modern setting in an intelligent and analogous manner and not merely as a pastiche. In the hot and humid climate of Mumbai, the strategies of the old traditional bungalow prove to be most beneficial. Correa modified this concept to suit the high-rise apartment complexes in Mumbai.

> "The old colonial bungalows solved this problem intelligently by locating the main living areas in the center, protected by a continuous verandah running along the periphery-a concept used in the Sonmarg Apartments (1962), the Rallis Apartments and later in the DCM Apartments, where a belt of verandahs, studies and bathrooms forms a protective zone around the main living areas."[10]

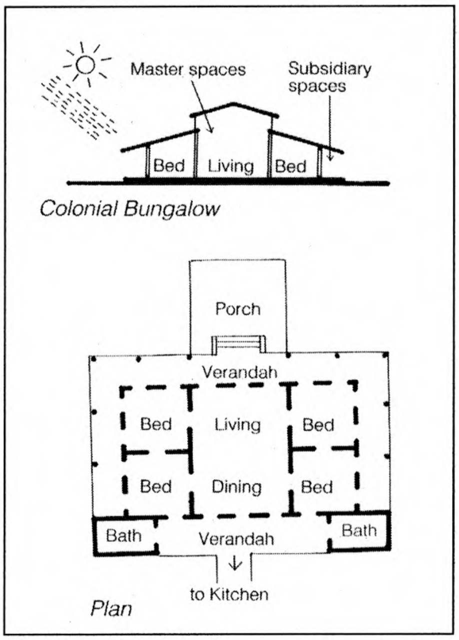

Fig. 3.2: Traditional Bungalow

He had a penchant for sectional displacement and creating dynamic cross sections of the houses that have a favorable microclimate of their own at different parts of the house. These cross sections would also be characterized by variations in floor levels.

In summary, Correa's residential architecture is reinforced by his beliefs in suitability to climate, lessons in the architecture of the past, the culture in the sense of living patterns of the people, emerging aspirations of the society and the prevailing technology.

[10] Correa, Charles. *Charles Correa: with an Essay by Kenneth Frampton.* (London: Thames and Hudson, 1996), 20.

CHAPTER IV: BIOCLIMATIC STRATEGIES

Bioclimatic Strategies for Hot-Humid climate

Comfort Zone and Bioclimatic charts:

A human being's body is basically affected by four factors of environment; air movement, vapor pressure, evaporation and radiation effect[1]. These four factors decide the condition of comfort of the body. For a human being to be comfortable, optimum conditions for these four factors should be achieved. To study these comfort conditions, Olgyay created bioclimatic charts that integrate various climatic elements and their relationships. "The bioclimatic chart was built up with dry-bulb temperature as ordinate and relative humidity as abscissa."[2]. Specific climatic conditions can be plotted in the chart to determine the comfort zone, which is the zone in the graph that represents the optimum conditions required for thermal comfort. To explain the concept of bioclimatic charts, an example of the following chart of Miami, FL is taken:

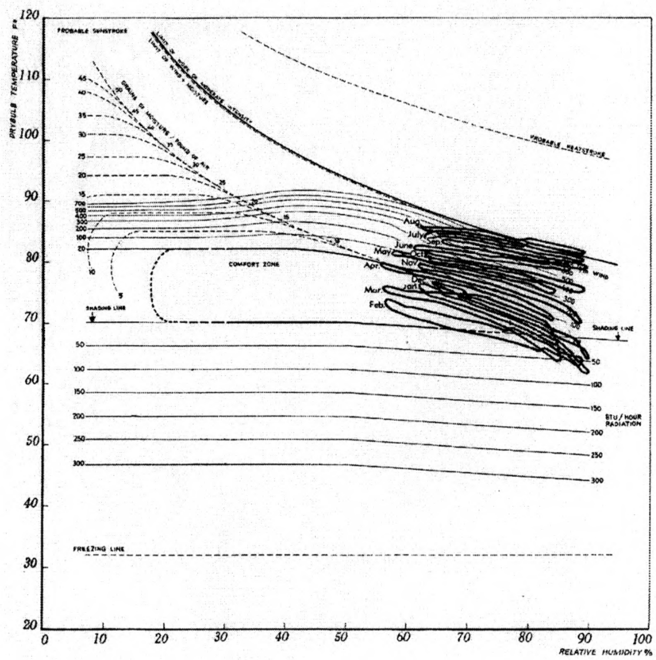

Fig3.1: Bioclimatic Chart-Miami, FL (Hot-Humid)

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[1] Olgyay, Victor. *Design with Climate: Bioclimatic Approach to Architectural Regionalism.* (New Jersey: Princeton University Press, 1963), 15.

[2] Ibid., 22.

This region is basically a hot-humid region next to the ocean. The chart shows the 'loops' for all the twelve months of the year based on the dry bulb temperature and the relative humidity. The chart indicates that the range of temperature in this region is not very fluctuating. The yearly temperature distribution is a very close range. Wind effects have a major role to play for thermal relief because of very high humidity and high temperature. Even when the temperature is in the comfort zone as seen in the chart for the months of January, February, March, April, November and December, the wind requirement is really high. The chart also shows shading requirements throughout the year. During daytime hours, the average yearly needs in a hot-humid climatic region are: 12% sun heat, 88% shade, 62% breeze period; 26% of the time is in shade comfort.[3]

For the purpose of the study, the climatic data of Mumbai has been plotted on Bioclimatic charts and presented in Appendix A. Based on these bioclimatic charts the comfort conditions for Mumbai are studied.

Hot-Humid Climate:

The principal requirements to satisfy in a hot and humid region are provision of continuous and efficient ventilation, protection from the sun, rain and insects, prevention of internal temperature elevation during the day and minimization during the evening and night[4]. Some of the general strategies[5] are as follows:

- Avoid heat storage and promote ventilation to dissipate humidity.
- Expand the use of outdoor living areas.
- Disperse structures to dissipate heat through ventilation.
- Use vegetative ground covers to block reflected radiation and glare.
- Sun shading on north rarely needed but they can screen reflection and glare.

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[3] Givoni, B. *Man, Climate and Architecture.* (New York: Elsevier Publishing Company Ltd., 1969), 30.
[4] Ibid., 323.
[5] Coates, Gary. *Bioregional Design Strategies Lecture Notes.*

- Use Venturi effect to channel desirable breezes. A trellis or other structure that offers a roof to the funnel can further enhance the cooling breeze.
- Use non-reflecting permeable paving material in the garden.
- Site building on slight rise to increase access to breezes.

Climatic Conditions of Mumbai

Mumbai, which was earlier known as Bombay, is situated on the western coast of India, and is the largest metropolis of the country. It is part of India's beautiful west coast of the Arabian Sea that runs down from Gujarat through Mumbai, Goa, Karnataka and Kerala. Mumbai is located at about 19°7'N 72°50' E and is situated at a height of about 46 feet above sea level[6].

Most of the year, Mumbai's climate is hot and humid. Between November and February, the skies are clear, and the temperature is cooler. From March the temperature becomes warm and humid until mid June. The monsoon begins around this time. During monsoon there are torrential rains, sometimes causing the flooding of major roads and streets of Mumbai. The average rainfall, which is brought by the southwest monsoon winds in Mumbai, is 180 centimeters. Monsoon ends by the end of September. October is comparatively hot and humid. More detailed climate characteristics of Mumbai are discussed in the following paragraphs.

Humidity and rainfall are high during most of the year. Mumbai is situated at the coastal region. The constant heating and cooling patterns of land and sea give raise to regular land and sea breezes. Inland regions may not get much affected by these winds. Mumbai experiences essentially three seasons: summer (March-May), monsoon (June-mid September) and winter (October-February). April-June is peak summer time, and temperatures are over 95 F. Rainfall averages 100 inches during monsoon. Temperatures sometimes drop as low as 45 F in January. But the temperatures during the rest of the year are high and have a constant diurnal pattern throughout the year. The weather data is presented in Appendix B.

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[6] Data from http://www.eere.energy.gov/buildings/energyplus/weatherdata/international/IND_Bombay_IWEC.stat

January:

In January, the required conditions from the data show that shading is required most of the daytime, and the wind direction is northeast. The existing wind speed is 255Ft/m. The bioclimatic chart for January in Appendix A, Figure A-1 shows that the required wind speed is very high in early morning time when humidity is the highest. At 10:00 pm comfort zone is achieved and the conditions are comfortable, as shown in the bioclimatic chart.

April:

In April, the wind direction is northwest. Shading is required most of the daytime. The relative humidity is the highest at 4:00 am and hence maximum wind speed of 787 Ft/m is required. According to the bioclimatic chart in Appendix A, Figure A-2, very high wind speeds are required in the first half of the day. There is not a large fluctuation in the temperatures throughout the day.

July:

In July, the wind direction is northwest. Shading is required most of the day. There is not much fluctuation in the temperatures. Existing wind speed is very low and hence high wind speeds are required as seen in the bioclimatic chart given in Appendix A, Figure A-3.

October:

The wind direction in October is west. The temperatures throughout the day are in eighties. The relative humidity is also high. The required wind speeds are high at 10:00 am and 3:00 pm as seen in the bioclimatic chart given in Appendix A, Figure A-4.

General Principles for bio-climatic comfort design for Mumbai

According to the climatic principles explained in the chapter about Mumbai's climate, thermal comfort can be achieved by applying certain bio-climatic strategies to the various components in a single residential unit. These strategies with respect to each component of the building are explained in the following paragraphs. The following strategies are accumulated by studying different climate analysis literature and design examples in a hot and humid region. Some of them are also derived from traditional bio-climatic techniques used in Mumbai and surroundings in the 'Bungalow' form of residences.

OVERALL MASSING STRATEGIES

The overall structure massing should mainly take into account the various external forces acting on it. The important external forces in hot-humid zones are the solar radiation, wind and the rainfall during the monsoons. In a region like Mumbai, buildings should be separated and scattered to make the spaces between them useful for catching winds. Individual high-rise buildings should be designed in special ways to make up for the advantages of scattered buildings. "Individual structures should be freely elongated; rooms preferably single blanked with access from open verandahs or galleries."[7]. The overall building massing should be configured in such a way that each floor should have minimum intervention from the external forces but at the same time the structure as a whole acts against the same forces.

BUILDING ORIENTATION

The bio-climatic needs of a building in a hot-humid environment are very much dependent on the orientation of the building. The two main determinants of orientation of a building are wind and solar radiation. Orientation should help reduce solar radiation, especially in high-rise buildings. Housing in the humid regions has

[7] Konya, Allan. *Design Primer for Hot Climates*. (London: Architectural Press, 1980), 58.

very crucial wind requirements too. Optimum conditions should be achieved by careful considerations of both these factors. Building orientation also affects the temperature patterns of external wall surfaces and as a result, internal temperatures too. But the most important consideration should be of the individual unit orientation and the rooms within the unit.

POROSITY OF FORM

Unlike buildings in cold climates, a higher degree of porosity of form in a hot climate can function advantageously. "The dominant characteristics required of buildings are openness and shading: they must be designed to provide continuous and efficient ventilation, and protection from sun, rain and insects."[8] The porosity of buildings in a hot and humid environment should be an interpenetration of indoor and outdoor spaces. Like in most other parts of India, even in Mumbai, outdoor living is a prevalent pattern of life. Because of the climate, outdoor living takes place for the maximum part of the year. Hence porosity should be maintained in such a way that these outdoor spaces are a part of the structure. Also, Mumbai has high humidity levels. Therefore through ventilation should be provided, which increases the porosity factor within the housing unit. This shows that housing in Mumbai can afford rather high degrees of porosity.

An important factor that acts against this argument is the heavy rainfall during the monsoon season. This can be addressed by efficient overhangs to keep the rain away and appropriate building materials to prevent moisture from seeping in. But at the same time, the humidity levels have to be restrained with thorough ventilation and porosity of form.

INDIVIDUAL ROOM ORIENTATION

To reach thermal comfort conditions in an indoor environment, there is always a trade-off between orienting the house to catch good wind movement or for good

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[8] Ibid.

shading. "...good solar orientation and the orientation most suitable for the prevailing wind very seldom coincide and the best compromise must be reached in each case"[9]. Hence the orientation of individual rooms depends on the location of these rooms within the unit. The orientation of each room depends on the activity in that room and what conditions it requires to achieve thermal comfort for that activity.

STRUCTURE

The Roof

The roof is a major source of heat gain in a building in hot climates. In hot climates, roofs act as the main source of heat and contribute significantly to the interior temperature. "Great heats are generated during the day, and the problem is one of reducing the penetration of heat to the interior, and dispensing any accumulation of day heat to prevent further radiation on sleeping quarters at night".[10] This can be manipulated by means of efficient roof design and appropriate materials usage. The structure massing also contributes to the heat gain through the roof.

A variety of roof forms are used in hot and humid regions. This variety in roof forms is usually dependent on the scale and density of the structures. For example in low-rise individual dwellings a sloped roof could be used with low overhangs for protection from external factors. In high density and high-rise housing, flat roofs are preferred because they are easier to construct. These roofs also act as outdoor sleeping areas when made accessible. The usage of terraces for sleeping is a common feature in India during the summer season. In high-rise housing complexes, where different floors share common roof, the topmost unit would typically have a terrace that could be insulated from heat. Residents also use techniques like washing the terrace with water or laying some heat reflecting material on it.

[9] Konya, Allan. *Design Primer for Hot Climates*. (London: Architectural Press, 1980), 52.
[10] Fry and Drew

Floors

Floors in hot and humid regions act as platforms for exchange of heat. Unlike the cold climates, floors are usually bare and the interaction with floors is more tactile than visual. This interaction is maximized when people walk barefoot like in India. The heat exchange takes place at this contact of the bare foot to the floor. Hence selection of the floor material is a very important issue.

The thermal capacity of floors should be considered carefully. Cooler temperatures in the night time help cool the thermal mass of the floor and keep the house cooler during the hotter part of the day. To make use of this property of floors, heavyweight construction from high density materials can be used in hot-humid regions. Raising of the floor levels is very beneficial in hot and humid climate as it facilitates access to breeze and this helps maintaining internal air temperatures.

Ceilings

Ceilings in hot and humid regions are a very important feature of bio-climatic design. The material selection for ceilings should be done carefully to reduce glare from the windows and verandahs. The ceiling plastering should be done in such a way that moisture from the precipitation does not seep into the housing unit. The ceiling heights can be manipulated to achieve dramatic results and can help create a microclimate within the enclosed space. Reduced ceiling heights can provide very good thermal results by increasing air velocities in a hot and humid region.

Exterior Walls

Unlike the hot and dry climatic zone, the walls in a hot and humid zone have less importance because they need not have a very high thermal value. They can be of lightweight construction of materials with low thermal capacity and light color. But the permeability of these walls plays a significant role in maintaining thermal comfort within the unit. These walls should be treated to absorb the least moisture and to facilitate maximum evaporation. This evaporation usually takes place from the external surface. To make this possible, the wall should be more permeable externally and porous from outside compared to the interior finish.

It is very important to make these walls as reflective as possible because they might absorb high external temperatures and transmit them to the internal areas because of conduction. Color plays a very important role in such a case. Light colors are most preferable to reflect solar radiation.

Interior walls

Interior walls in a hot and humid climatic zone should be carefully designed. Conduction through these interior walls increases the internal temperature considerably. Walls can be insulated to reduce this conduction. Cavity walls can be used to block the heat within the walls. But care should be taken to prevent moisture in the cavity by applying proper water proofing techniques to these walls.

The moisture gets trapped in the walls and can be transmitted to the interior wall surface. Efficient plastering on the inner side of the wall surfaces can control this. Care should be taken that condensation should not take place at the internal surface and hence external surfaces should be made more porous.

SPACE

The bioclimatic design principles contribute to the characteristics of the space within the housing unit. When the strategies are incorporated in the right manner, this space acts as a resource for the people living there. An important feature of a housing unit is the 'cross section' of the unit. A cross section study of the unit gives a visual interpretation of the living areas and the volumes of these areas. Strategies like ventilation, cross ventilation, and floor levels can be designed with the aid of a cross sectional study. One of the important strategies that can be used in a hot and humid region is the variation in ceiling heights. This variation within a housing unit, can lead to variation in the wind flow patterns. An important phenomenon called 'Venturi effect' or otherwise known as wind tunneling effect can be achieved by this variation. This phenomenon produces an increase in wind flow when wind flows from a larger volume of space to a smaller volume. This is very advantageous to buildings in hot and humid region that need high wind velocities during most parts of the year.

SHADE

In hot-humid regions, shading requirements are more a combination of protection from rains, free air movement and prevention of glare. Traditional techniques for effective shading have been used for ages in Mumbai and the surrounding regions. 'Bungalows' have been the most popular forms of housing that have consistently evolved using these traditional techniques. Some of them are the usage of semi open external spaces or verandahs, low overhanging roofs and adjustable screens at the external walls. These techniques are studied in depth in the 'Bungalow' case study.

During the seasons of high humidity and overcast conditions, in this region, the main source of glare is the sky. This requires the house to have low overhanging eaves, semi-open external spaces and devices to obstruct glare from the sky. Screens, lattices and grills etc. are used to allow airflow and prevent external glare.

A traditional way of keeping out external heat and at the same time allowing air to flow in was to hang *Chicks*. "Chicks, a type of roller blind, were made of split, thin, bamboo canes, from four to six feet long, loosely strung together and bound at the edge with tape."[11] These permeable curtains were controlled by means of a chord that can lower or raise this screen.

VENTILATION

Ventilation is one of the most important factors in the study of thermal comfort in a particular region. The purpose of ventilation is to provide comfortable indoor thermal conditions. Ventilation requirements not only depend on the type of the climate, but also vary based on the different seasons in that region. "In hot-humid zones, provision should be made to obtain an air velocity of up to 2m/sec (400

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[11] King, Anthony D. *The Bungalow: The production of a Global Culture.*(New York: Oxford University Press. 1995), 34.

ft/min); as far as possible that prevailing winds should be used to achieve this air movement."[12]

The ventilation patterns vary as external wind direction and velocity change. Hence it is important to consider these two factors for various times in a year. In Mumbai, the wind directions are shown in Figures ....to... for the months January, April, July and October that are typical of the four seasons in India.

For a house in a humid climate, maximum airflow is required during some seasons of the year. In situations of extreme humidity during the summer, natural cooling is required at body levels of the occupants. This happens when evaporation of perspiration is caused by the unobstructed airflow over the body. Cross ventilation is essential in such situations. The habitable rooms in houses in Mumbai should ideally have openings on both the windward and leeward side to facilitate maximum cross ventilation across and within the rooms of the house.

[12] Givoni, 330.

CHAPTER V: CASE STUDIES

Introduction to the Template

Thermal comfort in buildings depends on the climatic conditions in the occupied spaces of the building. These conditions are determined by plotting bioclimatic charts for that climatic region. The bioclimatic chart shows the relationship of the climate variables that determine human comfort. "By plotting temperature and relative humidity, you can determine if the resulting condition is comfortable (within the comfort zone), too hot (above the top of the comfort zone), or too cold (below the bottom of the comfort zone)".[1] The bioclimatic chart also includes the effects of air movement in helping to achieve comfortable interior conditions. The comfort levels of a building are evaluated by integrating the bioclimatic chart indications and the occupancy of the residential unit at a particular time. For the case studies done, the bioclimatic charts have been plotted for four months; January, April, July and October. These months are selected to include a typical month for each of the four seasons in India i.e., the summer, winter, monsoon and autumn. These are provided in Appendix A.

For the purpose of the evaluation of comfort conditions for each case study, a template has been adopted. This template consists of eight factors that are used for the evaluation. As seen in Appendix C, the eight factors give a description of the bioclimatic strategies Correa uses in these case studies. The eight factors are significant for the study in the following manner.

Overall Building Mass:

Massing is the three-dimensional configuration of a building. "Massing has the potential to define and articulate exterior spaces, accommodate site, identify

[1] Brown, G. Z. *Sun, Wind, and Light: Architectural Design Strategies*. (New York: John Wiley and Sons, Inc., 1985), 33.

entrance, express circulation, and emphasize importance in architecture."[2] Specific factors of form, proportions, scale, and orientation to the ground plane are analyzed for each building mass.

Orientation:

The compass orientation of the building suggests how the architect uses it advantageously to improve factors like ventilation and shading in a building. The orientation of the case study building is studied for its significance with regards to wind and solar orientation.

Porosity of Form:

Porosity of form gives an idea about the openness in different orientations of the building. This aspect of the building suggests to what extent the building is vulnerable or impervious to forces of nature. The architect can use the porosity as a parameter for control of the thermal environment inside.

Individual Room Orientation:

The study of the individual room orientation is very important since the interior environment in each unit depends on the orientation of these rooms to a large extent. The architect's trade off between orienting it to catch good wind movement or for good shading is always a factor to be considered while studying the building.

Structure:

The basic structure type of the building is identified. The structure is analyzed for its five components, the roof, floor, ceiling, exterior walls, and the interior walls. The importance of the study of structure in these case studies lies in the fact that it suggests the circulation and movement within the unit. The degree of openness in the space of the unit because of the structure, defines its ventilation pattern. The components are also studied for their material and the suitability of this material to the context.

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[2] Clark and Pause. *Precedents in Architecture*. (New York: John Wiley and Sons, inc.,1996), 4.

Space:

The study of space in a residential unit is done taking the cross section into consideration. A study of the cross section integrates concepts like variation in levels, ceiling heights and other volume related concepts. How space acts like a resource in this climate and for the activities of the residents is studied.

Shade:

Shading techniques for the building are studied in terms of the protection they offer from the glare, direct sunlight and rain for different seasons of the year. The usage of traditional and modern techniques by the architect is studied. A consistent strategy of semi open spaces by Correa for shading is studied in detail.

Ventilation:

Ventilation is one of the most important factors in the study of thermal comfort. In a hot and humid climate, ventilation is a crucial component of design considerations. The architect has to consider the high humidity levels during most parts of the year for adopting appropriate strategies. The ventilation patterns for the whole unit are developed in the 3-dimensional model of the case study for four months of the year based on the wind direction and wind speed data. Analysis is made for comfort in each room based on the climatic needs and the physical conditions in the unit.

Comfort Assessment:

The study of the above factors leads to the analysis of the comfort assessment for the building as a whole. The most comfortable and the least comfortable spaces according to the climatic conditions for different times are listed. A brief description of the overall comfort in the living and dining areas, the bedrooms and the external spaces is given.

After these factors are studied for each case study building, the comparative analysis is made from the study of this template. Each strategy is studied in light of three questions- the commonalities, the most successful strategies and the least successful design strategies used by Correa. Another important aspect of this study is its relation to the traditional strategies used by Correa. This is evaluated by comparing Correa's buildings to the traditional bungalow, which is also one of the case studies. This is essential because the conclusions are based on three possibilities, the possibilities of Correa using vernacular strategies as absolutes, or modifying the vernacular strategies to suit the present context or creating his own solutions that are successful.

CASE STUDY-TRADITIONAL BUNGALOW

The bungalow is a form of housing originated in India. The bungalow in its most primitive stages was a temporary *hut* structure made out of locally available bamboo and mud. But because of its versatile functional and climatic performance, the bungalow has been modified according to place, time and climate over the centuries.

The observations discussed as the part of the case study in this section are based on a generic model of the bungalow from the 18th century located in India based on the model described in *The Bungalow*, by Anthony D. King.[3] For all analytical purposes, the orientation as shown in the following figure is considered.

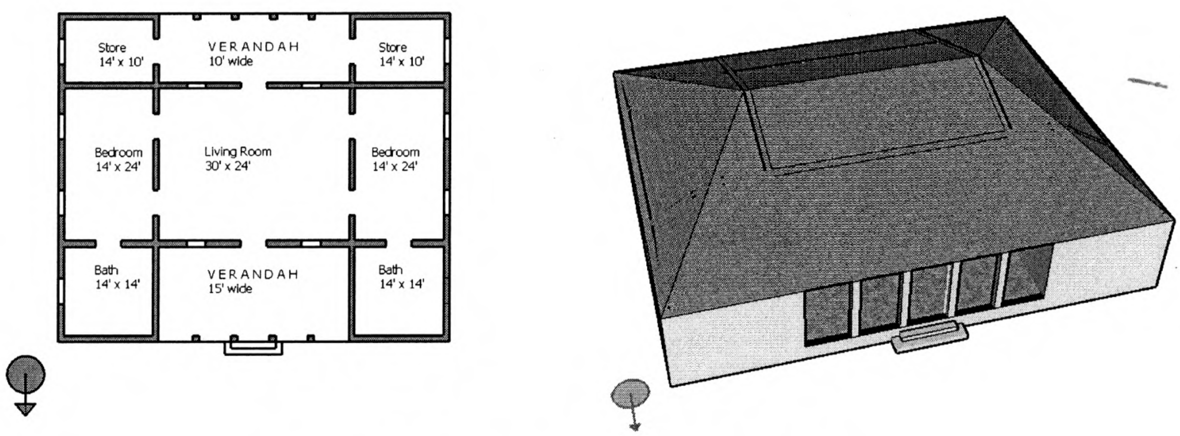

Fig. 5.1.1: Typical Bungalow-Plan and Roof Structure

OVERALL BUILDING MASSING

In its initial stages, the bungalow was mostly configured as a single floor. The main plan of the building was accommodated in a single storey house. It has the typical 'hut' structure that was very prevalent during the 1800-1900 in Bengal, India. In a 'hut' structure, the whole building is developed as one mass, with the exterior envelope divided into semi open spaces with columns to support the roof structure.

[3] King, 3.

The roof structure is sloping on all four sides. It extends over the verandah space and is supported by the columns at the periphery. These verandahs are raised on a base of brick at a height of 2-3 feet and this base acts as a plinth for the whole structure.

ORDER OF ROOMS

The rooms in a traditional bungalow are arranged with the living area as the core of the house. The advantages of this kind of an arrangement are the reason for its successful use for centuries. The rooms arranged in such a way are typically surrounded with semi-open verandahs and bathrooms at the corners.

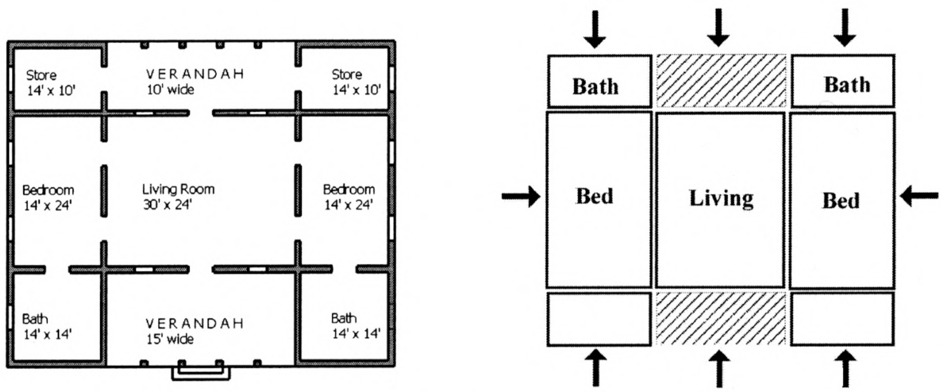

Fig.5.1.2:Bungalow plan and Room layout sketch.

As seen in figure 5.1.2, in the bungalow, the living room is ventilated from the front and back verandahs that envelope it. The surrounding rooms get their ventilation from the openings at the external walls. The privacy of the living and bedrooms is maintained by using operable shading devices. These devices are operated based on the climatic conditions outside. The strategy used in a bungalow is an antithesis of a central courtyard, but analogous to it in many ways.

ORIENTATION

The orientation of the bungalow always depended on the local site conditions and not any particular direction. Since the roof always covered the whole structure, the solar orientation is less significant than the orientation for wind. Usually, the north and south sides of the bungalow are provided with verandahs. The bungalow is always oriented towards the prevailing breeze.

POROSITY OF FORM

The bungalow is an excellent example for depicting the porosity of form. The local cultural and political conditions in India did not demand very much privacy for the residents in a bungalow, except for the bedrooms. The climate also required a higher degree of porosity for through ventilation. Hence, the porosity of form has been exploited in the design and planning features of a bungalow. The activities in a bungalow started at the compound level itself. The usage factor varied as one went from the external space, to the closed space, through the semi open spaces, cross sectionally. The activities of the residents and their usage pattern required higher level of porosity at the external envelope. This is achieved by the verandahs provided as a surrounding external feature for almost the whole bungalow perimeter at times.

STRUCTURE

The roof

In its most primitive form, the Bungalow's roof was made of bamboo covered with thatch or leaves from trees. But in later stages, a better framework for the roof was adopted. To make the roof structure, timber members were laid on top of exterior walls. Rafters were fastened to this member with nails. Bamboos were laid out on these rafters in both vertical and horizontal manner and were tied down with fine grass. This frame was then thatched with the locally available leaves and grass.

Much later towards the eighteenth century, the thatched roof was covered with tiles to protect the interior from excessive heat. The support system for this new heavy roof was given by strong wooden posts or by pillars of masonry.

Floors

The floors were basically made of the brick and finished with mud plaster on which the whole bungalow was raised. The plinth of the structure that was of solid masonry was the most important feature of the bungalow. This plinth did not have any ventilation from outside or below through openings. They were sometimes plastered with cow dung. But once more permanent structures started being built; the floor would be mostly finished in stone. The bungalows of rich people had marble flooring. With the advent of new technologies and materials, the floors were started being made of new materials like terrazzo and mosaic.

Ceilings

The ceilings form a very interesting part of the house interior. Because of the coarse roof work that could be seen from the inside, the main intention was to cover the ceilings. "The ceilings 'were rendered inconceivably neat', not by plaster but, by means of a double sheet…of very coarse cotton cloth called *guzzy* of which tents are usually constructed…"[4]. This cloth was fastened to the roof frame with tape or nails. This ceiling also helped the acoustics inside by blocking off the huge attic space beneath the roof that usually increased resonance. The cloth is not a thermally insulating material and hence did not contribute much to the thermal quality of the interior space. But this material provided additional water proofing to the already existing layers on the roof.

Exterior Walls

In the period where more permanent buildings were being constructed instead of the temporary mud structures, walls were constructed out of 'mud laid in strata of 18-20 inches in depth'. Mud is the most abundantly available material in India. Mud was laid in layers; each layer was dried before the next was laid on top of it. The wall thickness used to differ over height. The walls were 26 to 30 inches in depth at the base. These walls were also sometimes chipped down to a single thickness and

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[4] King, 31.

plastered with a mixture of sand and chaff (finely cut hay). Sand and chaff were also locally available. The thickness of these walls could pose problems in a hot and humid region. These problems were taken care of by the ample cross ventilation within the bungalow.

Interior Walls

The interior walls were finished smooth. These were also smeared with cow dung at places, a very popular technique in rural India. Towards later part of the eighteenth century, limestone plastering was more popular. The interior wall finish was not heat absorbent and hence gives a cooling effect.

SPACE

The space in a bungalow is used by residents in the most versatile character. The spatial order in a bungalow can be classified into three different spaces as shown in the figure 5.1.3. These are the open space within the compound, the semi open space in the verandahs and the closed space within the walls of the bungalow. The living activities of the people associated with the bungalow (whether the main occupants or the servants) are interwoven in these three forms of spaces.

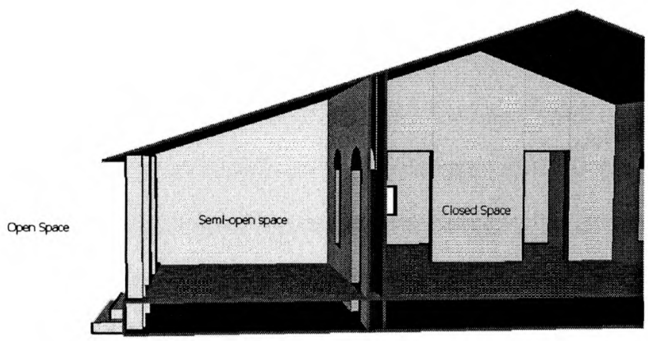

Fig. 5.1.3: Section showing spatial order

Fig.5.1.4: Activities in the semi-open space

The external space within the compound of a bungalow by itself serves very important functions. In India, climate can accommodate various activities to take place in the space outside the residence. "In fact, the compound was simply an extension of the bungalow's internal space, an outdoor room, fulfilling a variety of social, political, cultural and psychological needs"[5].

The semi-open space of the verandahs is the most dynamic space in a bungalow. These verandahs are multi functional as they serve both as servant and served spaces. The verandahs served as the best climatically controlled space of the bungalow. They were the activity areas of the house. They could be controlled by either enclosing or keeping open the external envelope of columns surrounding them. An interesting comparison could be made of the verandahs to the courtyards. Both these are integral features of traditional houses in India. The climatic functions of verandahs in bungalows will be discussed later.

> "The bungalow was in direct contrast to the courtyard house…here a central courtyard allowed the penetration of light and air; …Activity in this courtyard house was centripetal: movement was inwards, towards the courtyard. In the bungalow, it was centrifugal, outward, on to the verandah, and further into the compound"[6].

The interior closed space of the bungalow mainly serves the living and sleeping purposes. The main concentration of space is the central area used for living and eating. The bedrooms and bathrooms are provided at each corner of the structure. The single pitched roof structure gives these spaces a single entity from the outside.

SHADE

The bungalow's roof structure and the external semi open spaces, together serve as a shading strategy. The roof structure is always extended over the main building structure by one or two feet. The roof is configured lower than the external wall height. This helps in preventing glare for the middle part of the day. This also provides partial shading to the exterior walls. The wall openings are provided with operable windows at various heights. The verandah shading techniques used traditionally are very significant in this discussion.

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[5] King, 34.
[6] King, 35.

The verandahs are the most used spaces in a bungalow because of the versatile shading techniques used in them. One of them was to use bamboo battens and mats to control shade in the verandahs. These mats were hung by their upper borders fastened into the wall with hooks or rings at the external wall or colonnade of the verandahs. They could be raised and lowered as desired by bamboo stilts as shown in figure 5.1.5. "They also kept sun and rain off the doors and, when lowered close to the wall, kept out rain and dust" [7].

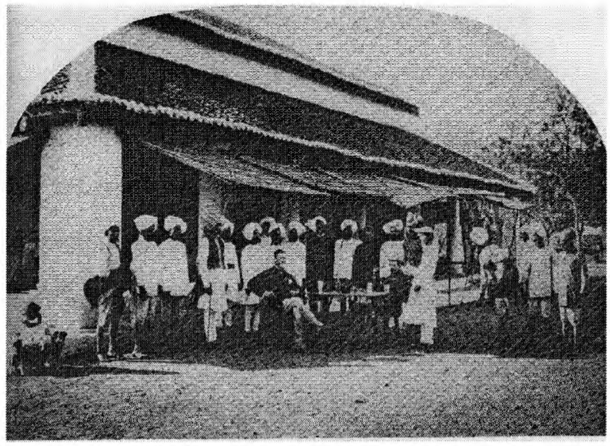


Fig. 5.1.5: Mats raised on bamboo stilts.

The bathrooms and bedroom windows were very high due to the required privacy. But the windows of the living area were as high as the doors and could be closed or opened for various arrangements of wind and shade. Another local device used very effectively and popularly for shading was the roller blind made of bamboo canes called "chicks". They were usually fixed to the lintels of windows and doors, or sometimes also to the beams between the columns in the verandahs. These could be rolled up and down depending on the sun's position to keep the glare off of the living areas. The effectiveness of these chicks lies in their ability to block sun and allow the wind to go through.

Another technique used at later stages of the development of the bungalow was the usage of wooden lattices as a permanent feature of the verandahs shown in Figure 5.1.6. This prevents glare and allows wind to penetrate effectively. They would typically be placed on the external walls of the verandahs where there are no entry or exit points.

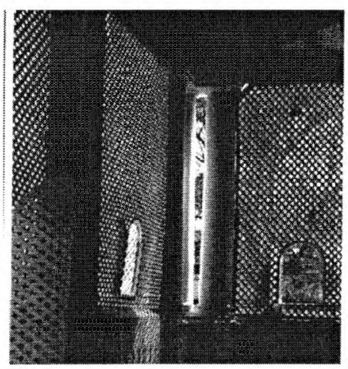


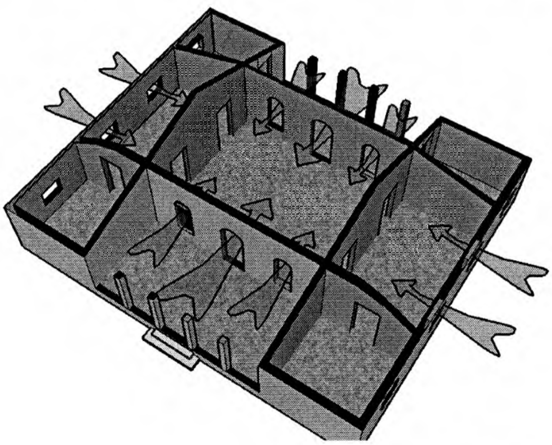
Fig. 5.1.6: Wooden lattices.

[7] King, 43.

VENTILATION

Ventilation in a bungalow has been the most important aspect of its design. This feature has been used over and over again because of its continuous success over time and especially because of its suitability in a hot and humid climate. The patterns of ventilation in a bungalow are very simple, yet effective. One of the significant aspects of this ventilation is the cross ventilation that is provided by the various openings, and hierarchy of spaces in the bungalow.

The cross ventilation patterns in a bungalow are achieved by the symmetry followed in providing openings, and open spaces like verandahs. Figures 5.1.7 (a) and (b) show the cross ventilation patterns in the generic model.



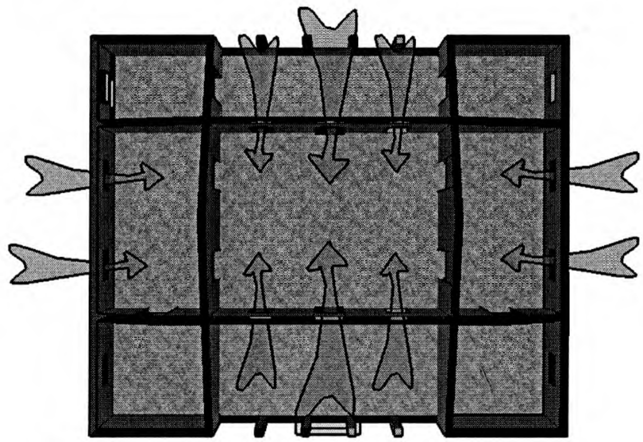


Fig. 5.1.7(a) and (b): Cross ventilation in a typical bungalow

Because of the privacy factor being comparatively low in bungalows of India, the ventilation system is even more effective. In India, the functionality of open and semi open spaces is very high. Hence during seasons other than monsoons, the open spaces are used extensively. The verandahs in a bungalow are covered with a low hanging roof and because of

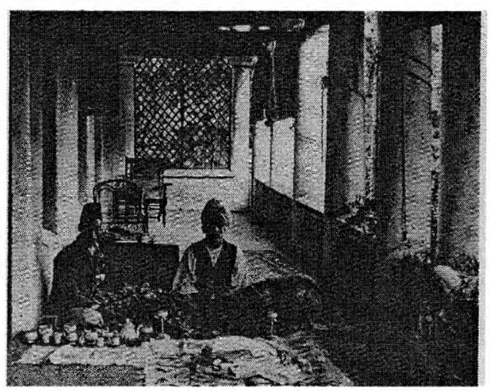


Fig.5.1.8: Verandah being used for sleeping and lounging.

their semi-open nature, are used for sleeping and other activities like lounging for most parts of the year.

The objective for the placement of openings and providing the hierarchy of spaces is that every corner of the bungalow should be ventilated. The primary purpose is to provide wind flow to each level of the spatial order while trying to reach the core internal space. All the rooms are individually provided with enough openings for cross ventilation. Even if the room doors are closed, the cross ventilation is still effective through windows.

As seen in the section in figure 5.1.9 below of the open, semi open and closed interior space, the wind enters from the open exterior through the low semi open space and is captured within the huge volume of space at the center of the building. This is achieved by keeping the roof level very low at the entry points and windows and other openings small to capture winds. The venturi's effect causes the wind to increase its velocity as it travels to the interior because of the roof and the small openings. In this way not only does the wind flow in but it flows with a high speed that is required at various seasons of the year. The increasing ground level from the external ground level to the high platform inside also facilitates this effect.

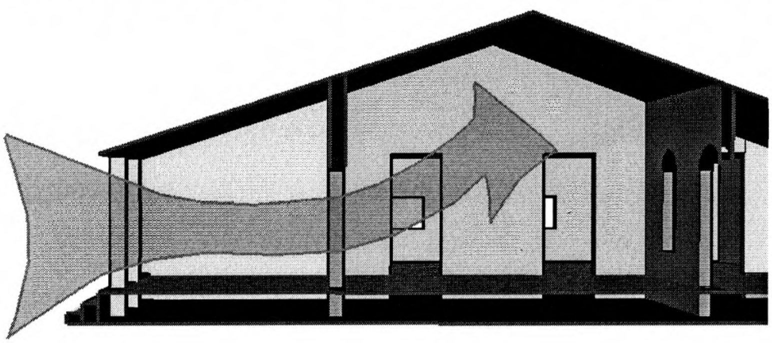


Fig. 5.1.9: Venturi effect because of roof

The windows also provide a good pattern of ventilation. The windows, especially at places where privacy is not so important, are as high as the doors. Two sets of double shuttered windows are provided at the top and the bottom of an opening. The wind enters through the lower half of the opening. Because of the stack effect, the air temperature increases and the heated air is vented out through the upper window at the opposite wall. The following figure shows how wind is controlled by opening and closing of these windows at different walls of the living area.

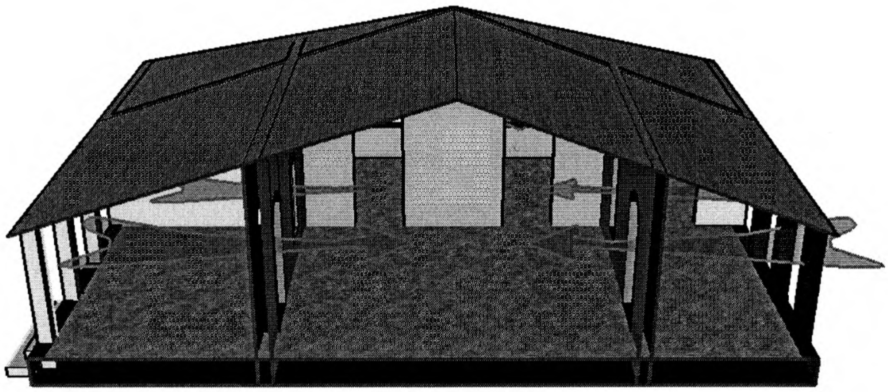


Fig. 5.1.10: Cross ventilation at windows

COMFORT ASSESSMENT

The generic model of the bungalow created for the study purpose is based on the typical bungalow style prevalent during the 1800-1900s. This unit was studied for four time of the day for four different months during a year. This study was based on the comfort provided by the structure climatically for the residents to carry on with the daily activities in each space of the bungalow.

One of the most important features of living in a bungalow was the versatile usage of spaces in it. To achieve comfort during different times of the day, during different seasons, the residents had flexibility in usage of spaces and control of shading devices. "The main method of controlling the thermal environment, however, was to modify behavior rather than the building: when the inside got too hot, the occupants moved on to the verandah."[8].

Also, the activity patterns in a typical bungalow during the early nineteenth century are quite unlike the typical residential activities of a family in the recent times. During the eighteenth century, there were different structures built for different activities like cooking, servants etc. The bungalow's programming was mostly done based on the socio-cultural setup of the locally ruling politicians. Hence the

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[8] King, 34

occupancy of a bungalow during the different times of the day varies drastically to the other case studies analyzed for comfort assessment.

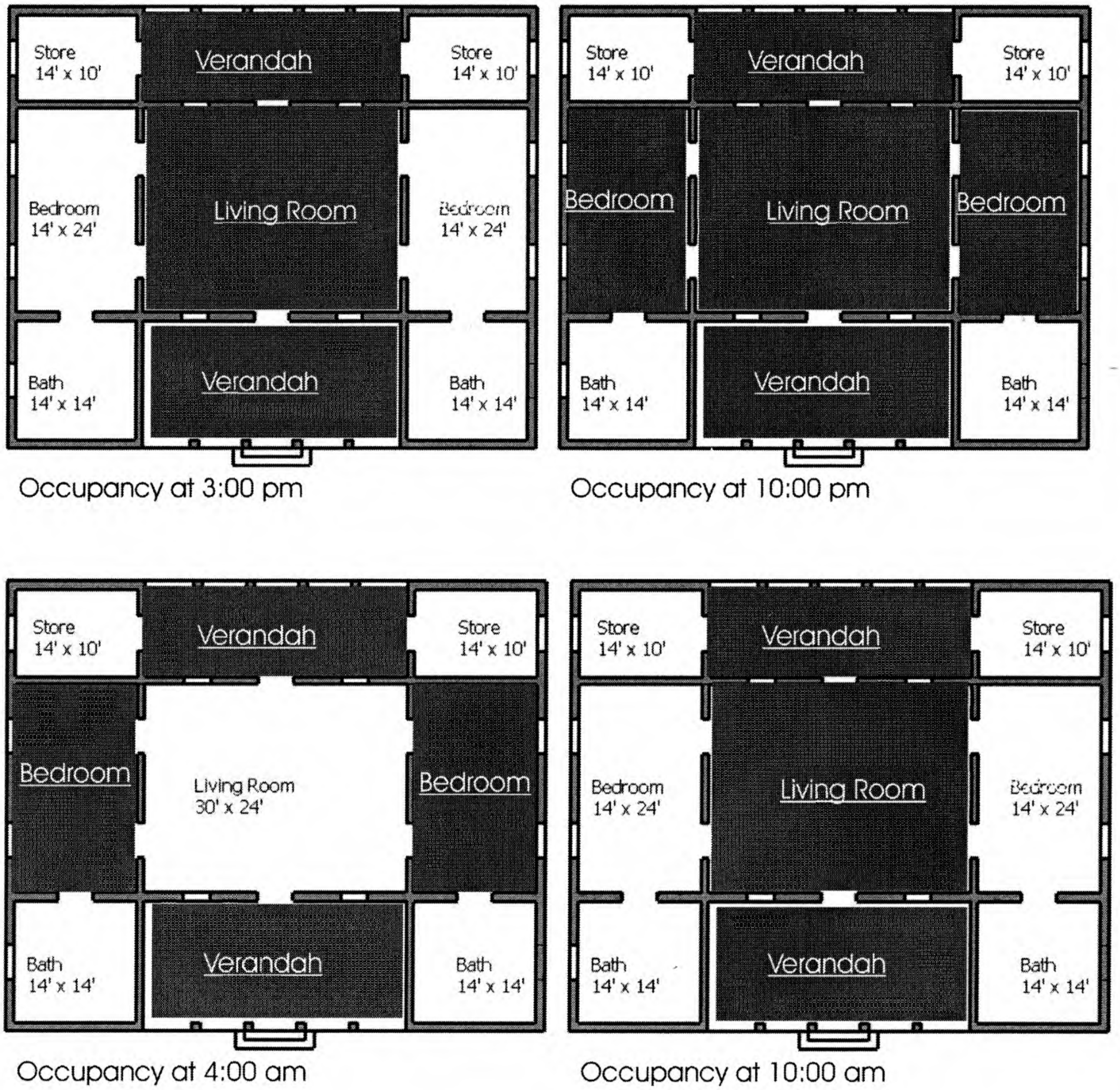


Fig. 5.1.11: Occupancy patterns for four hours of the day.

January:

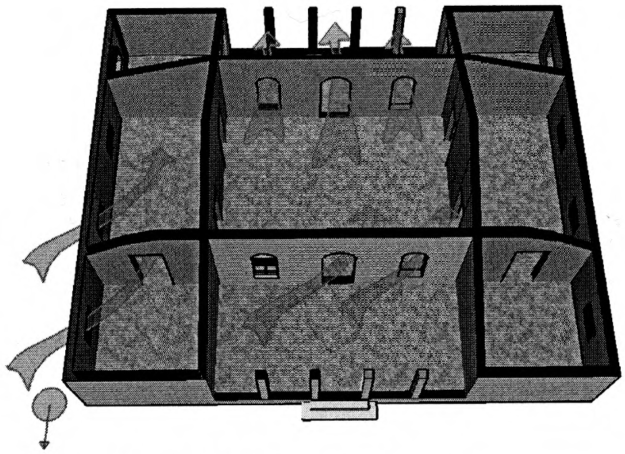


Fig. 5.1.12: Wind pattern-January

4:00 am:

The wind direction is North-east. The bedroom on the east side of the bungalow is well ventilated. The bedroom on the west side might not get the prevailing wind directly, hence not so well ventilated. The relative humidity is 76% at this time. Hence the residents sleeping in the west side might feel discomfort. Options of sleeping in the living area or the verandahs are open, but privacy has to be compromised.

10 am:

The living area and the verandahs that are occupied at this hour are very well ventilated. The required wind speed is less than the existing wind speed; hence an increase in wind speed is required. This is provided by the wind entering from the front of the bungalow that is swept to the inside. Shading is not required for the North and south facing verandahs. The east facing window's shutters could be closed to prevent glare and heat gain.

3:00 pm:

The temperature is the highest at this point, but the relative humidity is the lowest. Hence shading requirement is more significant than the wind requirement. The direct radiation from the sun can be blocked by the efficient window design. The mats supported by bamboo poles could be lowered to reduce glare in the verandahs.

10:00 pm:

The bungalow is in comfort zone, hence the sleeping and living activities are done without any intervention of climatic forces.

April:

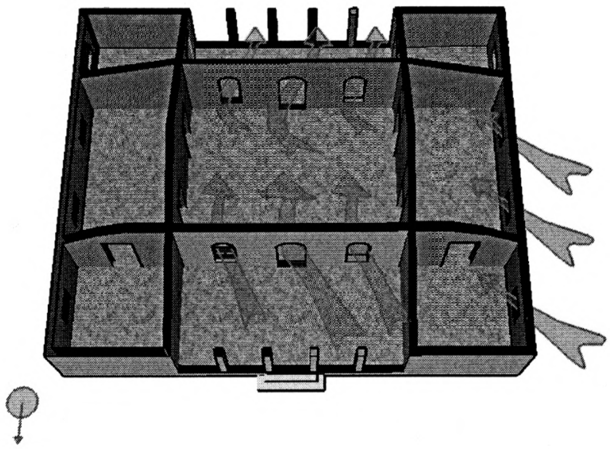


Fig. 5.1.13: Wind pattern-April

4:00 am:

The direction of the prevailing winds is north-west. The relative humidity is the highest at this point in the entire day. Since there is no shade required, if all the windows are kept open, it would not be difficult to increase the wind flow into the interior.

10:00 am:

This hour is a difficult situation since the humidity is high and the required wind speed is much higher than the existing wind speed. The wind velocities should have to be increased drastically by controlling window openings in the windward and the leeward sides to achieve maximum cross ventilation. Direct sunlight is handled by the low roof and shading devices like *chicks*.

3:00 pm:

The climatic conditions are the same as at 10:00 am, but the sun's position varies. Glare from sun is now controlled by the low roof at the south side and by closing windows on the west side rooms.

10:00 pm:

The relative humidity is high, but the required wind speed is comparable to the existing wind speed. Hence comfort situations might be achieved by keeping all windows open or by sleeping in the semi-open spaces.

July

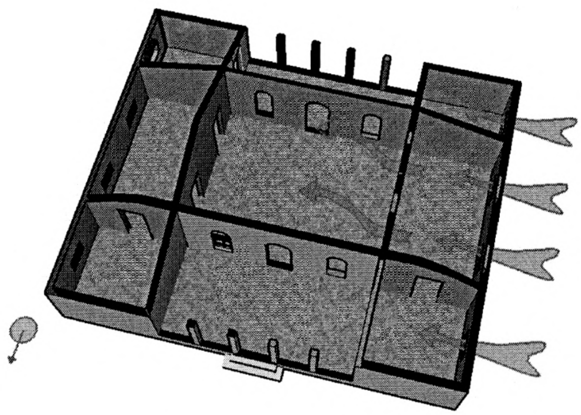


Fig. 5.1.14: Wind pattern-July

4:00 am:

The wind direction is west during this month. The relative humidity is very high because of high precipitation. An additional requirement of protection from rain is required during the monsoon season. The existing wind speed is much higher than the required. Hence, some openings might be closed to keep away rains. The verandahs are not suitable for sleeping during this month.

10:00 am:

Shading is required at this hour, and also high wind velocities. This poses a problem as some openings have to be closed for shading that might not give efficient ventilation. This is when the bamboo *chicks* prove to be very effective.

3:00 pm:

Conditions are similar to the conditions at 10:00 am.

10:00 pm:

Wind speed required is much lower than existing; hence winds have to be controlled. Because of high humidity, the higher wind speed helps in achieving comfort conditions.

October:

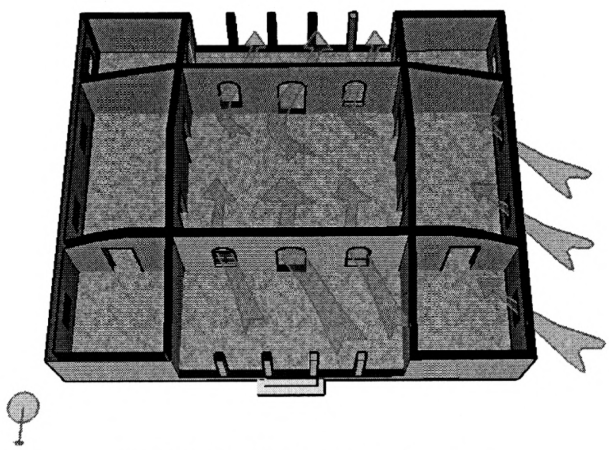


Fig. 5.1.15: Wind pattern-October

4:00 am:

The wind speed required matches the existing wind speed. Shading is not required at this hour. But since the relative humidity is high, the openings prove to be the most effective technique to achieve comfort.

10:00 am:

The wind speed required is very high. At the same time shading is required at the east. But at all times, the north and south verandahs are highly usable spaces. If the interior space is not usable, semi-open spaces prove more functional.

3:00 pm:

Conditions are similar to 10:00 am.

10:00 pm:

Shading is not required at this hour, but the other conditions are the same as 10:00 am and 3:00pm. Hence, comfort has to be achieved through the cross ventilation strategies of the bungalow.

SUMMARY OF COMFORT ASSESSMENT

The climate for which the typical bungalow has been assessed is the hot and Humid climate of Mumbai. Although the typical bungalow was prevalent geographically in a much wider area in India, to compare it relatively along with the other case studies, Mumbai's climate template has been used. The ventilation pattern within the bungalow varies for different times of the year. But the central living area that is the core and used for 75% of the time each day according to the occupancy charts, is very well ventilated for all directions of wind. The shading of this area is also well controlled because of spaces surrounding this area.

The bedrooms are located at either sides of the living area. Hence for two months, the east side bedroom is not very well ventilated and for the other two months, the west side bedroom is not well ventilated. The bathrooms are located at the corners of the bungalow. The verandahs are the important centers for activities throughout the day and are located at the center of the exterior envelope. Spaces for private activities like bathrooms and bedrooms are located at the corners and less accessible portions of the bungalow.

The essential strategy for comfort in a bungalow still lies in changing behavior during different parts of the day. The spaces in a bungalow are spread out in different locations. These different locations when integrated with different activities give a range of comfort locations for the different hours of the day and year.

CASE STUDY- SONMARG APARTMENTS (1961-66)

Sonmarg apartments are situated in Mumbai. They were constructed during 1961-66. These apartments were one of the initial climatically responsive designs by Correa in Mumbai. The apartment building is a high-rise multi residential complex with fourteen floors and two residential units per floor.

Each unit consists of a living room, three bedrooms, a kitchen attached to the dining room and a small servant's room. The two residential units share a service core in between. As seen in the plan in figure 5.2.3, the entrance to the apartment is through this service core and the apartment is open on all the other three sides to the exterior. These three external walls are provided with auxiliary spaces that serve as good buffer zones for external climatic forces. The strategies used to respond to the local climatic conditions are explained in detail following the format presented in the general principles for Mumbai.

OVERALL BUILDING MASS

The Sonmarg apartment complex is an elongated, rectangular, multilevel building. The composition of massing of the fourteen floors is done in a simple and symmetrical manner. The exterior envelope is divided into different faces. As seen in figure 5.2.1, the elevation shows a distinction in the interior layout by way of vertical columns and horizontal concrete beams. It clearly depicts the upper level bedrooms, the lower level living area and the central service core. This distinction breaks down the mass of the entire building into smaller components, and reduces the visually imposing vertical expression of the high-rise building to a more horizontal and perceivable scale.

Fig. 5.2.1: Elevation, Sonmarg Apartments

These smaller components of the individual units not only help visually but also act as bio-climatic elements. Each unit has covered exterior and interior spaces that act as climatic buffers. For example, the covered verandah on the east side, as seen in the plan of the unit, protects the dining room from rain and direct sunlight.

The proportion of the overall massing of the unit is configured in such a way that the portion of the unit that needs maximum interaction with the external environment, like the east and west sides, are located appropriately. The north side of the apartment, with the bedrooms, gets enough privacy and optimum ventilation.

ORDER OF ROOMS:

The rooms in the individual unit of the Sonmarg apartments are arranged in a bunched manner. This arrangement is very significant for the protection of the interior spaces. The rooms are blanked with balconies on the east and west elevations.

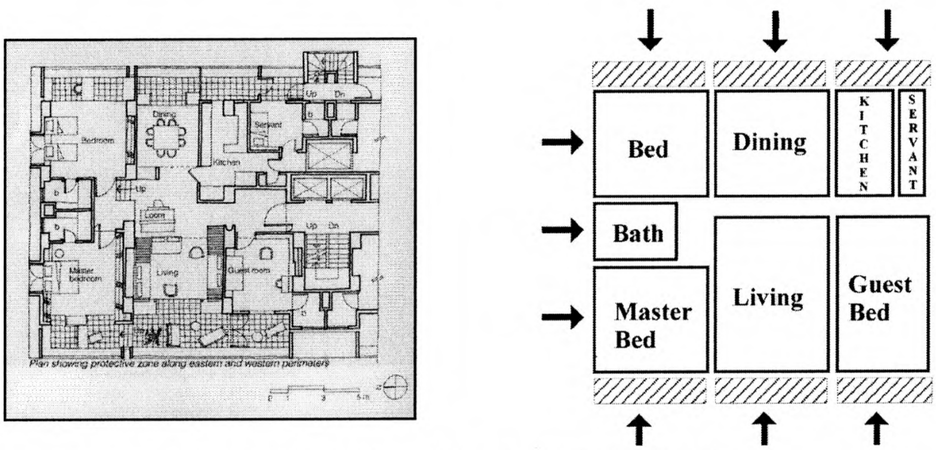


Fig. 5.2.2: Plan and Room layout sketch of individual unit.

This arrangement facilitates through cross ventilation because of the arrangement of openings. A special strategy of zoning, i.e., arranging auxiliary spaces like study, balconies etc. around the main living areas is used in these apartments. These zones help control the external forces at that level and keep the interiors comfortable.

But at the same time, the rooms bunched together were not restricted with a single form of ceiling. The ceiling was varied in height and took advantage of the heights by increasing wind velocities. The basic spatial order in the bungalow is the bunching of rooms around the living area; this is the same as bunching the rooms around the living and dining area in the Sonmarg unit. This order is functional in terms of 'flow' of air through the room.

BUILDING ORIENTATION

Solar Significance

The apartment building is oriented in the north-south direction. If only the building is considered, this orientation does not provide any significant solar comfort. But because it is a multilevel residential complex, the building orientation may not prove to be very significant as compared to the individual residence units within the building. The shade requirements for the individual apartment use appropriate shading devices that are discussed subsequently in this section.

Wind Direction significance

An east-west orientation provides better access to the prevailing winds in Mumbai for the year. The building's North-South orientation is not efficient for the wind required according to the prevailing wind direction for most part of the year. The effectiveness of orientation for individual units is more significant than the orientation for the building by itself.

POROSITY OF FORM

The concept of porosity of form is achieved by the architect, by way of making the building envelope permeable to the various forces of nature. Permeability is very significant in these units as there is always a need of cross ventilation but at the same time protection from sun and rain is required. The exterior envelope of the Sonmarg apartments is designed as a screen with openings distributed across the elevation. The porosity of this envelope is only as deep as the auxiliary spaces provided around the main living spaces within the unit. Hence the building can control this porosity by controlling the openings and balconies at the exterior level.

INDIVIDUAL ROOM ORIENTATION

The individual units in Sonmarg apartments are oriented in the East-West direction. This orientation helps catch the prevailing winds in a very effective manner. The prevailing winds hit the apartment wall at 45 degrees. This diagonal orientation of the unit to the incident winds proves to be more effective than a perpendicular incidence.

While considering the orientation of the rooms in the unit, the advantages and disadvantages of a particular orientation of a room were considered in a relative manner. For example, the master bedroom is more strategically located than the guest bedroom considering its comfort. More importance has been given to the master bedroom ventilation as compared to the servant's room or the guest room.

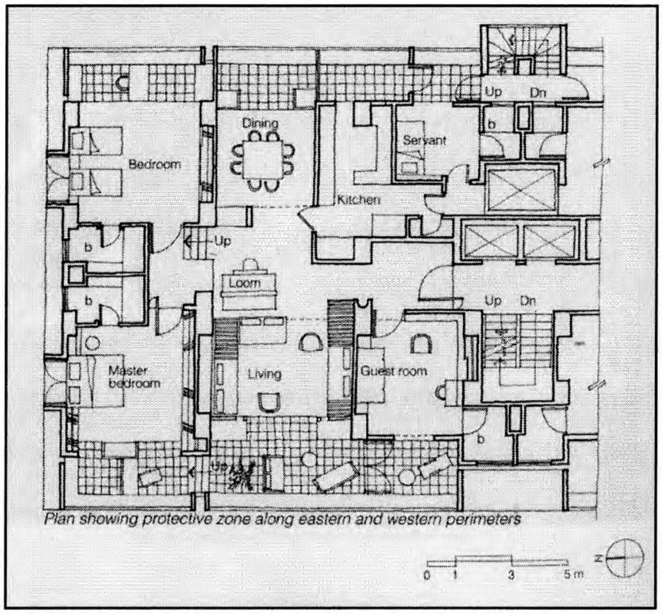


Fig. 5.2.3: Plan of Individual unit.

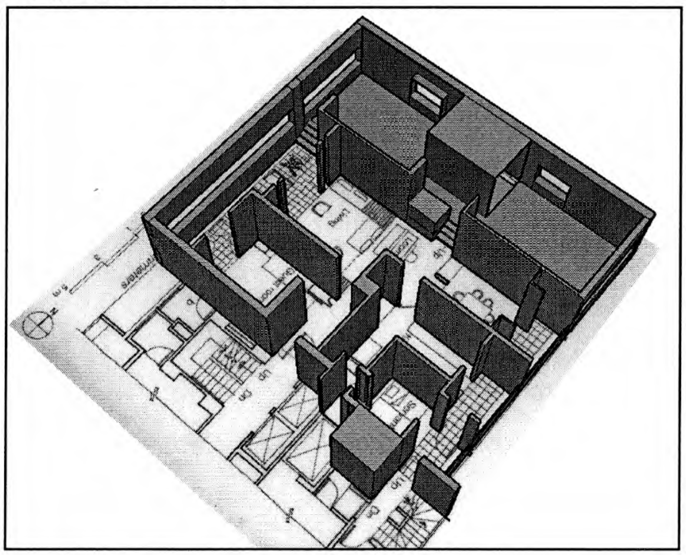


Fig. 5.2.4: Axonometric 3-D model of the unit.

Even though the broad side of the unit is oriented in East-West direction, none of the rooms have a problem with direct sunlight or rain. This is done by providing a blanket of small spaces around the main activity rooms. The main activities in rooms like the bedrooms, living and the dining room are never disturbed by external forces because of these spaces. These small spaces are in turn provided with efficiently designed windows and shading devices so that they also can be used for auxiliary activities like studying or lounging.

The orientation of the openings within each room has a strong influence on the ventilation of that interior space. This will be discussed more in the ventilation section of this chapter.

STRUCTURE

The Roof

Sonmarg apartments are structured in fourteen floors. Since there is only one exposed roof that is of the topmost apartments, the heat gain through the roof is not an important issue. The roof structure is flat and built of reinforced concrete. But since this is built of concrete, it would have a high heat capacity.

Floors

The construction technique used is the columns and beams technique with reinforced concrete slabs. These slabs form the floors between the different apartments. They are given various finishes like marble, ceramic tiles, or smooth finish concrete.

Ceilings

The ceiling height varies through the apartment. At the peripheral zone of small spaces, the ceiling height is more and it decreases as one goes inside. This helps in directing the wind flow and increasing the velocity towards the main activity areas inside. It helps provide cooling to the people at the body levels when they are sitting, sleeping or dining.

Exterior Walls

The external walls of the units in Sonmarg apartments consist of windows and parapet walls of balconies. These walls are made of brick and with cement plastering. These are porous to water and vapor. They have a high tendency of absorbing water when exposed to rain. Condensation is also another problem with this material in the monsoons and winters.

The walls are light in color and hence reduce the absorption of radiation by reflecting it to a certain extent.

Interior walls

The interior walls are given a smooth finish with cement plastering. These walls are finished with plastering from inside and are relatively more porous from outside. This facilitates evaporation from the external wall surface.

There is always a need to keep these walls as cool as possible from the inside since the external wall temperature cannot be controlled.

SPACE

The space when conceived in terms of volume in Sonmarg apartments proves to be very resourceful for the various activities performed. The cross sectional space is very well organized. Each volume of space when considered individually is provided with its own ventilation and shade pattern. In these apartments, not only is comfort achieved in these individual spaces, but residents also have options to change the usage patterns during different times of the day within these areas. In a hot and humid region like Mumbai, such options are invaluable.

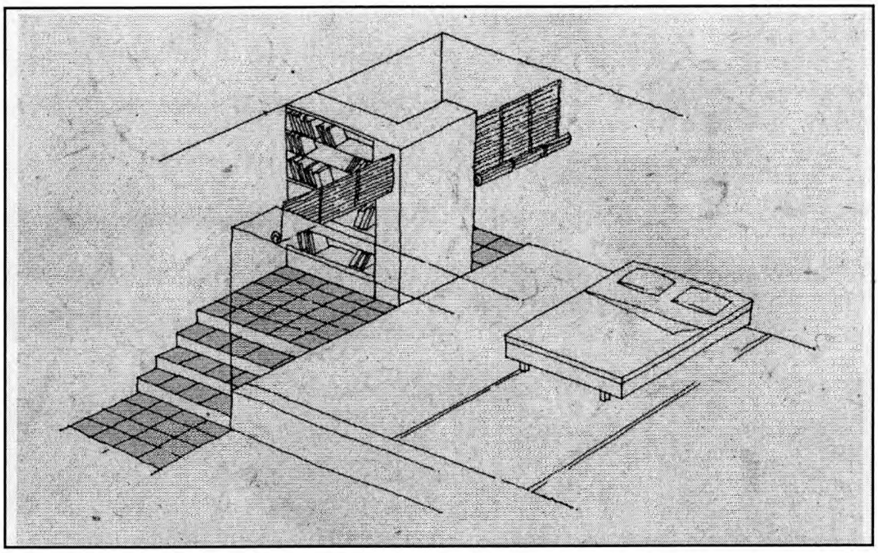


Fig.5.2.5: Protective zone between external wall and bedroom used as a study.

The auxiliary spaces that surround the main activity rooms are very functional in terms of activities like studying or lounging. The ventilation and shade patterns can be varied by manipulation of the devices and this can make the ventilation dynamic rather than a standard pattern. A vital cross section that explains this concept is the east-west axis section through the living and the dining room.

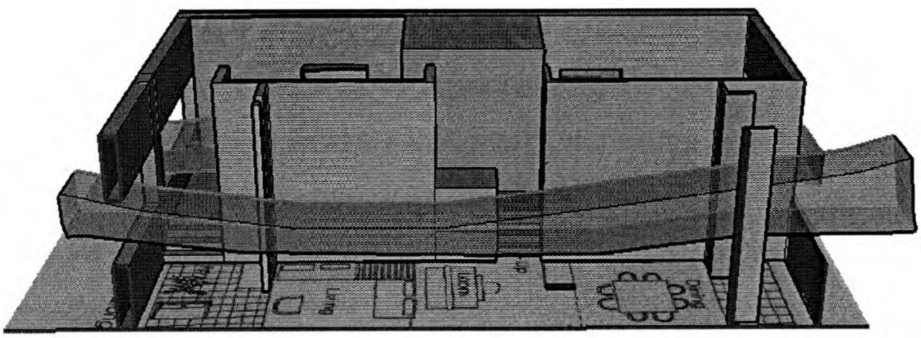


Fig. 5.2.6 :East-west Section across the unit.

SHADE

To control sunlight radiation and glare, Correa tried to design each wall of the unit in the most versatile way. The external walls in this design act like 'environmentally interactive membranes'. These walls try to interact with the outside environment like membranes by keeping away the non-essential and letting in the essential forces of nature. This is done by the nature and location of the window openings on the external walls of the unit. A combination of fixed and operable windows is used at different elevations.

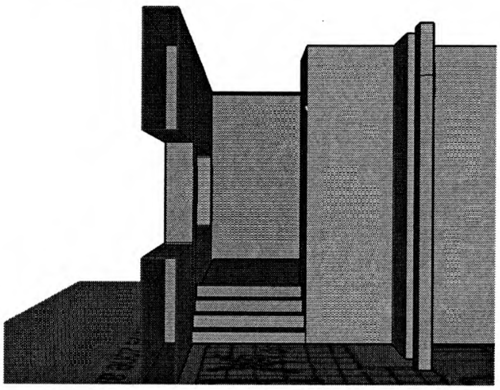


Fig.5.2.7: Section at window, external wall

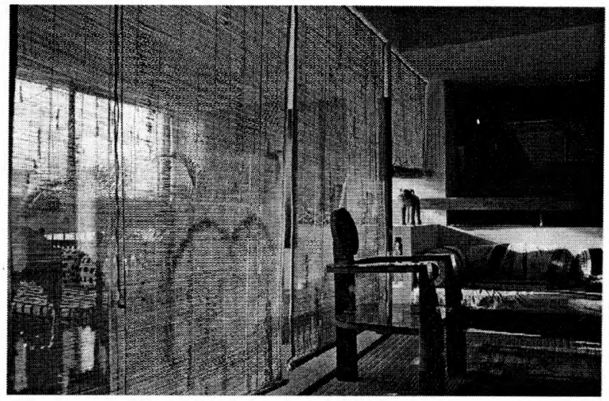


Fig.5.2.8: Use of bamboo chicks for controlling glare and wind.

A set of operable windows are provided on the north elevation for the bedrooms. These windows are recessed into the wall and hence protect the bedrooms from direct sunlight and rain. The south side of the apartment does not need any openings as it is shared by the service core. The east and west elevations are the most important and require shading throughout the year. The west elevation is provided with sets of operable windows at different levels. These windows can create a ventilation pattern that can be modified by the residents by adjusting these operable windows according to the time of the day and the season. The east side elevation is broken up into two verandahs for the dining and the kitchen, and a study in the bedroom. The verandahs are covered with the extended roof slab of the upper floor apartment and hence are protected from sun and rain.

A more dynamic pattern of ventilation has been adopted by the residents over the ages in Mumbai. This is the traditional usage of bamboo mats or the chicks for shading. These chicks provide protection from both rain and glare. Seasonal analysis was made of the unit's performance at four times of the day. The detailed analysis of climate data, summarized in the following text, can be found in Appendix B. Throughout the year, no shading is required at 4:00 am and 10:00 pm. Shading is required during the rest of the times studied, i.e., 10:00 am and 3:00 pm. The shading devices provide good protection from sun during all the months studied; January, April, July and October. At times where the sun is low in the sky, the *chicks* are used to avoid glare. Correa employs 'layers of protection' at the external walls for different functions. This is discussed in later sections.

VENTILATION

The ventilation patterns created by means of the sizes and positions of openings are very effective in this unit. Ventilation is provided by two kinds of openings; the operable windows and the additional devices to control air movement. The verandahs are provided in the east side of the apartment. These verandahs act as balconies and serve as good place to lounge during the evenings when the sun is setting to the other side in summers. They also serve as good sun decks for the rare days when sun is needed for warmth. The verandahs in Sonmarg apartment could be closed to eliminate rainfall and sometimes-even close at the parapet wall to increase internal space.

In January, the wind direction is northeast. At 4:00 am when the bedrooms catch winds from the windward direction and at 10:00 am when the dining, living and kitchen are occupied, the cross ventilation offers enough winds to these areas. At 3:00 pm there is sufficient wind available. Hence shading devices can be used even enough some wind flow has to be compromised. At 10:00 pm, the conditions are most comfortable outside, hence very favorable for sleeping or lounging activities. Verandahs are also used popularly for these activities.

In April, the wind direction is northwest. At 4 am, the relative humidity is the highest in the day of 84%. The wind speed is 334 Ft/m as against the required, which is 787 Ft/m; hence there is a need for faster winds. Since the wind direction is oblique to the window openings, more effective ventilation is achieved. The bedrooms that need most ventilation at this hour get it from the windows at the windward side and the outlets at the leeward side.

In July, the wind direction is from west. This is a difficult situation since there is always a lot of radiation and glare on the west side for the most part of the day. Hence dynamic ventilation devices are used to protect against glare and at the same time allow winds. At 4 am in July, the wind speed is very high, much higher than the required. An 87% relative humidity requires all the wind the bedrooms need at this hour. At 10 am, the activity areas get enough ventilation by means of cross ventilation from the dining towards the living area. The wide openings at the verandah next to the dining can be kept open because the wind speed required is much higher than the existing. At 3:00 pm, the existing wind speed is sufficient for comfortable conditions. At 10 pm, there is a very high speed of wind. It is more than the required; hence openings can be closed or open according to the activity.

In October, the wind direction is the same as January, i.e., northeast. At 4 am there are comfortable conditions of wind, but at 10 am, more wind speed is required. The openings at the west can be utilized because of no sun from that side at this hour. But since the wind direction is from the east, *chicks* can be employed to catch winds and keep away sun at this hour. At 3:00 pm also there is a requirement of high wind speed because of low existing winds. But because of the sun position towards the west, the east side openings could all be used effectively. At 10 pm, high winds are required. But at this hour since no shading is required, the openings can be adjusted to catch all the winds from the northeast.

COMFORT ASSESSMENT

The unit considered for study in the Sonmarg apartments was analyzed at four different times of the day for four months, representing the four seasons in Mumbai. This was done to integrate the activities that take place in this unit, the climate and the architecture, which is the crux of this study. The effectiveness of the architecture in terms of activities, gives us a broader perspective of how well the architect's design concepts help the residents naturally overcome the resistance to the climate, during different times and seasons.

The activity patterns are localized to certain parts of the unit at certain times of the day. The probable occupancy charts were used to analyze the effectiveness. For explanation purposes, the following activities were taken into account according to the respective times:

- 4 am: Sleeping
- 10 am: Dining, Bath
- 3 pm: Siesta, Cooking, Lounging/Leisure
- 10 pm: Dining, Sleeping, Lounging/Leisure

These activities were studied by preparing occupancy charts according to the activity area, for four times of the year.

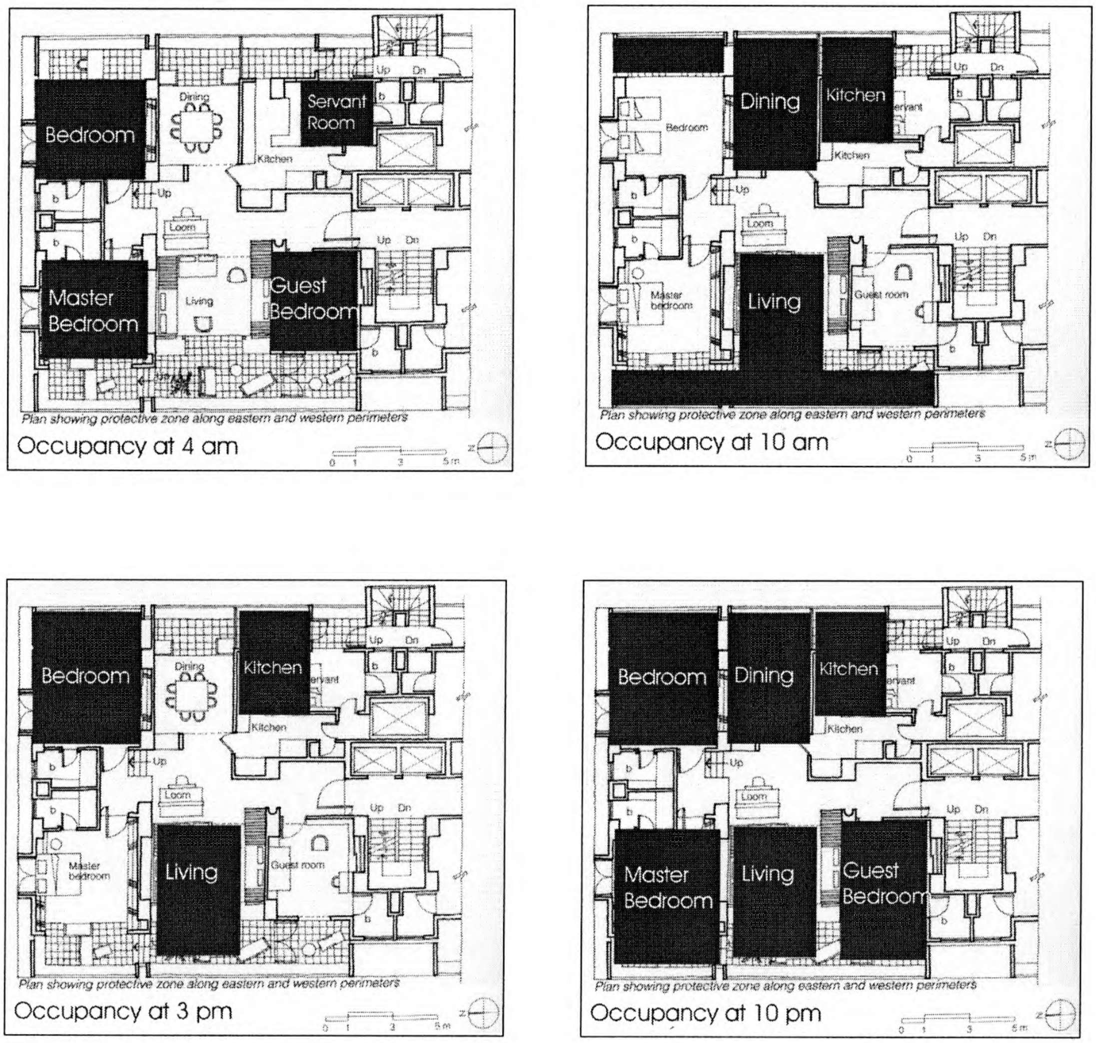


Fig. 5.2.9: Occupancy charts for the four hours of a day, Sonmarg Apartments.

January

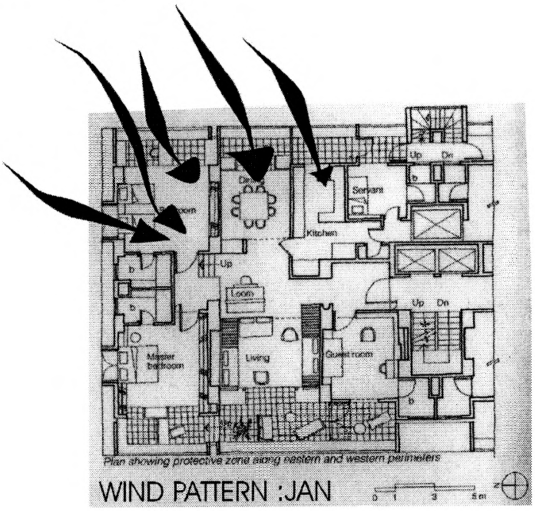


Fig.5.2..10: Wind Pattern- January

4:00 am:

The sleeping activity required ample ventilation and high wind speeds because of high relative humidity. This was efficiently provided in the bedrooms. The ventilation required wind flow over occupant's body level that was provided by good positioning of openings and cross ventilation.

10:00 am:

The climatic conditions are in the comfort zone of the chart. The dining room is well ventilated at this hour because of the prevailing wind direction. The air flows from dining to living for other possible activities. The wind required is much less than existing. Shading is well provided in the dining area by the covered verandah and the operable windows and *chicks* at verandah.

3:00 pm:

The temperature is the highest at this hour, therefore cooling is required. The activity areas are set deep inside, away from the exterior wall. Hence thermal levels are comfortable in the bedrooms for a siesta or in the living area for lounging.

10:00 pm:

The apartment conditions are well within the comfort zone indications. Hence no additional strategies are needed. At this point, the terraces and verandahs could also be used for sleeping.

April

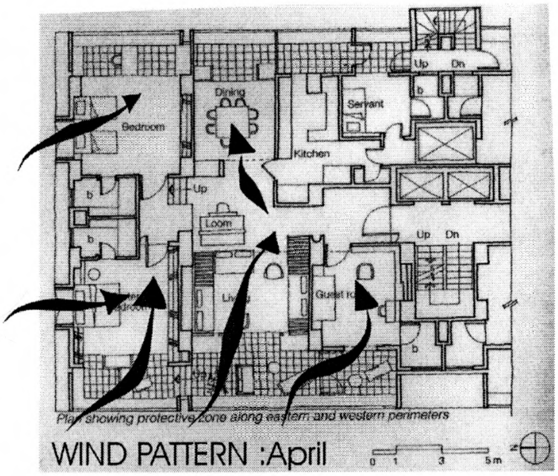


Fig. 5.2..11: Wind Pattern- April

4:00 am:

All the bedrooms are well ventilated at this hour. The required wind speed is higher than existing. Humidity is also very high. To achieve maximum comfort, the wind speed has to be increased by keeping the windows open at the northwest side.

10:00 am:

The wind speed required is much higher than existing. The temperature is very high. Shading is required. The east side windows have to be controlled to allow wind and to protect from glare and sun. This is done by using bamboo *chicks.* The variation is ceiling heights increases wind speed when wind enters from the larger volumes to the smaller volumes in the interior.

3:00 pm:

Conditions are the same as at 10:00 am.

10:00 pm:

Conditions are very favorable for thermal comfort at this hour. Wind speed required and existing are the same. The temperature is high but since shading is not required, the exterior winds can circulate and cool the interiors.

July

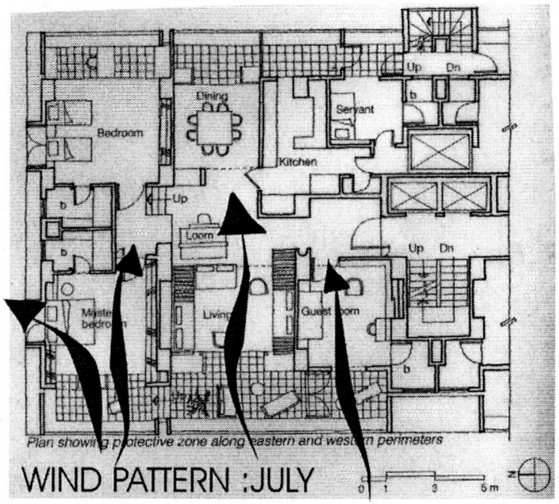


Fig.5.2.12: Wind Pattern- July

4:00 am:

The wind speed existing is much higher than required. The relative humidity is at the highest for that day. Temperature is also very high. Hence the high wind speed and the exterior cool breezes can cool the interiors at this hour.

10:00 am:

The wind speed required is higher than the existing. Shading is required from the east and at the same time prevailing winds are flowing from the east. This is the time for using bamboo *chicks* to keep away direct sun but at the same time catch the winds from the east.

3:00 pm:

Conditions are the same as at 10:00 am except that the wind speed required is almost comparable to the existing wind speed. This would still require the screening strategy at east.

10:00 pm:

The existing wind speed is higher than the wind speed required. Since the relative humidity is high, this wind can be used for evaporative cooling in the interiors. The windows should be controlled to catch maximum winds to cool the high temperatures at this hour.

October

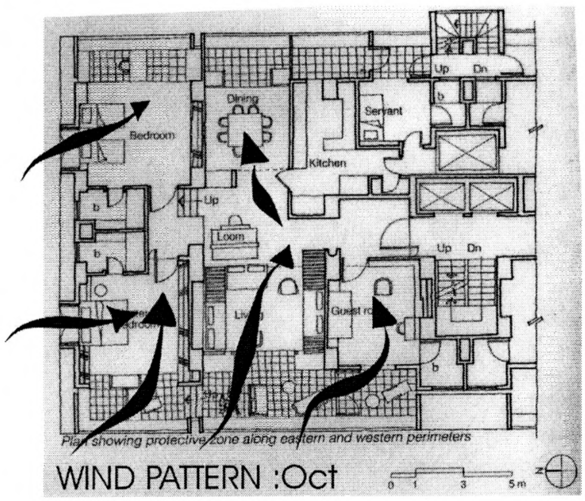


Fig.5.2.13: Wind Pattern- October

4:00 am:

The wind speed required is almost the same as wind speed existing at this hour. But since the relative humidity and temperature is high, the wind speed should be increased in order to cool the temperature.

10:00 am:

The wind speed required is very much higher than the wind speed existing. Shading is required. The windows should be controlled to improve the wind speed and at the same time block the sun from the east.

3:00 pm:

The conditions are similar to those at 10:00 am.

10:00 pm:

The wind speed required is very high. Humidity and temperature are also high at this hour. Since shading is not required, the windows and doors could be kept open without any screening. This helps easier flow of wind through the unobstructed space.

SUMMARY OF COMFORT ASSESSMENT

During most part of the year, the crucial conditions are at 4:00 am in the morning when people are sleeping. At this hour the bedrooms are well ventilated and cross ventilation at body levels also improves thermal comfort. The unobstructed space between the dining and living area is the most functional since it is ventilated even if the prevailing winds are from the dining or the living area.

The bedrooms form a separate zone at a height of 75 centimeters above the level of the rest of the house. This allows privacy to the bedrooms, but during January and July, one of the bedrooms is not very well ventilated. In Correa's other designs, keeping the bedroom doors open used to help this situation. But here, because of the level difference, the winds from the rest of the unit can not enter the bedroom. Only if both the bedroom doors are kept open, there would be air flow from one to the other. The guest bedroom has very low cross ventilation.

CASE STUDY- KANCHANJUNGA APARTMENT (1970-83)

Kanchanjunga apartments were built in 1983. The structure is a high-rise structure with twenty-seven floors. Charles Correa attempted to apply the bio-climatic comfort principles of old traditional bungalows to the apartments[9]. These apartments show one of the most complex spatial organizations of living spaces amongst his designs. The overall design of the Kanchanjunga apartments was intended to be climatically responsive. The analysis of the building design and the strategies applied is as follows.

OVERALL BUILDING MASS

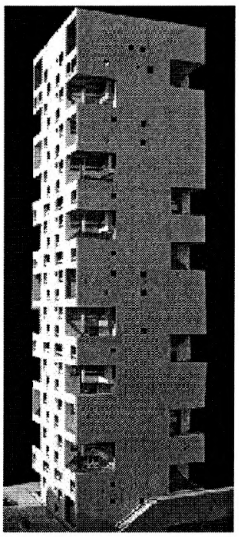


Fig. 5.3.1: View of Kanchanjunga apartments

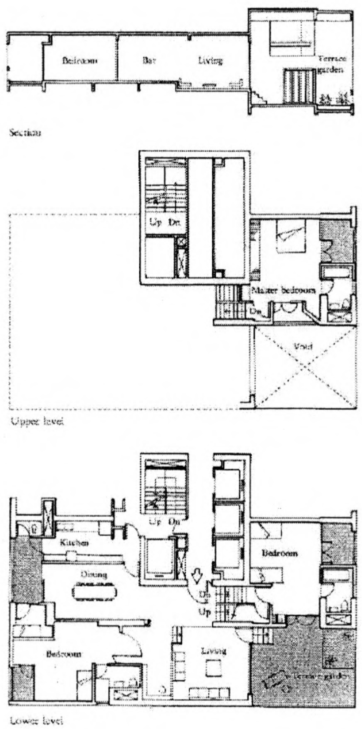
The building mass is the most important feature of the Kanchanjunga apartments. The architect has developed a unique plan to accommodate a large number of apartments in a restricted site area and at the same time making each apartment climatically responsive. The building's footprint is a 21m x 21m square. The height of the building is 85 m, hence forming a tower with a 1:4 proportion of width to height. The building mass is distributed equally in the floors. There are a total of 32 apartments. These apartments have different numbers of bedrooms each.

The apartments are interlocked into a cuboid tower, to create variations in the plan. This interlocking pattern makes the apartments seem like they have a very huge internal space because of the mezzanines created in them. "Repeating the basic interlock… enriched this basic pattern, giving the tower rhythm and energy, like a Tree of life" [10]

[9] Correa, Correa. Charles Correa: With an Essay by Kenneth Frampton. (London: Thames and Hudson Ltd., 1996), 21.
[10] Ibid, 129.

The central core of the structure houses lifts and other services. This core, which is 7.8 m x 6.9 m, also provides the main structural element for resisting lateral loads. Each apartment has a terrace garden that is almost two floors high. The architect has tried to design each apartment such that the apartment can have its own microclimate within the high-rise complex.

ORDER OF ROOMS



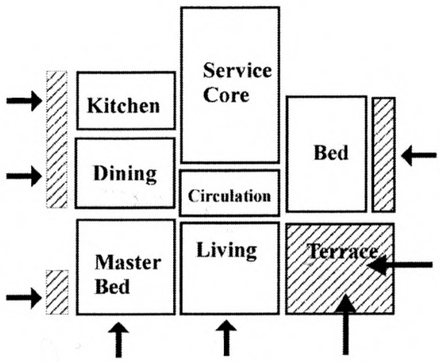


Fig.5.3.2: Plan and Room layout

In the individual unit of Kanchanjunga apartments, the rooms are arranged linearly with sectional displacement of rooms. The bedrooms are stacked vertically. The variation in levels in the linear arrangement of these rooms by itself is a strategy to facilitate good cross ventilation and increasing wind velocities.

The usage of semi-open spaces in the front and back of the unit is analogous to the verandahs used in traditional architecture. They control wind and shade at various times of the day.

An important concept of this design is that Correa uses the traditional courtyard within the unusual context of a multiunit high-rise building and this facilitates increased air movement within the individual unit

ORIENTATION

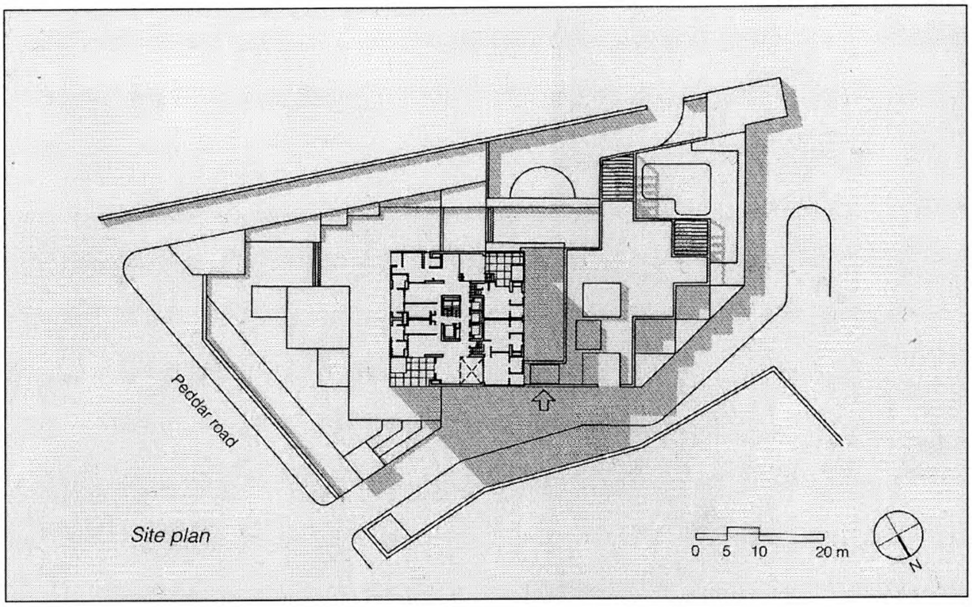


Fig. 5.3.3: Site plan and orientation.

Solar Significance:

The orientation of the apartment complex is diagonal to the cardinal directions. This orientation is very efficient because it prevents glare from entering directly into the rooms lined up along the external walls of the apartment complex. Where there are chances of more sun exposure, the elevations are designed with minimum openings, for example the wall facing the southwest direction. It has minimal number of openings. Also the windows provided on this wall are very small in size.

Wind Direction Significance:

The orientation of the building with regards to the wind is very significant in the hot and humid region of Mumbai. The Kanchanjunga apartment complex is located very close to the Arabian Sea. The prevailing breezes are as shown in the wind diagrams in the Appendices. The orientation is very well suited to catch these prevailing winds for most part of the year. Apart from the whole building orientation, each apartment has been well designed for the same purpose. This will be discussed in detail when we discuss the individual room orientation.

POROSITY OF FORM

The building's porosity lies in the inter-locking feature of the apartments. Each apartment's form is exclusively porous. The terrace garden and the openings in each room provide for good porosity in the building's form. In most traditional apartment complexes, the apartments are lined up vertically on each other. This restricts ventilation to some of the interior areas of the apartment. But in Kanchanjunga, this is overcome by providing mezzanine floors and double height terraces for each apartment. Because of the interlocking of apartments, each apartment's mezzanine floor is lined up parallel to the other apartment. In this way, both the apartments are well ventilated and are directly connected to the exterior. Hence the porosity of the structure is multi-directional instead of the typical uni-directional when considering the apartments within.

INDIVIDUAL ROOM ORIENTATION

The individual rooms are oriented in the east-west direction. This is a very good orientation considering the prevailing wind directions for the whole year. The orientation of rooms has been done in such a way that the interior livable spaces of the rooms do not face the problem of direct sunlight at any period of the day or year. This is a very good technique and improves the living patterns drastically.

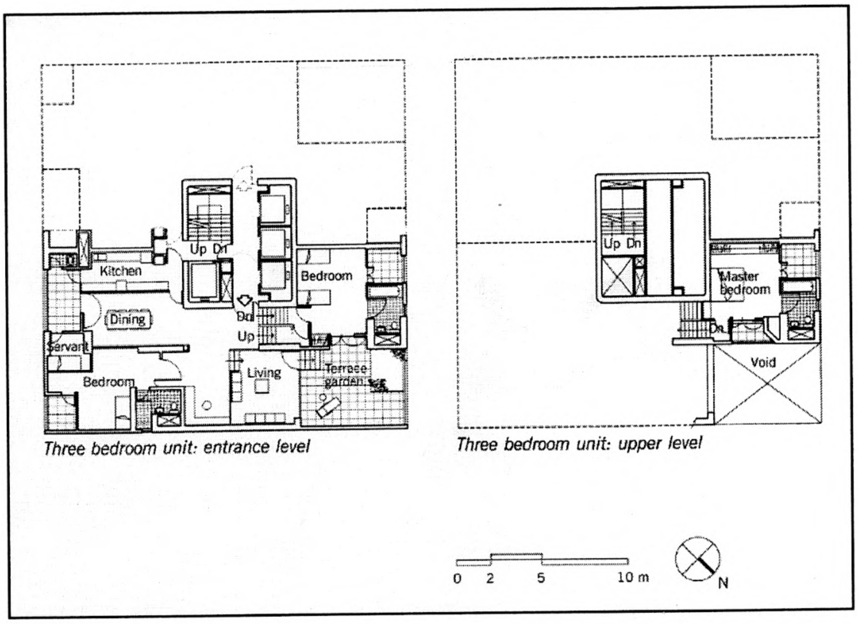


Fig. 5.3.4: Lower level and Upper level plans of the three-bedroom unit studied.

At the time these apartments were built, the technique of using duplex structure for apartments was very unique and novel. It is very common in apartments that ventilation and shading has to be compromised for one of the bedrooms because of facilitating optimum conditions for other important areas of the apartment. But this has been overcome by the duplex technique. Two bedrooms are vertically stacked in the three-bedroom apartment studied. These two bedrooms get all the required wind and shade. One of the walls of these two bedrooms faces the terrace garden. This is also a very useful feature. It protects them from rain and sometimes sun.

STRUCTURE

The roof

Kanchanjunga apartments are structured in twenty-seven floors. Only the topmost apartment's roof is exposed to sun. Because of the high-rise structure of the building, the heat gain through the roof is not significant. The roof/slab is flat and built of reinforced concrete. Concrete is used because of its high strength factor and easy availability in India. Concrete has a high thermal capacity. Hence the heavy roof absorbs heat during the daytime and keeps the interior cool. During the nighttime, when the roof dissipates heat, the openings help the inflow of outdoor cooler air and keep the internal temperature low.

Floors

The basic construction technique used is the columns and beams technique with reinforced concrete slabs. These slabs form the floors between the different apartments. Concrete slabs are popular because of their strength. They are given various finishes like marble, ceramic tiles, or smooth finish concrete.

Ceilings

The ceiling height is constant across each floor area. But the duplex structure of each apartment gives a variable ceiling height within the apartment. The internal ceilings are flat and white in color.

The ceiling height in the outdoor terrace is double the height of a typical floor. This helps ventilation of the living areas within a floor more effectively. Ceilings in these terraces form an interesting pattern of variable heights as seen in figure 5.3.5. The variable heights are because of the sunken slabs of the upper floors. This helps reduce the glare from reflected sunlight.

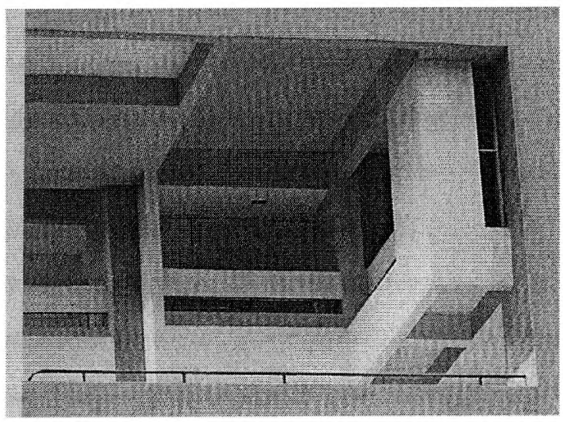


Fig. 5.3.5: Ceiling of the Terrace Garden.

Exterior walls

The external walls of Kanchanjunga apartments are treated with a variety of materials. The basic wall material is brick with cement plastering. The wall surfaces are finished with smooth concrete plaster finishing. These materials are problematic during heavy rainfall due to the porosity and tendency to absorb water.

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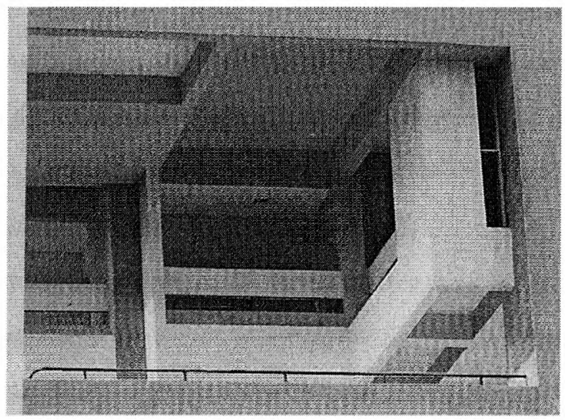

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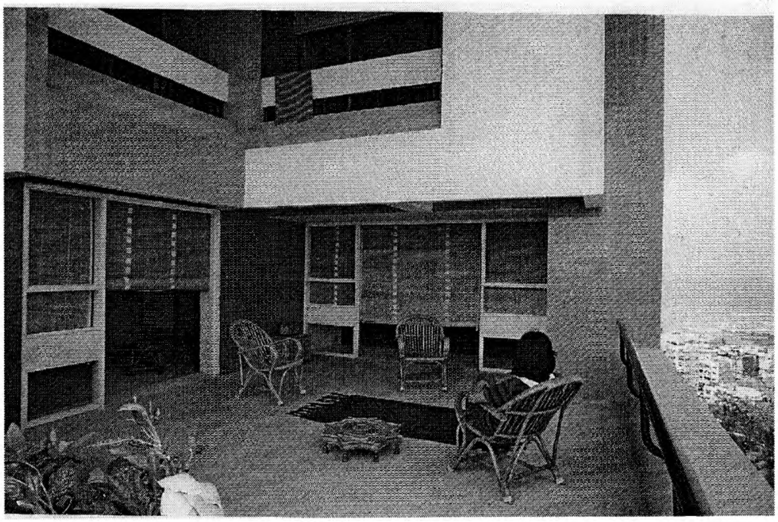

Fig. 5.3.6: Double height Terrace garden.

All the areas in the apartment are related to the terrace through the spatial sequences. This 6.3 meters cantilevered terrace forms the central feature of the apartment. It is oriented away from the sun to increase its functionality. The cross sectional volume of space created around this terrace improves the ventilation drastically in both the floors that have a wind access through this terrace.

SHADE

Kanchanjunga apartments are well provided with shading techniques and devices. The trade off between providing for good ventilation and good shading has been achieved to a good degree. He uses his signature concept of 'layers of defence', also used in the Sonmarg apartments, again. But the concept has been modified to suit the duplex structure of apartments. The modifications made are very different, but serve the purpose in a similar way.

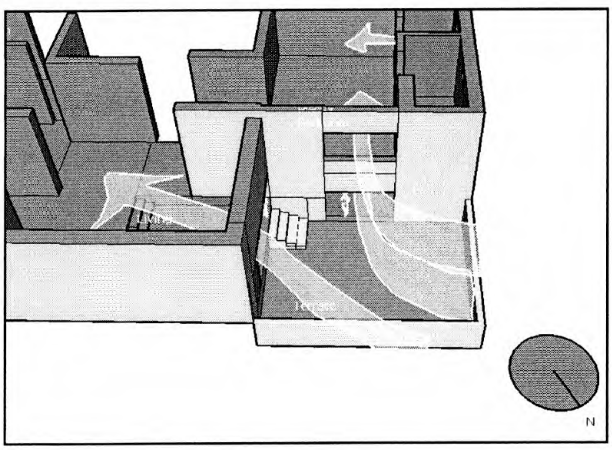

Fig. 5.3.7: Terrace garden

The terrace garden serves as an important shading feature in the apartment. The terrace in the apartment studied is located in the north side. Hence it is well shaded during the whole year. The roof of this terrace shades the rooms in the unit externally. As seen in figure 5.3.7, the openings of the upper bedroom perennially get shading from this terrace roof.

All the windows of the apartment units are recessed. These recessed windows do not require external sunshades. The verandahs and balconies provided for rooms are all covered. They are more or less like external rooms. The living area, the dining and the bedrooms are provided with a belt of spaces in front of them in the northwest and the southeast directions. They protect them from direct sunlight and glare. At the northeast side, where the rooms have a wall exposed to the sun, minimal and very small openings are provided.

Apart from these permanent features, the apartments are furnished with controllable devices at the openings. The doors to the terrace garden are wide and operable to adjust shutters to widen or narrow the opening. The windows are also operable. The traditional bamboo *chicks* are used extensively to prevent glare and allow wind. These are used very effectively at the openings to the terrace garden.

VENTILATION

Correa deals with the ventilation in Kanchanjunga based on different strategies. The main ventilation pattern depends on the levels of the various spaces within the apartment unit and also the whole apartment complex. One of the strategies was to deal with extensive corridors in apartment complexes that have a tendency to block wind. The central service core in Kanchanjunga serves two units per floor. This core is located in such a way that it occupies partial space in both the units, but does not divide the unit space in any direction. This helps wind to flow through the whole unit, independent of the core blocking the cross ventilation. The corners formed by this core also help the wind to flow around the corners of the core into the unit.

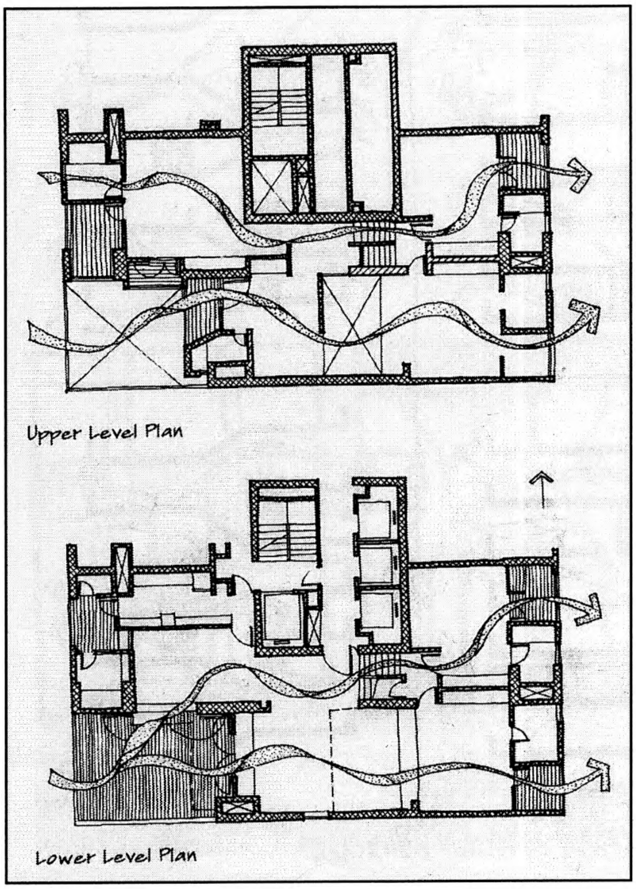

Fig. 5.3.8: Plans showing horizontal ventilation patterns.

Another very important strategy used in designing each apartment complex was using levels as a method to create ventilation patterns. Each unit is divided into various levels depending on the function of the area. These levels facilitate winds to move through the apartment. "Because air must move from the windward rooms through one or two more rooms, the plans and sections are both treated in a loose, open manner, with private bedrooms on the upper levels for privacy"[11].

Study of the cross section suggests a stack effect of air from the lower level to the upper level. The location of openings also facilitates this more. The stack effect works in two directions. One is the wind flow from the lower level of the terrace to the upper level into the dining. The other is the wind flow from the dining area to the upper bedroom when the doors are open. This is seen in the following figures.

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[11] Brown and Dekay. *Sun, Wind and Light: Architectural Design Strategies*. (New York: John Wiley and Sons Inc. New York. 2002), 150.

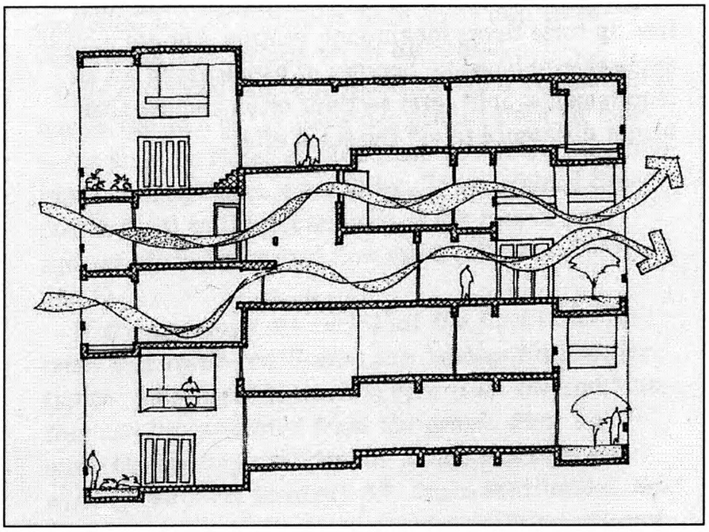


Fig. 5.3.9: Section showing stack ventilation patterns.

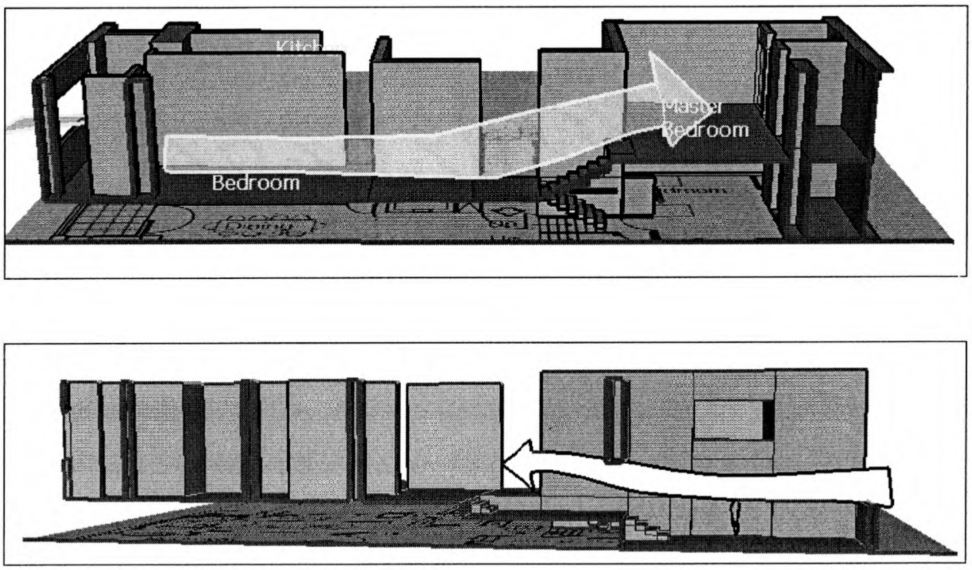
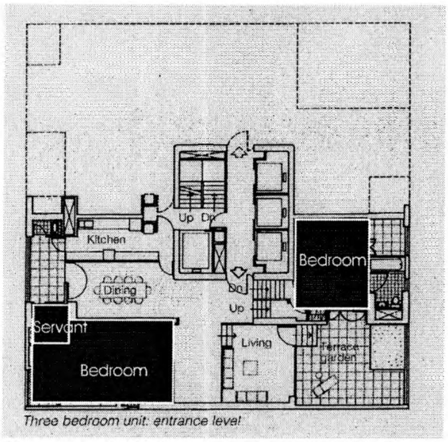


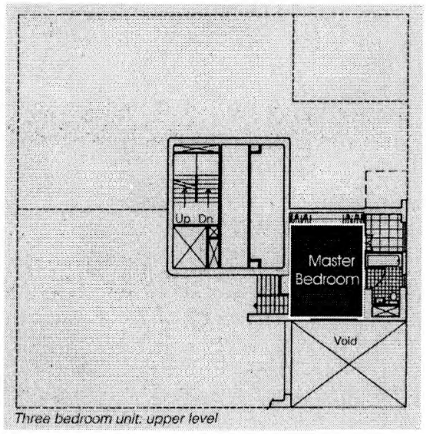
Fig. 5.3.10: 3-D model section showing stack ventilation patterns.

COMFORT ASSESSMENT

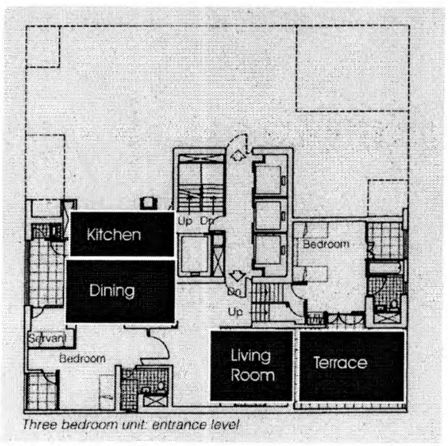
The comfort assessment of the residents in a typical three bedroom apartment was made based on the comfort conditions of the residents as shown in the occupancy charts during different times of the day for four different months. The comfort conditions are analyzed based on the bio-climatic charts plotted for fours different times of the day.



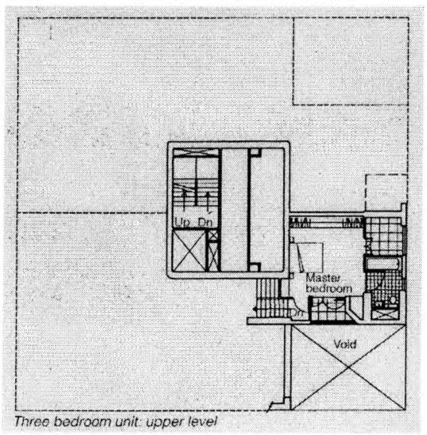
Occupancy at 4 am



Occupancy at 4 am



Occupancy at 10 am



Occupancy at 10 am

-Contd.

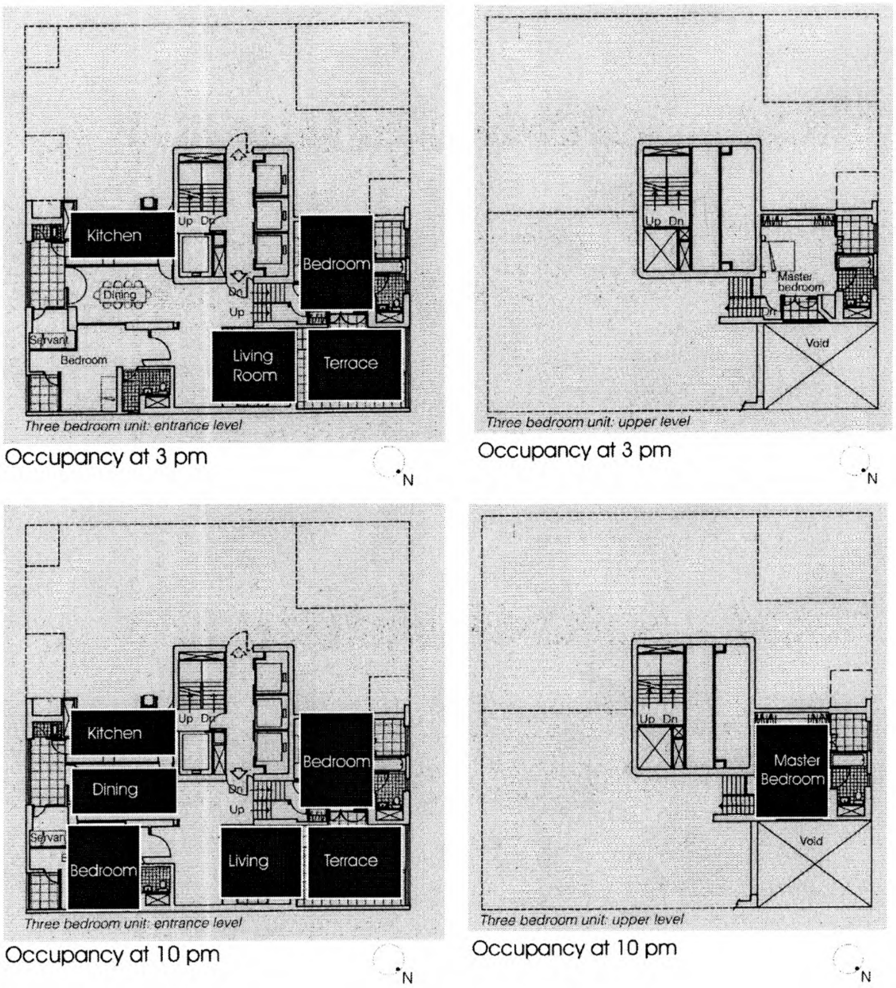
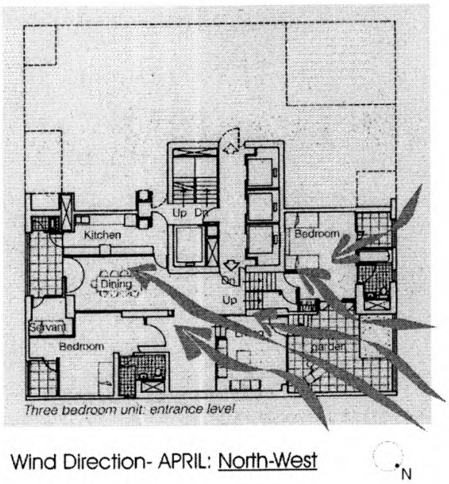
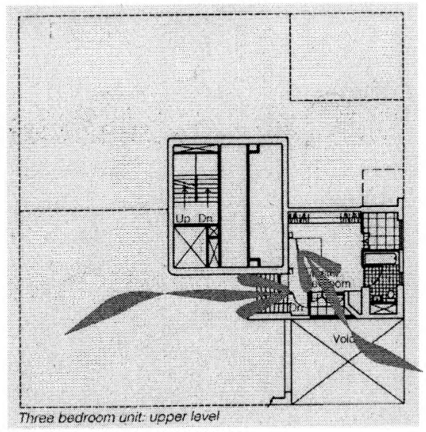


Fig. 5.3.11: Occupancy charts for different levels for four hours of a day, Kanchanjunga Apartments.

January:



Wind Direction- APRIL: North-West



Wind Direction- JANUARY: NORTH-EAST

Fig. 5.3.12: Wind Pattern for January at Lower and Upper levels.

4:00 am:

All the rooms have ample cross ventilation because of the openings towards the windward side and leeward side. Shading is not required at this time. Stack ventilation is seen in the vertically stacked bedrooms.

10:00 am:

The occupancy is in the dining and living areas at this hour. Direct sunlight is blocked into these areas because of the diagonal orientation of the building. The wind speed required is much lower than the existing wind speed. Hence conditions are comfortable at this hour to carry on with activities.

3:00 pm:

The climatic conditions are comparatively better at this time of the year. The relative humidity is very low. The required wind speed is less than the existing wind speed. But the temperature is high and shading is required. Openings and screens have to be adjusted to achieve optimum wind and shade conditions. The living room need not be protected from direct sunlight because of its location and the terrace in front of it.

10:00 pm:

There is through ventilation in the apartment because of the open and loose plan with minimal internal partitions. The apartment is well within the comfort zone at this hour of the day.

April:

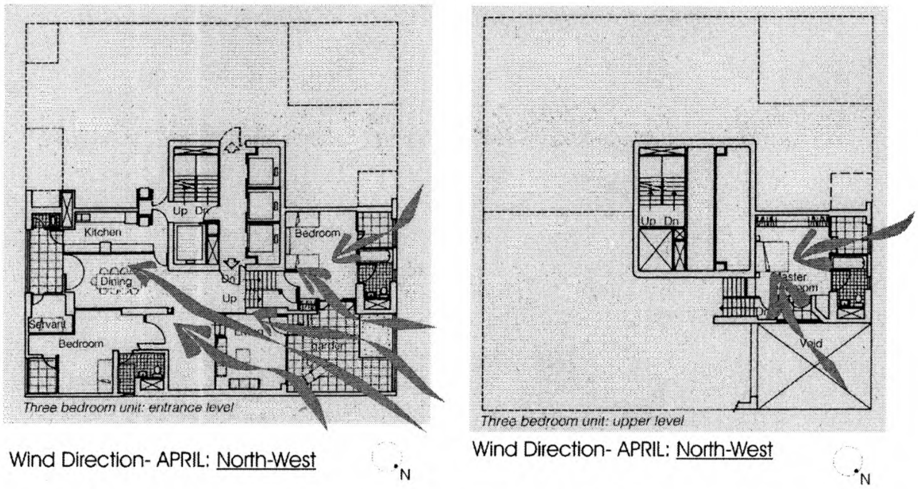


Fig. 5.3.13: Wind Pattern for April at Lower and Upper levels..

4:00 am:

The two bedrooms stacked vertically are directly ventilated by the northwest directional winds. The bedroom towards the east corner of the apartment gets its share of these winds only if the door is kept open. Hence a compromise is needed about whom to accommodate in that bedroom. Master bedroom is highly ventilated because of the location and the access to wind from the terrace and externally.

10:00 am:

Relative humidity is very high and the required wind speed is also high at this time. The occupied rooms are all well shaded. Direct sunlight does not affect any part of the unit. Hence, openings can be controlled to get the entire breeze from the Northwest. The winds from the Northwest direction have a tendency to go all the way till the dining because of no obstructing walls in between. Stack ventilation also helps facilitate increasing the wind speed in the occupied areas.

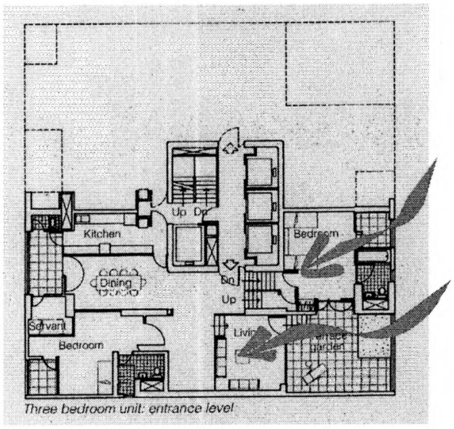
3:00 pm:

Wind speed requirements are much higher than the existing at this hour. Shading is well provided throughout the apartment. The terrace could be used at this hour in case of need for wind comfort. Stack effect plays a dynamic role inside the house to capture winds.

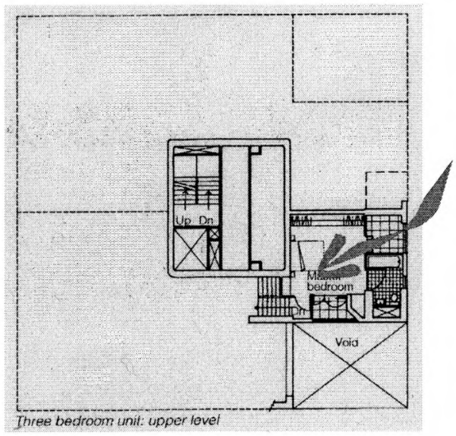
10:00 pm:

The wind speed requirement is well matched with the existing winds. But the temperature and relative humidity are very high. But since no shading is required at this hour, the openings should be controlled to enable winds to enter to cool the interior and provide evaporation. The plan's split-levels that define areas instead of partitions also help enhance winds inside.

July:



Wind Direction- JULY: West



Wind Direction- JULY: West

Fig. 5.3.14: Wind Pattern for July at Lower and Upper levels..

4:00 am:

The bedrooms at the west side of the apartment are well ventilated by the West side winds. The bedroom on the east side of the apartment is not so ventilated if the doors are shut. The terrace is located well to catch the prevailing winds. Since the existing wind speed is high and the humidity is very high, the terrace garden might be a good alternative to sleep in.

10:00 am:

Rains are a big problem in this region around this time. Because of the terrace, the rains do not affect the living area directly. The terrace acts as a buffer zone. Glare is totally avoided by not providing many openings in the east side of the apartment.

3:00 pm:

High wind speed is required during this hour. But since glare does not create a problem, the openings could be controlled for better cross ventilation and an increase of wind speed.

10:00 pm:

Shading is not required and the existing wind speed is very high. Hence thermal conditions are easily achievable for sleeping in all the bedrooms.

October:

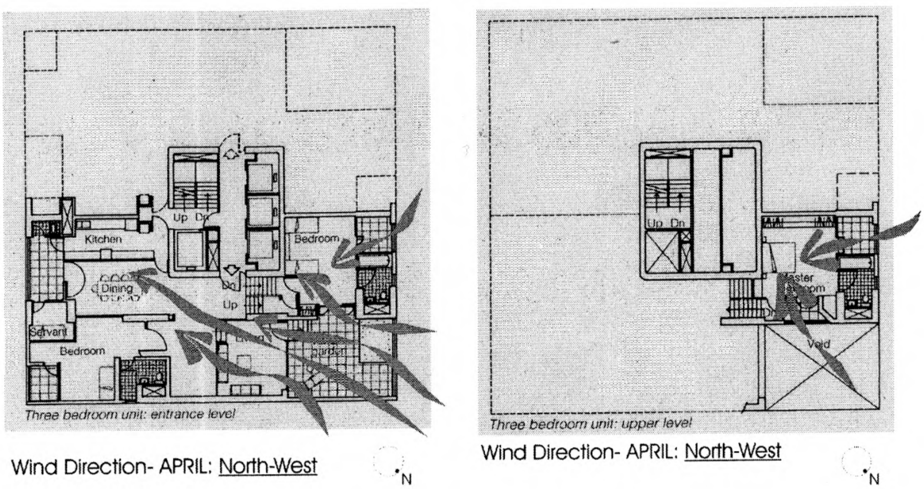


Fig. 5.3.15: Wind Pattern for October at Lower and Upper levels..

4:00 am:

The relative humidity is at its highest. But the wind velocity is the same as the required. The cross ventilation is achieved through stack ventilation effect across different levels.

10:00 am:

High wind speeds are required at this hour. Shading is also required. With all windows and doors kept open, wind velocity could be increased. Glare could be blocked by the bamboo *chicks* while catching the winds where required.

3:00 pm:

The conditions are the same as at 10:00 am but with a lower relative humidity.

10:00 pm:

Extreme conditions of humidity exist. Very high wind speed is also required. This can be achieved by controlling openings at various levels. Stack ventilation would be helpful in making the conditions comfortable.

SUMMARY OF COMFORT ASSESSMENT

The comfort assessment analysis show that the living area and the two bedrooms stacked vertically next to the terrace garden are well ventilated throughout the year. The bedroom, the dining area and the kitchen that are lined up on the southeast side of the unit are not very well ventilated throughout the year. Looking at the number of hours the dining area is occupied; this ventilation strategy could be acceptable. But the kitchen should have been at a better location because of its occupancy and also the traditional cooking activity that needs natural exhaustion of air. The shading has been very well handled. All the areas are well shaded from sun at 10:00 am. But usage of shading devices, like the bamboo *chicks* is essential at 3:00 pm when the sun is comparatively low in the sky. The unit studied seems to be successful because of its orientation against many external forces. But the other units might pose ventilation and shading problems because of orientation.

CASE STUDY-BELAPUR INCREMENTAL HOUSING (1983-86)

GENERAL INTRODUCTION

Belapur Incremental housing is a high density, low rise and low-cost housing developed in New Bombay in 1986. It is located on a land area of six hectares. One basic configuration of a cluster is repeated to achieve the layout of the houses. Each unit is a single-family house ranging from 45 square meters to 70 square meters. The clusters are arranged around a central courtyard. The families that occupy these houses come from varied financial backgrounds.

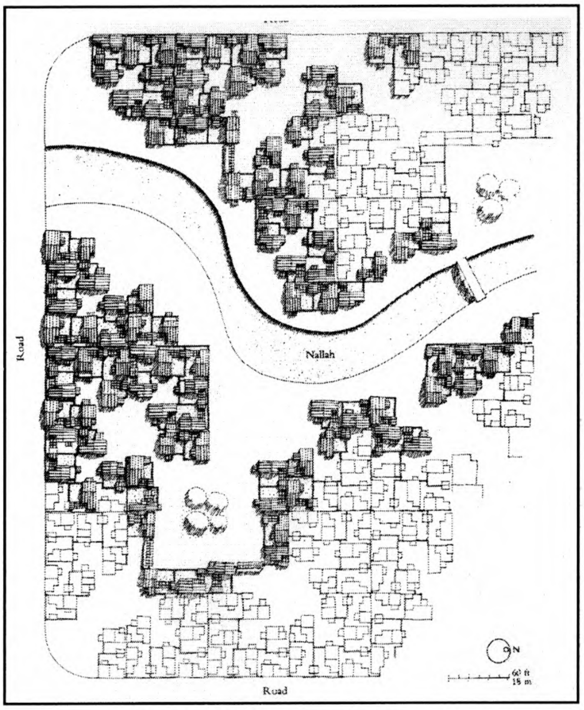


Fig. 5.4.1: Layout of units, Belapur Housing

The principles of 'equity' and 'incrementality' were two of the important design concepts adopted by Correa for this housing[12]. Equity is achieved in this design by keeping the range of plot sizes very small and by keeping the design concept very simple and common for most housing units. The incremental nature of the units comes by having individual plots without sharing any party walls with other units. In this way, every residential unit can be expanded according to the owner's choice within the plot. Open courtyards have been a constant feature to take advantage of the climate and to encourage community feelings. Each principle discussed for this case study will be discussed for two levels of design. One is the overall layout level and the other is the individual unit level.

[12] Correa, Charles. *Charles Correa: With an essay by Sherban Cantacuzino.* (Singapore: Concept Media Pvt. Ltd., 1984), 70.

OVERALL BUILDING MASS

The Belapur housing is divided into many clusters of individual houses arranged around courtyards. Each small cluster has seven units grouped together around an 8m by 8m courtyard. Three of such clusters are again arranged around a bigger 12 m by 12m courtyard. Again, three of such bigger modules are interlocked around a space of 20m by 20m. This helps in achieving a particular hierarchy based on the area of the open space and hence helps residents achieve intimacy with their community space depending on scale.

With regards to the individual residential units, the design is very simple. The structures are mostly one-storied and sometimes two-storied. The massing of each unit is very independent. None of the units share any common walls with any other unit. Each has space surrounding it for possible expansion. This open space is very helpful for ventilation of individual units. The courtyards around which these units are arranged also help ventilation to a large extent. Massing of these units plays a major role in utilizing the climatic strategies used for these apartments.

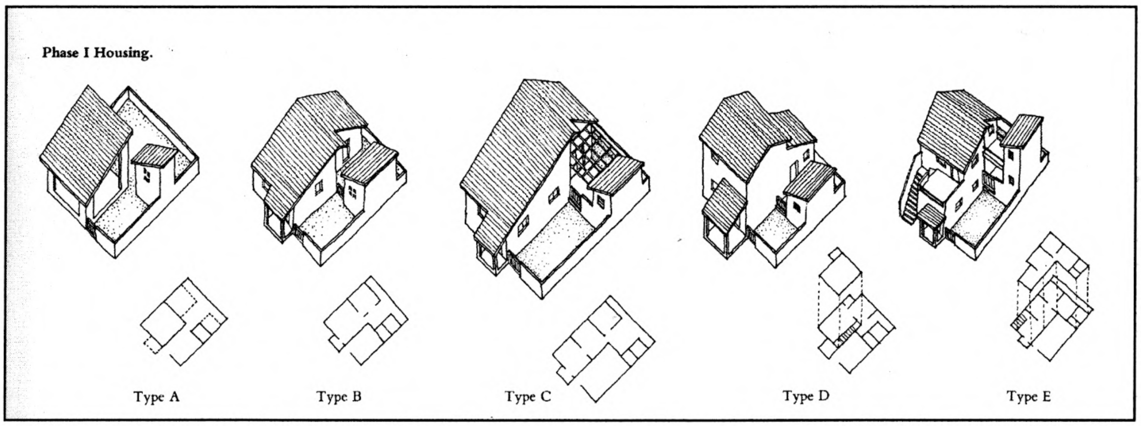


Fig. 5.4.2: Massing of Individual Units at Belapur Housing

ORDER OF THE ROOMS:

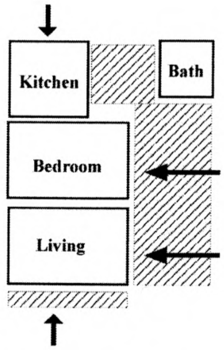


Fig. 5.4.3: Layout and view of an Individual cluster.

The arrangement of the housing clusters is an important issue in this housing. The repetitive courtyard feature of the housing is in many ways similar to the arrangement of different structures within the compound of the bungalows. Correa uses the linear vs. clustered arrangement in many interesting ways depending on the context. This housing brings out a question of tall and low-rise building needs in a city. Correa believes that optimizing densities and re-adjusting land-use allocations can solve this problem in developing countries. In Belapur housing, the cluster arrangement is basically arrived because of maintaining low cost of the housing, using the local material and technique and characterizing it to be incremental so that residents themselves can make changes or additions to it.

Each cluster is arranged around a courtyard, which is the main feature of the housing. The cluster arrangement brings many advantages to the housing with regards to ventilation, community area and service cores. The courtyard caters to the through ventilation by catching winds and directing them to the interiors of each unit. The rooms within the unit are arranged in a strictly linear fashion. This linearity helps cross ventilation by the winds from the courtyard. A combination of cluster and linear arrangement is the strategy used for achieving comfort.

ORIENTATION

Solar Significance

The orientation of the clusters does not offer much solar control when the whole layout is considered. The emphasis is more on the arrangement of the cluster rather than the orientation because it is high-density housing and also because of the importance given to the concept of courtyard arrangement. The courtyards concept helps provide shading in most of the cluster arrangements. Each unit's roof gives ample shading in the front and backyards during some parts of the day. Landscape features around and within these clusters may be an alternative solution to compensate for this strict arrangement.

Wind Direction Significance

The clusters are all oriented in different directions. Some of them have a better chance of catching winds than the others. But the prevailing wind directions change with every month. Hence, all the arrangements get their share of winds during different times of the year.

Each unit has enough space around it to let incoming and outgoing winds from the courtyard. These winds cross ventilate the unit thoroughly. This is discussed in detailed in the ventilation section.

POROSITY OF FROM

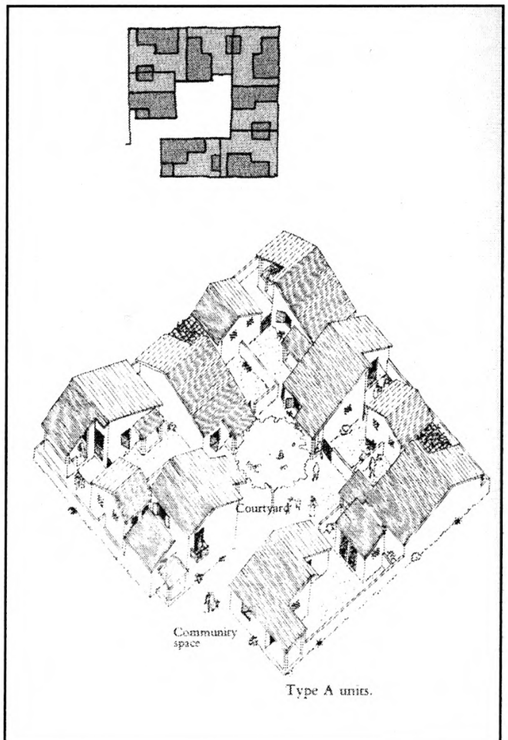


Fig. 5.4.4: Layout and view of an Individual cluster.

Porosity of the whole layout lies in its open character. The design of the layout is done in such a way that not only does each cluster have its own open central courtyard, but an arrangement of these clusters is also done around a bigger courtyard. This helps in achieving porosity of form in three different levels i.e., based on the hierarchy of the smaller courtyard to the biggest courtyard.

Porosity of form in an individual unit is achieved by means of the hierarchy of the open space of the courtyard, the semi-open space of the small porch and the closed space inside the unit. Each unit is provided with an open verandah in the backyard also. In this way porosity of the individual unit's form is from different elevations. The walls that face another unit or the abutting road are not provided with any windows for privacy. These walls have restricted porosity.

INDIVIDUAL ROOM ORIENTATION

The individual rooms in each unit are not oriented in any particular direction. The orientation of rooms depends on the orientation of the unit within the cluster. Hence the orientation aspect of the individual rooms or an individual unit by itself has not been very significant. This is because of the high density of the residential layout. This can also be seen as a limitation of this strict hierarchical formal ordering system.

STRUCTURE

The materials used for the construction of the Belapur housing units are all locally available and low cost materials. The masonry techniques used were deliberately kept simple so that locally available masons and skill could be used. The basic construction is very simple so that the residents can conceptualize changes and have their units expanded or altered very easily.

The Roof

The roof structure is very simple. The roof is a pitched roof that is supported by gable ends on the external walls. The framework of the roof is made of wooden battens running horizontally and vertically. A layer of 'terracotta' tiles is then used to cover this framework. These tiles serve as good waterproof material for the framework that is usually very vulnerable to rainfall. Wood is not so well known for its use as a roofing frame in the modern times, but it is very affordable and helps in keeping the

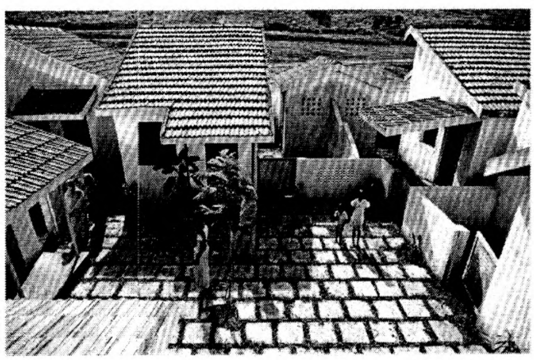


Fig. 5.4.5: Units showing roof structures.

cost very low in a low-cost housing. Another reason for the usage of this material could be the ease at which this structure can be dismantled and changed.

Floors

The floor is raised in different levels from the courtyard to the inside of the unit. It is made of timber. The timber flooring is helpful when the ground temperature is cool. But it is disadvantageous when the ground surface is heated up that can increase the interior temperature because of convection.

Ceiling

The roof made of timber and clay tiles is not covered in any way in the interior of the house. This helps in good wind flow from the exterior to the volume below the roof.

Exterior walls

The exterior walls are made of brick and cement plaster. Brick and cement plaster are easily available in India.

Interior walls

There is not enough information with regards to the interior wall treatment.

SPACE

The space in Belapur housing can be perceived in two different ways. One is taking the cluster of houses with the internal courtyard into account and the other is the interior space within the unit. The units arranged around the courtyard resemble a closed community in the traditional housing layouts. The courtyard provides for a common community space that is also special to that cluster of seven units. These spaces outside the house, give a vernacular character to the housing layout. Correa describes space as a resource in warm climates. “About 75 percent of these essential functions (e.g. cooking, sleeping, entertaining friends) can be accommodated in verandahs, terraces and courtyards, for at least 70 percent of the year”[13]. He summarizes the activities and their relation to the spaces in four kinds of spaces; the courtyard, the doorstep, the water tap and the community centre.

The space inside the unit is very simple and functional. The unit studied is a two-room unit with a kitchen. The variation in levels is used like that in a bungalow. The level increases as one goes inside.

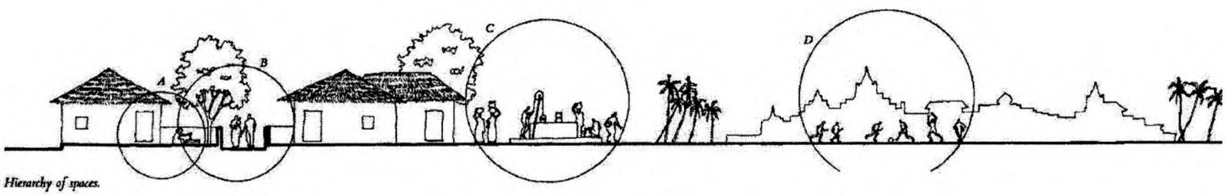


Fig. 5.4.6: A-Courtyard, B-Doorstep, C- Water tap and D-Community center.

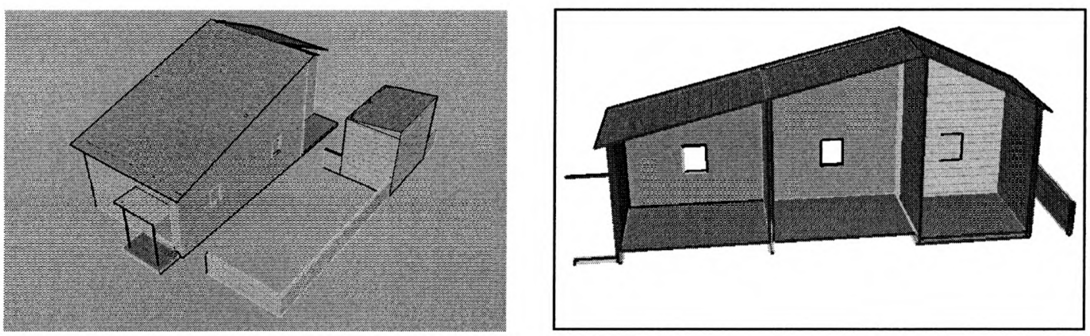


Fig. 5.4.7: View and Sectional view of the case study unit.

[13] Correa, Charles. *Housing and Urbanization*. (New York: Thames & Hudson Inc.,1999), 106.

SHADE

The shade in the courtyard is mainly controlled by the roof forms of the structure. The higher the units, the more shade the courtyard gets. Some units are two-storied and give more shade to the courtyard. There is scope for plantating within the courtyard. This might help shade it further.

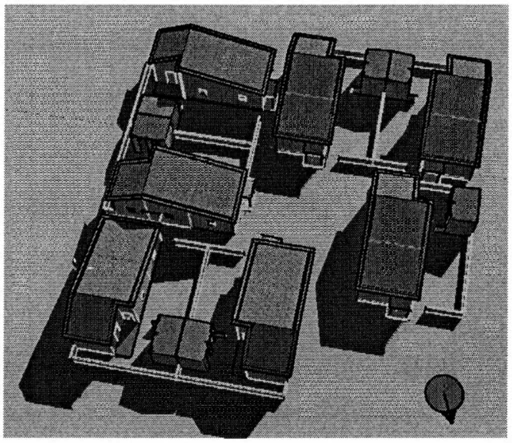


Fig. 5.4.8(a) & (b): Shade pattern in the courtyard of a typical cluster.

The shade for an individual unit is also through the pitched roof form. The front verandah of the unit is well shaded for most part of the day by the extended roof over it. But the backside porch is not well shaded. Hence the utility of the backside porch is limited during high sun positions because of direct heat.

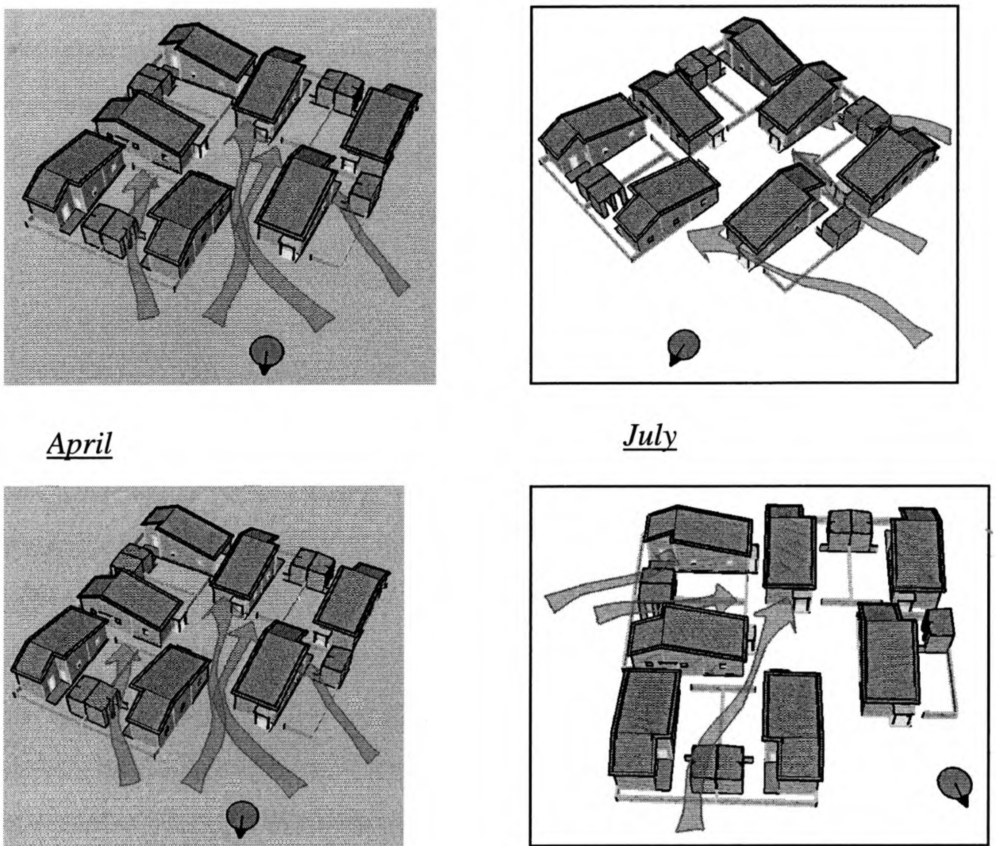
The windows are not very well shaded. They do not have sunshades or any other form of protection from direct or inclined sunlight. The windows have double shutters and are glazed. Hence some form of blinds or curtains are needed to control glare in the interior spaces. The concept of layers of defence for protection from sun and rain is not adopted in this design by the architect. This maybe because of the space considerations and the restricted budget.

The material used in the courtyard is very efficient to prevent reflected glare from the ground surface. The courts are paved with terracotta tiles with grass between the tiles. This helps cool the surface during hot seasons and make it more usable. The plantations, pavement material and the embedded grass together prevent the glare of incident sunlight. They also reduce the heat gain.

VENTILATION

Courtyard:

The courtyard is an essential feature for providing ventilation to the units surrounding it. Courtyards provided between housing units are low and wide to facilitate winds from different directions during different times of the year. They act as wind catchers. This is because of the possible Venturi effect. The air is dragged into the courtyard because of the narrow spaces between the units. Courtyards are made more permeable by leaving free margins around the units and narrow spaces between the units. Because none of the units share common walls, spaces are created in between them. The property of wind flowing around corners is well utilized in the courtyard. Planning of the clusters is an important feature in guiding winds to individual units.



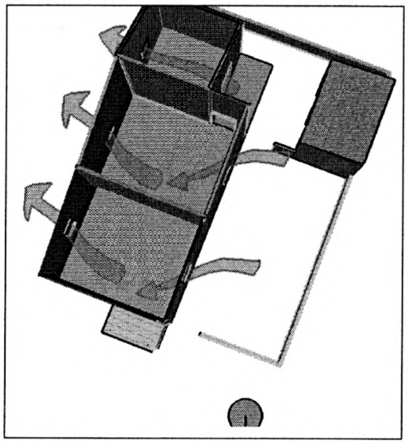
April *July* *October* *January*

Fig. 5.4.9: Wind patterns in the cluster for four months

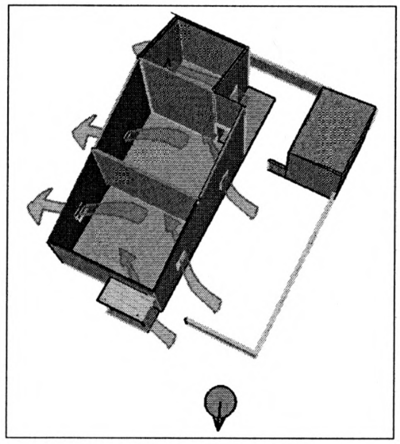
Individual Unit:

Each unit is well ventilated with windows and doors. The winds that enter the courtyard provide good cross ventilation because of these windows and doors. The cross ventilation pattern within the unit is easily achieved because of the location of these windows and doors.

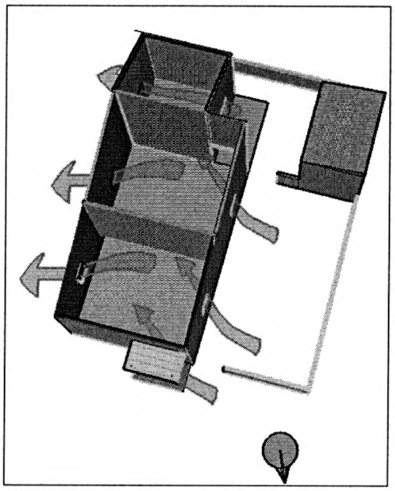
The pitched roof form of the unit helps in catching the winds from the courtyard into the interior spaces. These winds also achieve considerable speeds because of the Venturi effect. This is seen in the backside of the unit also where the wind comes form the road. This concept is similar to that seen in the typical bungalow.



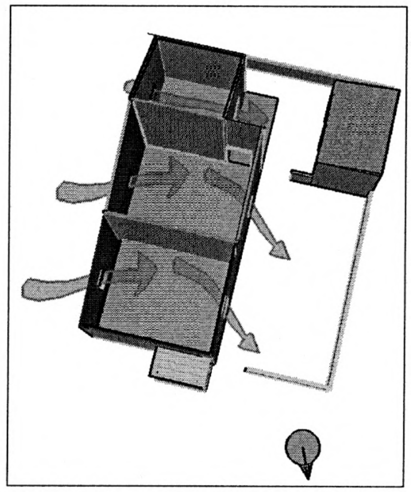
April



July



October



January

Fig. 5.4.10: Wind patterns in the individual unit for four months

The bathrooms are located outside the house as a separate block. Each unit's bathroom is attached to another unit's bathroom to share the plumbing lines. This helps in achieving a separate ventilation pattern for the bathrooms. The bathrooms do not have controllable windows. The windows are in the form of a grid with pigeonholes.

COMFORT ASSESSMENT

The comfort assessment is done based on the occupancy of the residential unit at different times during different days. For the purpose of studying an individual unit in Belapur, a two room unit is selected. This unit includes a kitchen and external bathroom. Because of the scale factor and the number of rooms in this unit, total occupancy can be assumed at all times.

January

4:00 am

At this hour the wind requirements are optimum. No shade is required. There is a high humidity level. This can be dealt with by controlling the windows and doors. The climate is not so suitable for sleeping outside because of slight chill factor.

10:00 am

Existing wind speed is higher than that required. Hence the windows and doors need to be closed accordingly. The sun is not incident directly into the units because of the close cluster arrangement. Shading is required but not very significantly.

3:00 pm

The conditions are the same as at 10:00 am. Shading is required. Relative humidity is very low at this hour.

10:00pm

The climatic conditions fall well within the comfort zone.

April

4:00 am

The humidity level is very high at this hour of the month. The wind speed required is much higher than the existing. Since shading is not required, the outdoor spaces can also be used for sleeping activity.

10:00 am

The wind speed required is much higher than the existing. Shading is required. Activities are hence restricted to the interiors. The windows and doors need to be kept open to achieve required wind speed.

3:00 pm

The conditions are the same as 10:00 am.

10:00pm

The wind speed required is lesser than the existing wind speed. Since shading is not required at this hour, outdoor spaces could be used for sleeping or lounging.

July

4:00 am

The wind speed required is much lower than the existing wind speed. This helps controlling the high humidity level. Shading is not required. Temperature is very high at this hour. To achieve body comfort, outdoor sleeping is suggested.

10:00 am

The conditions are very critical at this hour. Both the temperature and the humidity levels are very high. The wind required is quite higher than the existing.

Precipitation can also occur during this month to make matters worse. Hence optimum levels of comfort have to be achieved through shading devices. The roof form helps in increasing wind speed in the interior space.

3:00 pm

The wind speed required is almost same as the wind speed existing. The other conditions are almost similar to 10:00 am. But the high wind speed helps achieve optimum interior conditions significantly.

10:00pm

The conditions are the same as 10:00 am. But shading is not required. Hence the windows and doors could help in increasing cross ventilation.

October

4:00 am

The wind speed existing is almost similar to the wind speed required. The temperature and humidity are high. But wind factor helps in achieving comfort and also because shading is not required.

10:00 am

Wind speed required is very higher than the existing wind speed. Shading is required but is radiation is much less because of the shaded courtyard and the surrounding units in the cluster.

3:00 pm

Conditions are the same as that at 10:00 am.

10:00pm

Conditions are the same as 10:00 am except that shading is not required.

SUMMARY OF COMFORT ASSESSMENT

The ventilation patterns are optimum and consistent throughout the four months for the studied unit. It might not be the case for other units because of difference in orientation. The simplicity of each individual unit's plan is an asset to this easy ventilation. Shading is not so consistent, but is controlled to a large extent because of the closely placed units. The semi-open and open spaces are well utilized. The privacy of single storied structures with the windows of the living rooms is compromised. The materials used for construction perform well thermally, but do not appear to be durable over the long run.

The courtyard is a significant feature of the design of the layout. It performs well functionally during all parts of the year. But this functionality if effected during the monsoon season. The design is based in a big way on the functionality of the courtyard. Hence it can be concluded that the courtyard can be comfortably used for 80 % of the year.

CASE STUDY- VILLAS AT VEREM (1982-89)

The Verem villas are located in Goa along a river called Mandovi. These residences were basically conceptualized as holiday homes for people who lived in Mumbai. There are a total of thirty-eight houses, laid out in a single line along the river. These villas are single-family residences with 2 to 3 bedrooms each. The basic concept for these residences was to exploit the breezes from the river and hence keep the plan open while defining spaces through floor levels.

OVERALL BUILDING MASSING

All the units are arranged in a linear fashion facing the river. Four single family residential units form two attached blocks. Each block is two storied. Such blocks are spread out in a single line to face the river. These blocks formed semi-detached villas that are bound together with low garden walls that surround them. The overall massing of the layout is linear but each single block of units is very interestingly configured. The two blocks are connected by extra bedrooms for the internal units stacked one above the other. This stacking helps these bedrooms with a whole different ventilation pattern from the unit itself.

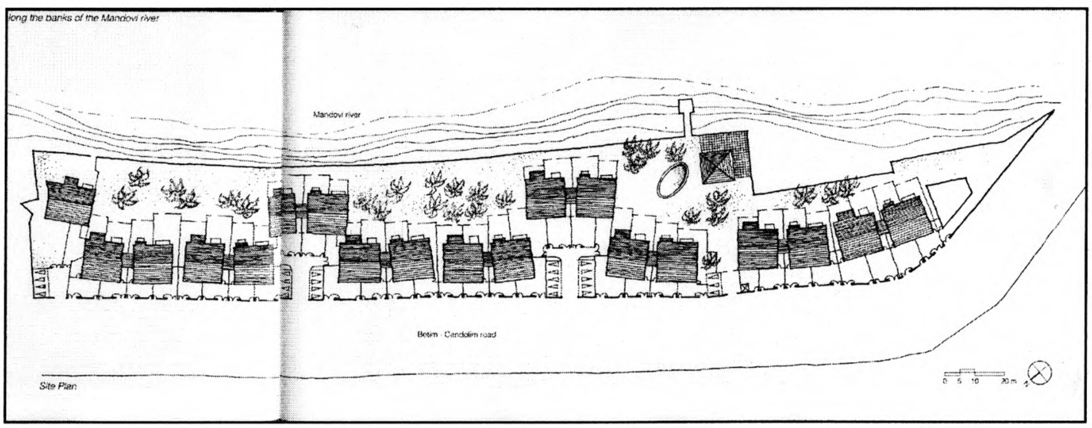


Fig. 5.5.1: Layout of the Verem villas

The individual unit studied is configured in two levels. The lower level includes the living and the dining. The upper level included two bedrooms. The porch facing the river is a double height columned space. The roof structure is supported by these two columns in the front. The roof structure gives the structure more weight at the riverside elevation and the structure seems to diminish towards the roadside elevation. This seems appropriate with regards to the privacy of the unit. At the same time this roof structure helps a lot with regards to the wind flow towards the interior of the house.

ORDER OF ROOMS:

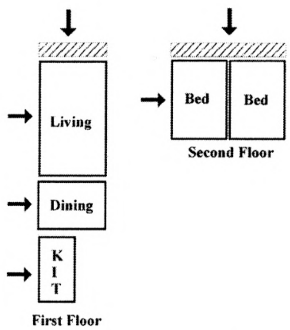


Fig. 5.5.2: Layout of the rooms

The arrangement of the units in this housing is linear. The units are lined up in front of the riverside. This arrangement utilizes the river breezes to the maximum. The rooms within each unit are also linearly arranged. This arrangement is again enhanced with the sectional displacement strategy where the bedrooms are in the upper floor and the living and dining areas are laid out with level variations. This helps the bedrooms have their own ventilation system by being able to directly catch winds from the outside. The roof structure also gives the whole unit an advantage by way of Venturi effect.

ORIENTATION

Solar Significance

The orientation of all the units is mostly southwest-northeast with a slight stagger of some blocks to orient better to the river view. Each unit is designed in such a way that the big porch and verandahs that face the river are in the south-west direction. This shows that importance has been given more to the river view and the breezes from the river rather than the sun.

Fig. 5.5.3: View from Northeast of the villas

Wind Direction Significance

Wind direction plays a significant role for consideration of orientation of the units. The location of the river Mondovi is the defining factor for orientation. A river acts like a cooling body to the buildings next to it. The wind pattern near large bodies of water is formed by the heat gain and heat loss between the land and the water mass. This factor is utilized by the villas at Verem. Hence the houses are oriented towards the river front. This is a very significant strategy for the ventilation.

POROSITY OF FORM

The porosity of from for the units is mainly from the front and backyards of the house. The roof form is low without any clerestory or skylights in it. This restricts porosity from the roof level. The design is based on the entry points at the front and back external walls. For maximum wind flow within the structure, this porosity level at entries helps a lot. The overall form of all the units is the same, and the porosity is from the three external walls of the unit.

INDIVIDUAL ROOM ORIENTATION

The villas at Verem primarily house a living and dining area, a kitchen and, two or three bedrooms. The orientation of these rooms is similar to the orientation of the residence itself because of the minimum usage of differentiating interior walls, especially in the lower level. In the upper level the bedrooms are also oriented in the same direction as the house. Hence the study of individual room orientation is synonymous to the study of the overall house orientation.

STRUCTURE

The Roof

The roof form is pitched. It is supported by load bearing walls and concrete columns. The form of the roof is mainly low with overhangs that cover the front and back yards of the structure. This helps in catching breezes along the longitudinal central axis of the unit. This roof type protects the inner volume of the unit from sun and at the same time facilitates cross ventilation. The roof frame is basically made of wooden rafters and is covered with clay tiles.

Floors

The floor is raised in different levels like that of a bungalow. The floor level increases from the ground level as one goes inside the apartment. The floors are finished with smooth ceramic tiles. These help retain the cool temperatures within the interior space.

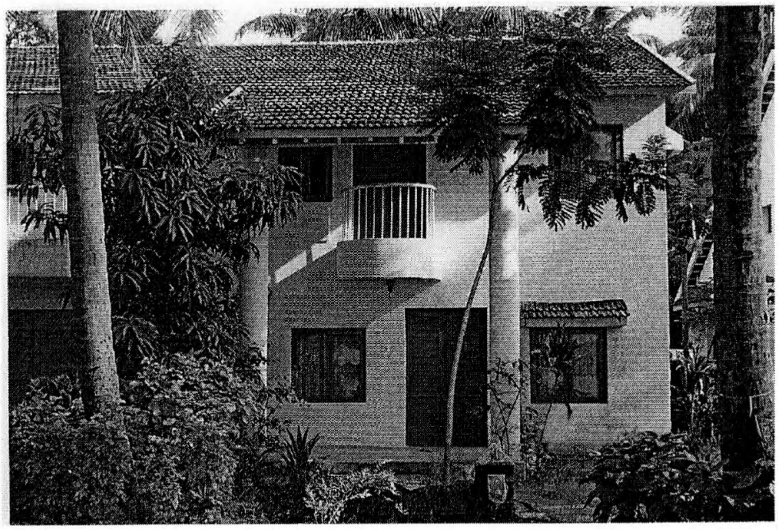


Fig. 5.5.4: Elevation of a villa showing roof form and materials.

Ceiling

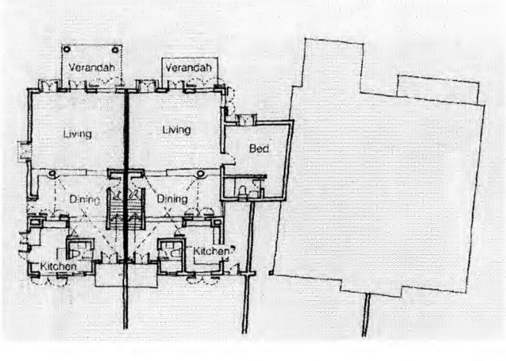
The ceiling is not treated in any special material in the upper floors of the villa. It reflects the same material as the roof from below the roof. Because of this, the volume of the rooms seems bigger. The ceiling of the living room, which is the slab for the upper bedrooms, is a reinforced cement concrete slab, finished with smooth plaster.

Exterior walls

The exterior walls are given a smooth finish of stucco, which is cement, sand, and lime plaster. This is a good material for water resistance during the heavy monsoons. They are white in color. This helps in reducing radiation by reflection.

Interior walls

There is not enough information regarding the treatment of the interior walls.



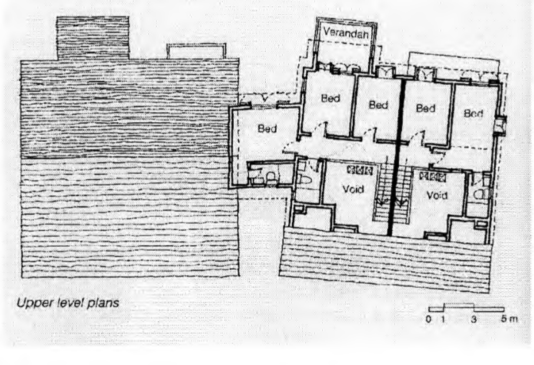


Fig. 5.5.5: Individual unit plans

SPACE

Space in Verem villas is conceived in different levels. These levels bring a dynamic character to the cross section across the length of the unit. The plan of the villa has been kept very simple and open. The openness of the unit aids in a very good ventilation system. The lower floor that accommodates the living area, dining area and the kitchen is laid out with different floor levels. The living area is the lowest level, the next is the dining area at a higher level and finally the main entrance lobby and the kitchen at the highest level. Such a theme of spaces has been incorporated by Correa in more than one of his designs, especially in his buildings in tropical climate.

The bedrooms are located at the upper level so that they can also take the advantage of the breezes from the river and its view. The volume of space within the apartment seems much more than what is imagined looking at the floor plan. This is because of the roof with a height of about 10 meters at the ridge. The roof enhances both the space quality and quantity.

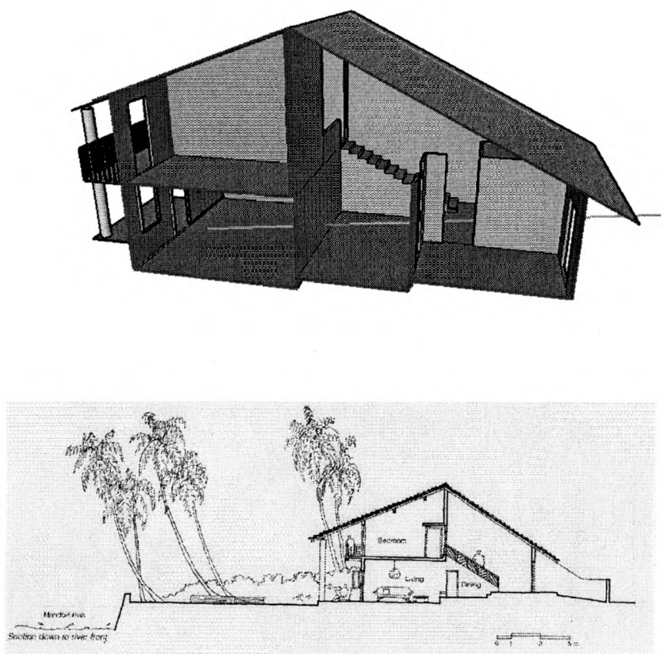


Fig.5.5.6 (a) & (b): Individual unit sections

SHADE

The orientation of the units requires sufficient shading especially during the first half of the day because of the units facing east partially. This has been well achieved by the architect. There are different levels at which shading techniques have been used.

Roof:

The roof by its very form acts as a very good shading device, the low-hanging roof like the one used in typical bungalows gives significant shading to the verandahs, balconies and the porches at the front and backside of the units. The balconies and windows at the upper floors are shaded primarily by the overhanging roof.

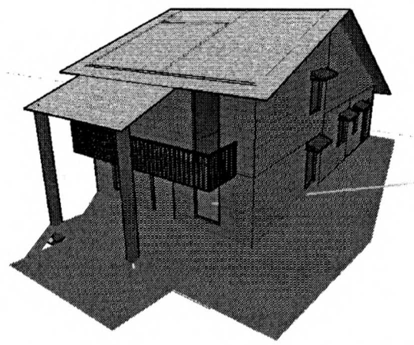


Fig. 5.5.7: Individual unit shading by the roof

The roof form is even lower at the street side entry of the units. This is very useful to protect the units from the extreme sunlight from the southwest.

Sunshades:

All the windows that are not covered by the roof or the extended balconies of the upper floors are provided with individual sunshades made of the same material as the roof. Sunshades are used extensively in residential architecture in India. The sunshades not only prevent sunlight and glare but are also very effective to block rainfall into the house.

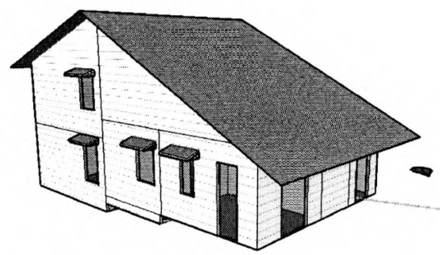


Fig.5.5.8: Individual unit sunshades.

VENTILATION

The ventilation system inside the villa is very simple. It is achieved in the following ways:

Unobstructed space:

The differentiation of spaces inside the house is done by using different levels. This facilitates long spans of unobstructed space because of which the wind flow is continuous within the house. The unobstructed space is achieved by using the brick load bearing walls instead of the popular reinforced concrete column and beam structure. The column and beam structures need to have columns in between the area of the unit to support the structure. These can cause obstructions, where as load bearing walls allow more volumes of unobstructed spaces.

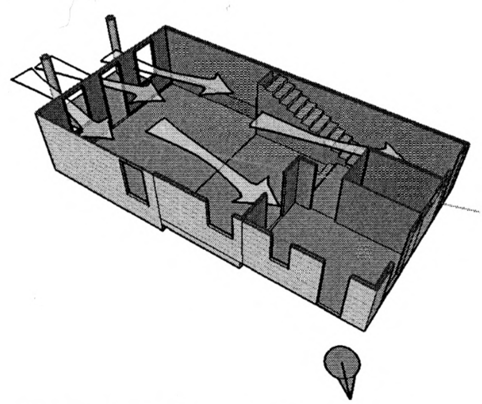


Fig.5.5.9: Unobstructed interior space.

Roof form:

The roof form provides faster in-flow of winds into the house in different ways. The roof form of the unit at the riverside is high and supported by two tall columns. This allows capturing of maximum wind from the river into the house through the windows and doors. The wind flow from the river facilitates ventilation to the upper level bedrooms.

The roof level towards the street-side entrance is low. This helps in an increase in wind speed of wind coming from that direction because of the Venturi effect.

Openings and cross ventilation:

The openings are provided at the external front and back walls of the house. This is sufficient for good cross ventilation. The common wall within the block does not have any openings. Hence the axis of the wind flow is mainly across the length of the house. The windows are double shuttered operable windows. The cross ventilation is achieved through these openings and by locating these openings in the open-side walls.

COMFORT ASSESSMENT

OCCUPANCY PATTERNS

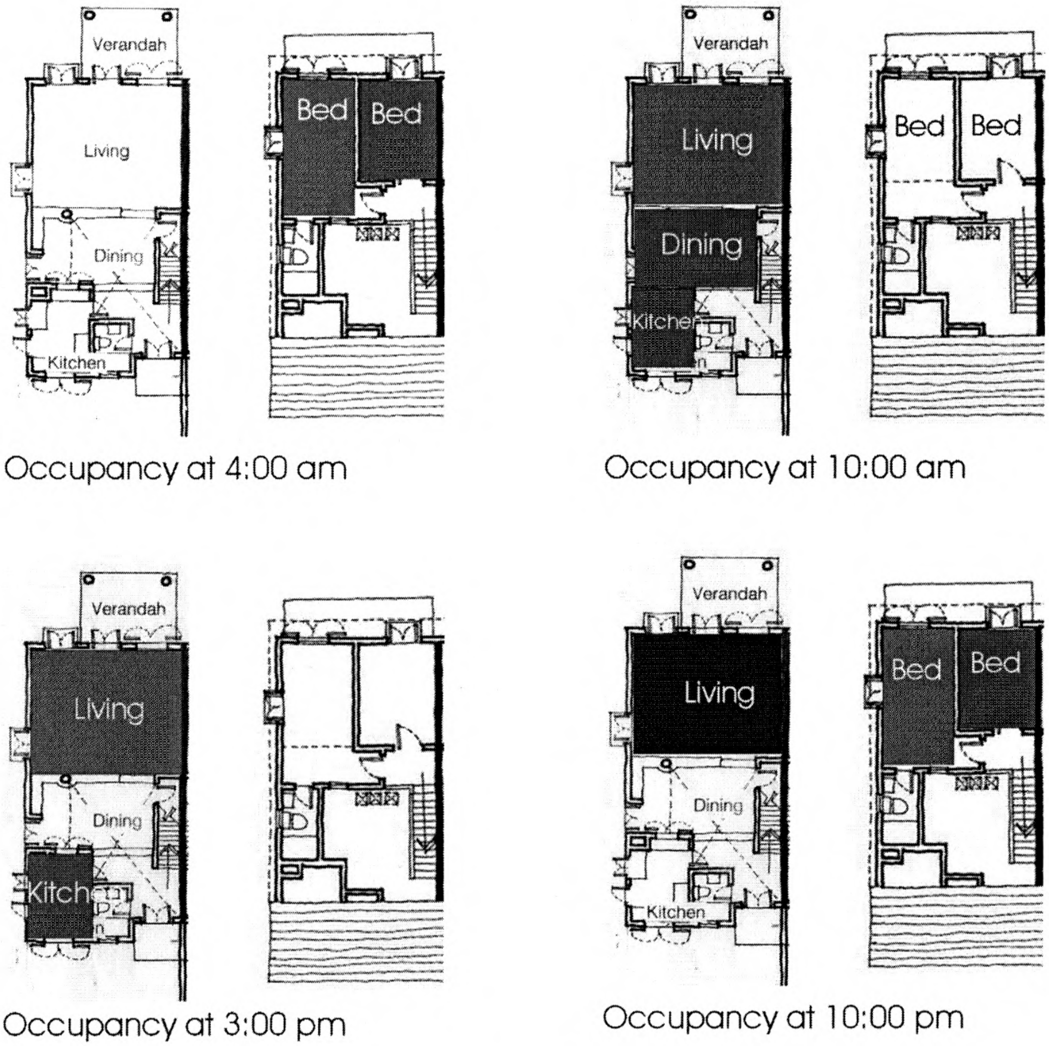


Fig.5.5.10: Occupancy charts for different times of the day.

January

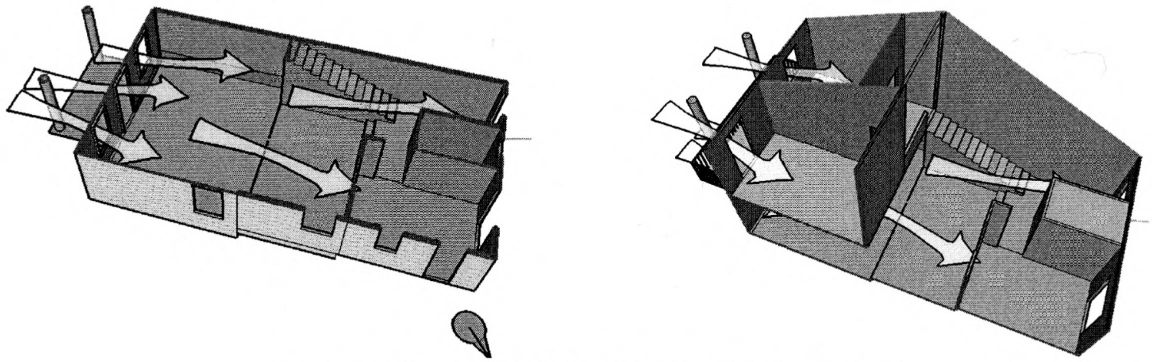


Fig. 5.5.11(a), (b): Wind direction-January, Lower level and Upper level

4:00 am

The required wind speed at this hour is much lower than the existing wind speed. There is not much need for extra wind flow. The bedrooms where the main activity at this hour is concentrated are well cross ventilated.

10:00 am

Required wind speed is higher than the existing. The occupied portions of the house can be better ventilated by controlling the openings. Shading is required.

3:00 pm

The required wind speed is almost same as the existing wind. The relative humidity is the lowest for the whole day. Hence this situation could be the closest to comfort zone situation if shading is controlled.

10:00pm

The required wind speed is lower than the existing. Shading is not required. Humidity is high; hence if all windows are kept open, thermal comfort conditions can be achieved.

April

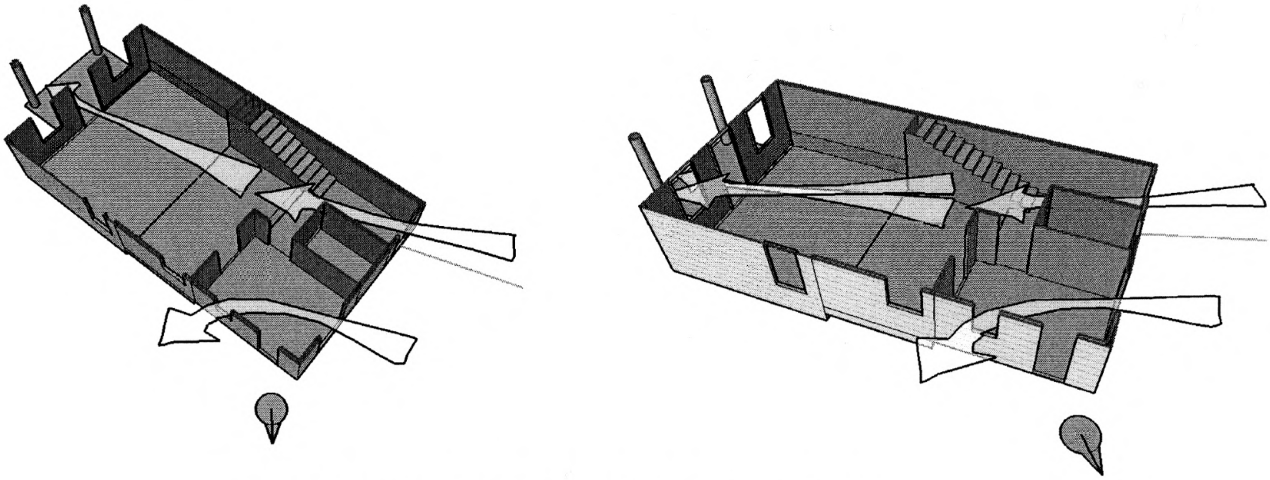


Fig.5.5.12(a), (b): Wind direction-April, Lower level and Upper level

4:00 am

The wind speed conditions are optimum. The high humidity could be controlled in the bedroom by opening the windows. Shading is not required.

10:00 am

The wind speed required is less than the existing wind speed. Shading is needed. This should be taken care of by controlling window and door shutters. The high humidity level can be controlled by cross ventilation from the openings of the walls other than the east-facing wall.

3:00 pm

The wind required is higher than the existing wind levels. Shading is required. The openings on the west side have to be closed for shading. But the wind flow could be improved from the rest of the openings.

10:00pm

The wind speed existing is much lower than the wind speed required. The river breezes help significantly if the windows facing the river are kept open.

July

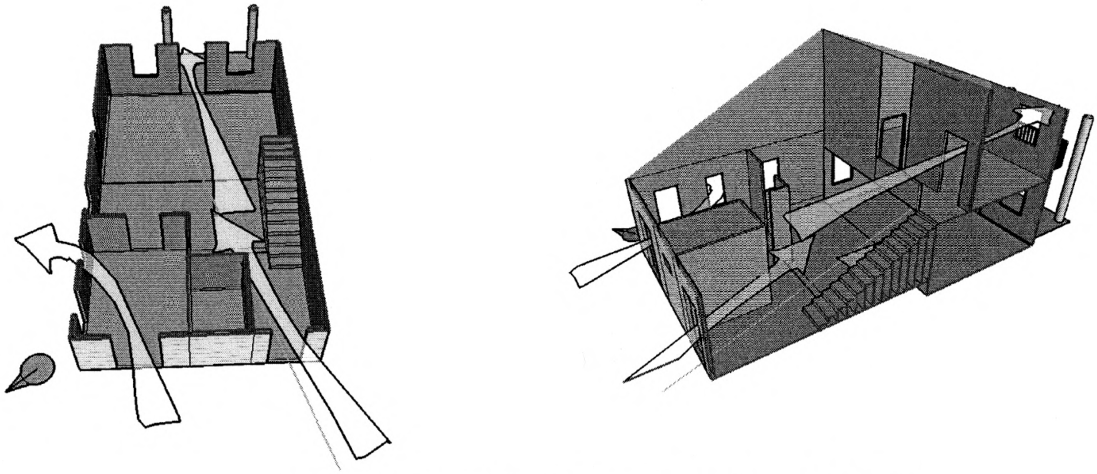


Fig.5.5.13(a), (b): Wind direction-July, Lower level and Upper level

4:00 am

The humidity level is the highest at this hour. The wind speed existing is lower than the required wind speed. Hence humidity has to be taken care by keeping the wind flow high in the bedrooms. This is achieved by the low roof form that catches the breezes from the river in the bedrooms.

10:00 am

The wind requirement is critically high at this hour. Shading is also required. The cross ventilation patterns should be optimized by controlling openings. The residents need to change their activity areas if needed.

3:00 pm

The conditions are the same as at 10:00 am.

10:00pm

The wind speed required is higher than the existing. But during this hour no shading is required. This factor of shading is advantageous during night times since all windows and doors can be kept open.

October

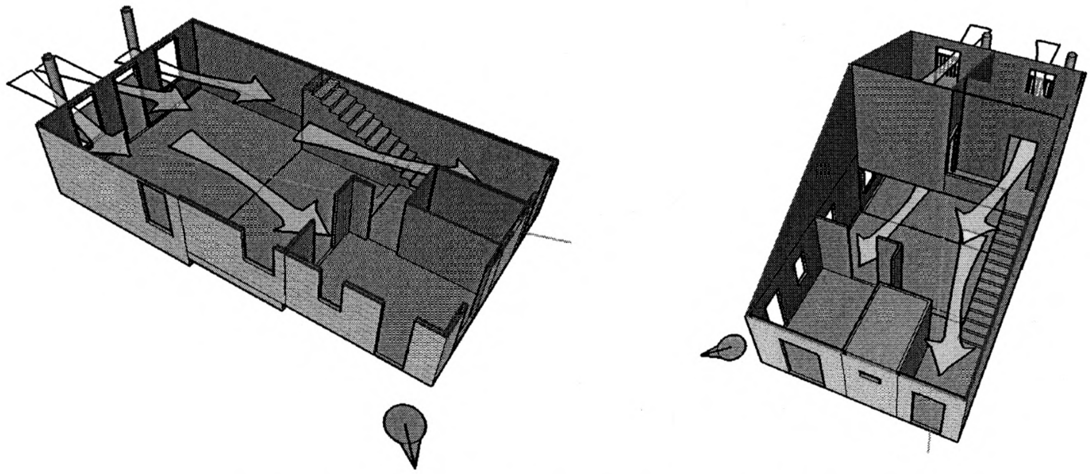


Fig.5.5.14(a), (b): Wind direction-October, Lower level and Upper level

4:00 am

The humidity is the highest in the four months studied. The wind speed required is also higher than the existing. But since shading is not required, there are better chances for the cross ventilation pattern to control humidity.

10:00 am

Shading is not required at the occupied portions at this hour due to their orientation. But still the wind speed needs to be higher than the existing. Hence the cross ventilation patterns in the living and dining areas should be kept at maximum.

3:00 pm

Conditions are same as at 10:00 am.

10:00pm

The humidity level is still high and increases as time passes during the night. Hence the wind patterns should be controlled by keeping the windows open. The bedrooms are also at a higher humidity level because of the humid air from the river. Hence they should be highly ventilated.

SUMMARY OF COMFORT ASSESSMENT

The comfort conditions assessed for each of the four months studied give us different results for different days. The shading requirements are well taken care of at all times of the year by the roof form, sunshades and the controllable devices. For each of the days studied, the results suggest that the cross ventilation within the house because of the orientation, strategy of openings and controllability of devices, is the best during the months of January and October. These months have the best ventilation patterns. During July, though the humidity levels are high, the living areas are less ventilated. The bedrooms are also not directly ventilated by the prevailing winds. This is the case in April too. During these two months, the residential units have to depend more on the locally originated winds from the riverside. These units are well furnished with openings to the riverfront to catch these winds. Hence it can be concluded that the importance given to the orientation towards the riverfront is well justified and the unit is well designed to reciprocate this importance.

CHAPTER VI: COMPARATIVE EVALUATION OF CASE STUDIES

Pattern Identification

OVERALL BUILDING MASS:

Configuration of the overall building mass determines the heat loss and gain of the building. This property of buildings can be used advantageously for the building. In the case studies, the overall massing of the Bungalow, Villas of Verem, and individual units of Sonmarg and Kanchanjunga apartments could be compared. The mass of each unit is compact and hence has less heat gain which is a primary concern in this region. The compactness also helps all the rooms to connect to an outside wall.

The scale of each unit is maintained at a level where it is easy to achieve an internal space of comfortable thermal conditions. The massing of the units is done in such a way that some rooms are vertically stacked to get better patterns of cross ventilation by being able to catch winds from more than one side. For example in the Kanchanjunga and Verem villas, the second floor accommodates the bedrooms so that they have exclusive ventilation and shading patterns. In the Sonmarg apartments, where Correa had not yet implemented an actual duplex system in his high-rise buildings, the bedrooms are located at a slightly higher level.

The bungalow's scale has been a very constant feature during its evolutionary process. If the requirements of a certain bungalow exceeded its traditional scale, they were accommodated in different bungalows within the same compound. This was to make sure all the rooms of the bungalow were well ventilated and to avoid excessive building mass. This feature is seen in the overall mass of the individual units of the case studies in Sonmarg apartments, Kanchanjunga apartments, and Verem Villas. Belapur's concept for massing is more oriented towards the cluster arrangement of the units rather than a single unit.

ORDER OF ROOMS:

The external building mass integrated with configuration of rooms work towards thermal comfort at the interior level. The hierarchy of spaces within the unit is defined by the order of rooms. This hierarchy can be manipulated by strategic planning of the order of rooms. The rooms can be put in an order where the core living areas can be protected or left open depending on the climatic needs to be catered.

The order of rooms in Correa's designs is different in each building. The order in the unit in Sonmarg apartments is similar to the bungalow. The bedrooms and verandahs protect the living area in the bungalow. The living area in Sonmarg's unit is also protected by the auxiliary spaces and the balconies, which protect it from external forces by acting as buffer zones. The 'bunched' form of the room layout acts as a strategy of protection. The order of rooms in all the other case studies is linear in nature. This arrangement is not very traditional in nature. Correa redefined the spaces of the bungalow in a linear manner and tried to incorporate the climatic strategies by the method of sectional displacement. This new method he invented for the modern context has been successful in all these designs. This is seen by the cross ventilation and shading patterns achieved inside the apartment.

ORIENTATION:

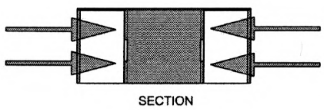
From the case studies, it is seen that the orientation of the building as a whole has been given less importance and the orientation of the individual rooms has been more significant. In all of the case study buildings in Mumbai, the sites are oriented in north south direction. The buildings are oriented perpendicular to the site, in a way this suggests the individual rooms get most of the prevailing winds that flow from the east west, which is the predominant windward direction in a year.

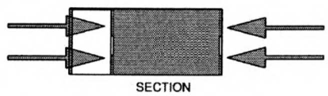
POROSITY OF FORM

Porosity is achieved in the case studies at two levels of the exterior envelopes. One strategy is the semi-open spaces around the core interior area, and the second is through the external wall openings at the wall level. This porosity determines the extent to which external forces have been allowed or blocked to achieve comfort conditions.

The most predominant strategy used by Correa is to incorporate semi open spaces at crucial locations of the house to catch winds and then continue the wind flow to the interior by means of effective openings and various combinations of stack and cross ventilation.

In the traditional Bungalow, and units of Sonmarg and Belapur, the porosity of form is seen at both ends of the units through the semi open spaces that surround the interior space. Whereas in Kanchanjunga apartments and the Verem villas, it is mainly through the semi-open space at one end and the external wall openings at the other end.





When compared to the usage of the semi-open spaces strategy of the Bungalow, Correa's residential units at Sonmarg and Belapur show similar effectiveness because of the direction of porosity.

STRUCTURE

Roof:

The roof form is configured low to provide ample shading to the semi open spaces and the external walls in two ways. The independent houses are designed to have a pitched roof form which hangs low over the semi-open spaces, in the apartments, the roof is flat and covers all the semi open spaces.

The material used is locally available and the technique is also local. After the advent of modern era, reinforced concrete is used for modern high-rise buildings. The Bungalow, Belapur houses and Verem villas share the same type of roof with a slight modification in material. This roof form helps in providing good ventilation and shading. The roof structures having several layers of construction have more capacity to 'breathe' and reduce heat conduction.

Floors:

Variations are created in the floor level to help improve wind circulation and also to define different spaces without internal walls.

The floor variations are seen in the form of split-levels in Sonmarg and Kanchanjunga apartments, Belapur units and Verem villas. In Kanchanjunga and Verem villas, the duplex system is used to improve ventilation in individual rooms. This will be discussed in more detail in the following sections.

The concept of a raised level from the ground level by the plinth is a characteristic of the Bungalow. This has been applied in the various case studies but the plinth used is not as heavy as the Bungalow. The material of the plinth in Belapur units is different from the other case studies.

Ceilings:

Ceilings in some case studies are left uncovered to get a huge volume of space under the roof that acts as a wind collector space. Ceiling heights are varied to increase the wind velocity by means of Venturi effect, which is the increase in the velocity as wind travels through a smaller section to a larger volume. They could also promote stack ventilation if there were openings in the roof.

The uncovered ceilings are seen in the Bungalow, Belapur and the Verem villas where a pitched roof form is used. The ceiling heights are also variable because of this roof form. Where the roof form is flat, false ceiling and split floor levels are used to create variations like in Kanchanjunga apartments.

SPACE

The space in Correa's residential units is treated in a very unique way. A dynamic cross section is created in each unit in one of the cardinal directions. This cross section is embedded with various characteristics of ventilating and shading techniques. The other cross section of the unit is dependent on this dynamic cross section for various needs of ventilation and shade. In a way the dynamic cross section is incorporated with the primary bioclimatic strategies that cater to all the space in the unit.

A typical cross section is a hierarchy of open, semi-open and closed spaces. Each of these spaces has a function to perform to maintain optimum thermal conditions. The dynamic nature of the conditions in these spaces leads to a special behavior of the residents, in which they change the activity centers to different places based on the conditions.

The dynamic cross section is a commonality amongst all the case studies. It is in the east-west direction in the units studied in Mumbai, and varies for Belapur units and Verem villas because of the different contexts.

The study of the Bungalow is very crucial for the study of modification in behavior in this context. In the traditional Bungalows, the dynamic behavior of the residents was the most significant strategy used for protection against the dynamic nature of the climate. This strategy of the traditional Bungalow can be applied to all the Correa's buildings studied.

SHADING:

- **Roof Form**: Usage of the roof form as a shading device is seen in most of the case studies where the scale factor permits it. The roof form shades the semi-open spaces that are used extensively during various periods of the year.
- **Buffer Zones**: Usage of 'buffer zone' is applied in most of the case studies. "Rooms that can tolerate temperature swings can be located between protected rooms and undesired heat or cold."[1]. This buffer zone provides space for auxiliary activities like study and lounging. This zone may also be an in between layer of the 'Layers of Defence' against the external forces used by Correa.
- **'*Manipulability*' of environment**: This refers to the non-structural and structural shading devices that can be controlled to achieve desirable thermal conditions inside the house. The double windows at upper and lower heights can be closed and opened to create stack ventilation at the opposite walls. The double windows can also be controlled to block direct sun at one level and allow winds at the other depending on the hour.

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[1] Brown and DeKay. *Sun, Wind & Light: Architectural Design Strategies*. (New York: John Wiley and Sons. 2001), 163.

Roof form as a strategy is seen in the bungalow, Belapur and Verem villas. The flat roof of the Sonmarg and Kanchanjunga apartments essentially shades the semi-open spaces like the Balconies and terraces. The buffer zones are seen in Sonmarg and Kanchanjunga. The *manipulability* of environment is a commonality seen in the bungalow, Sonmarg and Kanchanjunga apartments.

The bungalow by its very form provided shading strategies throughout the day. The modifiable environment was a crucial technique. The bamboo mats on stilts and the bamboo chicks were traditional devices for shading during various times of the day to block sun and glare. The bamboo chicks are still used in the modern residential units of Sonmarg and Kanchanjunga apartments. These devices provide for the various layers of defence against sun and wind.

VENTILATION:

- **Zoning of Rooms**: Rooms are stacked vertically or zoned at different corners horizontally to take maximum advantage of the prevailing winds. Vertical stacking or variation in room levels helps in stack ventilation across the house. It also helps achieve cross ventilation in the individual rooms that are stacked.
- **Cross Ventilation**: Strategic Placement and size of openings improve cross ventilation in a drastic manner. Placement of openings at the windward and leeward sides increases wind velocity. Size of openings can be controlled and openings can be closed and opened to increase velocities by stack effect.
- **Wind Catchers**: Semi-open spaces can act as wind catchers. Sometimes these spaces can be integrated with the roof form to increase incoming wind velocities.

Zoning of rooms is seen in the traditional bungalow, Sonmarg, Kanchanjunga apartments and Verem Villas. The minimal number of rooms in Belapur cannot apply this strategy. Placement and size of openings as a combined strategy is applied in the Bungalow and the Sonmarg and Kanchanjunga apartments. The verandahs in the

Bungalow and Sonmarg apartments, terrace garden in Kanchanjunga units, and the courtyard in Belapur units act as wind catchers.

The ventilation strategies of the bungalow have been incorporated in most of the case studies. Correa has not only attempted to incorporate these strategies in similar scale structures but also tried to facilitate them in the high-rise structures with different material and construction techniques.

UNDERLYING TOPOLOGICAL ORDER:

In all the case studies, a commonality between the underlying topological orders is seen. The essential quality of flow through centralized space is the basis for this topology. The integration of interior spaces within a housing unit defines the patterns in the unit. The 'open plan' of the rooms was a modified concept that Correa used in all of his case studies. In the traditional bungalow, the open central room was well ventilated throughout the year in two directions at least. A modified version of this central room is seen in case studies of Correa. The main living areas, i.e., the living and the dining area are either linearly arranged or staggered along a diagonal path without any walls in between.

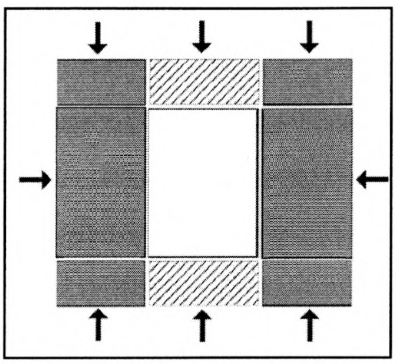

Fig.6.1 : Bungalow order

This is seen in the Sonmarg and Kanchanjunga apartments. They can also be arranged in a simple open two-storied tube following his early tube house concept. This is seen in the Verem villas. The last case study, Belapur housing shows the use of the traditional courtyard where the central flow through space is an exterior space.

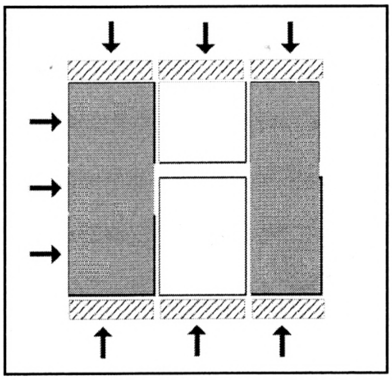

Fig.6.2: Unit of Sonmarg

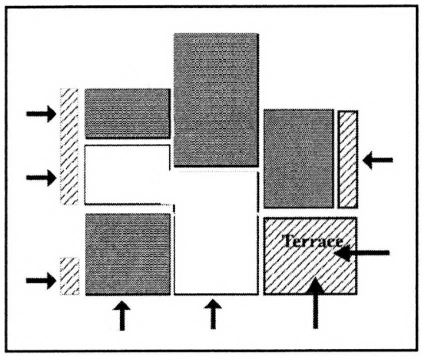

Fig.6.3: Unit of Kanchanjunga

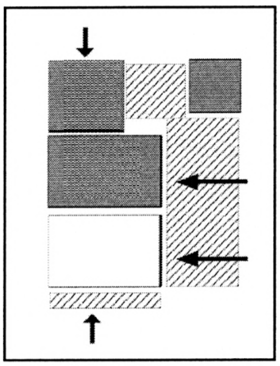

Fig.6.4: Unit of Belapur

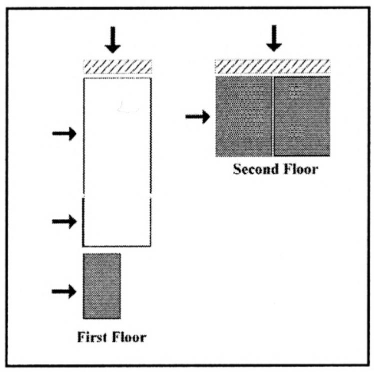

Fig.6.5: Verem Villa

Conclusions and Socio-cultural Implications

The analysis of the case studies brings the study to a state of addressing Correa's ideologies in the light of the proven observations of the case studies. One of the most important ideologies discussed earlier was the one that described four forces acting on the architecture in a society. These four forces are culture, aspirations, technology and the time and place. The conclusions presented here show to what extent these forces and various others have acted on the case studies.

Integrative Process:

Correa's architecture can be described as an integrative process. It has a deep insight into the nature of traditional and modern architecture. The integration of these two forms the basis of his designs. For Correa, design is a result of cultural and social forces. " Styles of architecture tend to be conceived as either the result of cultural and social forces, or else as something which is applied to architecture."[2].

The importance given to the local culture and social forces is seen in the design of all the case studies. The usability of spaces in the case studies shows the extent of living patterns as a contributing factor to the design. The indoor and outdoor spaces suggest the thought process that goes into Correa's design with regards to the integration of the time seen as hour of the day and the living patterns interpreted by the occupancy charts.

> "The specific characteristics of a culture-the accepted way of doing things, the socially unacceptable ways, and the implicit ideals-need to be considered since they affect housing and settlement form; this includes the subtleties as well as the more obvious or utilitarian features"[3].

In his hypothesis about socio-cultural factors being the determining factors of the house form, Rapoport suggests some aspects that affect built form in housing. Some of these are studied with regards to Correa's designs in the following paragraphs.

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[2] Abel, Chris. *Architecture and Identity: Towards a global eco-culture.*(Boston: Architectural Press, 1997), 152.

[3] Rapoport, Amos. *House Form and Culture.* (New Jersey. Prentice-Hall, Inc., 1969), 47.

Some basic needs:

The basic needs for a family in India can vary depending on many factors like the financial condition, geographic location and culture. But for everyday activities the general needs are needs for comfort while sitting, sleeping, lounging and socializing. For the proper functioning of these needs, first of all space should be provided for each function and this space should be comfortable for the users.

Correa's designs are a success with regards to built form being a response to the socio-cultural needs. Comfortable spaces are dedicated in each house for various activities. These spaces could be used during different hours of the day. The spaces can be controlled for more comfort. There are adequate spaces provided to be able to change behavior within the house in case of discomfort. The available choice for comfortable spaces within the house ranges from entry and departure points, through the verandahs and spaces in between the main living areas, to the living rooms and bedrooms.

Social Interaction:

The spaces provided for community and social interaction are well suited to the scale and setting of the project wherever possible. The clustered arrangement of units around courtyards provides ample opportunities for social interaction. The material used for the courtyards is very well suited for the climate. The space used for social interaction can be seen as a commonality between traditional examples and Correa's buildings. In a bungalow, the open and semi-open spaces are extensively used for social interaction. Especially the verandahs are used throughout the day for various purposes by making adjustments or controlling the glare, shade and wind entering into the verandahs.

The Need for Privacy:

"In fact, the dwelling is not isolated from its surroundings but is a constituent part of its environment...how societies regard their relationship to external space is often a measure of the importance that they place on privacy"[4].

The need for privacy changes for different cultures and sometimes even different periods of time. In India, privacy is dealt with in various ways depending on the needs of

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[4]Oliver, 141.

religion and culture. The houses are built within the premises of a boundary wall and they can either consist of an internal courtyard or external verandahs like the bungalows. But it is very challenging to design residences with adequate privacy in a hot and humid climate where there is a constant need for openness for ventilation and comfort throughout the day.

Privacy in most of Correa's buildings was achieved in the same way as the bungalow, i.e., by providing the main living areas with an envelope of exterior, semi open or sometimes closed but controllable buffer zones. Sometimes in closely located units like in Belapur, the privacy was maintained by providing openings on walls that do not look into each others houses.

Transformations of the past:

Frank Lloyd Wright observed:

> "the true basis for any serious study of the art of architecture still lies in those indigenous structures; more humble buildings anywhere (are) to architecture what folk-lore is to literature or folk-song to music and with which academic architects were seldom concerned....It is the traits of these many folk-structures that are of the soil. Natural. Though often slight, their virtue is intimately related to the environment and to the heart-life of people. Functions are usually truthfully conceived and rendered invariably with natural feeling. Results are often beautiful and always instructive" [5]

The usage of traditional strategies like those seen in the Bungalow show the importance of the past in Correa's architecture. His ideology of understanding the past and reinventing it again in the modern context is clearly seen in the high-rise housing in which the versatility of the bungalow was incorporated. Correa uses the concept of semi-open spaces as buffer zones in the Sonmarg apartments as seen in the bungalows. But the unit in Sonmarg apartments is set in a modern context and hence he modified the functionality of the verandahs of the bungalow to suit the setting of a modern family by redefining those spaces for modified usage.

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[5] Wright, Frank Lloyd. "The Sovereignty of the Individual in the Cause of Architecture" Preface to *Ausgefuhrte Bauten und Entwurfe* (Berlin, 1910). Reprinted as introduction to exhibition, Palazzo Strozzi, Florence, p. 1, 1951.

The shading devices used in the case studies are very much analogous to the temporary devices that were also adjusted according to the varying conditions of the day. They are as operable as the old ones and at the same time adjustable to different sun positions. Correa has utilized technology to transform the utilitarian concepts of the past to suit the present requirements.

In Belapur, he used courtyards as central features to provide the residential units with various functions. He uses the courtyards as a climatic strategy for catching winds and for shade. But the modification of the semi-open low roofed verandahs to the courtyard and small roof projections of the unit tend to expose the walls to the sun, which proved to be an unsuccessful strategy.

The constraints of construction techniques and material could never make Correa compromise in form or space. Correa's usage of modern materials in his designs has only enhanced his designs in functionality and response to climate. For example the Kanchanjunga apartments show Correa's usage of traditional concepts, but his usage of modern techniques has made it possible for him to interlink units and create a dynamic form of building that is a success with regards to climate. Correa uses modern simplicity in the configuration of the building and conceives the structure with the use of locally available material and synchronizes it with the old buildings with respect to strategies.

'Quest for Identity' and Correa

Correa's professional career since the 1960s both in India and abroad had a deep relation with his quest for identity. His understanding of this identity has initiated his responses to the design issues he faced. The basic question underlying this study is the relation Correa's residential architecture has with climate and the vernacular context. In one of his essays called 'Quest for Identity', Correa writes:

> "I find that climate helps determine form on two different levels: One, it is an immediate determinant, finding expression in courtyards (hot, dry) or on through-ventilation (hot, humid). Two, at a much deeper level, climate helps determine the patterns of culture and rituals. And in that deeper sense, since it is a primary determinant of ritual, it also determines built form."[6]

The two questions that arise from this study are whether Correa's architecture is an effective response to the climate, and whether his architecture, is culturally appropriate for the daily rituals and living patterns of the residents in the context.

The answers to whether his architecture is successful as a response to climate is discussed in detailed in the earlier sections of the conclusions. The answers to whether it is successful culturally and whether the residences are easy tools for the ongoing living processes of everyday lives of the people, are embedded in the analysis of the case studies. As Sherban Cantacuzino writes in his essay called 'Ideas and Buildings':

> "...there are perhaps two kinds of beauty in architecture, an inner and an outer beauty. Inner beauty can come from something as intangible as an idea, from the organization behind the plan and section, from the inherent harmony of the whole. Inner beauty tends to be hidden from the uninitiated. It is not easily perceived except by those who can understand three-dimensional relationships."[7].

This is absolutely true with Correa's designs. They are based on deep-rooted cultural and traditional ethos of the people residing in these houses. The plans, sections and the three dimensional spaces of the residences show Correa's sensitivity towards the

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[6] Correa, Charles. 'Quest for Identity' Database on-line. Available from http://archnet.org/library/downloader/document/4558/dpt0500.pdf . Accessed October 18, 2002.

[7] Cantacuzino, Sherban. "Ideas and Buildings." In Correa, Charles. *Charles Correa: with an essay by Sherban Cantacuzino*. (Singapore: Concept Media Pvt. Ltd., 1984), 16.

living patterns of people in a warm climate, the needs of the people at different hours of the days in different seasons. There is always a variety in the spaces provided that leaves the residents with options more than the number of times the climate outside changes. The organization of the rooms in these houses reflects the living patterns. The organization also shows a deeper connection to the traditional hierarchy of spaces like that in the bungalow. Charles Moore describes a quality called 'Order of Dreams', which is a set of aspirations that the residents have for there 'home'[8]. The organization of the rooms about a center in Correa's designs is a common feature of the set of aspirations of people living in vernacular context and the contemporary context.

The four problems that Correa's 'Quest for identity' is based upon are the living patterns, the passive energy buildings, urbanization and the nature of change[9]. These are explained in the section about Correa's design philosophies. The study shows that Correa's housing designs try to address all these issues depending on the context. The individual residences that he designed are responsive to the first two problems, whereas the high density and high rise residential complexes are responsive to all the four problems.

Another important philosophy of Correa's is that architecture should always be simultaneously both old and new for it comes into being at the intersection of three major forces. The first represents technology and economics; the second, culture and history; and the third, the aspirations of people[10]. The study shows the commonalities between the vernacular architecture and Correa's designs, the unsuccessful features of his designs and the most successful aspects of the same with respect to the three major forces. On the whole, it can be said that Correa's designs for the people of India have put the modern movement of architecture in this country at its best. His ambitions and goals lie in the questions he tries to answer by way of his designs. These questions are summed up in the following paragraph:

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[8] Moore, Charles, Allen, Gerald, and Lyndon, Donlyn. *The Place of Houses*. (New York: Holt, Rinehart and Winston, 1974).
[9]Correa, 6.
[10] Cantacuzino, 13.

"Quality in architecture and planning is the result of understanding constraints, not of ignoring, or avoiding them. How well does a building fit into its site? How intelligently does it deal with the hazards of climate? What materials and technology does it use-and how appropriate are they in terms of cost and local availability? What is the scale and ambience of the whole environment-and is it in consonance with the sensibilities of the people who live there?"[11]

Through my research, I have found that Correa has answered many of these questions by way of his designs. These questions not only are design guidelines for him but also reflect the problems of designing in countries like India. My research has provided me with valuable information about the user comfort, spatial characteristics and spatial alternatives in his designs. The socio-cultural values embedded in the residential examples showcase his philosophies. The commonalities found between the vernacular examples and the contemporary case studies show the influences of past architecture on his design concepts.

I feel this is the direction that should be followed by architects in developing countries. These countries that are rapidly being influenced by the global technologies and western ideas need to have at the very basic level a habitat that reflects the culture of their place and readily supports daily activities. These daily activities that represent culture in the form of function, should be done in comfort and should be provided with the same variety of spaces that used to exist in the past when economy or space were not a constraint. I feel Correa has successfully achieved this.

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[11] Correa Consultants (Brochure), Bombay.

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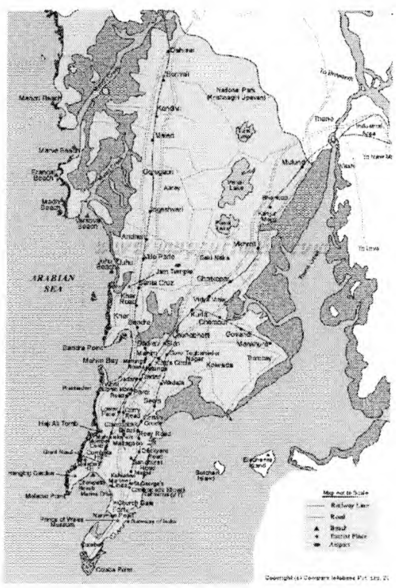


Fig. A-0: Map of India with Mumbai, map of Mumbai

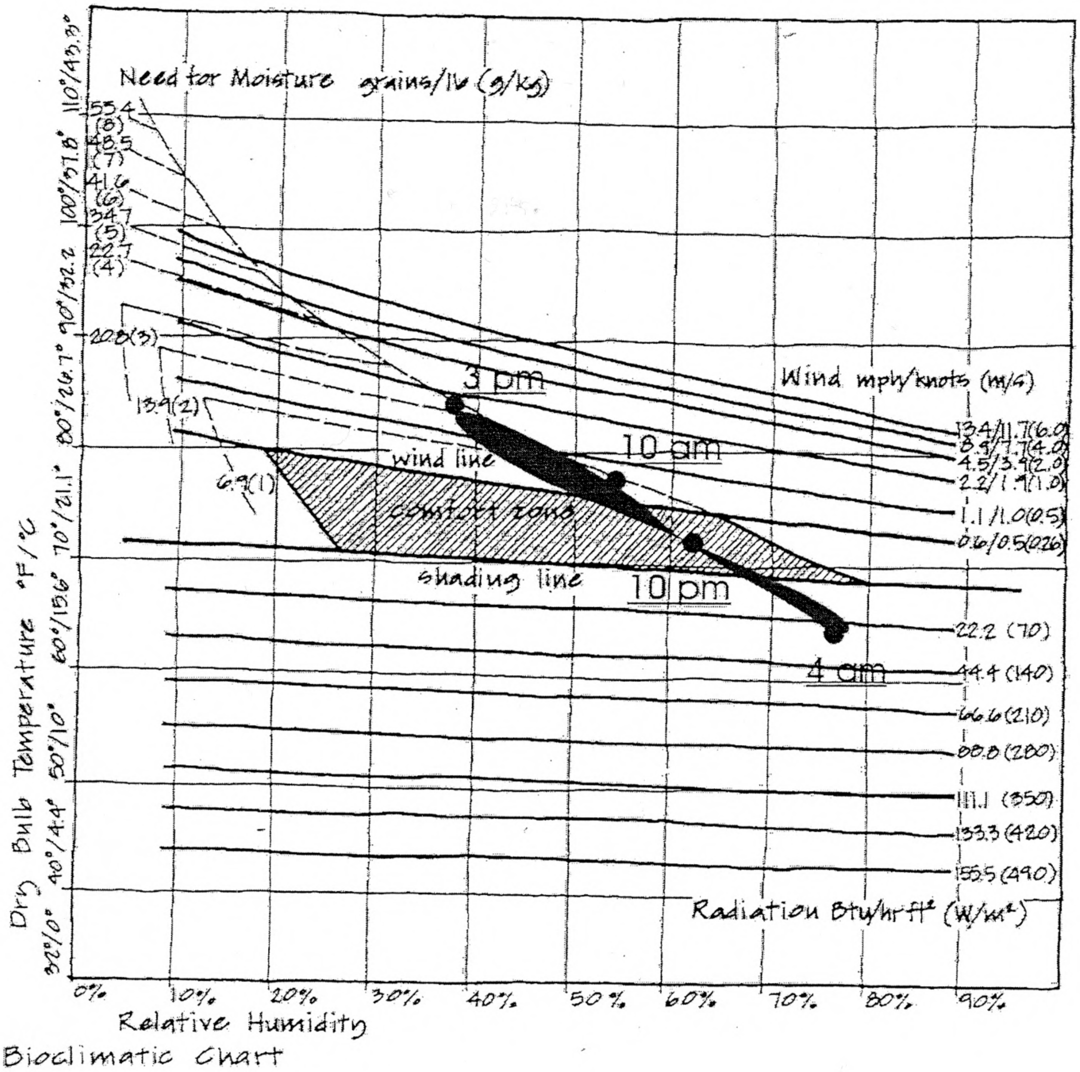


Fig. A-1: Bio-Climatic Charts for Mumbai, India-January.

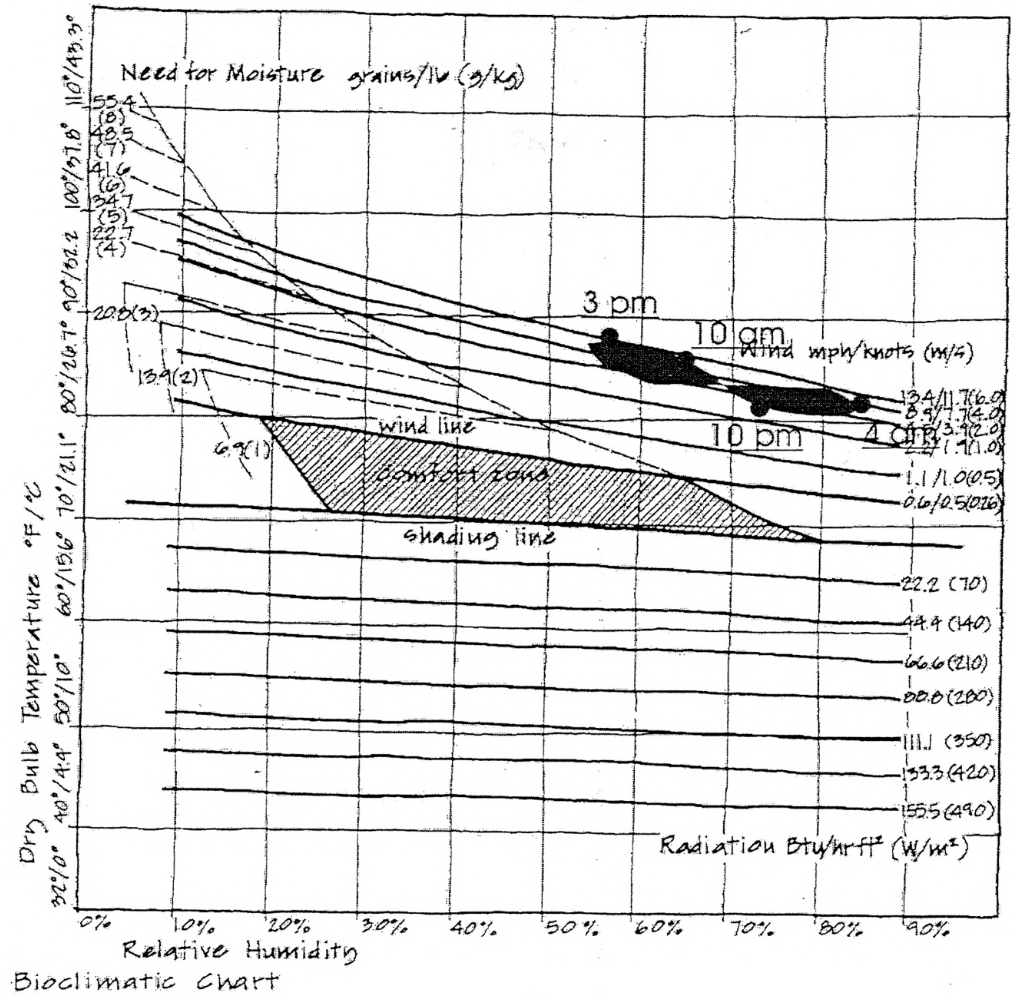


Fig. A-2: Bio-Climatic Charts for Mumbai, India-April.

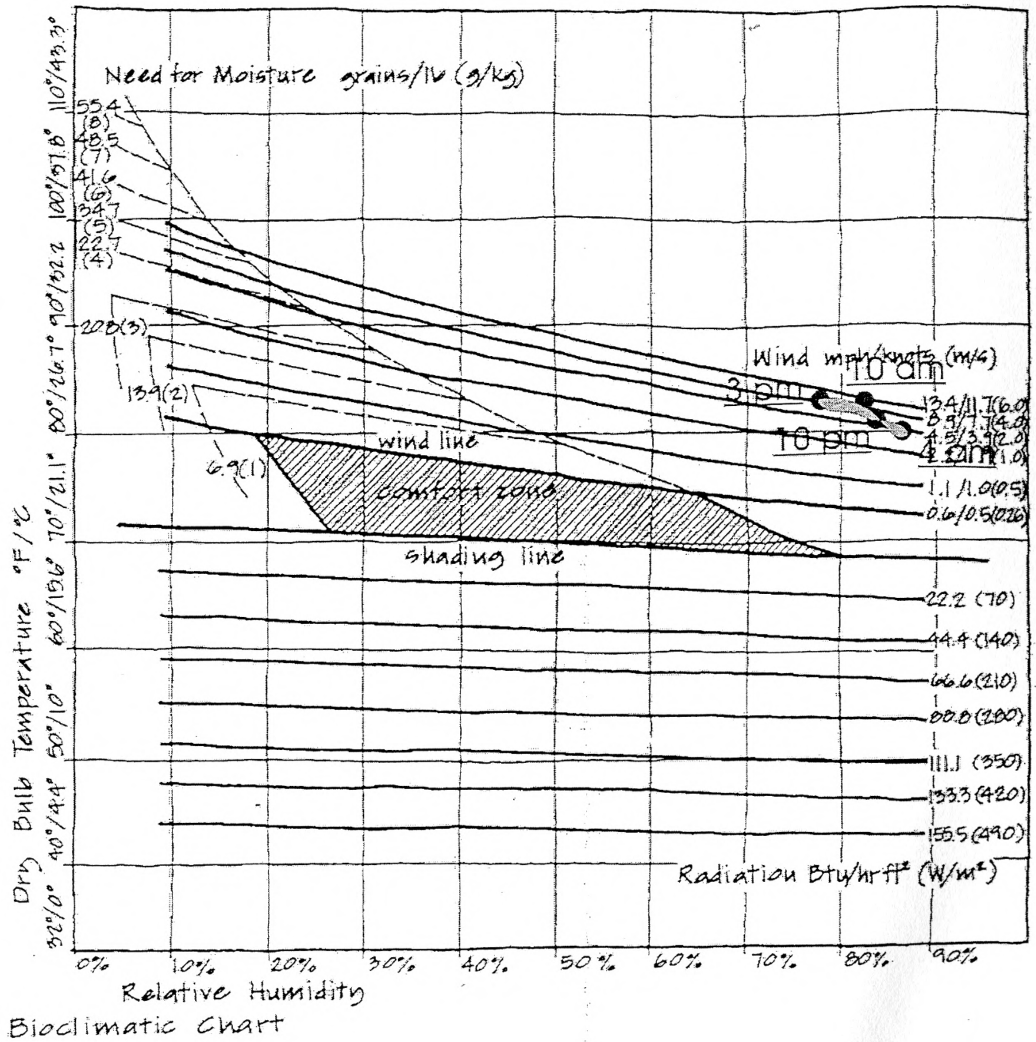


Fig. A-3: Bio-Climatic Charts for Mumbai, India-July.

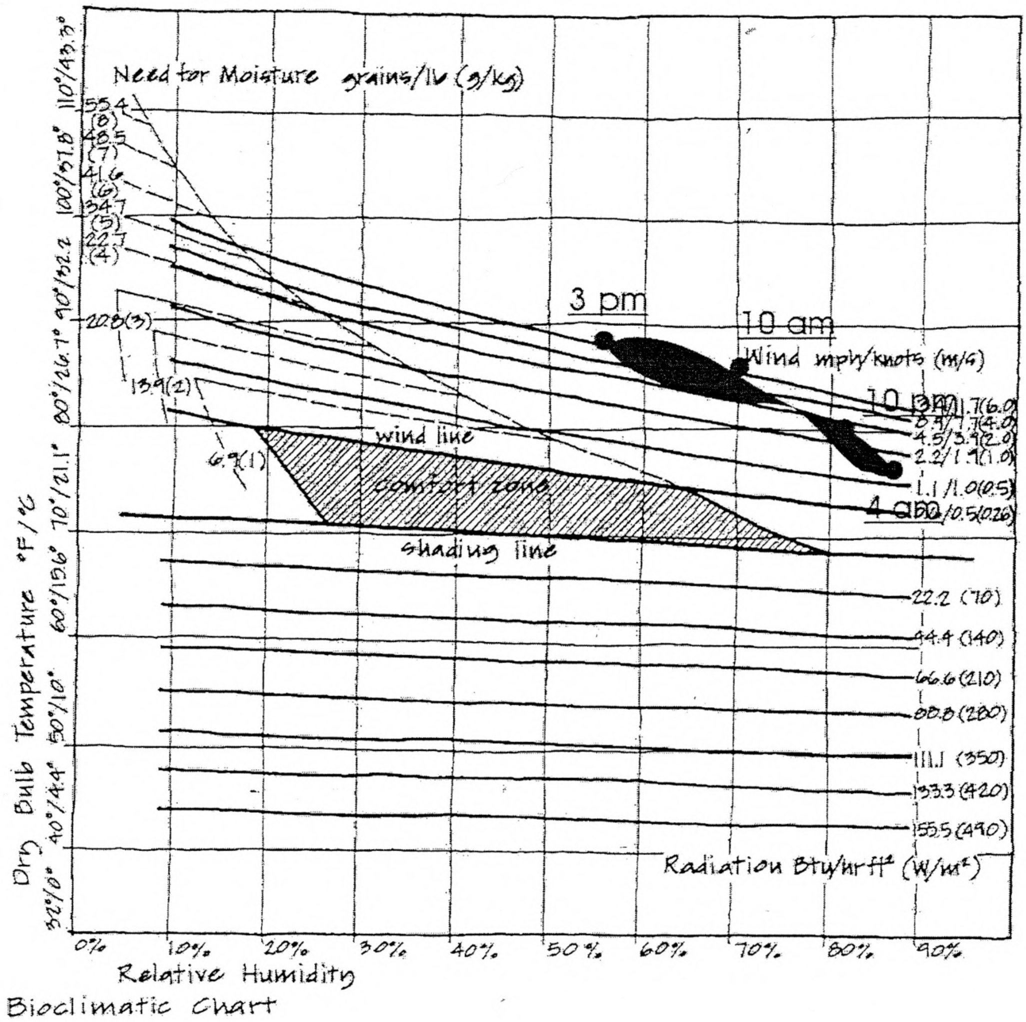


Fig. A-4: Bio-Climatic Charts for Mumbai, India-October.

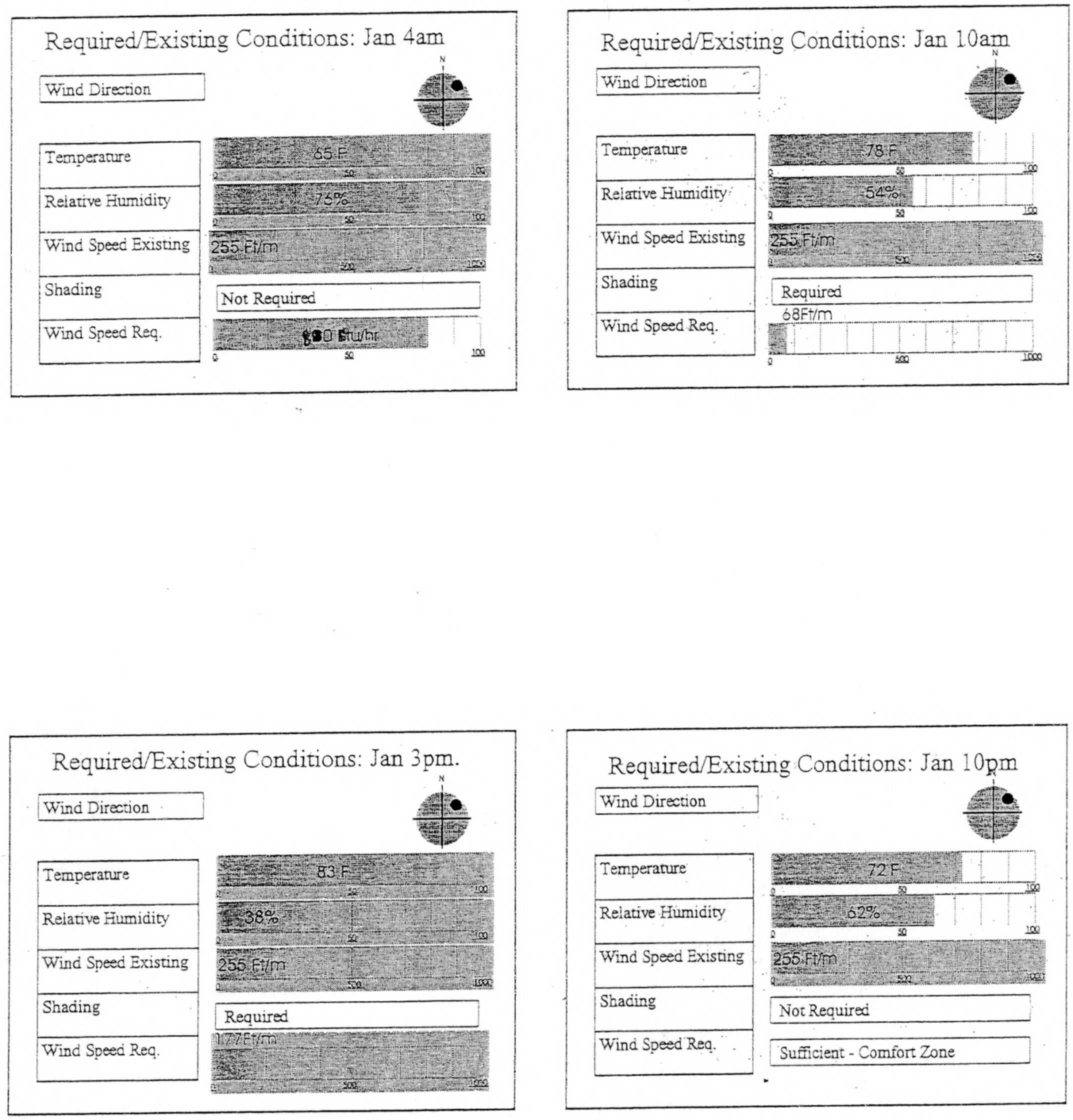


Fig. B-1: Climatic Data for Mumbai, India-January.

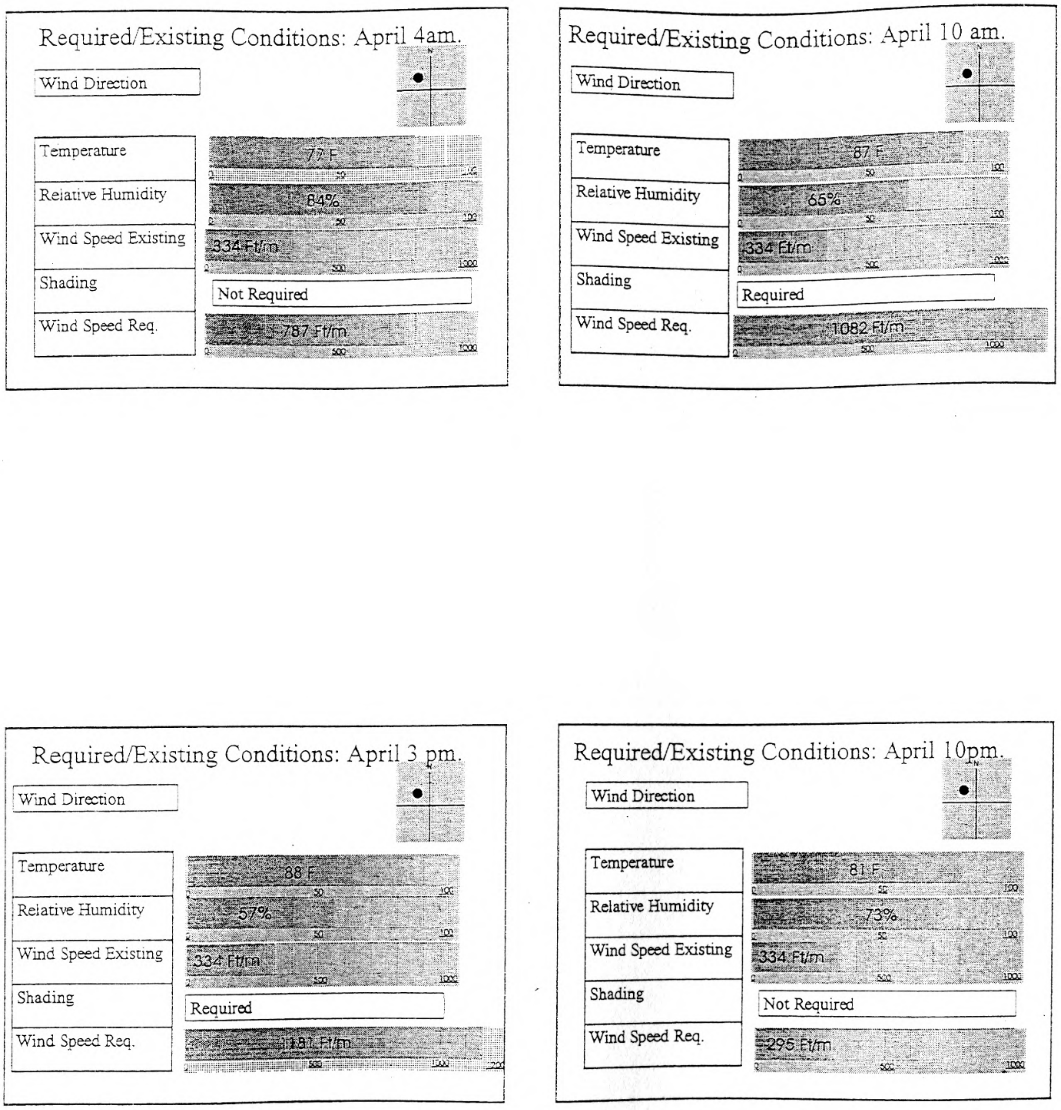
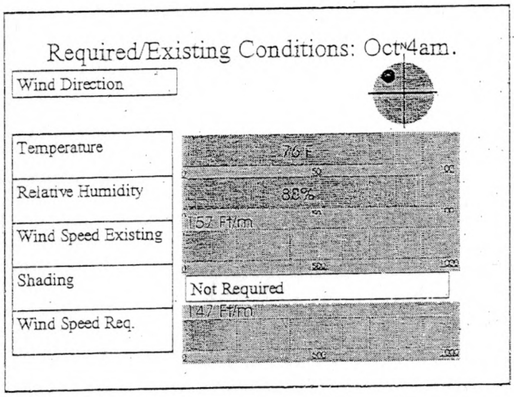
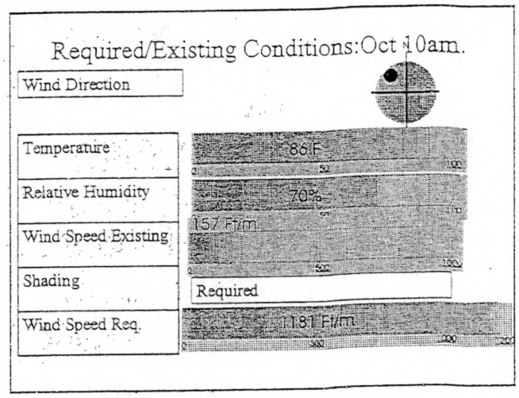
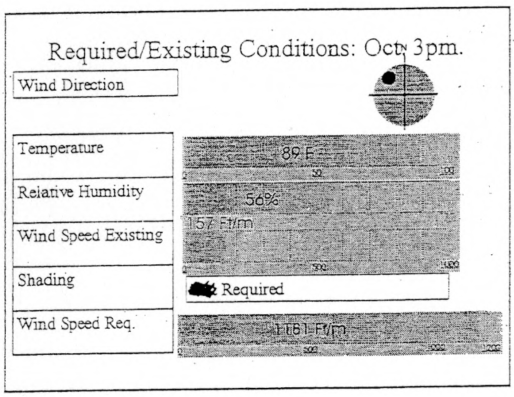


Fig. B-2: Climatic Data for Mumbai, India-April.







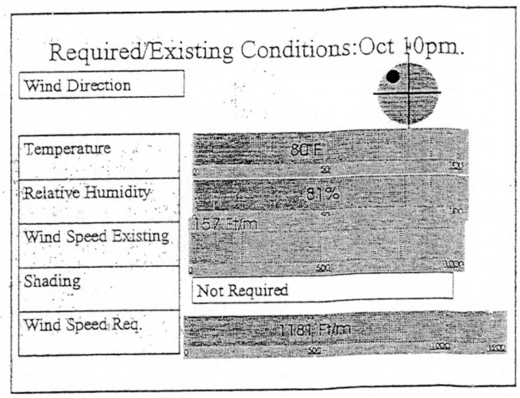


Fig. B-3: Climatic Data for Mumbai, India-July.

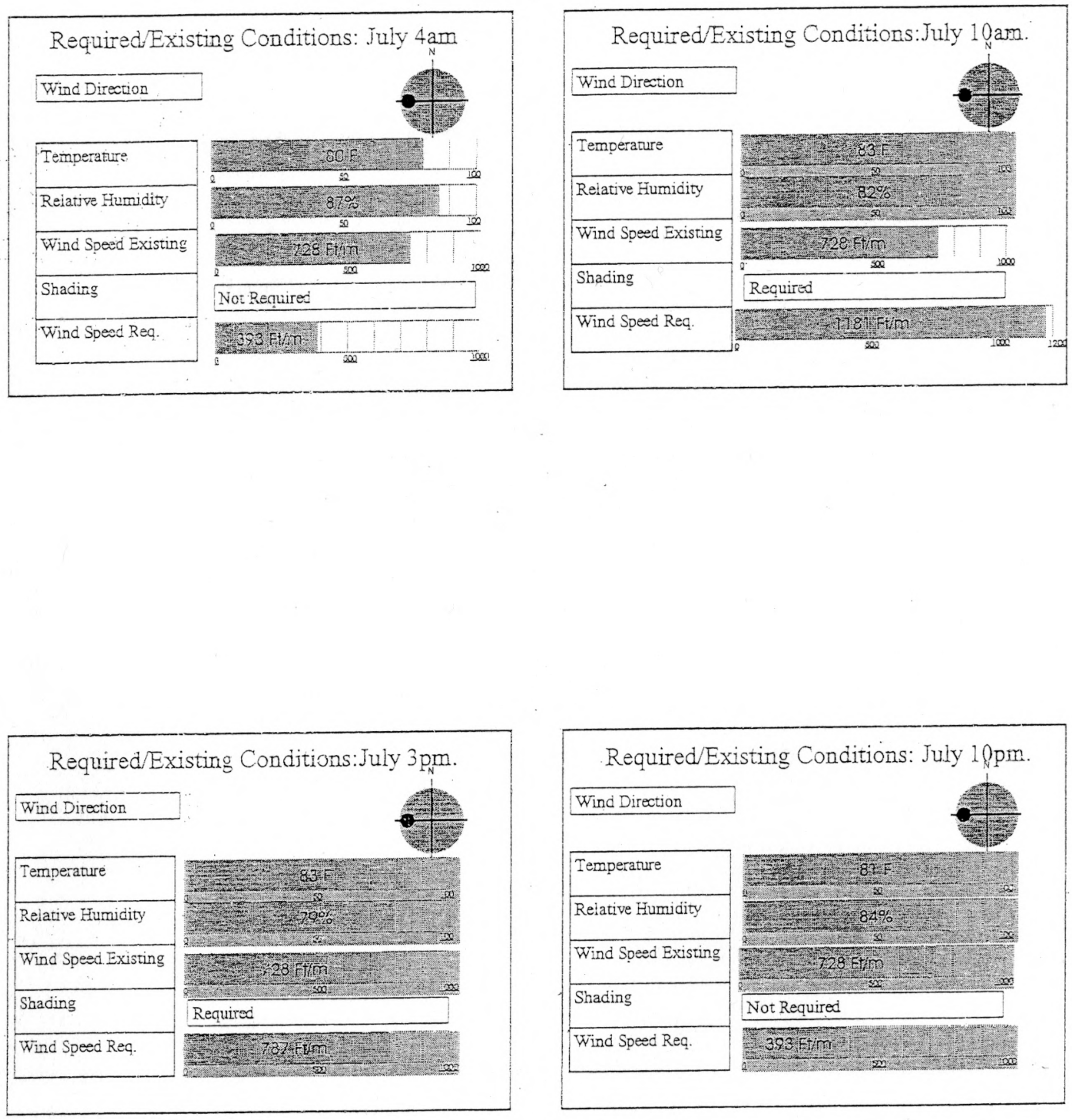


Fig. B-4: Climatic Data for Mumbai, India-October.

Fig. C-0: Map of India with Goa, Map of Goa.

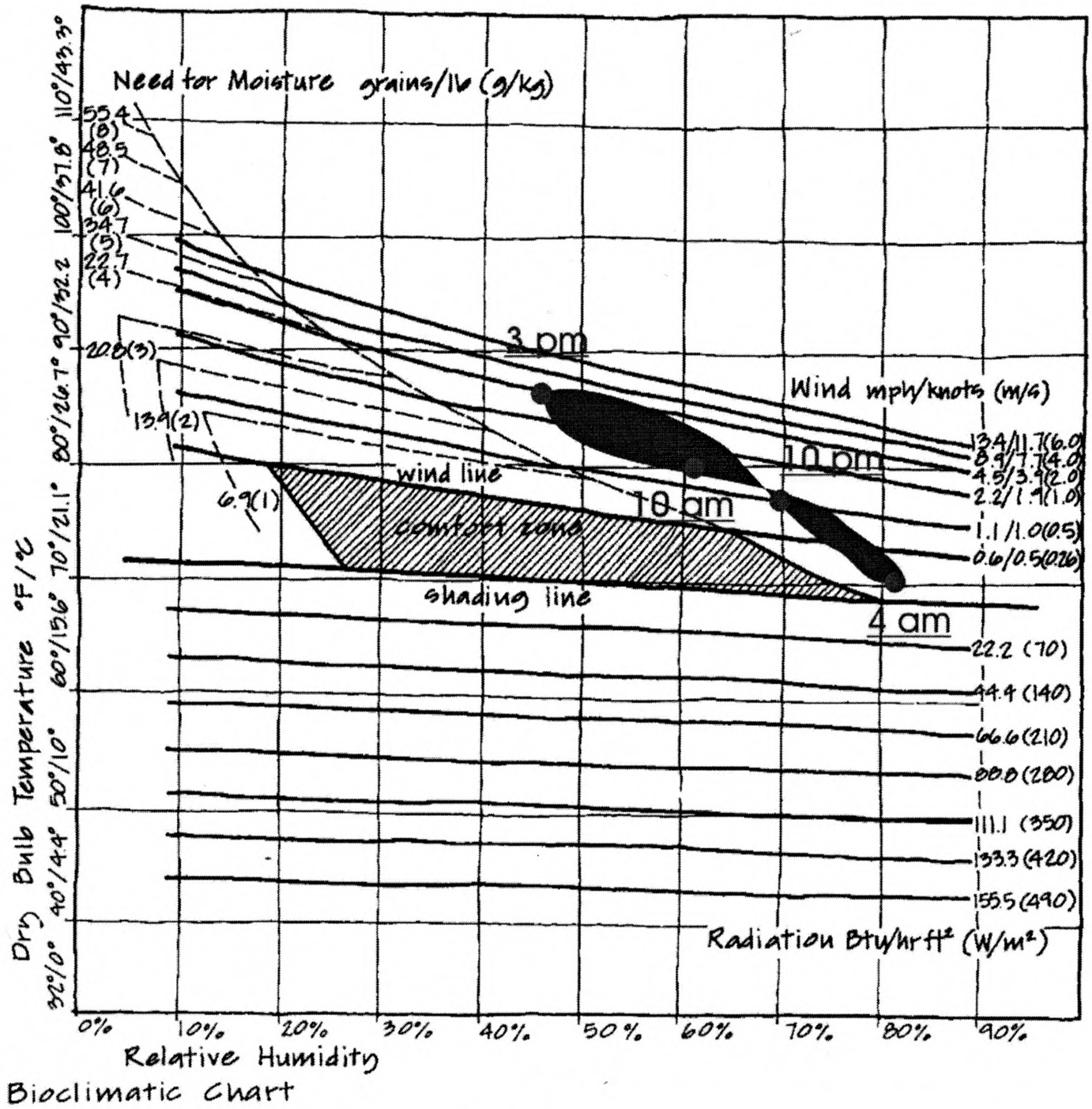


Fig. C-1: Bioclimatic Chart for Goa-January

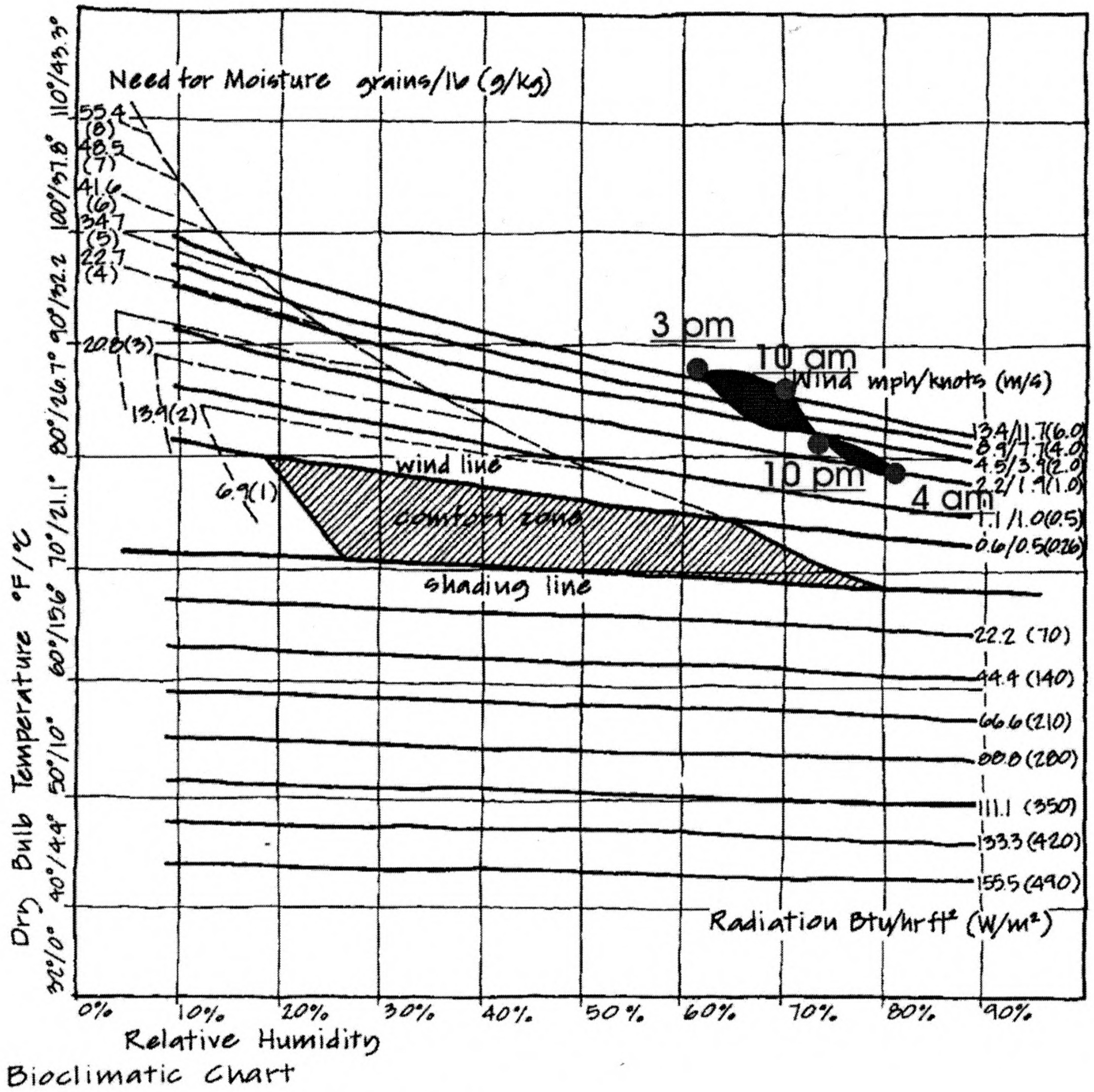


Fig. C-2: Bioclimatic Chart for Goa-April

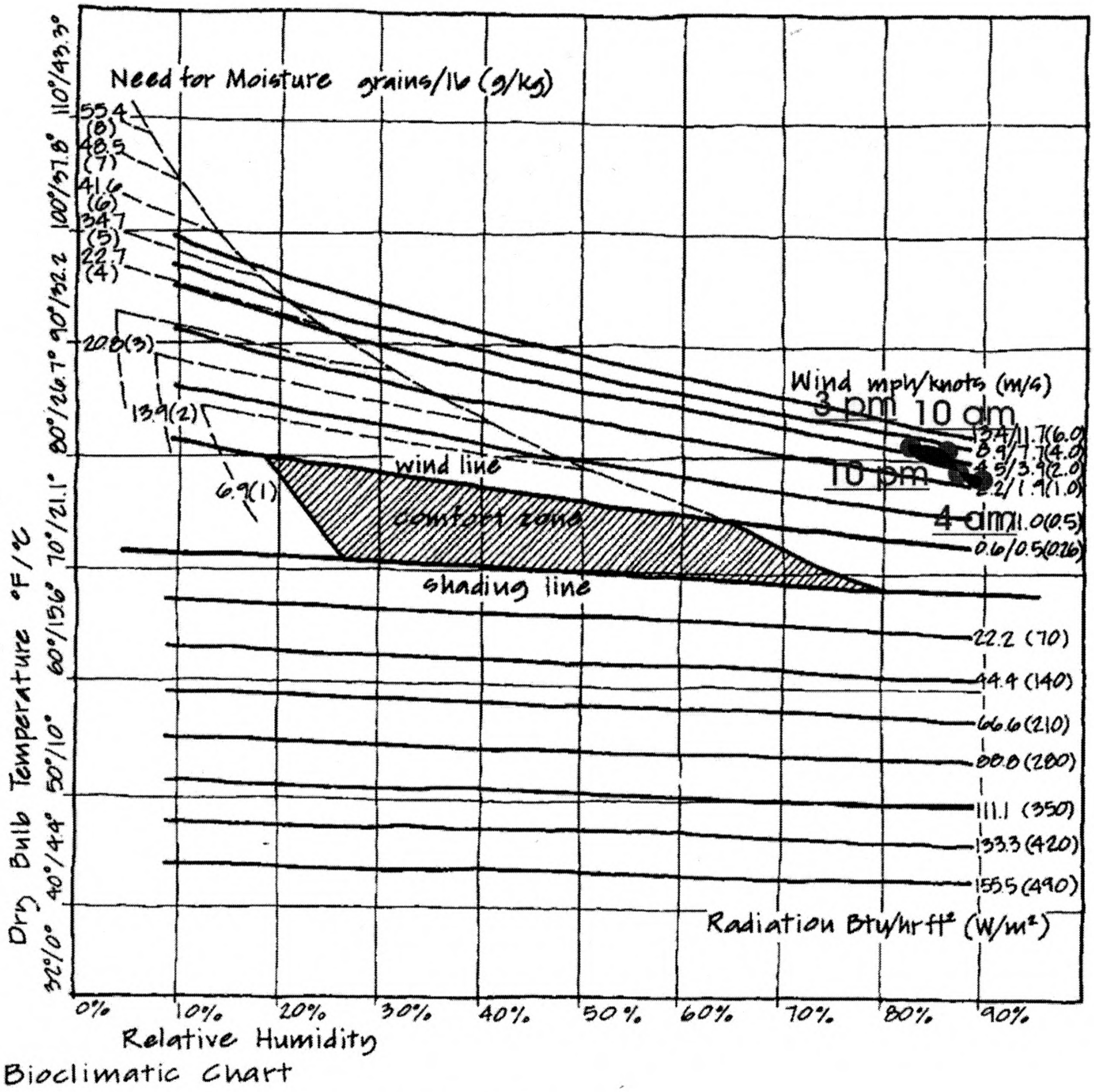


Fig. C-3: Bioclimatic Chart for Goa-July

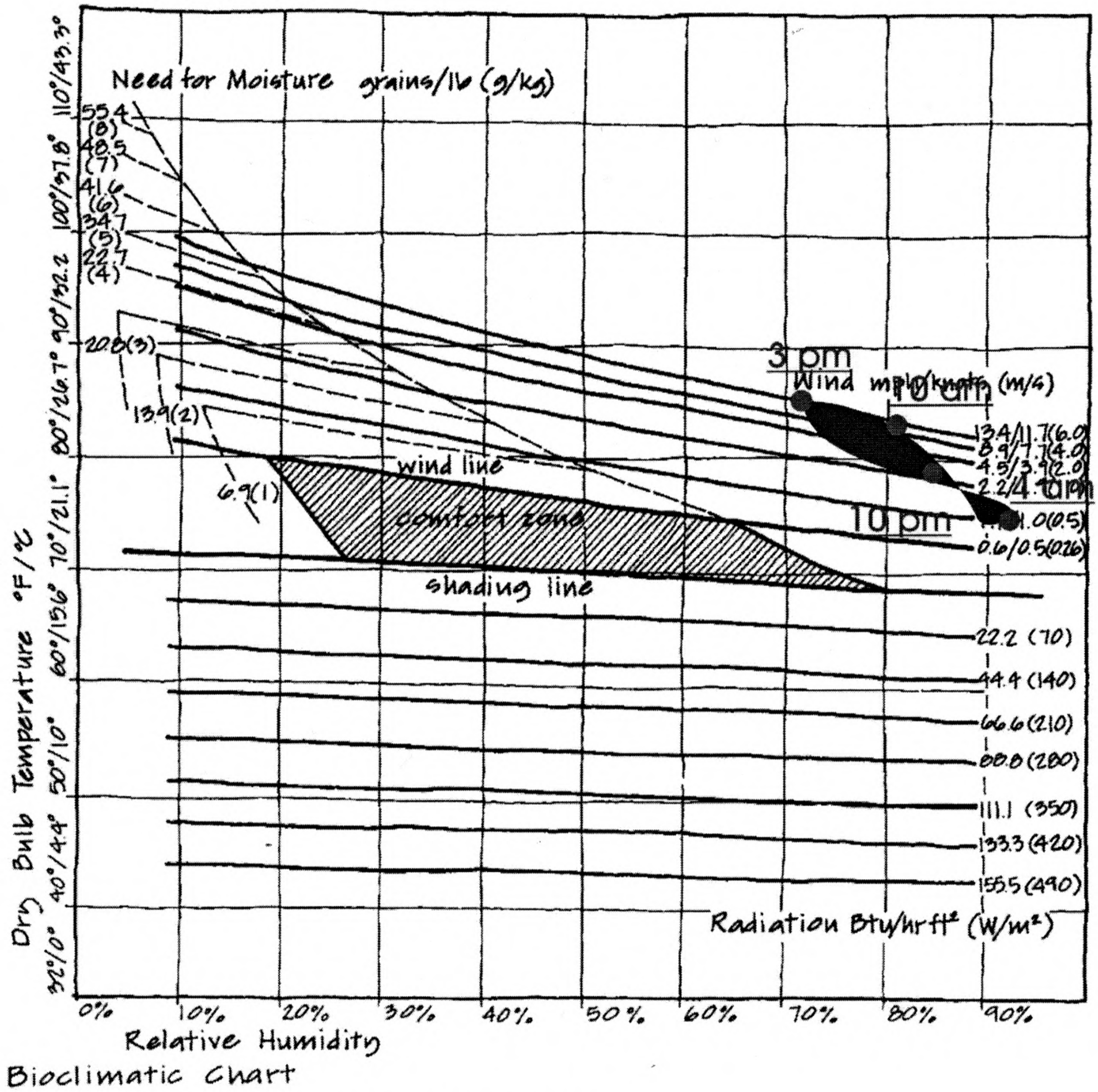
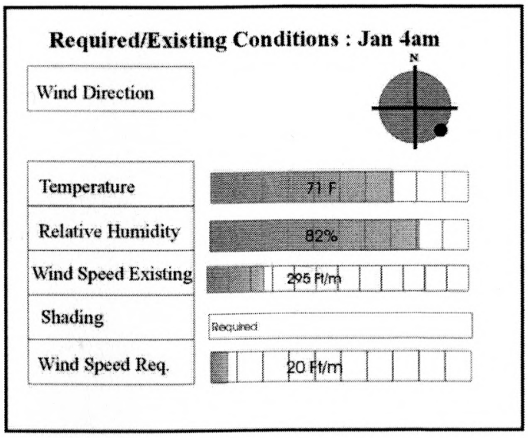
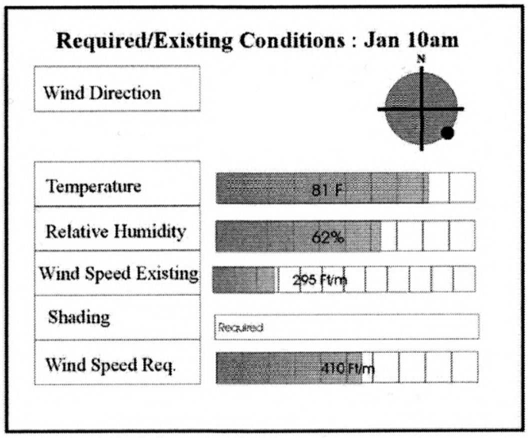
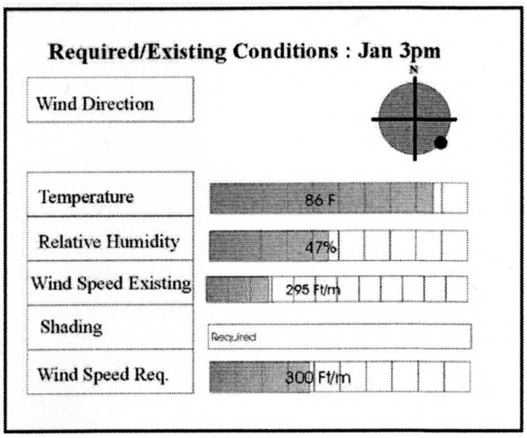


Fig. C-4: Bioclimatic Chart for Goa-October







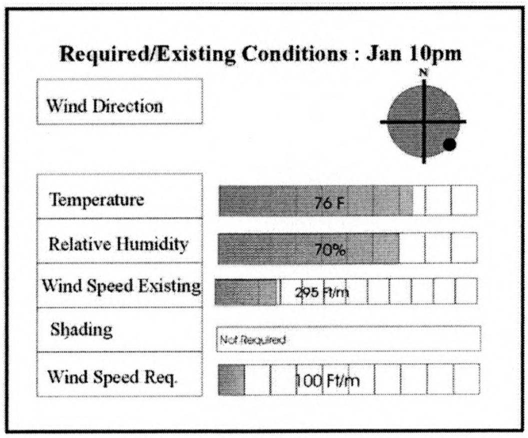


Fig. D-1: Climatic data for Goa, India-January

Fig. D-2: Climatic data for Goa, India-April

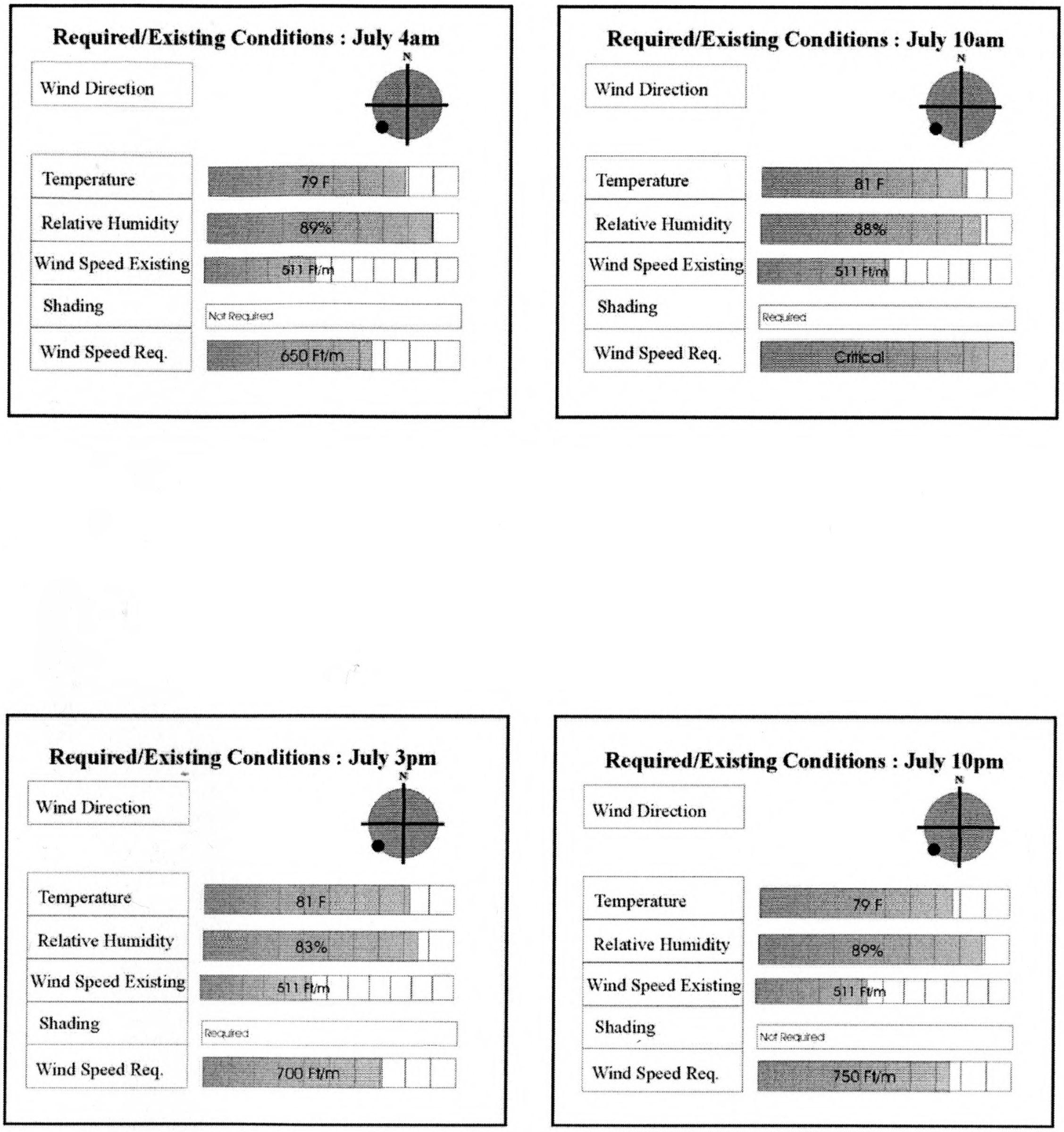


Fig. D-3: Climatic data for Goa, India-July

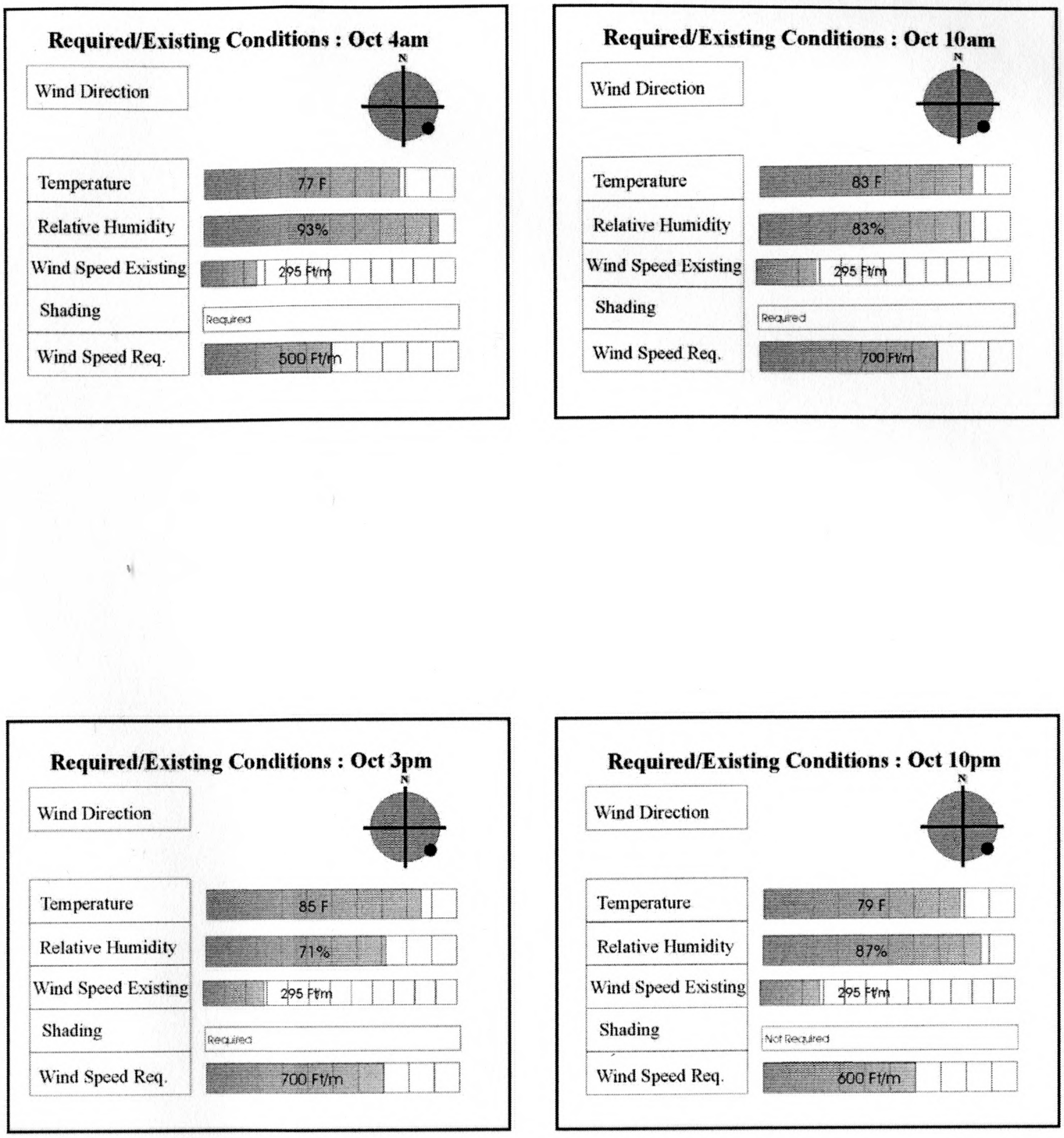
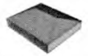
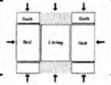
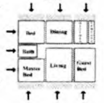
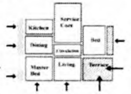
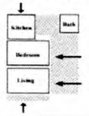
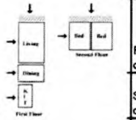
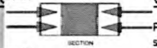
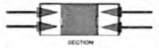
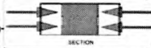
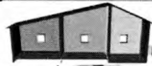
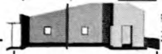
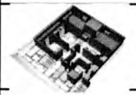
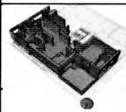
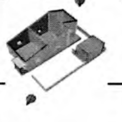
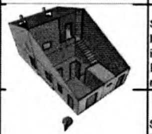
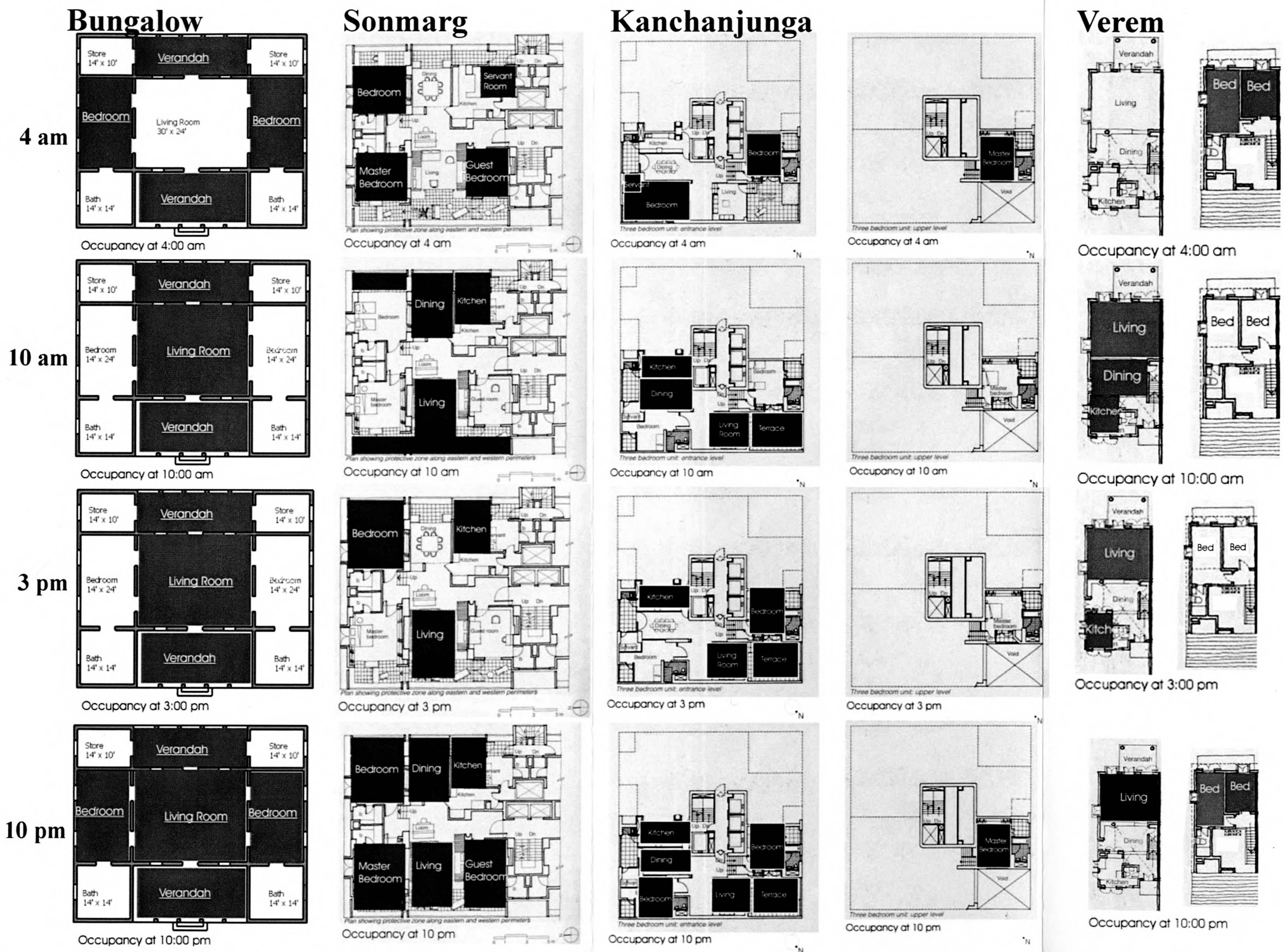


Fig. D-4: Climatic data for Goa, India-October

	Bungalow		Sonmarg		Kanchanjunga		Belapur		Verem		Comparison	Comparison with Bungalow
Overall Building Mass		Square plan, with a proportion of 1:2 of the width is to height of the elevation. Horizontal orientation to ground. Single storey,single pitched roof form, heavy plinth.		A rectangular base plan, with a proportion of 1:3 of width is to height of elevation. Vertical alignment to the ground. High rise multi level building with flat roof.		Square plan, 1: 4 ratio of width is to height. Vertical alignment to ground.Twenty seven storied high rise structure.		Clustered arrangement of units around individual courtyards of 8m x 8m. Low rise and horizontal alignment to ground.		Low rise and Linear arrangement of thirty-eight houses in front of the river. Individual units are duplex style.	The mass and scale of Bungalow, verem villa and individual units of Sonmarg and KJ can be compared. Belapur is different in scale.	The mass and scale of Villas at verem, Individual units of Sonmarg and KJ are similar to that of the bungalow.
Order of Rooms		Rooms are bunched together around the central living area.		Rooms are bunched together around the central dining and living area		Rooms are linearly arranged with semi-open spaces at either ends.		Rooms are linearly arranged in an individual unit and units are clustered around a courtyard.		Rooms are linearly arranged and sectionally displaced.	The order of rooms in Sonmarga matches that of the Bungalow. The other three case studies have similar linear arrangement with variation in levels.	The order of Sonmarg is very similar to the bungalow. Though the other case studies have different arrangement of rooms, some of the strategies used are the same.
Orientation		General orientation of a bungalow is North-South and usually perpendicular to the site orientation.		North-South, perpendicular to the site orientation.		Northeast-southwest, perpendicular to the site orientation.		Varied orientation.		Southwest-northeast, perpendicular to the site orientation.	All structures except Belapur units are perpendicular to the site orientation.	Sonmarg individual unit orientation matches to the Bungalow orientation to make most rooms take advantage of sun and wind orientation. Rest of the case studies differ from the Bungalow.
Porosity of Form(Overall f		Verandahs bring porosity to form.		Exterior envelope made of windows.		Multi-directional porosity achieved by interlocking units with double height terraces of units oriented in different directions.		Porosity lies in open layout of the clusters.Porosity is multidirectional.		Porosity of the linearly arranged units is from the front and back sides.		
Porosity of Form(Unit)		Porosity of the Bungalow is achieved through the semi open spaces that are arranged around the closed interior spaces.		Porosity is achieved by the auxiliary spaces surrounding the interiors space.		Porosity is achieved 1) Through North-west and south-east walls and 2)through the terrace garden.		Porosity is achieved by semi open and open external space at the unit level, through the central court and the compound around the unit.		Porosity is mainly achieved from the front semi open spaces and partly from back entry of the unit.	Bungalow and Individual units of Sonmarg and Belapur have similar porosity levels. Kanchanjunga unit and verem villa have similar porosity levels.	Individual units of Sonmarg and Belapur match porosity of the Bungalow. Units of KJ and Verem differ.
Individual Room Orientation		Rooms are oriented in east-west direction.		Rooms arranged along north-south axis but oriented in the east-west direction.		Rooms are oriented in the east-west direction.		Varied orientation.		All rooms oriented in the same direction as the units, southwest-northeast.	Room orientation for all case studies in Mumbai have same orientation to catch prevailing winds. Room orientation in Verem villas which is in Goa is different to match loacl wind directions.	The individual room orientation in a bungalow varies in a bungalow. But the orientation of the bungalow is usually North-south.
STRUCTURE												
The roof		Pitched roof form, Material: Bamboo framework thatched with leaves and roots		Flat RCC roof.		Flat RCC roof.		Pitched roof supported by load bearing walls and covered by terracotta tiles.		Pitched roof supported by load bearing walls and concrete columns. Roof is made of wooden rafters and covered by clay tiles.	The Bungalow, units f Belapur and Verem share same basic material and roof form. Units of Sonmarg and KJ share same material and form. All roofs utilize locally available material.	Concept of using locally available material and technique of all ase studies matches that of the Bungalow. Structure of Belapur and Verem matches that of the Bungalow because of the scale factor.
Floors		Solid plinth made of bricks and mud mortar.		Reinforced concrete slabs supported by columns. Finished i marble or ceramic tiles.		Reinforced concrete slabs supported by columns. Finished in marble or ceramic tiles.		Floor raised to different levels and made of timber.		Gradual increase in floor levels like that of a bungalow. Floor finished with ceramic tiles.	Floor structure of the Bungalow, Belapur, Verem villas is the same. Variation of floor level within unit to catch winds is seen in Belapur and Verem.	Bungalow floor os a solid plinth without any level variations inside the unit. Variation in floor is seen in all other case studies.
Ceilings		Variable ceiling heights because of roof form. False ceiling made of coarse cotton cloth.		Variable ceiling heights created by gypsum board false ceiling.Ceiling height decreases towards the interior, hence improves air flow over activity centers at body levels.		Variable ceiling heights created because of duplex structure.		No information.		Variable ceiling heights, Ceiling is partially the same as the roof and an RCC slab over the living area.	Bungalow, Belapur and Verem villas have a variable ceiling height becase of the roof structure. In units of Sonmarg and KJ, variations in ceiling heights are created in an otherwise flat roof to incorporate advantages of a pitched roof form.	Roof form of units of Belapur and Verem have the same roof form as the Bungalow. But units of Sonmarg and KJ differ owing to the high rise construction. But varying ceiling heights is a commonality between all of the case studies.
Exterior walls		Mud laid in strata and levelled.		Walls made of brick and cement mortar, finished with cement plastering.Light in color.		Walls made of brick and cement mortar, finished with cement plastering.Light in color.		Walls made of brick and cement plaster.White in color.		Walls made of brick and smooth finished with stucco.White in color.		
Interior walls		Finished smooth with mud or stucco, thermal mass absorbs heat from room during day and can be cooled at night with ventilation.		Smooth finished with cement plasterig.		Smooth finished with cement plastering.		No information.		No information.		
												
Space		Space divided into three kinds: open, semi-open and closed. North-south cross section is dynamic. Functinality of each space is not limited to a particular hour. Activities can be interchanged within spaces.		East-west cross sections are dynamic and vital.Functinality of each space is not limited to a particular hour. Activities can be interchanged within spaces.		Space is conceived analogous to that of the bungalow. Northest-southwest cross section is dynamic.The functionality of the verandahs has been incorporated in the terrace garden. Activity is centered in this terrace garden.		External space has the same character as that around the bungalow but enhanced by the functionality of the central courtyard. The internal space of the unit is a linear arrangement of two rooms and a kitchen at varied levels.		Space within the unit is in different levels. These levels are used to differentiate spaces instead of interior walls in the dining and the living areas. Bedrooms are at the upper level. The tall roof resembles the traditional bungalow roof.	The Bungalow, units of Sonmarg, KJ, verem and Belapur each have a cross section that makes quality of space in that direction dynamic in sense of sun, wind and shade. This cross section is North-souht in case of Mumbai and varies in the Verem villas.	The qualities of the cross sectional space in the Bungalow are the same as the qualities achieved in the cross ections of Sonmarg, KJ, Belapur and Verem.
Shade		Shading achieved by way of heirarchy of spaces.Shade provided by low hanging roof form.Non structural devices:mats on bamboo stilts, and shading with bamboo chicks, wooden lattices.		Usage of 'Layers of defense' against sun and glare at various levels. Shading achieved by way of heirarchy of spaces. Structural: auxiliary spaces acting as buffer zones and operable windows. Non structural: bamboo chicks.		Usage of 'Layers of defense' against sun and glare at various levels. Shading achieved by way of heirarchy of spaces. Structural: Semi open terrace garden as the buffer against sun and rain, covered balconies for the bedrooms and dining.Non structural: bamboo chicks.		Shade controlled by roof form.Shading achieved by way of heirarchy of courtyards. Structural:roof, courtyard, courtyard floor material. Non structural: vegetation.		Shading is achieved by roof form. The whole unit is shaded by one single pitched roof that is seen in the traditional bungalow and Belapur housing unit. Sunshades are provided in these units	All case studies achieve shading at external envelope level by the roof form. The Bungalow, Sonmarg and KJ are provided with buffer zones that reduce glare and block direct sunshine into the interior space. All case studies use structural and non structural devices. Sunshades were seen only in Verem villas.	The traditional Bungalow shading techniques are utilized in the Belapur, Sonmarg untis, KJ and the Verem villas. These are the semi-open spaces, controllable devices and roof form.
Ventilation		Orientation towards prevailing winds for maximum time of the year, symmetric location of openings, low roof form increasing wind velocity, Windows with shutters at two levels to enhance rate of stack ventilation. Zoning of rooms.		Orientation towards prevailing winds for most part of the year. Location and sizes of openings.operable windows shutters for stack ventilation.Location of semi open spaces. Zoning of rooms.		Orientation at 45 degrees to the prevailing winds for most part of the year. Usage of levels for stack ventilation, zoning and stacking of rooms for individual ventilation patterns. Zoning of rooms-vertically and horizontally.		Varied orientation of units. Courtyards help catch winds, space between units increases wind velocities. Location of windows helps cross ventilation.		Unobstructed space within the unit helps enhance the ventilation. The high roof at the river side and the low roof at the streetside entrance help catch better breezes from the rivers. Loctaion and size of openings also help. Zoning of rooms-vertically.	The orientation of the Bungalow, and Sonmarg apartments is perpendicular to the windward side whereas KJ apartments are oriented 45 degrees to it. Unobstructed interior space is seen in all case studies. Strategic location and size of openings is common. Zoning of rooms is seen in all case studies.	The traditional Bungalow showed techniques of windows placement and sizes that are seen in Sonmarg and KJ. The semi open spaces in KJ, Verem and courtyard in Belapur act as wind catchers like verandahs in the Bungalow.
Location of Bathrooms		Bathrooms located at the corners for more privacy.		Bathrooms are located in between bedrooms.		Bedrooms located at the corners of the apartment.		Bathrooms located outside the main unit as a separate core.		Bathrooms located at one end of the external wall.		

Appendix E : Template - Comparative Analysis of Case Studies



Appendix F : Occupancy Charts for Case Studies