ANALYSIS OF PASSIVE COOLING TECHNIQUES PREFERABLE IN VERNACULAR ARCHITECTURE OF BENGAL

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CHAPTER 1

- INTRODUCTION –

1.1 RESEARCH BACKGROUND

A building has significant impacts on the environment and the same holds true reciprocally. The design of buildings, to a very large extent, depends on building practices. Changes are slow, and have come about through an evolutionary process of trial and error (Hutcheon, 1983).

Building science is a field of knowledge that draws upon physics, chemistry, engineering, architecture, and the life sciences. Understanding the physical behavior of the building as a system and how this impacts energy efficiency, durability, comfort and indoor air quality is essential to innovating *high-performance buildings*[1]. Modern building science attempts to work with models of the building as a system, and to apply *empirical techniques*[2] to the effective solution of design problems (National Institute of Building Science; www.wbdg.org).

Building science is sometimes associated with "modern" buildings and new approaches in building industry, which is not completely correct. Innovation is definitely vital for advancement. However in a more rational context, it is also important for architects, planners, engineers and builders to understand the past, in order to build a better future. This acknowledgement is essential because building science has been fundamentally inherited from the past, and modified further by factors such as climate, economy, social habits, local aesthetics, skills and materials available.

Climate and environmental conditions are two very important parameters in the scientific analysis and design of a building. Buildings are designed to achieve and create a suitable atmosphere for human comfort. Comfort may be defined as the sensation of the complete physical and mental well-being of a person within a built environment (National Institute of Building Science; www.wbdg.org).

[1] A building that integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life-cycle performance, and occupant productivity. (www.nibs.org)

[2] Techniques provable or verifiable by experience or experiment.

Traditional builders used limited resources to achieve maximum comfort and climate which was the major determinant in traditional building techniques (Radhakrishnan S 2011). Modern buildings follow the National standards with little response to local climate. Building construction methods have changed greatly in the last two to three decades and modern designers often choose to ignore fundamental aspects such as climate.

Modernization[3] is a forward-looking phenomenon. It is a result of economic growth, refined standard of living along with advanced technological developments. Modernization is quite essential in the successful functioning of a society, and also evolution of mankind with the passage of time.

"Without continual growth and progress, such words as improvement, achievement and success have no meaning."

- **Benjamin Franklin (1706-1790)**

However, simultaneously, it has its own drawbacks. Lifestyles of people have evolved from the ancestral kind as per their own customized needs. Man has metamorphosed in terms of his living patterns, food habits, beliefs and customs, social behaviour as well as occupational needs. Gradually, there has been a notable change in the environmental conditions of places due to *metaphysical*[4] variations. These climatic factors sometimes contribute to this evolution, and sometimes get lost in the urge to modernize. In such a transformative process, man tends to forget the glory of his traditions.

If the term '*traditional"*[5] can be dated around 200 years back, the people then lived a life with minimum long term effect on the environment. It can judiciously be called 'sustainable', as the definition of Sustainable Architecture is the architecture that utilizes environmentally conscious techniques (Maria 2009).

Prior to the era of *industrialization*[6], *bio-climatic*[7] practices were exclusively used to achieve moderately comfortable conditions inside buildings. Man was unaware in terms of technological capabilities and artificial means of achieving the above, and

[3] The transformation from a traditional, rural, agrarian society to a secular, urban, industrial society.
[4] Concerned with the basic causes and nature of things.
[5] The thoughts, ideas, stories, beliefs, etc., that have been part of the culture of a group of people for a long time.
[6]The introduction of manufacturing, advanced technicalenterprises, and other productive economic activity into an area, society, country, etc. on a massive scale.
[7] Relating to the effects of climate on living organisms.

thereby mechanical means of lighting, ventilation and indoor comfort were not followed. Bioclimatism is a concept that integrates the micro-climate and architecture with the human thermal comfort conditions (Sayigh and Marafia 1998).

With the advancement in the building technology, maintenance of comfort conditions in buildings has become simplified for *contemporary*[8] buildings. The role of climate and environment in maintaining comfortable indoor conditions had declined. Today, *active heating and cooling devices*[9] ensure interior comfort, but require major energy inputs. Given the dual challenge of an increasing fuel crisis and concerns of global warming, the amount of energy used to provide *thermal comfort*[10] levels is soon to become unsustainable. Sustainable, *ecological*[11], and *climate-responsive architecture*[12] offers possible solutions to these challenges. Many architectural volumes and journals state and promote the fact that traditional as well as vernacular structures formulate the base of environmentally conscious designs.

In the present context, regional architecture is starting to lose its identity. This has occurred mainly due to globalization as well as industrialization. Consequently, the newly developed buildings are totally anonymous in nature and have no regard of their region and its vernacular character. This type of architecture does not mould its materials as well as techniques as per the local requirements and variations. It follows a typical trending style creating monotony and extremely *conventional designs*[13]. Also, these buildings create massive wastes in terms of space, skills and materials. Additionally, this kind of contemporary architecture offers design of buildings with high construction, maintenance or operation costs.

The built environment of any region directly affects the level of human comfort. It is hence relevant to study and enhance the sensible design solutions practised traditionally. It may seem a bit unwanted and inappropriate to look back and devote ourselves to analysing vernacular building practices. Yet vernacular architecture represents more than a nostalgic longing for things and ways that have not only become obsolete, but rather a learning method by which new global challenges such as global warming, housing crises and economic quality can be addressed (Kazimee 2009).

[8] Belonging to or occurring in the present.
[9] System that involves the use of energy to heat or cool something,
[10] The comfort of human beings under given room conditions.
[11] Concerned with the relation of living organisms to one another and to their physical surroundings.
[12] Architecture aimed at achieving occupant thermal and visual comfort with little or no recourse to non-renewable energy sources by incorporating the elements of the local climate effectively (Yannas, 2003).
[13] Designs that have ordinarily been accepted and in use for a long time.

Vernacular architecture is a result of the insight of local craftsmen and builders, who have specific customized apprehension about their place, its climate and responses of its environment.

"Historically built environment was a result of the responses to many factors in the society; at the physical level it included the knowledge regarding orientation, climate, building material and construction technique, at the spiritual level, the built form was inter-woven with the lifestyle in all the daily as well as seasonal rituals"

- **B. V. Doshi, Architect, 1985**

Hence, its study is valuable to promote climate-specific *passive building technologies*[14] to modern architecture.

Vernacular Architecture is believed to integrate certain building features that were developed in a long process of adaptation and adjustment, and therefore, may embody valuable solutions for maintaining desirable indoor conditions (Shanthi Priya R 2014). This claim however, should not be taken for granted and must be critically examined in different contexts and settings.

This paper aims to decipher and document the evolution of design, techniques and construction methods in a specific climatic condition, and thereby identify optimal technologies and design solutions from vernacular architecture.

This analysis would include both positive and negative aspects gathered from the evolutionary study of building sciences all the way, and would help in creating a better understanding of the needs of the society. It also intends to prove to a certain extent, that it is desirable to merge local architecture traditions and meticulous design knowledge with modern building design.

The research aims to put forward a method of assessment of the environmental characteristics of different building *typologies*[15] in Southern part of Bengal, through the integration of architectural and historical survey. The appropriateness of these design principles needs to be understood in the present context, with specific focus on the vernacular domestic sector.

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[14] Design techniques that maximise the use of 'natural' sources of heating, cooling and ventilation to create comfortable conditions inside buildings.

[15] The study or systematic classification of types that have characteristics or traits in common.

The outcomes of this research may help future researchers, historians, architects and planners to cope with and judiciously utilize the interaction between local architecture and energy conservation in the context of creating a successful building design.

1.2 STATEMENT OF THE PROBLEM

In India, Building Sector consumes 40-50% of the total delivered energy. Of this, climatic control systems, namely ventilation, cooling and heating can account for as much as 70% of the total energy use (Shanthi Priya R 2014).

Modern architecture is widely dependant on HVAC systems and thereby, electricity, reliant on fossil fuels and unable to adapt to the microclimatic conditions. The design of these buildings does not consider local climate and it leads to extreme uncontrolled use of energy for the maintenance of desired indoor conditions.

In contrast, vernacular architecture follows design ideologies that have evolved over a vast period of time and focus on functionality, aesthetics, low-energy use, human comfort, durability and affordability. These buildings use locally available materials, passive cooling and heating strategies, and renewable sources of energy. They are well adapted to the local environment and are often considered as an appropriate base for a sustainable design.

Different civilizations have produced their own architectural styles based on their local conditions. Several researches are being done to study the climate responsiveness of traditional buildings in different parts of the world.

The relationship between architecture and climate is being explored as an important component in the recent architectural studies. These studies mainly focus on qualitative description of the relationship between the building types, materials, *finite construction*[16] and the local climate and thereby, help in developing a fair understanding of the advantages and disadvantages of a particular localized set of architectural styles (Radhakrishnan S 2011). They intend to analyse which of the practised methods can be preferable for adaptation to create comfort conditions in the modern context.

A number of researches have been conducted to prove that vernacular architecture is more climate responsive than modern architecture. This study in particular, is carried out with the intention to recognize the construction methodology of buildings in a particular region through different time periods, which would enable us to understand their behavioural pattern under different physical phenomena such as:

- Climate
- *Subterranean*[17] Conditions (like seismic activity)
- Characteristics of building materials

[16] Construction limited to any specific size, extent or set of resources.
[17] Existing, situated, or operating below the surface of the earth; underground.

History can impact our work in several different ways. By studying the building science applied to the structures that developed gradually from the past to the present, vernacular building styles can be efficiently used to deduce and come up with some efficient architecture and innovative design solutions that could help promoting sustainability in a traditional but non-conventional manner.

In the context of this research, it is vital to note and realize that in the different parts of Southern Bengal, domestic vernacular architecture is comprised of different building typologies. These buildings may have evolved one after another, and some may have developed simultaneously as per customized requirements. Thereby, they behave disparately with respect to thermal comfort, visual comfort and aural comfort.

Also, these typologies vary in terms of their usage, not only depending on the comfort conditions, but also the affordability of the occupants. This is a very important and influential factor, when the context is confined to any part of Rural Domestic India.

The reason for choosing this region as the area of study is that Lower Bengal, despite of its variant vernacular typologies, has not yet undergone any solidified research and analysis of this type, including all its variations and styles, that would help further researchers and scholars to understand their climate-responsive tendencies.

This research aims to compare these divergent typologies and analyse their climatic behaviour accordingly.

This classification will be evaluated through a considerable time period. A study will be conducted on various diversified terms and parameters, on the basis of architectural aspects as well as bioclimatic aspects, which are discussed in the later stages of this analysis.

1.3 OPERATIONAL DEFINITIONS

BUILDING SCIENCE

Building Science can be referred to the study of the interaction between the various materials, techniques used in building construction, the systems affecting the performance of a building, the occupants, and the environments in which they are located.

It is an analysis that is not concerned with the aesthetics of a building, but rather on technical components of design that separate the interior from the exterior environment.
It is dependent on various other disciplines of science for its substantiation –

- Physics (Understanding the structural composition and stability of structures against physical forces etc.),
- Chemistry (Dealing with the behaviour of building materials as well as the surrounding elements like soil, vegetation etc.)
- Engineering (Study of the technologies used in the construction of the building and understanding their feasibility, durability, energy efficiency as well as economics in customized situations)
- Architecture (Analysis of the building orientation, form, spatial planning and envelope design in terms of the above factors)

On one hand, an ideal built environment is one with environmental separation and protection from weather variations, unwanted radiations, noise and intrusion. On the other hand, it is also expected of these enclosures to have natural ventilation, daylighting, access and view of the external environment. Hence, the primary challenge of Building Science is to blend these two variant requirements and create a balanced building design.

TRADITIONAL

A "Tradition" can be defined as a thought, behaviour or activity that has been accepted and followed by a particular set of people for a very long time. It can be personal, societal, regional or even national. Consequently, "Traditional" can be defined as something that follows tradition.

In the context of this research, Traditional Architecture is a way of designing vernacular buildings in the past, which has formed the base of contemporary building design, also in vernacular style. "The Past" here refers to a period around 200 years back in Bengal (the area of study), and not before that, because the relevance of this study marks its evolutionary beginning during this time period in India.

Therefore, Traditional Architecture in this research will be dealing with the building planning and design, materials and methods of construction of the structures that began to be built in rural Bengal at the advent of the 19th Century, partly as a result of the British Colonialization.

CONTEMPORARY

"Contemporary" is an adjective used for any object or activity belonging to the present time. Hence, Contemporary Architecture can be defined as the architecture practised in current times. It is broadly the building style of the present day. The examples do not necessarily have similar or easily recognizable features, as the practice of architecture varies in innumerable ways from one part of the world to another, or even one region to the other.

A significant part of this research aims to study and analyse the architectural character of rural Bengal, evolved from Traditional to Contemporary styles in the past 200 years.
Thereby, in the context of this research "Contemporary Architecture" refers to the present day building style in rural areas of Bengal. Here the contemporary architecture that is being taken into consideration is totally vernacular in character. It is important to note that the non-vernacular buildings existing in the same region presently are not to be considered for this study.

VERNACULAR

"Verna" is a Latin word meaning home-born. It later evolved and formed the word "Vernaculus" meaning domestic, from which the English word Vernacular has been derived. Clearly, vernacular is anything that has been created in a particular region, for the particular region, by the particular region.

Vernacular Architecture, therefore, is the simplest form of architecture, with the prime agenda of addressing human needs. It originated when man was forced to make use of the natural resources around, and provide himself shelter and comfort which is responsive to the climate. It is a pure reaction to an individual person's or society's building needs, and has allowed man, even before the architect, to construct shelter according to his circumstance (Edwards, 2011).

In plain words, vernacular architecture is the local style of architecture mainly concerned with domestic and functional rather than public buildings.

Vernacular architecture adheres to basic green architectural principles of energy efficiency and utilizing materials and resources in close proximity to the site. These structures capitalize on the native knowledge of how buildings can be effectively designed as well as how to take advantage of local materials and resources. (Edwards, 2011). Hence, the study of building science evolution from traditional to contemporary in a particular region (Bengal in our context), becomes well justified and complete with the scope being restricted to vernacular architecture.

The study intends to analyse and compile the various local architectural practises that were prevalent in rural Bengal in the past, and the ones that are currently being practised. It is important to note that functionality of the buildings and comfort of its occupants are the prime issues of concern here, and not aesthetics, which further compliments to the definition of Vernacular Architecture.

HUMAN COMFORT or THERMAL COMFORT

Human comfort is a state achieved when the internal or external environment provides the appropriate conditions to avoid feeling too cold or hot, according to the existing weather predictions.

Thermal comfort is that state of mind that is satisfied with the thermal environment; it is thus the condition of minimal stimulation of the skin's heat sensors and of the heat-sensing portion of the brain.

The factors that primarily influence human comfort are temperature, clothing, wind speed, sunlight, humidity and evaporative cooling.

1.4 AREA OF THE STUDY

Fig 1.1 Painting showing rural Bengal in 19th century

The Earliest British settlers invaded India in the early 17th century through its coast along the Bay of Bengal. They settled along the Southern parts of Bengal, thereby analysing the lifestyles, cultural and social scenario of India at that time.

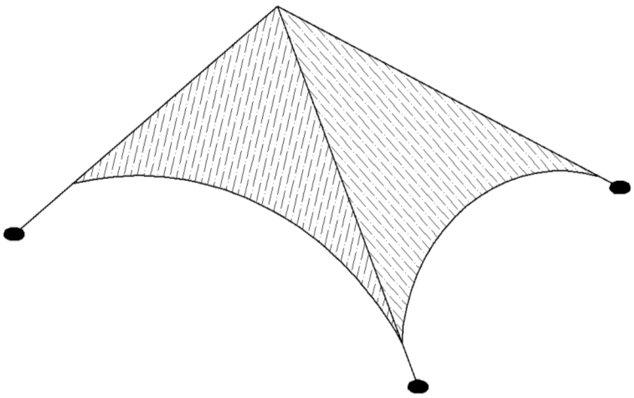


Fig 1.2

To these invaders, weather conditions in India was a new challenge.

They had no environmentally appropriate building model for the Indian warm-humid climate.

Consequently, struggling with the scorching heat, they started living in Canvas service *tents*[18], generally used by the military.

This however was not very comfortable for them to use for a long period of time. The inside temperature within the tent used to rise very quickly.

The design for these tents evolved into a structure much more permanent and durable. This curved roof came to be known as the "Bangla" Roof hut. These huts developed in the early 19th century, as pictorial sources of information indicate.

[18] A portable shelter made of cloth, supported by one or more poles and stretched tight by cords or loops attached to pegs driven into the ground.

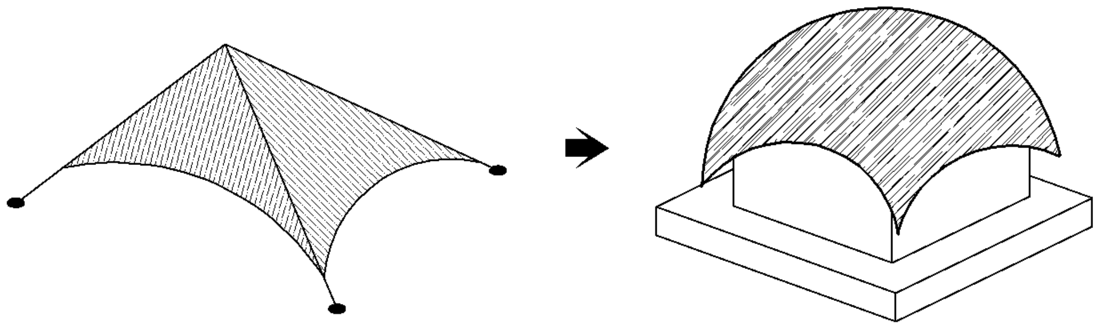


Fig 1.3

Fig 1.4 Painting depicting the newly evolved Bangla Roof

A Bangla Roof developed as a canopy defined by a uniquely bent roof meant to thwart the intense sun as well as *torrential rain* [19] and directional wind.

The doors used to be the only openings, mostly covered by a mat "Jhanp", tied to the upper part of the door. If windows would be present, they were also covered with Jhanp.

[19] Rain falling rapidly and in copious quantities.

"Thatched huts of fishing village on lower Ganges," photo by William Henry Jackson, 1895 (Library of Congress)

Source: http://lcweb2.loc.gov/cgi-bin/query/D?wtc:1:./temp/~ammem_kRJx::

Fig 1.5

This kind of a hut is still prevalently used, mainly built of thatch and mud walls, or straw mats with bamboo framework.

The buildings were mostly small in size, and consisted of single households.

"Another possible explanation for this peculiarity may be climatic adaptation, as in the humid region of Bengal, small buildings scattered to allow air movements between them could help to maximize the effects of any available breeze."

- Olgyay. 1963

Further it was also assumed that the peculiar shapes of the roofs, with the absence of ridges on each slope, made it less vulnerable to any kind of leakage in the rainy season.

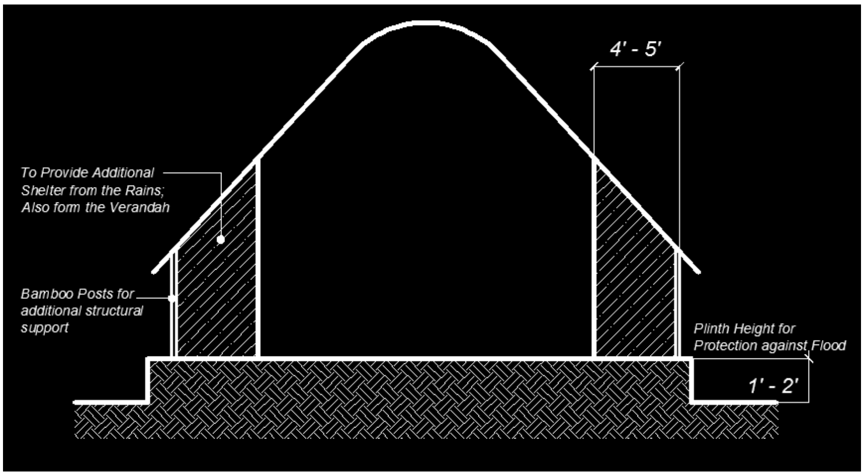


Fig 1.6

The design gradually improvised from its initial phases and by the 1860s, developed in a distinctive roof shape.

As the eaves grew more projected forming *verandah*[20] like spaces, galleries began to develop on sides of the structure.

The eaves descended lower at the corners. Extended roof of thick paddy straw thatch protected the mud walls from heavy monsoons as well as provided shade.

Fig 1.7

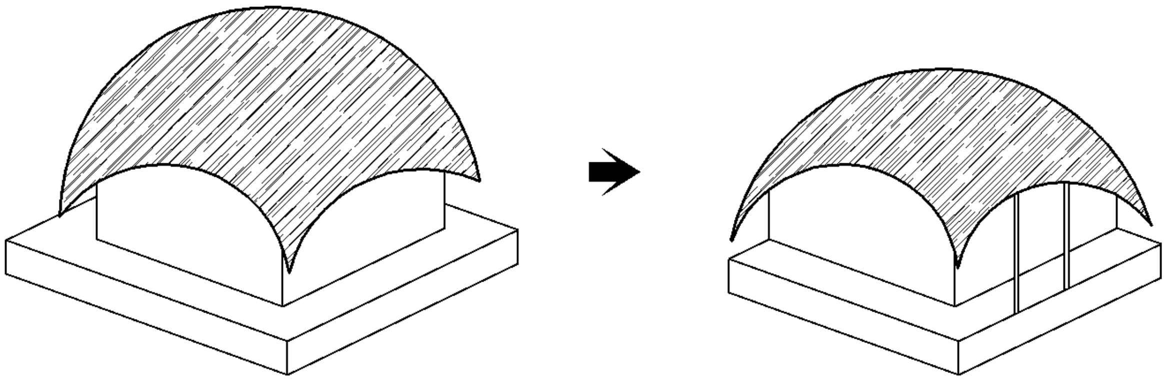


Fig 1.8

With the passage of time, by the advent of the 20th century, house forms in the region became simpler. Pyramidal Roof Structures with square plans developed, and gradually metamorphosed into rectangular forms. However, both these built forms continued to be prevalently used as per individual affordability and requirements.

This type of Roof came to be known popularly as the "Charchala" or "Chauchala" Roof.

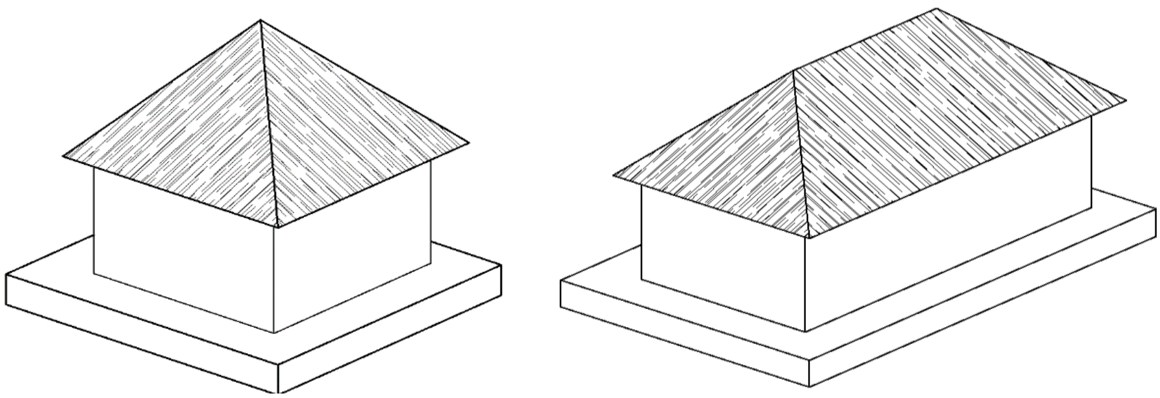


Fig 1.9

The British further modified the building design to make it more adaptive to the local climatic conditions.

[20] A roofed platform along the outside of a house, level with the ground floor.

- They expanded the verandahs, encircling the house, sometimes semi-enclosing them for privacy with mat / brick walls.

- The roller shades or "Jhanp" continued to be used, transformed into *Venetians*[21]. They were often were often splashed with water to cool the passing breeze.

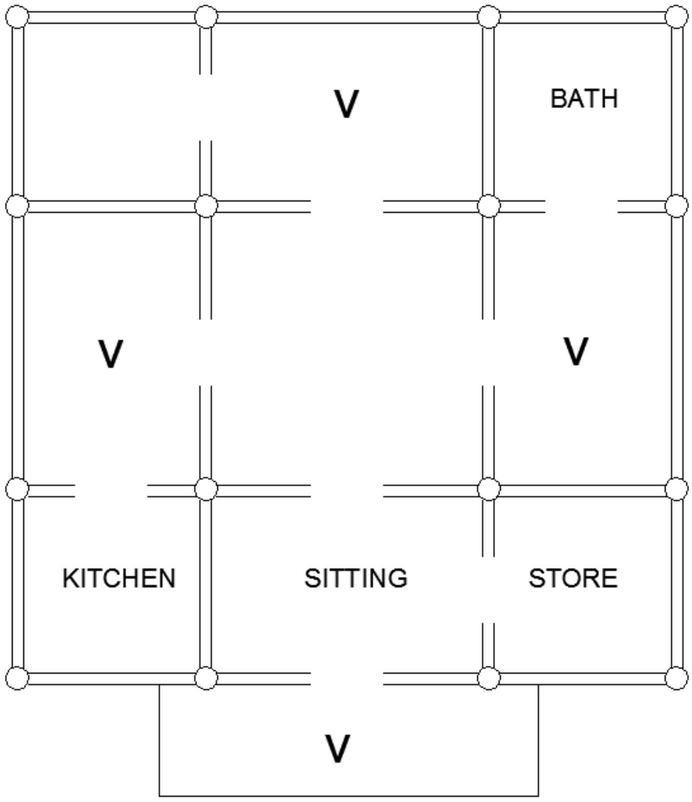


Fig 1.10

Plans gradually transformed such that each room opened into a verandah on at least two sides to take advantage of the cooled air and allow access to available breeze.

As time and technology prospered, the Charchala roof modified in certain aspects and formed a unique style of roofing, followed prevalently in the warm parts of the country. This typology came to be known as the "Aatchala" Roof.

The Aatchala roof was composed of eight slopes, forming a double roofing system. This was mainly done to increase the roof depth as well as formation of clerestories within these houses for natural lighting as well as ventilation.

[21] A window blind consisting of horizontal slats which can be pivoted to control the amount of light that passes through it.

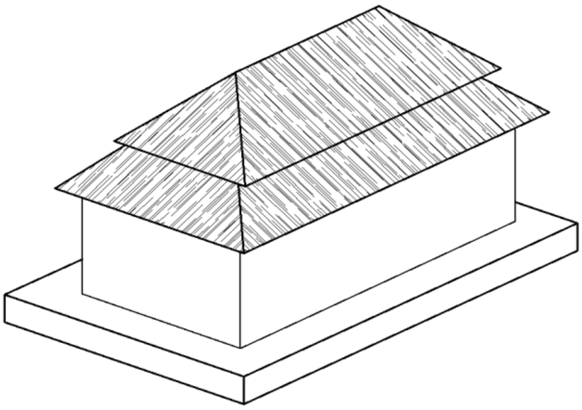


Fig 1.11 The Aatchala Roof

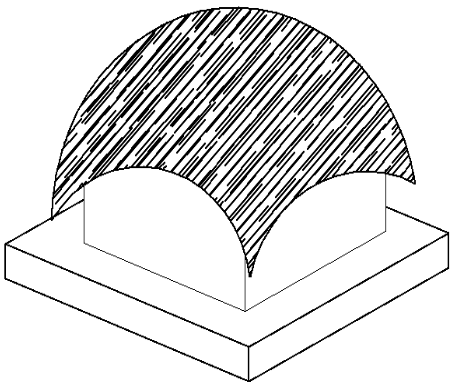
These typologies form the prime classification for analysis in this research.

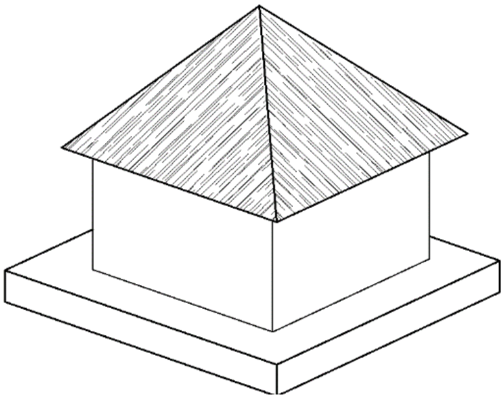
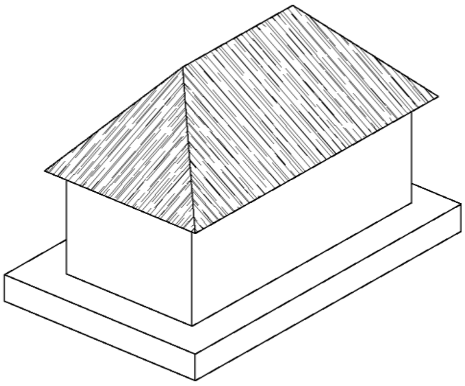
The study will thereby, be conducted classifying the local architecture into five selected typologies (identified as random *samples*[22] based on the built form and profile) in different settlements within Southern part of Bengal.

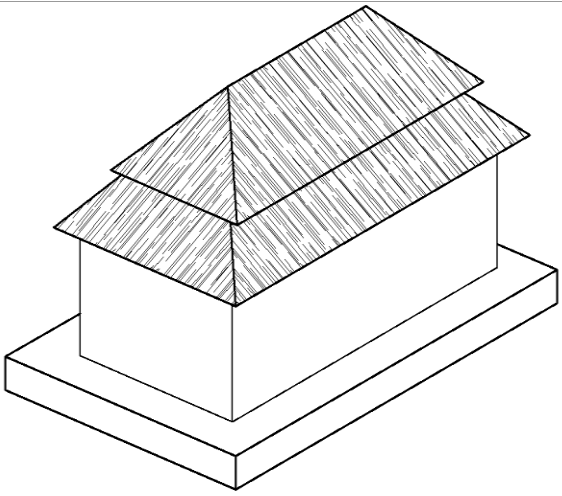
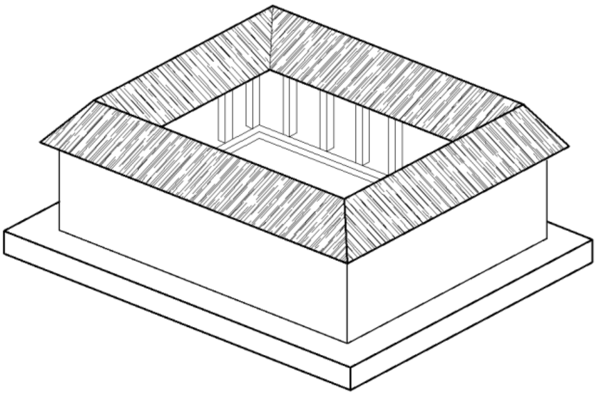
This is done in order to understand the variation in the generic sustainable principles in the vernacular architecture of this region.

[22] A finite part of a statistical population whose properties are studied to gain information about the whole.

Based on architectural as well as bioclimatic aspects, the following typologies are identified for conducting the study:

Type	Description	Diagrammatic Representation	Remarks
A	Traditional Bengali Dwelling with Bangla Roof – "Dochala" Style		One of the initial forms of rural architecture developed in Bengal; Inspired from tents; Roof forms have refined with time; Roofs of many famous temples in Bengal follow the same style
B	Pyramidal Roof Structures with		The simplest form of rural housing developed;

	Square Plans		Mainly built to be used by the lower income groups; At times, used as clustered settlements of small structures for climatic performance
C	Charchala / Chauchala Houses		A more refined form of Type B; Suitably used by lower as well as middle income groups of the rural society; Can conveniently fit in one or more rooms in the plan; In more advanced profiles, may have courtyards in the centre
D	Aatchala Houses		House having roof with eight slopes; Such type of construction usually not afforded by people having lower economic stature; Can conveniently fit in one or more rooms in the plan;

			In more advanced profiles, may have courtyards in the centre
E	Courtyard Houses		This type of rural houses are prevalently used in carious parts of India; Can have different varieties of roofings; Climatologically very responsive and comfortable in warm humid climates

1.5 AIM

Modern Architecture is gradually taking over the techniques and principles of traditional architecture, which used to employ natural materials and simple concepts that were energy efficient.

This research aims to analyse the climate responsive architecture and design techniques that promote adequate lighting, ventilation and thermal comfort in traditional houses located in the warm humid climatic zone in Southern part of West Bengal in India.

This is a study of the evolution in the design of these houses, due to varied environmental, social, historic or economic factors. It intends to provide useful insights for designing energy efficient houses that promote thermally comfortable conditions. The analysis is to be done in terms of *(i)* architectural aspects like building typologies, forms, materials and construction techniques, as well as *(ii)* bioclimatic aspects.

The ultimate motive behind this research is to document the design techniques, materials and concepts from the evolutionary study that can be practically infused together and incorporated in logical contemporary design that has its roots and influence from the past.

1.6 OBJECTIVES

- To study and identify the different building construction techniques and materials used in domestic buildings of a particular region in different time periods.
- To identify the Climate Responsive principles that were incorporated and effectively used in these building typologies and analyse them.
- To understand and appreciate the traditional and vernacular building science and its relevance in present context.

- To identify the relevant materials or technology that can be successfully implemented in contemporary architecture in a design that would ultimately be
  - Cost Effective
  - Functional/ Operational
  - Productive
  - Sustainable

1.7 SCOPE, LIMITATIONS AND CONTEXT

Scope -

- The study would be focused on a particular region of India, showing evolution of vernacular architecture there as an influence of physical, climatic and scientific factors. The chosen region to which this study would be confined is Southern part of West Bengal.

  Lower Bengal experiences a hot and wet tropical monsoon climate. The architecture of the land is essentially an expression of an agricultural society who make their living from the soil.

- The study of evolution of the architecture in this part, its different stages and the factors resulting in the change will all be discussed in this research.

- Settlements and homesteads will be identified in this region which have the different typologies existing within them for analysis.

- However, the bioclimatic aspects of the regional architecture here will be discussed and documented only for those stages or typologies in this evolutionary timeline, which are structurally existent in the contemporary scenario.

- Five sample dwellings belonging to each typology will be chosen from the identified settlements for the performance evaluation, study and analysis.

Limitations -

- The analysis intends to be limited to :

    - architectural typologies,
    - forms,
    - building materials,
    - planning and spatial organization,
    - climate responsiveness of the structures, and
    - their thermal performance,

  with the conclusive aim to identify the generic sustainable principles, and analyse if they can be successfully implemented in the present context.

- Additionally, non-vernacular buildings existing within these rural areas have not been taken into consideration and are beyond the scope of this research.

- Also, aural comfort factors have not been included in the analysis and scope of this research, because these are conditions which do not affect the timeline, hence, do not show evolving tendencies.

1.8 RESEARCH QUESTIONS

- What were the different styles of architecture practised traditionally in Lower Bengal?

- What are the parameters of assessment of Building Science for a particular structure that vary with the evolution of architectural styles?

- What are the parameters of assessment of Building Science for a particular structure that remain constant with the evolution of architectural styles?

- What is the current scenario of vernacular settlements and individual houses in the rural patches of Lower Bengal?

- How the presently existing vernacular structures are performing in terms of their spatial design, climatic response and structural stability?

- What are the generic sustainable principles being practised and responsible for the performance of these structures?

- What are the design principles and the elements which are suitable for architecture of the present condition?

Research Questions Analysis Table

What were the different styles of architecture practised traditionally in Lower Bengal?		
Pre Study Requirements	**Tools and Techniques to be used**	**Expected Outcomes**
• History of Bengal • Detailed documentation of Vernacular Architecture of Bengal	• Literature; • Maps; • Personal Observation; Unstructured Interviews • On-site Sample Study – Documenting plans, elevations, site sketches	• Understanding the vernacular architecture of South Bengal; • Understanding the architectural characters of the five typologies of dwellings; • Factors responsible for the evolution of the different typologies

What are the parameters of assessment of Building Science for a particular structure that vary with the evolution of architectural styles? What are the parameters of assessment of Building Science for a particular structure that remain constant with the evolution of architectural styles?		
Pre Study Requirements	**Tools and Techniques to be used**	**Expected Outcomes**
• Climatological Study Factors and Parameters • Trend Analysis of Climate	• Literature – NBC Chapter 11 • Literature on Climatology • Expert Survey • Software like Climate Controller	• Understanding the climatic behaviour and its associated consequences • Finalizing a set of Basic Design Parameters to conduct the research further

What is the current scenario of vernacular settlements and individual houses in the rural patches of lower Bengal?		
Pre Study Requirements	**Tools and Techniques to be used**	**Expected Outcomes**
• A pre visit data sheet with images and information about rural Bengal from the internet, to help pick the main zones of study within the region • Literature on the scenario of vernacular architecture in the specified region • A basic reference from previous analyses done in the same field but in different regions of the world	• Site Visit • Typology Mapping • Visual Methods like photography • Tabular Analysis of existing information about vernacular architecture of Bengal on the internet with proper citation	• Identifying the types of houses existing in different parts of the same region • Finalizing the main typology classification of different forms of houses coexisting for further study • Identification of the regions in which the particular typology is found • Marking the location and number of houses of each typology present in the selected regions.

How the present vernacular structures are performing in terms of their spatial design, climatic response and structural stability?		
Pre Study Requirements	**Tools and Techniques to be used**	**Expected Outcomes**
• A set of Basic Design Parameters finalized to access the climate responsiveness of the buildings • A set of factors that formulate the climatic comfort of a built structure • Results of Typology Mapping • Proper understanding of surroundings of each sample	• Site Visit • Final Inventory / Fact Sheet for site visit • Visual Analysis tools like photography and videography	• Detailed Sample Study Analysis • Performance evaluation of the studied samples in terms of climate responsiveness

What are the generic sustainable principles being practised and responsible for the performance of these structures? **What are the design principles and the elements suitable for architecture of the present condition?**		
Pre Study Requirements	**Tools and Techniques to be used**	**Expected Outcomes**
• The Performance Evaluation from the sample study • List of basic design parameters and factors the affect sustainability	• Results of Detailed Sample Study	• Identifying the design features in each typology that are climate responsive and thermally efficient • Understanding the feasibility of the identified features in present context of vernacular architecture in the particular region

Legend –

Parts of study that are ongoing

Parts of study that have been completed

1.9 STRUCTURE OF THE RESEARCH

The purpose of this research is to promote the reduction in demand of active means of achieving thermal comfort and lower the energy requirements of contemporary small-scale buildings. This intends to be done here by unwinding potential strategies that passively promote thermal comfort in these buildings, thereby increasing the quality of life for occupants.

This study aims to document the traditional vernacular principles, which may be variant to a certain extent, to promote a sustainable community.

This research is divided into five broad sections.

Part 1

BASIC INTRODUCTION TO THE RESEARCH

- Research Background
- Statement of Problem
- Area of the Study
- Aim
- Objectives
- Scope, Limitations and Context
- Research Questions
- Structure of the Research

Part 2

LITERATURE REVIEW AND PRIMARY CONTEXT

- Introduction to Building Sciences
- Introduction to Vernacular Architecture
- Idea of Thermal Comfort
- Architectural Aspects and Bioclimatic Aspects
- Climatic Conditions of Lower Bengal
- Vernacular Architecture of Lower Bengal
- Evolution of Traditional Architecture in Lower Bengal

Part 3

RESEARCH METHODOLOGY

- Framework, Limitations and Detailed Methodology
- Data Collection and Associated Analysis

Part 4

ANALYSIS, EVALUATION AND DOCUMENTATION

- Evolution of Vernacular Dwellings
- Different Housing Typologies
- Detail Description of Samples
- Complete Architectural Assessment of Samples
- Complete Assessment of Climatic Response of Samples

Part 5

CONCLUSION OF THE RESEARCH

- Findings of the Study
- Analysis of the Results
- Probable Recommendations
- Inference

CHAPTER 2

- LITERATURE REVIEW –

2.1 The Idea Of Building Science

2.2 Vernacular Architecture

2.3 Research On Climate Responsive Vernacular Architecture In Jharkhand, India

2.1 THE IDEA OF BUILDING SCIENCE

Peter Harris, "*What is Building Science, Anyway*?", Environmental Building News, Vol 21, No. 2, February 2012

Through his article "What is Building Science, Anyway?" Peter Harris helps in formulating a very clear understanding of the term Building Science. He defines and explains the basic concept of Building Science in a simple but justified manner. He terms Building Science as an integrated blend of technical disciplines, including physics, chemistry, biology, climatology, and even ecology.

He beautifully separates Building Physics from Building Science, saying that Building Physics focuses only on the complex interplay of heat, air and moisture flows within and across the building enclosure, while Building Science includes building physics and adds occupants to it, thereby affecting the building performance.

In addition, Harris discusses that Building Science is more associated with the enclosures rather than the mechanical systems. However, it would be justified to state that it requires a good level of understanding of the mechanical systems and their effects on heat, moisture and air flows.

This piece of article helps to perceive the interdependence of enclosures, mechanical systems and occupants. Furthermore, it justifies the significance of a firm idea of building sciences in studying the evolution of architecture and its bioclimatic behaviour.

Lastly, this literature gives a clear apprehension of the language, framework and systems that Building Science provides, in order to make our buildings resource-efficient, comfortable and durable in a changing environment with ever increasing demands for efficiency and durability.

……

Tamasin Sterner, "*Building Science for the rest of us*", Fine Homebuilding 245, pg. 64-69, July 9, 2014

The thinking and ideologies of practitioners all around the world differ as per the climatic conditions as well as economic status of the regions. A. Tamasin Sterner states to work *to lower utility costs for those who cannot afford their utility bills.* Thereby, in simpler words, he works to reduce the consumption of energy within a building. But he does this by making the built environment properly insulated and prevent its contact with the outside environment.

Such practices are highly contemporary in nature. They can be successfully utilized in economically outward countries, where energy costs and building costs do not go hand in hand. Builders have the liberty to choose whichever material reduces energy consumption, irrespective of its associated factors like costing, maintenance and durability. However, such policies cannot be successfully implemented in a country like India on the scale of the common population. In India, cost and thereby affordability is a major concern for the common man.

Sterner does not support the idea that "A House has to breathe". He despises the use of uncontrolled air movements to keep the house dry and ventilated. But in Indian context, such ideas are welcomed are practically more feasible. Alternately, some simpler sustainable practices can be used to control the magnitude of this air movement in quite a convenient manner.

Therefore, when discussing in terms of occupant comfort, building longevity and energy efficiency, the contextual region or location is a key factor that further guides the principles that can be followed.

However in the middle of this ideology which does not fit very well into the context of India, Sterner makes a generalized but extremely logical comment that building science practitioners all over the world should make note of.

"Any changes made in one area must be thought in terms of how they may affect the other areas of the house"

……

Kevin Ireton "*The Trouble with Building Science*", Fine Homebuilding 194 , pg. 70-75, April, 2012

Kevin Ireton, in his work "The Trouble with Building Science" puts forward the establishment of Building Science as a concept, further evolution of relative ideas and associated practises in a chronological manner. According to him, Building scientists or engineers rose with the intention to make homes more comfortable.

Ireton describes how building sciences evolved from the traditional passive methods to active ones, thereby increasing the exhaustion of energy. Further he states that houses and their associated technologies have grown more complex. In fact in the later stages of modernization, passive heating and cooling has become difficult for people to adapt and incorporate, and it requires extensive experience and training, such as the Passive Housing Planning Package (PHPP).

Further, the most relevant part of this literature is the discussion on the validity and understanding of the term "Building Science". Ireton still calls it an immature discipline, whose scope is not well defined. He howsoever accepts that regardless of the definition, one of the most important purposes of establishing Building Science as a concept for residential construction, is to emphasize on a house as a system.

Lastly he elegantly puts forward a concluding statement that

"Good Building Science not only requires that all parts and pieces of a house work together, but it also demands that they be figured out ahead of time."

2.2 VERNACULAR ARCHITECTURE

Bernard Rudofsky, "*Architecture without Architects*", The Museum of Modern Art, New York, 1965. 128 pages

This book by Bernard Rudofsky talks about the kind of architecture that has remained anonymous throughout, and was meant for the common folk. He has used several terminologies like communal, vernacular, indigenous, spontaneous or rural architecture as per various context and has tried to throw light on its significance and beauty on a global scale. Thereby, this helps in formulating a basic idea of vernacular architecture on a global scale, before the research narrows down to the Indian context.

Through this compilation, Rudofsky aims to modify thought process, the narrow-minded ideas of present world, dominated strongly by official and commercial forms of architecture. He criticizes the fact that the architectural history that we study is of a much later time period, and is full of orthodoxy and tales of praises for individual architects. Instead, he encourages the appreciation of such communal architecture.

"It may be argued that this art has no place in a raw civilization, but even so, the lesson to be derived from this architecture may not be completely lost to us."

The author has used a wide range of examples- housing communities to individual public buildings, complete towns to even unique public structures like fertilizer plants, to show how these so-called "anonymous" structures have cumulatively marked the identity of the place and prove his point.

He acknowledges the admirable talent of these untutored builders for fitting their conventional buildings so wonderfully into the natural surroundings. With its diverse collection of data and photographs from instances all over the world, especially the developing and under-developed countries, this illustration is an informative, enlightening and useful read, when looking for undefined architecture of the common man.

……

Ilay Cooper & Barry Dawson *"Traditional Buildings of India"*. London: Thames and Hudson Ltd, 1998. 192 pages.

This book has been written by Ilay Cooper, who has done extensive study and research on the Indian art and architecture in its traditional context. Here, he has brought together the various vernacular typologies of buildings that exist in India, majorly for the common population, as well as the climatic, cultural and social factors contributing to it. He has beautifully compiled the not only small but also significant variations in the building styles and materials, dividing it geographically as per the climatic diversifications. But, there are instances where it is not clear if the author is appreciating or criticizing the fact that this is architecture practised without architects.

"India's traditional architecture has evolved within these constraints: it may be defined as architecture without architects. Not that it dispenses with overall supervision just that this is not in the hands of a sophisticated urban professional. Instead, it is vernacular in that it is the product of well-tried local craftsmen raised in the use of local materials to confront local social and environmental conditions."

Also, the author perceives the idea that the introduction of Urban Architecture in India has been done by the British, and that colonization was essential in a way for urbanization.

Apart from this, he promotes the Gandhian idea of using indigenous materials for building construction, and appreciates the Kachha Architecture practised in various parts of the sub-continent. Also, he broadly elaborates the various building materials that are used for Pakka construction within the country, discussing both its merits and demerits in an unbiased manner. Cooper strongly presents the role of climate and topology in the variation of building styles throughout the land mass. He proves with justified examples and detailing how these parameters influence the material selection, planning, design and orientation of the structure.

Lastly, he concludes by showing his concern towards the lack of interest shown by the government in this regard. It is a gradual but very slow and procedure. Logically, it is not possible to go back to the truly traditional phase of construction, because it did not have structural stability and durability. However, Kaccha architecture has a wide range of positive factors and characteristics which should be appreciated and used in present context, for a naturally comfortable living.

"Renewed interest from architects in traditional forms and materials is a positive force towards rejecting the steel and concrete block. Old methods were thrown aside thoughtlessly, but there can be no return to the truly traditional. By its nature it was the product of local masons supplied with whatever was near the site and geared to confront the surrounding environment. It was not produced by sophisticated architects with a wide knowledge of universal solutions to structural problems."

Manoj Kr. Singh, Sadhana Mahapatra & Jacques Teller, "*Design Optimization of Vernacular Building in Warm and Humid Climate of North-east India*". 30th International Plea Conference, CEPT, Ahmedabad, December 2014

This paper has been written with the intention of studying the design aspects of a vernacular house for its energy efficiency. At the end of it, the researchers target the necessity to understand the thermal behaviour of the vernacular house with respect to design modification required in building design.

Talking on a common subject, this paper mentions that vernacular architecture being constructed on a "design-based" approach suited to a particular climatic condition and socio-cultural setup rather than emphasizing technological solutions. The researchers further signify the role of vernacular architecture in creating an identity of itself as well as of the place. They also mark the significance of these buildings and how they draw attention of researchers representing excellent harmony between environment, materials, socio-economic status, socio-cultural needs, climatic pattern and comfort. Consequently, the house located in the north-east region of India, which is the site for the study is commonly known as the "Assam" type house. This built form is very popular in this area and has a wide acceptance because it fits well into socio-cultural setup, economical to build, easy to maintain and above all, meets the climatic constraints. These specifications and features of the Assam type of house are discussed in proper detail in this paper.

The paper conclusively talks about at the energy saving potential and sustainability presented by bioclimatic aspects of vernacular buildings. The analytical data is very precise and cover a longer duration of observation for the particular site area. Hence the climate analysis is very accurate and dependable. However, the paper lacks general basic literature that needs to be followed for a structure with good thermal performance.

2.3 **RESEARCH ON CLIMATE RESPONSIVE VERNACULAR ARCHITECTURE IN JHARKHAND, INDIA**

Avinash Gautam *"Climate Responsive Vernacular Architecture: Jharkhand, India"*, Department of Architecture, College of Architecture, planning and design Kansas state university Manhattan, Kansas, 2008.

In his research, Avinash Gautam intends to discover potential strategies for contemporary buildings that passively promote thermal comfort in them. In this process, he analyses the passive solar design techniques that help in reducing external energy inputs in the vernacular houses in Jharkhand, India.

This study provides useful directions and ideologies for designing energy efficient houses with thermally comfortable conditions.

Within the state of Jharkhand, vernacular buildings meant for domestic use of two types: Huts and Havelis. Both these typologies are built to act in a climate-responsive manner in order to provide high thermal comfort levels. Gautam aims to signify the thermal performance levels of these buildings in relation to the present day built environment.

For this, he took two houses of each type and did a detailed experimental for them. The results indicated that all the four samples exhibited lower ambient temperature than outside during the day and higher ambient temperature at night. Gautam also analysed what building materials helped to attain such levels of thermal comfort. It was found that brick bat coba, and lime mortar were the key materials used to construct the high thermal mass walls. He also focussed on the significance of good amount of daylight as well as ventilation in achieving thermal comfort.

Courtyards and verandahs were found to be favourable external spaces that helped to make the occupants more comfortable.

Gautam concludes his research by stating that a universal approach in understanding and defining comfort conditions fails because the users of these houses were comfortable in conditions defined by ASHRAE and Nicol as uncomfortable.

CHAPTER 3

- RESEARCH DESIGN –

3.1 Initial Outline

3.2 Research Framework

3.3 Methodology Adopted

3.4 Research Procedure

3.5 Description of the Research Stages

3.6 Climatic Factors

3.7 Mahoney Tables – Interpretation of Climatic Factors for Lower Bengal

3.8 Climate Consultant – Design Recommendations for Lower Bengal

3.9 Parameter Selection and Ranking

3.10 Parameter Analysis

3.11 Inventory for Sample Study

3.1 INITIAL OUTLINE

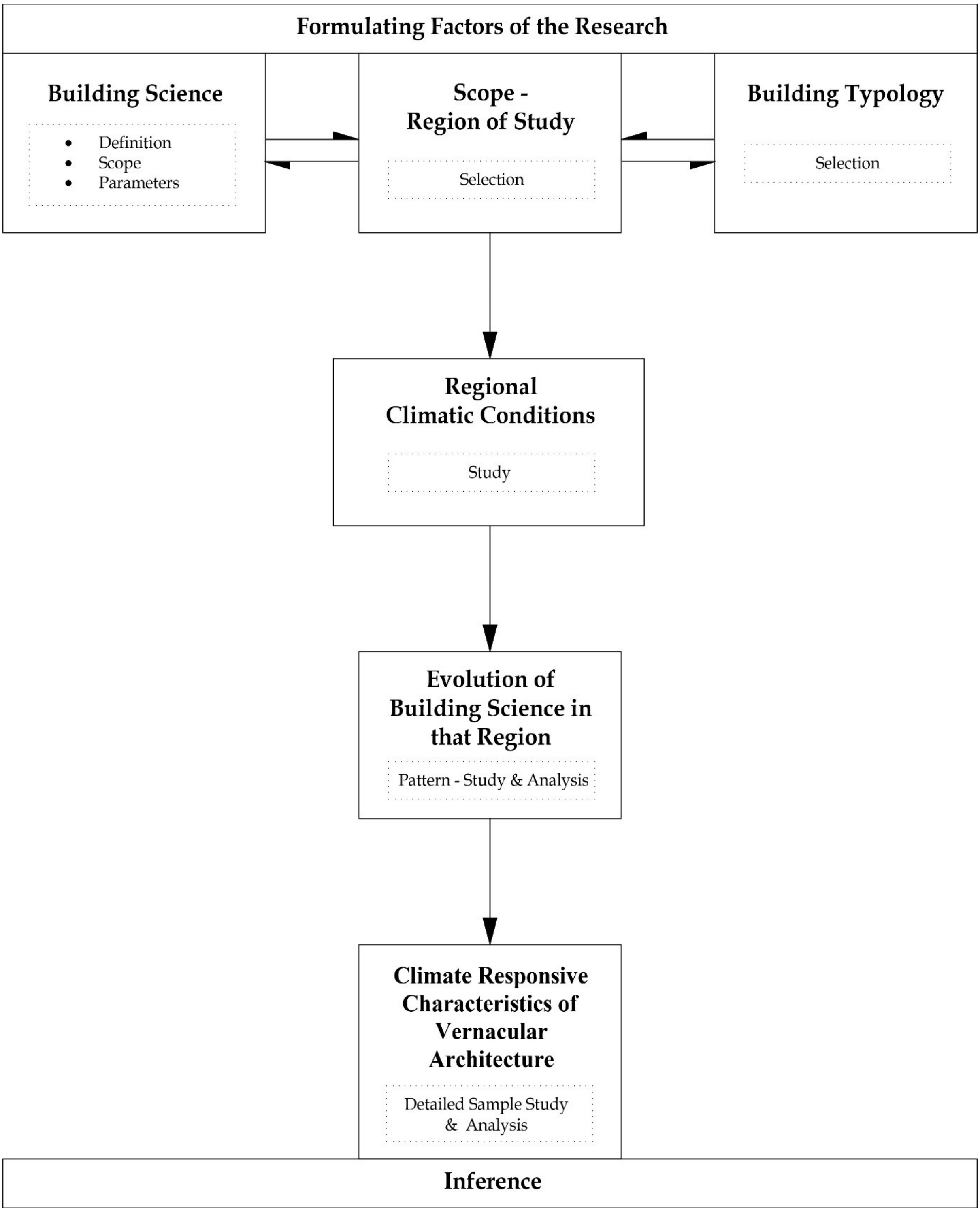


Table 3.1 Initial Outline of the Research

3.2 RESEARCH FRAMEWORK

Stage 1 - Study of the Local Climate of Southern Bengal

- Understanding the microclimate
- Noting the parameters that affect the architectural styles and practices
- Trend Analysis of the chosen parameters

Stage 2 - Study of the Vernacular Architecture of Southern Bengal

- Exploring the evolution of rural houses
- Architectural analysis of the phases of evolution
- Finding out which of these styles are still prevalent in the region
- Detail sample study of these typologies in terms of spatial design, planning and architectural elements

Stage 3 – Analysis of Climatic response of the Typologies

- Understanding the sustainable principles practised in the presently existing vernacular dwellings
- Detail analysis of the Selected Samples in terms of :
    - Day lighting and ventilation
    - Thermal Performance

Stage 4 – Recommendations and Conclusion

- Understanding the contextual relevance of the observed sustainable practices
- Assessing the appropriateness of these principles in the modern context
- Proposing certain generic practises and design guidelines suitable for tropical composite climates

3.3 METHODOLOGY ADOPTED

The Table 3.2 is self-explanatory, which describe the two main aspects formulating the study methodology.

Qualitative Analysis
Majorly focussing on Architectural Aspects
Orientation of the Structure
Spatial Arrangement and Planning
Building Envelope - Walls, floors, roofs, and openings
Building Materials used
Methods of construction
Any Specific building practices
Majorly focussing on Bioclimatic Aspects
Outdoor Climatic Conditions:
Air Temperature Analysis Wind Velocity Analysis Relative Humidity Measurements Solar Radiation

Table 3.2 Basic Framework of Qualitative Analysis (Source – Radhakrishnan S, Assessment of the Climate Responsive Architecture of Traditional Houses of Warm Humid Climate Zone - A Case Study of Chettinadu Dwellings of Tamilnadu, 2011)

Tools and Techniques used to achieve the above:

- Inventory with design parameters
- Typology Mapping for 5 villages
- Reference to the works of the researchers and scholars who have studied the allied domains of the vernacular tradition of South Bengal region.

- Reference to the works of the researchers and scholars who have done the bioclimatic analysis of vernacular settlements located in different regions of India.

- Sample Typology Chart -1

Typology	Location of Sample House	House Description	Diagrammatic Representation	Remarks

Table 3.3 Sample Chart for Assessment of Building Samples selected on the basis of typology

3.4 RESEARCH PROCEDURE

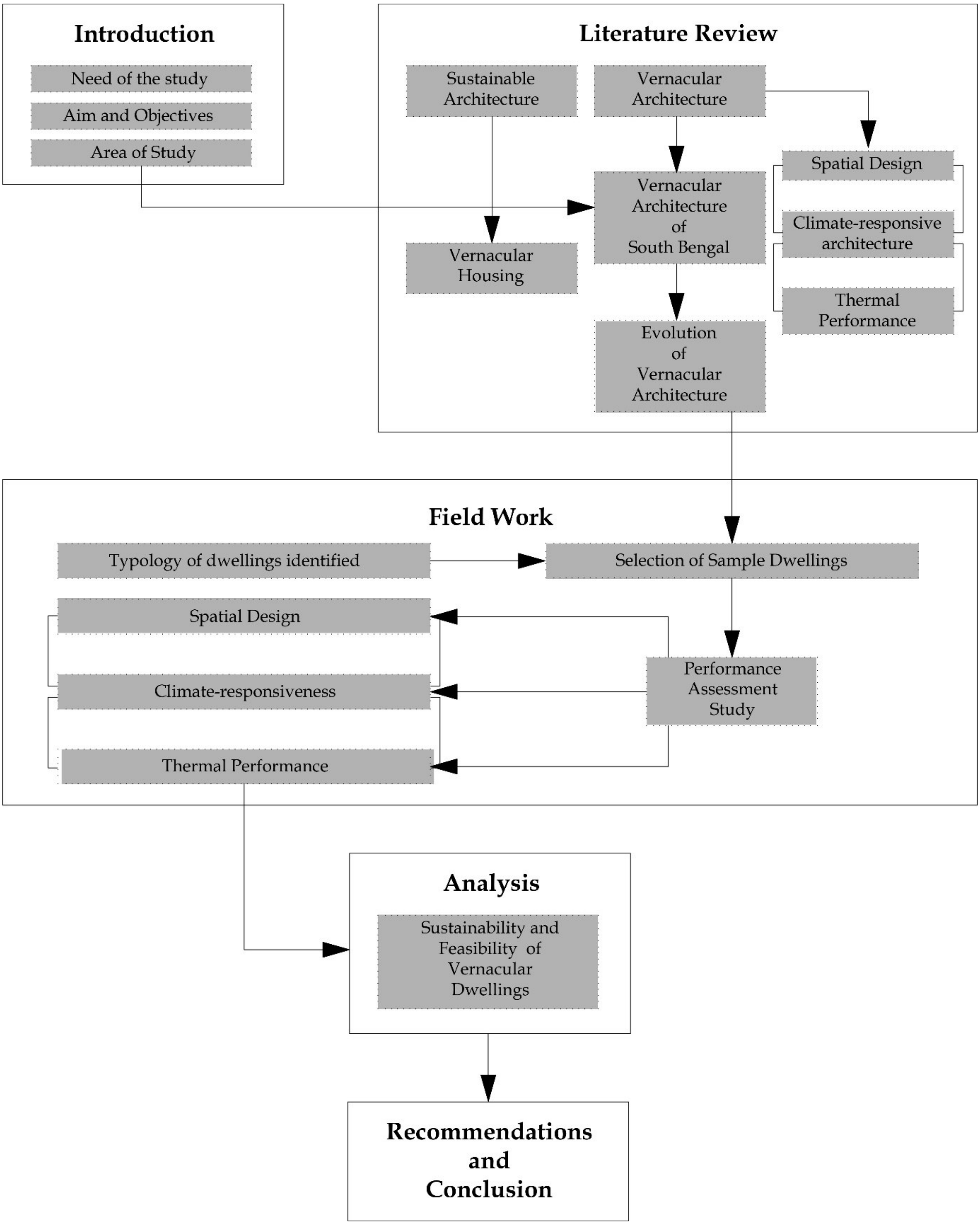


Table 3.4 Flow Chart Showing the Research Procedure in Detail with associated keywords

3.5 STAGES OF RESEARCH

Stage of Research	Data Collection / Sample Study/ Case Study	Tools and Techniques used	Analysis
Stage 1: Study of Local Climate of Bengal	Basic Idea of tropical regions, warm humid climate; Climatic Trend Analysis of Southern Bengal	Literature; Data Collected from IMD; Mahoney Table; Climate Consultant Software	Understanding the climatic behaviour and its associated consequences
Stage 2 : Study of Vernacular Architecture of Southern Bengal	Concept of existing housing typologies in Southern Bengal, their evolution, and then sample study of each type based on chosen parameters	Literature; Mapping; Personal Observation; Inventory; On-site Sample Study – Documenting plans, elevations, site sketches	Understanding the vernacular architecture of South Bengal; Understanding the architectural characters of the five typologies of dwellings; Factors responsible for the evolution of the different typologies
Stage 3 : Analysis of Climate Response on these Typologies	Identification of Sustainable practices and principles within these buildings; Detailed architectural analysis of the samples in terms of daylighting, ventilation and thermal performance	Parameter Ranking; Inventory; On-site Sample Study; Photography; Documented Drawings; Results from Climate Consultant and Mahoney Table; Bioclimatic analysis methods relevant in the context used by previous researchers	Analysing how the design and architectural elements in these buildings vary because of climatic and environmental conditions; The variations in material sources as well as indigenous techniques adapted to provide a comfortable indoor environment; Analysing Quality of life in terms of flexibility of spaces, activities, privacy, social interaction, etc.
Stage 4 :	Study and Drawing of	Analysis done in stages 1,2 and 3 :	Identifying the appropriateness of the

Recommendations and Conclusion	conclusions from the above mentioned stages	Literature, Charts and Drawings	sustainable practices discovered in modern context; Suggesting generic practices and design guidelines suitable for tropical composite climate.

Table 3.5

3.6. CLIMATIC FACTORS

In developing countries, due to lack of funds, information, awareness or insight to build in synchrony with the environment, architecture is usually created without taking sufficient account of the climate. One such example is India. Factors like surroundings, site characteristics, orientation, choice of building materials, etc. are not given enough importance. Consequently, buildings often have a poor indoor climate, which affects comfort, health and efficiency.

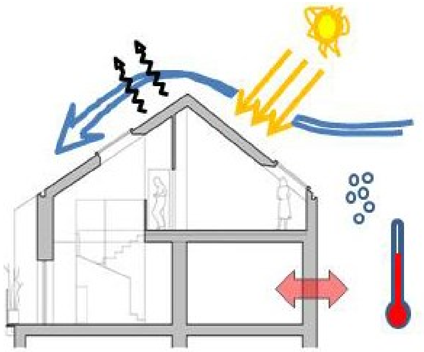
As living standards rise, people intend to install heating and/or cooling equipment to improve thermal comfort within their structures. For buildings not built in integration with the climate, the energy being consumed to run the equipment, and its cost increase substantially, and it results in severely detrimental impact on the environment.

An acceptable indoor climate can often be achieved with little or no extra input of energy. Apart from a general lack of norms and regulations, one reason why buildings are poorly adapted to the climate is lack of knowledge among architects, planners and engineers. Central concepts such as thermal capacity and thermal insulation are often misunderstood. The knowledge from traditional construction, which was fairly well adapted to the climate, is often lost or difficult to translate to modern techniques and society. (Rosenlund, 2000).

An analysis of the climate of a particular region can be useful in determining the time periods during which a person may feel comfortable or uncomfortable. It further helps to identify the climatic elements, as well as their intensity, that cause discomfort. Such awareness and information influences and supports a designer to build a structure that challenges adverse climatic effects. Discomfort and the corresponding energy demand for mechanical systems can be effectively reduced by judicious control of the climatic effects.

A designer is primarily concerned about those aspects of climate that affect human comfort. These factors include changes in temperature, diurnal ranges, humidity, sky conditions, incoming and outgoing radiation, rainfall and its distribution, air movements and special irregular activities like thunderstorms, dust storms and hurricanes.

Conclusively, it is the responsibility of the designer to do a proper evaluation of climatic data and utilize it in his design, identifying features that are beneficial or harmful in achieving human comfort.



Both weather and climate are characterised by the certain variables known as climatic factors. They are as follows:

- Solar radiation
- Ambient temperature
- Air humidity
- Precipitation
- Wind
- Sky condition

Fig 3.1 (Nayak & Prajapati, 2006)

Climatic factors, considered for one particular place along with the local factors form the "Site Climate". Site climate is particularly distinguishable from "microclimate", because the latter is conditionally variable. On the other hand, the Site Climate establishes a scale, however big or small the project is.

It implies the climate of the area available and is to be used for a given purpose, both in horizontal extent and in height. (Koenisberger & Ingersoll, 1975).

Temperature

Temperature is the degree of heat contained in a body or a fluid medium or some region. Air temperature is measured with a dry bulb thermometer protected from solar and heat radiation.

This data is generally available in meteorological records as monthly means, maximum and minimum values (both normal and extreme).

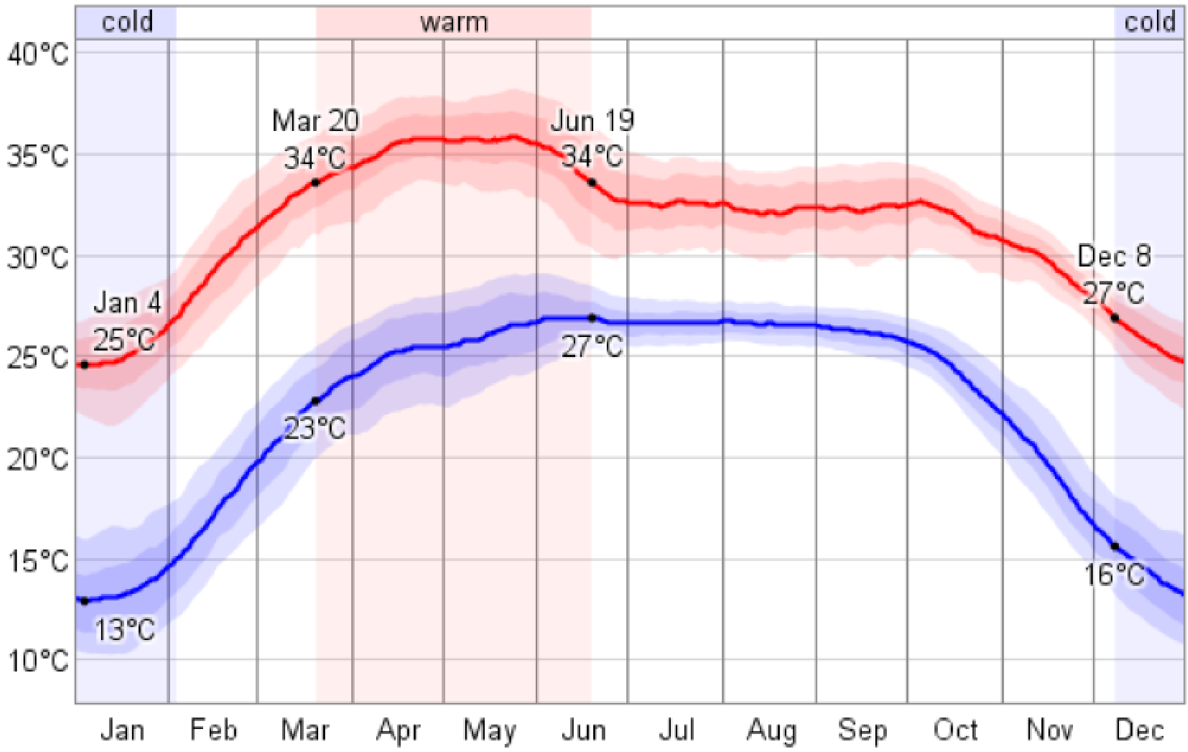


Fig 3.2 The daily average low (blue) and high (red) temperature for Kolkata*

OBSERVATIONS:

- The warm season lasts from March 20 to June 19 with an average daily high temperature above 34°C.
- The hottest day of the year is May 23, with an average high of 36°C and low of 27°C.
- The cold season lasts from December 8 to February 3 with an average daily high temperature below27°C.
- The coldest day of the year is January 5, with an average low of 13°C and high of 25°C.

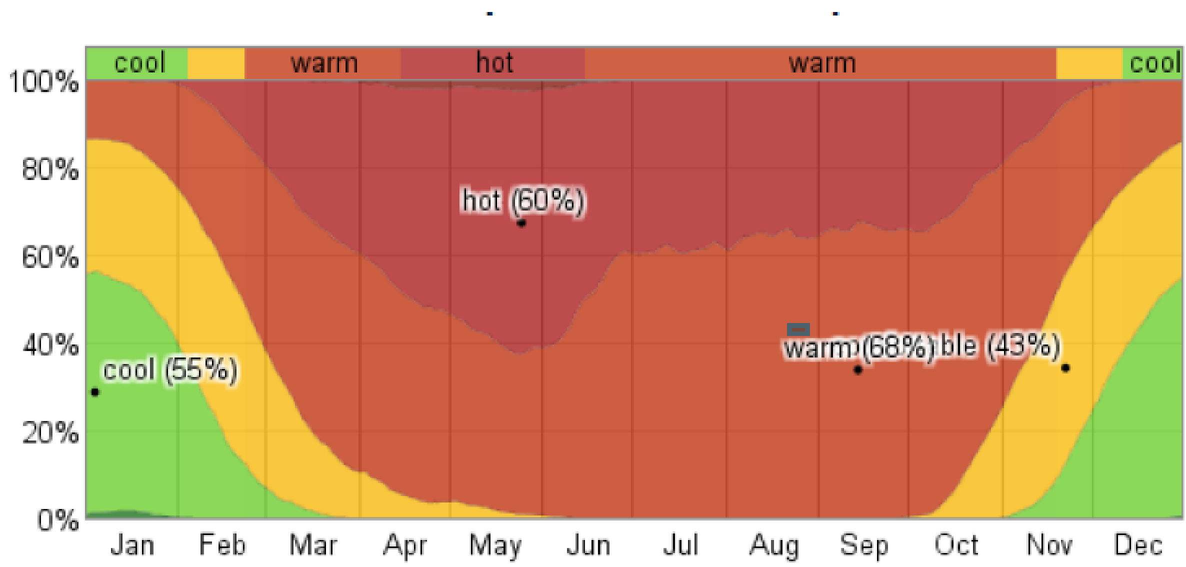


Fig 3.3 The average fraction of time spent in various temperature band for Kolkata

OBSERVATIONS:

- The warm season ranges from May to September when O% of coolness in climate is experienced.
- The hottest day of the year is May 23, with maximum percentage of hot temperature band occurs.
- The cold season lasts from December to February with maximum percentage of coolness is experienced.
- The coldest day of the year is January 5, with an average low of 13°C and high of 25°C.

INFERRED DESIGN CONSIDERATIONS:

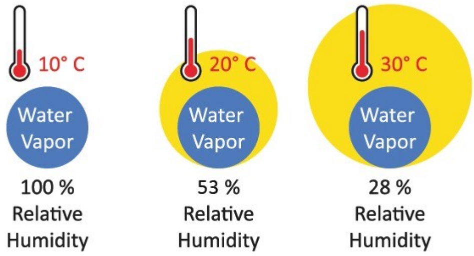
- More than 75% of the year, the climate is ranging from warm to hot. Thus, dealing with higher outdoor temperatures is the prime challenge in Lower Bengal.
- Some minor parts of the year also experience 55% of cold, hence in maximum cases, extreme temperature is a concern in this region. Hence, proper insulation needs to be achieved in the building designs.
- Also, couple of months undergo moderate climates, hence provision to reduce insulation and enhance ventilation should be taken care of in the design.

DESIGN PARAMETERS AFFECTED:

- Building Envelope

- Building Materials
- Openings

Humidity



Hotter air can contain more vapour than colder, and when cooled to the limit – the dew point – the surplus condenses.

Fig 3.4

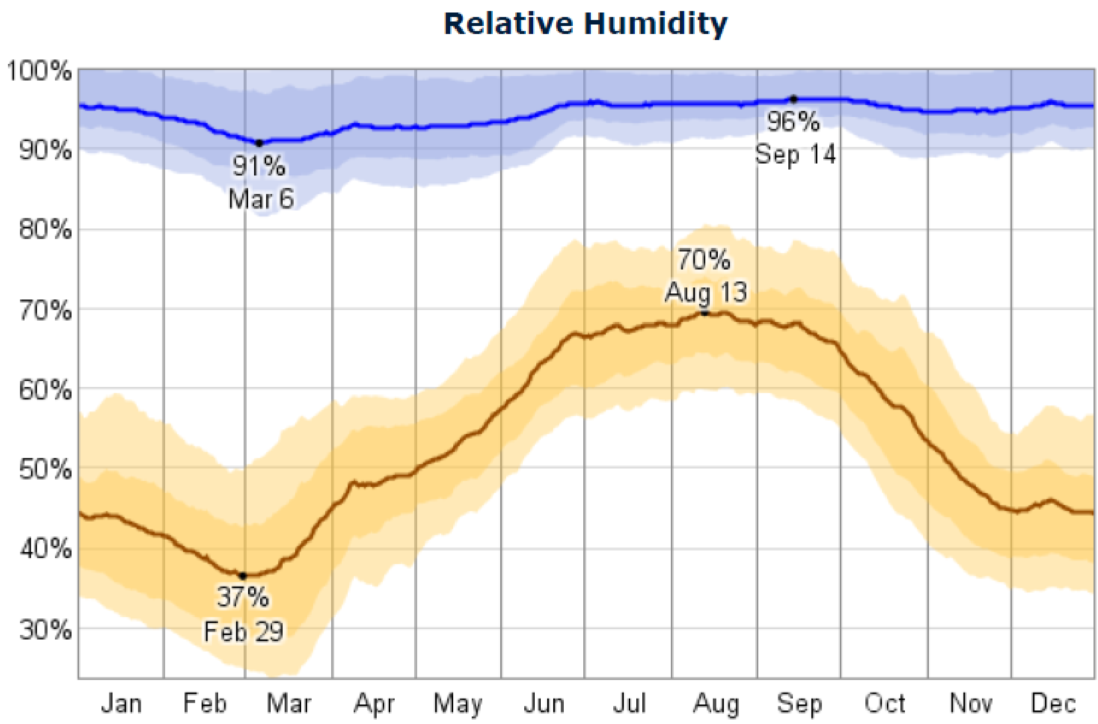


Fig 3.5 The average daily high (blue) and low (brown) relative humidity for Kolkata

OBSERVATIONS:

- The relative humidity typically ranges from 37% (comfortable) to 96% (very humid) over the course of the year.
- It is most humid around September 14, exceeding 94% (very humid).
- The air is driest around February 29, at which time the relative humidity drops below 43 %(comfortable).

INFERRED DESIGN CONSIDERATIONS:

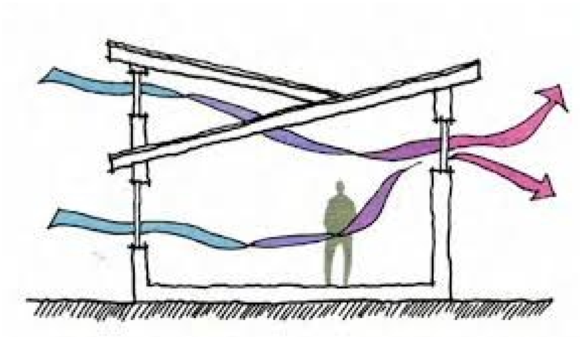
- Since, it is humid most times of the year, it is preferable to keep the building well ventilated.
-
- It is important to keep the breeze channelized and utilized to the maximum, to reduce the effect of humidity, and make inner conditions comfortable.

DESIGN PARAMETERS AFFECTED:

- Building Envelope
- Form, Spatial Planning and Organization
- Vegetation and Surroundings
- Openings

Wind

At local level wind is the most irregular and varying component of the climate. It is described by its speed and direction.



FFig 3.6

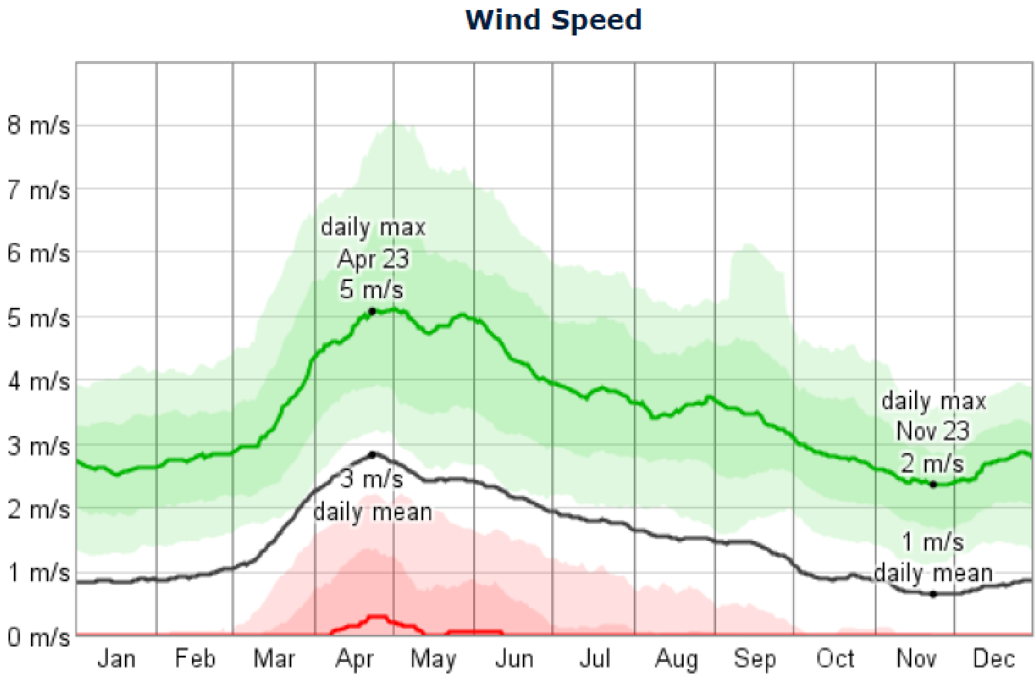


Fig 3.7 The average daily minimum (red), maximum (green), and average (black) wind speed for Kolkata

OBSERVATIONS:

- Over the course of the year typical wind speeds vary from 0 m/s to 5 m/s (calm to gentle breeze), rarely exceeding 8 m/s (fresh breeze).
- The highest average wind speed of 3 m/s (light breeze) occurs around April 23, at which time the average daily maximum wind speed is 5 m/s (gentle breeze).
- The lowest average wind speed of 1 m/s (light air) occurs around November 23, at which time the average daily maximum wind speed is 2 m/s (light breeze).

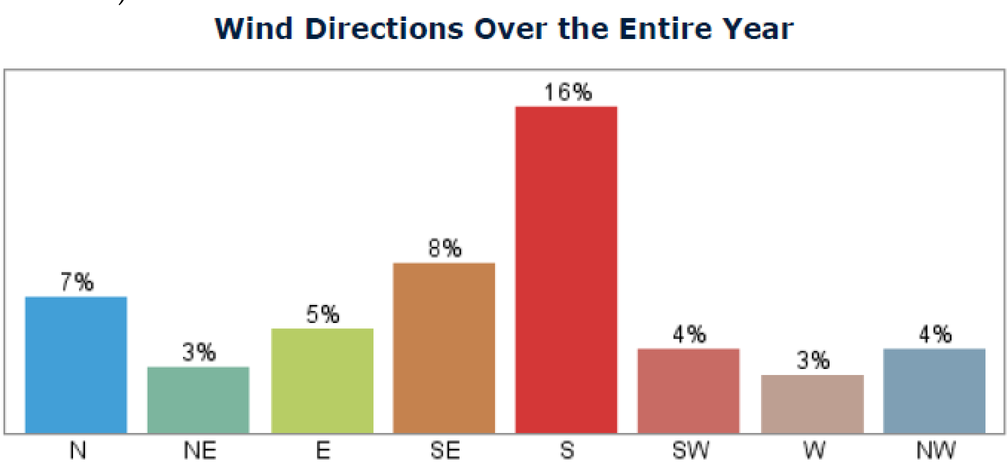


Fig 3.8 The fraction of time spent with the wind blowing from the various directions over the entire year in Kolkata

(Values do not sum to 100% because the wind direction is undefined when the wind speed is zero)

OBSERVATIONS:

- The wind is most often out of the south (16% of the time).
- The wind is least often out of the west (3% of the time), north east (3% of the time), south west (4% of the time), and north west (4% of the time).

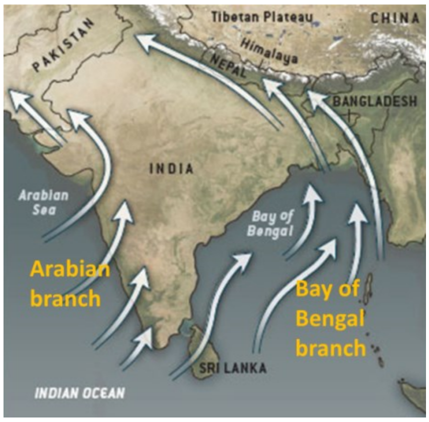


Fig 3.9

INFERRED DESIGN CONSIDERATIONS:

- The wind speed in this region is moderate. So, in order to make best use of the wind, the spatial planning and surroundings should be taken care of for a good climate responsive design.

- The wind direction is primarily south, and slightly in east as well. Hence, the orientation of structures should be accordingly for maximum utilization.

DESIGN PARAMETERS AFFECTED:

- Orientation
- Form, Spatial Planning and Organization
- Vegetation and Surroundings
- Openings

Precipitation

Precipitation may vary considerably between seasons.

Combinations with other elements could be interesting in relation to building design, e.g. at strong winds it rains ‘horizontally’ (driving rain).

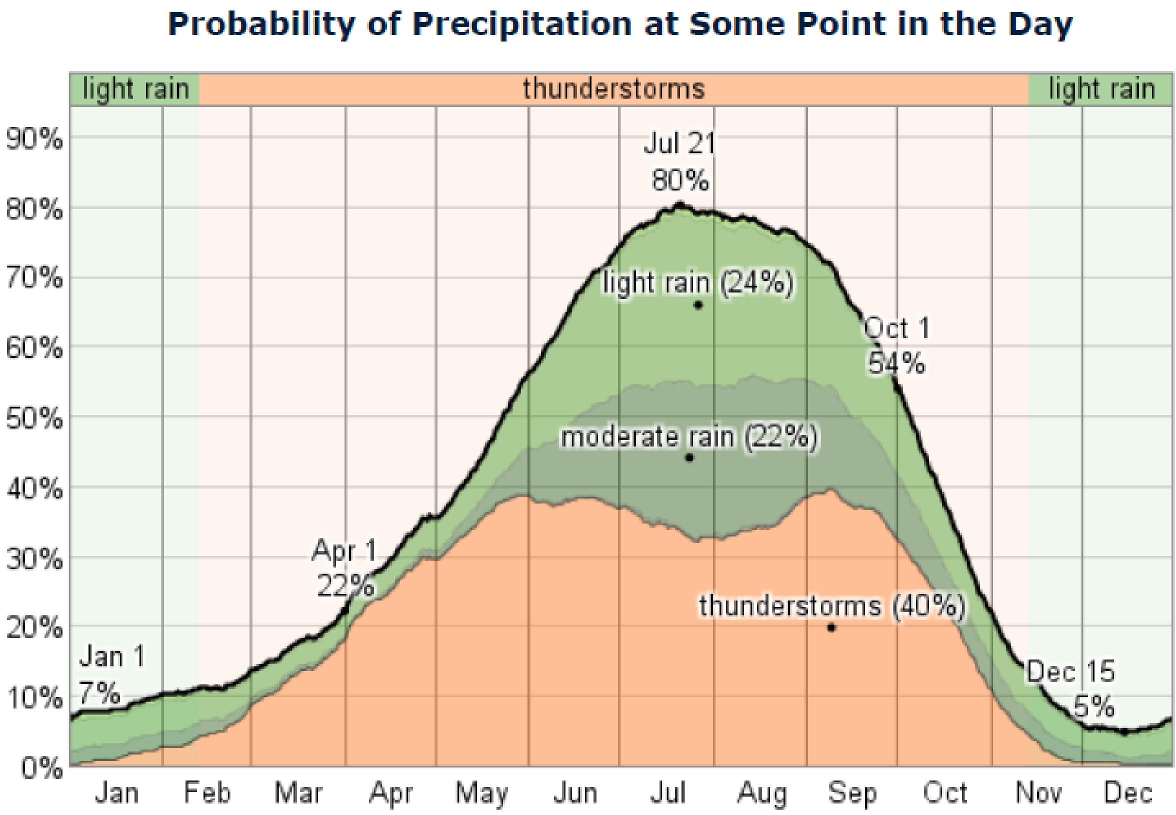


Fig 3.10 The fraction of days in which various types of precipitation are observed for Kolkata

If more than one type of precipitation is reported in a given day, the more severe precipitation is counted.

OBSERVATIONS:

- The probability that precipitation will be observed at this location varies throughout the year.
- Thunderstorms are observed most likely around September 9, when it is observed during 40% of all days.
- Light rain is observed during 24% of those days with precipitation. It is most likely around July 27, when it is observed during 24% of all days.
- Moderate rain is observed during 18% of those days with precipitation. It is most likely around July 24, when it is observed during 22% of all days.

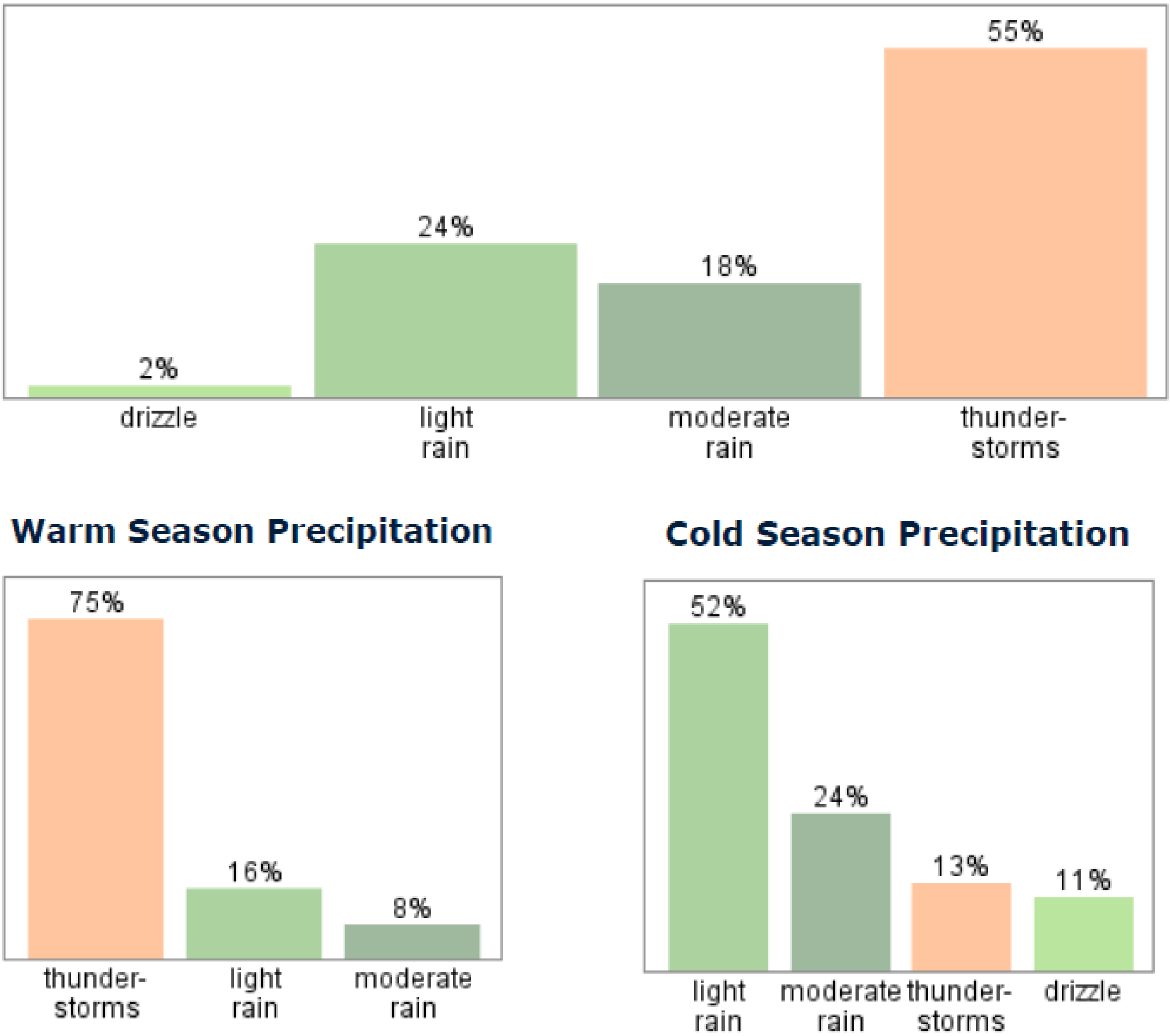


Fig 3.11 Types of Precipitation throughout the Year in Kolkata

OBSERVATIONS:

During the warm season, from March to June, there is a 40% average chance that precipitation will be observed at some point during a given day. When precipitation does occur it is most often in the form of thunderstorms (75% of days with precipitation have at worst thunderstorms), light rain (16%), and moderate rain (8%).

During the cold season, from December to February, there is a 7% average chance that precipitation will be observed at some point during a given day. When precipitation does occur it is most often in the form of light rain (52% of days with precipitation have at worst light rain), moderate rain (24%), thunderstorms (13%), and drizzle (11%).

DESIGN PARAMETERS AFFECTED:

- Form, Planning and Spatial Organization
- Building Envelope
- Building Material
- Openings

Solar Radiation

Solar radiation is an important consideration in any building that strives for energy efficiency.

Understanding the significance of solar radiation helps to mass, orient and program a building to capitalize on the solar radiation characteristics of the site and climate.

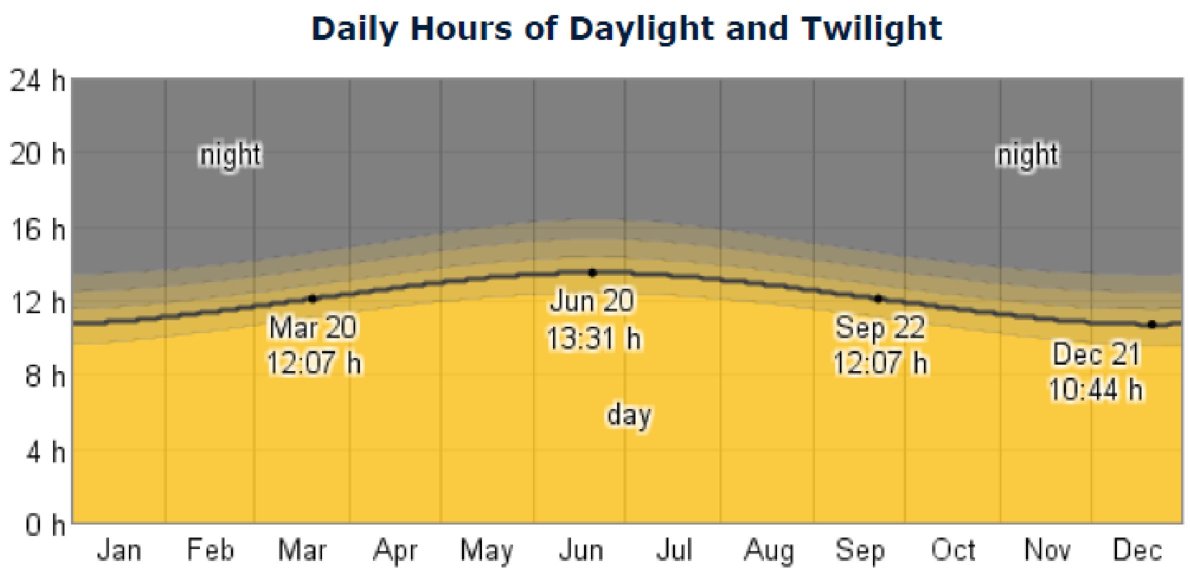


Fig 3.12 The number of hours during which the Sun is visible (black line) in Kolkata

OBSERVATIONS:

- The length of the day varies significantly over the course of the year.

- The shortest day is December 21 with 10:44 hours of daylight; the longest day is June 20 with 13:32 hours of daylight.

INFERRED DESIGN CONSIDERATIONS:

- As mostly throughout the year, the sun is present for more than 10 hours, keeping the building isolated from solar heat is essential.

DESIGN PARAMETERS AFFECTED:

- Orientation
- Building Envelope
- Openings

Sky Conditions

Sky conditions are comprised of solar visibility and cloudiness.

Cloudiness refers to the state of clouds in a given area and time. Different types of clouds signal different weather conditions and consequently affect the other climatic factors. For instance, lighter clouds indicate little or no precipitation, while dark, heavy clouds point to heavy rain or thunderstorms.

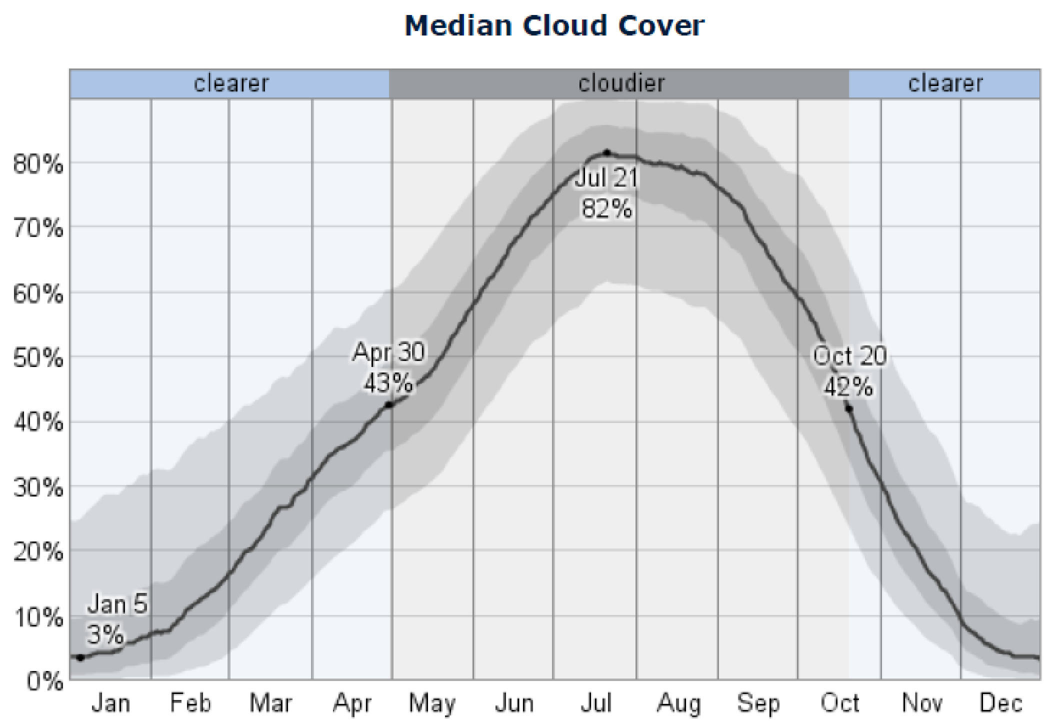


Fig 3.13 The median daily cloud cover (black line) in Kolkata

OBSERVATIONS:

- The median cloud cover ranges from 3% (clear) to 82% (mostly cloudy).
- The sky is cloudiest on July 21 and clearest on January 5.
- The clearer part of the year begins around October 20. The cloudier part of the year begins around April 30.

INFERRED DESIGN CONSIDERATIONS:

- Therefore, the sky conditions change and effect other climatic factors like temperature, humidity, amount of radiation and glare.
- It shows that the sky is clear mostly, and hence solar intensity will be high. Associated precautions need to be taken.

DESIGN PARAMETERS AFFECTED:

- Orientation
- Building Envelope
- Openings
- Vegetation and Surroundings

Generalized Conclusion

<u>Planning Aspects</u>

- Orientation and spatial organisation affect the ability of a building to ventilate and receive solar radiation.

- To minimise solar gain and maximise ventilation, traditional buildings in warm humid climates usually employ spread-out plans and permeable internal organization.

Building Material, Colour and Texture

- Materials with low embodied energy like stone, adobe blocks, have low U values. This can be an advantage for buildings in daytime as it prevents the heat from entering inside for a longer time.

- Smooth and light colour for exterior can help to reflect the solar radiation without allowing to transmit inside.

- Light colour walls and roof can reduce the heat from entering inside.

Vegetation

- Vegetation can be an effective in moderating the temperature around a building and reducing its cooling requirement.

- Vegetation in the form of trees, climbers, high shrubs and pergolas, can provide effective shading for the walls and windows.

- Ground cover by plants also reduces the reflected solar radiation and long-wave radiation emitted towards the building, thus reducing solar and long-wave heat gains.

3.7. MAHONEY TABLES– INTERPRETATION OF CLIMATIC FACTORS FOR LOWER BENGAL

Mahoney tables propose a climate analysis sequence that starts with the basic and monthly available climatic data of temperature, humidity and rainfall.

These tables provide design guidelines by using climatic data and simple calculations.

There are six relevant tables; four are used to enter climatic data for comparison with the requirements for thermal comfort; and two reading off appropriate design criteria.

The following Mahoney Tables have been analysed and evaluated in the context of Kolkata, falling in Lower Bengal to establish some guidelines for climate responsive design in the climate.

Location	**Kolkata**
Latitude	22.5726° N
Longitude	88.3639° E

Altitude	9 meters

Table 3.6: Mahoney Table 2 – Design Conditions for Kolkata

Months of the Year	J	F	M	A	M	J	J	A	S	O	N	D
Monthly Mean Max.	23	27	29	30	30	29	28	28	29	29	27	24
Monthly Mean Min.	10	12	16	18	16	20	19	20	18	19	15	12
Monthly Mean Range	10	15	13	12	14	09	09	08	09	10	12	12

Table 3.7: Mahoney Table 3 - Air Temperature in Celsius (2005-2015) for Kolkata

Months of the Year	J	F	M	A	M	J	J	A	S	O	N	D
Monthly Mean Max.	94	92	91	93	93	94	95	95	96	95	95	95
Monthly Mean Min.	43	39	38	48	54	63	68	69	68	55	47	46
Average	68.5	65.5	64.5	70.5	73.5	78.5	81.5	82	82	75	71	70.5
Humidity Group	3	3	3	4	4	4	4	4	4	4	4	4

Table 3.8: Mahoney Table 4 - Relative Humidity in % (2005-2015) for Kolkata

Humidity Group	Avg. RH %
1	Below 30%
2	30-50%
3	50-70%
4	Above 70%

Table 3.9: Mahoney Table 5 - Humidity Group

Comfort limits		AMT over 20°C		AMT 15-20°C		AMT below 15°C	
		Day	Night	Day	Night	Day	Night
Humidity group	1	26-34	17-25	23-32	14-23	21-30	12-21
	2	25-31	17-24	22-30	14-22	20-27	12-20
	3	23-29	17-23	21-28	14-21	19-26	12-19
	4	22-27	17-21	20-25	14-20	18-24	12-18

Table 3.10: Mahoney Table 6 - Thermal comfort limits for different humidity groups

Diagnosis °C	J	F	M	A	M	J	J	A	S	O	N	D
Monthly Mean Max.	23	27	29	30	30	29	28	28	29	29	27	24
Day Comfort - Upper	29	29	29	27	27	27	27	27	27	27	27	27

Day Comfort - Lower	23	23	23	22	22	22	22	22	22	22	22	22
Monthly Mean Min.	10	12	16	18	16	20	19	20	18	19	15	12
Night Comfort - Upper	19	19	21	20	20	20	20	20	20	20	20	18
Night Comfort - Lower	12	12	14	14	14	14	14	14	14	14	14	12
Thermal Stress - Day	O	O	O	H	H	H	H	H	H	H	H	O
Thermal Stress - Night	C	C	O	O	O	H	O	H	O	O	O	C

Table 3.11: Mahoney Table 7 - Diagnosis ^{o}C*

The thermal stress is obtained by comparing the temperature with the comfort limits. The maximum temperature is compared with the day comfort limits while the minimum temperature is compared with the night comfort limits. When the temperature is higher than the upper limit there is hot discomfort (H) while there is cold discomfort (C) when the temperature is lower than the lower limit. Temperatures falling between the comfort limits are comfortable (O).

Indicator totals from table 2									
H1	H2	H3	A1	A2	A3				
7	1	4	2	0	1				
									Layout
			0-10			•	1	★	Orientation north and south (long axis east-west)
			11,12		5-12				
					0-4		2	★	Compact courtyard planning
									Spacing
11,12							3	★	open spacing for breeze penetration
2-10						•	4	★	As 3, but protection from hot and cold wind
0,1							5		Compact lay-out of estates
									Air Movement
3-12			0-5			•	6	★	Rooms single banked, permanent provision for air movement
1,2			6-12				7		Double banked rooms, temporary provision for air movement
0	2-12								
	0-1						8	★	No air movement requirement
									Openings
			0,1		0		9		Large openings, 40-80%
			11,12		0,1		10	★	Very small openings, 10-20%
Any other conditions						•	11		Medium openings, 20-40%
		3-12					17		
									Walls
			0-2				12	★	Very small openings, 10-20%
			3-12			•	13		Medium openings, 20-40%
									Roofs
			0-5				14	★	Light, insulated roofs
			6-12			•	15		Heavy roofs, over 8 h time-lag
									Out-door sleeping
				2-12		•	16		Space for out-door sleeping required
									Rain Protection
		3-12					17	★	Protection from heavy rain necessary

Table 3.12 Evaluation Table

Indicator totals from table 2									
H1	H2	H3	A1	A2	A3				
7	1	4	2	0	1				
									Size of openings
			0,1		0		1		Large: 40-80%
					1-12		2	★	Medium: 25-40%
			2-5						
			6-10			•	3		Small: 15-25%
			11,12		0-3		4		Very small: 10-20%
					4-12		5		Medium: 25-40%
									Position of openings
3-12						•	6	★	In north and south walls at body height on windward side
1-2			0-5						
			6-12				7		As above, openings also in internal walls
0	2-12								
									Protection of openings
					0-2	•	8	★	Exclude direct sunlight
			2-12				9	★	Provide protection from rain
									Walls and floors
				0-2			10	★	Light, low thermal capacity
				3-12		•	11		Heavy, over 8 h time-lag
									Roofs
10-12			0-2				12	★	Light, reflective surface, cavity
			3-12				13	★	Light, well insulated
0-9			0-5						
			6-12			•	14		Heavy, over 8 h time-lag
									External features
				1-12		•	15		Space for out-door sleeping
		1-12				•	16	★	Adequate rainwater drainage

Table 3.13 Evaluation Table cntd.

CONCLUSIONS FROM MAHONEY TABLE FOR CLIMATE RESPONSIVE DESIGN IN LOWER BENGAL

- Orientation north and south axis(long axis east-west)
- Compact courtyard planning
- Opening spacing for breeze penetration but protection from hot and cold wind
- Rooms single banked, permanent provision for air movement
- Very small openings,10-20%
- Light, insulated roofs
- Protection from heavy rain necessary
- Size of openings –Medium – 25-40%
- Position of openings in north and south walls at body height on windward side
- Protection of Openings – Exclude direct sunlight and provide protection from rain
- Walls and Floors – Light, low thermal capacity
- Roofs – Light, well insulated, reflective surfaced, cavity
- Adequate rainwater drainage

These design conclusions will help in setting standard requirements for a climate responsive design when analysing the different samples from different typologies in the research.

3.8. CLIMATE CONSULTANT – DESIGN RECOMMENDATIONS FOR LOWER BENGAL

Climate Consultant is a simple, graphic-based computer program that helps architects, builders, contractor, homeowners, and students understand their local climate. It helps to plot climate data, organize and represent this information in easy-to-understand ways that show the subtle attributes of climate, and its impact on built form.

The goal is to help users create more energy efficient, more sustainable buildings, each of which is uniquely suited to its particular spot on this planet. It seeks to translate outdoor conditions to indoor comfort, so make generalized assumptions about building design.

This software has therefore, been used to automatically conduct a quantitative analysis of the local climatic conditions in Kolkata, which is a notable city falling in the region of study- Southern Bengal. Average climatic data have been taken for the past twenty years (1996-2016). Further, this data is analysed and various design solutions have been deciphered which properly fit into the climatic conditions. These results are further verified and justified using additional site studies and mathematical tests conducted. But the most significant role of this study is that it provides the guidelines and standards which can be followed while conducting site studies for this location.

WEATHER DATA SUMMARY

LOCATION: Kolkata, West Bengal, IND
Latitude/Longitude: 22.65° North, 88.45° East, **Time Zone from Greenwich** 5
Data Source: ISHRAE 428090 WMO Station Number, **Elevation** 6 m

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	338	391	405	408	389	340	313	335	306	319	294	321	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	344	367	285	220	193	132	102	121	112	183	215	328	Wh/sq.m
Diffuse Radiation (Avg Hourly)	132	158	205	241	245	242	240	247	226	201	162	131	Wh/sq.m
Global Horiz Radiation (Max Hourly)	772	880	953	970	939	956	857	770	816	791	730	819	Wh/sq.m
Direct Normal Radiation (Max Hourly)	1147	1039	970	863	743	869	591	581	619	949	881	1190	Wh/sq.m
Diffuse Radiation (Max Hourly)	334	404	462	496	506	504	508	494	474	437	367	316	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	3643	4393	4819	5120	5096	4552	4154	4276	3721	3649	3204	3413	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	3712	4120	3399	2767	2527	1764	1352	1553	1356	2086	2344	3496	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	1429	1780	2440	3026	3215	3242	3185	3152	2749	2309	1775	1396	Wh/sq.m
Global Horiz Illumination (Avg Hourly)													lux
Direct Normal Illumination (Avg Hourly)													lux
Dry Bulb Temperature (Avg Monthly)	18	23	27	29	29	29	28	29	28	26	24	20	degrees C
Dew Point Temperature (Avg Monthly)	13	15	20	23	25	26	25	26	26	22	20	14	degrees C
Relative Humidity (Avg Monthly)	72	66	72	72	78	81	86	85	87	81	79	72	percent
Wind Direction (Monthly Mode)	320	20	230	180	180	180	160	140	140	0	10	0	degrees
Wind Speed (Avg Monthly)	0	0	0	1	2	0	0	1	1	0	0	0	m/s
Ground Temperature (Avg Monthly of 3 Depths)	22	22	22	23	25	27	28	29	29	28	26	24	degrees C

Table 3.14 (Source: Climate Controller 6.0)

California Energy Code Comfort Model, 2013 (select Help for definitions)

1. COMFORT: (using California Energy Code Model)

20.0	Comfort Low - Min. Comfort Dry Bulb Temp (°C)
23.9	Comfort High - Max. Comfort Dry Bulb Temp, up to 50% RH (°C)
80.0	Max. Relative Humidity (measured at Min. Comfort Temp) (%)
18.9	Max. Wet Bulb Temperature (°C)
-2.8	Min. Dew Point Temperature (°C)

2. SUN SHADING ZONE: (Defaults to Comfort Low)

20.0	Min. Dry Bulb Temperature when Need for Shading Begins (°C)
315.5	Min. Global Horiz. Radiation when Need for Shading Begins (Wh/sq.m)

3. HIGH THERMAL MASS ZONE:

8.3	Max. Outdoor Temperature Difference above Comfort High (°C)
1.7	Min. Nighttime Temperature Difference below Comfort High (°C)

4. HIGH THERMAL MASS WITH NIGHT FLUSHING ZONE:

16.7	Max. Outdoor Temperature Difference above Comfort High (°C)
1.7	Min. Nighttime Temperature Difference below Comfort High (°C)

5. DIRECT EVAPORATIVE COOLING ZONE: (Defined by Comfort Zone)

63.8	Max. Wet Bulb set by Max. Comfort Zone Wet Bulb (°C)
48.8	Min. Wet Bulb set by Min. Comfort Zone Wet Bulb (°C)

6. TWO-STAGE EVAPORATIVE COOLING ZONE:

50.0	% Efficiency of Indirect Stage

7. NATURAL VENTILATION COOLING ZONE:

2.0	Terrain Category to modify Wind Speed (2=suburban)
0.2	Min. Indoor Velocity to Effect Indoor Comfort (m/s)
1.5	Max. Comfortable Velocity (per ASHRAE Std. 55) (m/s)
3.6	Max. Perceived Temperature Reduction (°C)
90.0	Max. Relative Humidity (%)
22.8	Max. Wet Bulb Temperature (°C)

8. FAN-FORCED VENTILATION COOLING ZONE:

0.8	Max. Mechanical Ventilation Velocity (m/s)
3.0	Max. Perceived Temperature Reduction (°C)

(Min Vel, Max RH, Max WB match Natural Ventilation)

9. INTERNAL HEAT GAIN ZONE (lights, people, equipment):

12.8	Balance Point Temperature below which Heating is Needed (°C)

10. PASSIVE SOLAR DIRECT GAIN LOW MASS ZONE:

157.7	Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
3.0	Thermal Time Lag for Low Mass Buildings (hours)

11. PASSIVE SOLAR DIRECT GAIN HIGH MASS ZONE:

157.7	Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
12.0	Thermal Time Lag for High Mass Buildings (hours)

12. WIND PROTECTION OF OUTDOOR SPACES:

8.5	Velocity above which Wind Protection is Desirable (m/s)
11.1	Dry Bulb Temperature Above or Below Comfort Zone (°C)

13. HUMIDIFICATION ZONE: (defined by and below Comfort Zone)

14. DEHUMIDIFICATION ZONE: (defined by and above Comfort Zone)

Table 3.15 (Source: Climate Controller 6.0)

RECOMMENDATIONS FROM CLIMATE CONTROLLER FOR CLIMATE RESPONSIVE DESIGN IN LOWER BENGAL

1) In this climate air conditioning will always be needed, but can be greatly reduced if building design minimizes overheating.

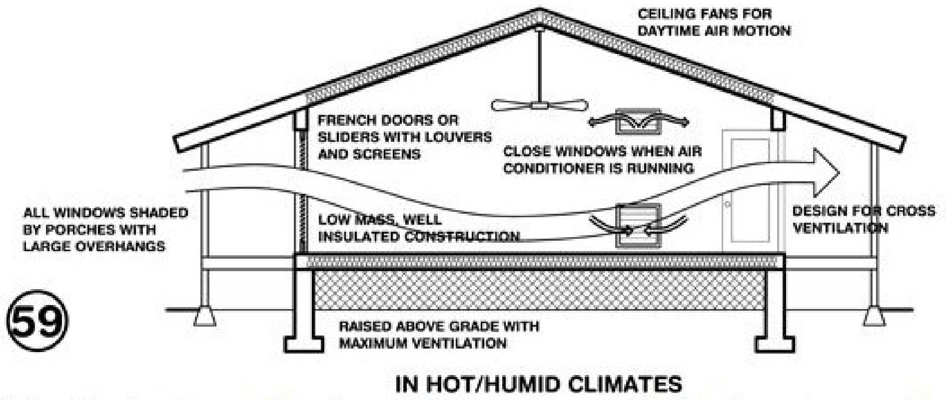


Fig 3.13

2) Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning.

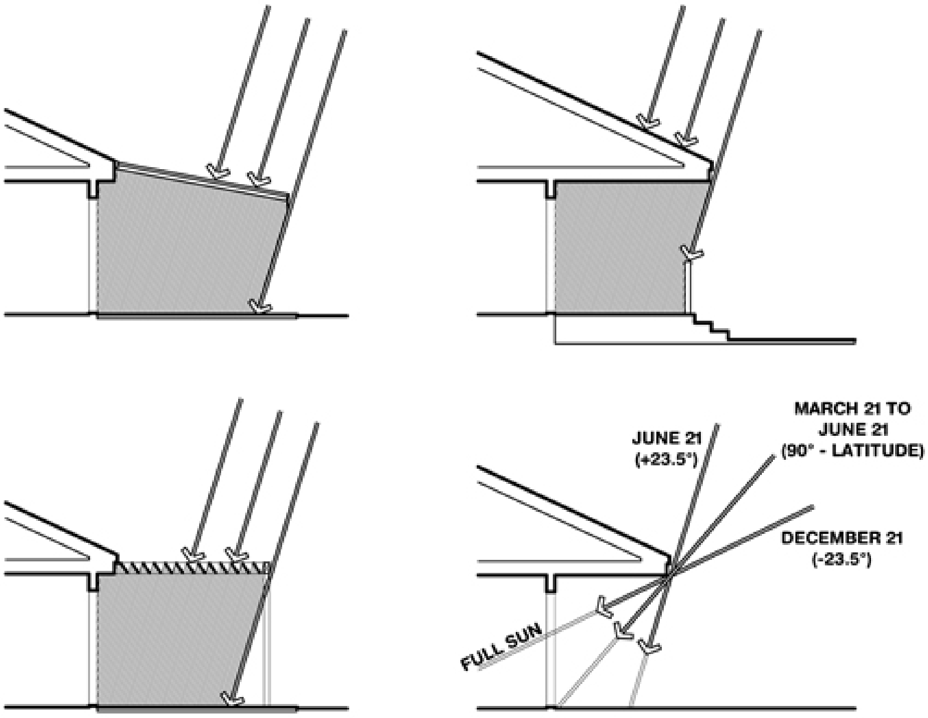


Fig 3.14

3) Traditional passive homes in hot humid climates used light weight construction with openable walls and shaded outdoor porches, raised above ground.

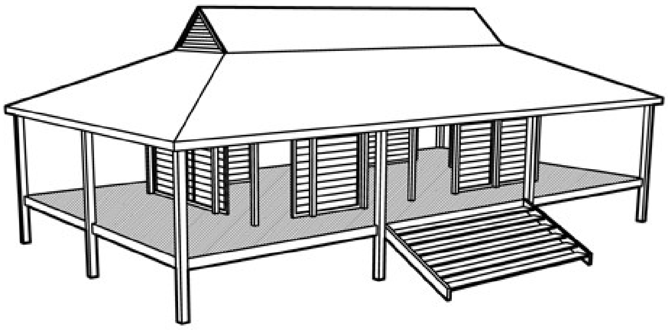


Fig 3.15

4) Traditional passive homes in warm humid climates used high ceilings and tall operable (French) windows protected by deep overhangs and verandahs.

Fig 3.16

5) Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain.

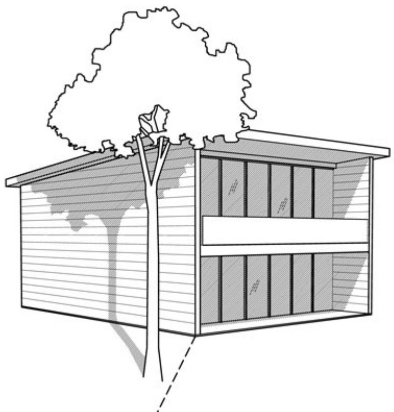


Fig 3.17

6) A radiant barrier (shiny foil) will help reduce radiated heat gain through the roof in hot climates.

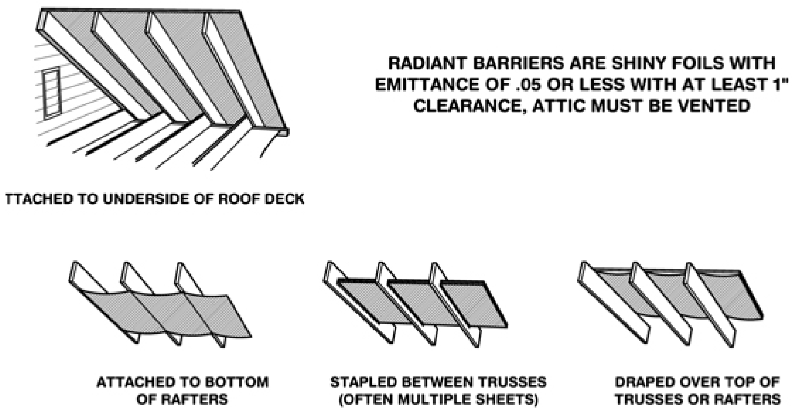


Fig 3.18

7) Use plant materials (bushes, trees, ivy-covered walls) especially on the west to minimize heat gain (if summer rains support native plant growth).

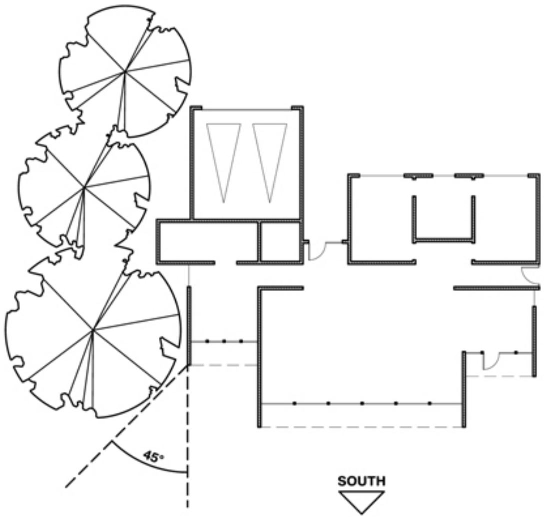


Fig 3.19

8) Orient most of the glass to the north, shaded by vertical fins, in very hot climates, because there are essentially no passive solar needs.

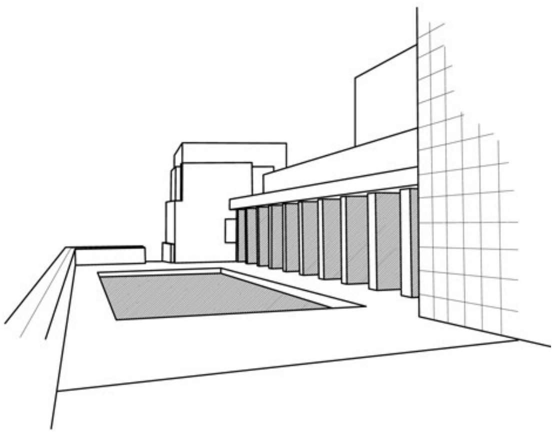


Fig 3.20

9) Screened porches and patios can provide passive comfort cooling by ventilation in warm weather and can prevent insect problems.

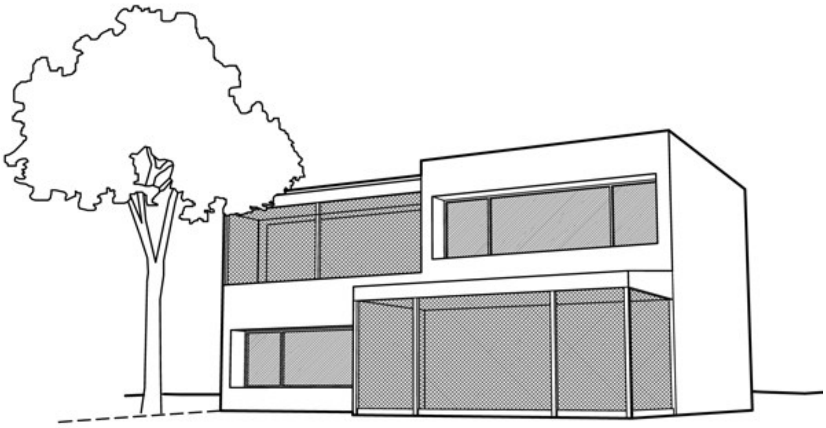


Fig 3.21

10) Use light coloured building materials and cool roofs (with high emissivity) to minimize conducted heat gain.

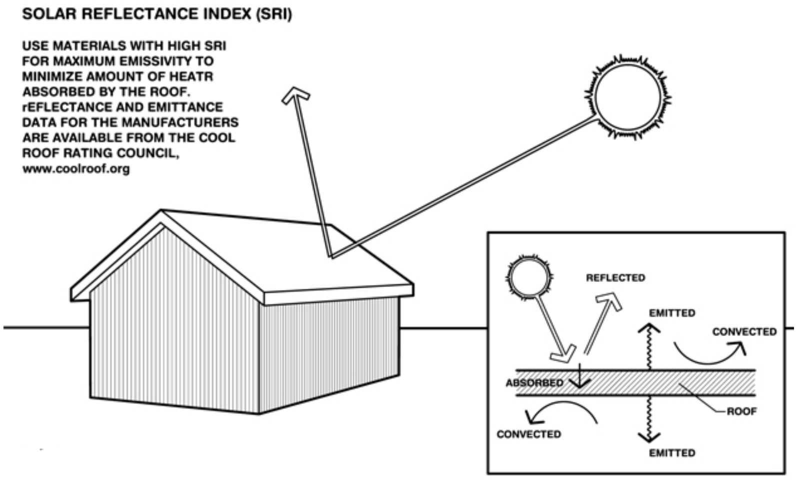


Fig 3.22

11) Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes.

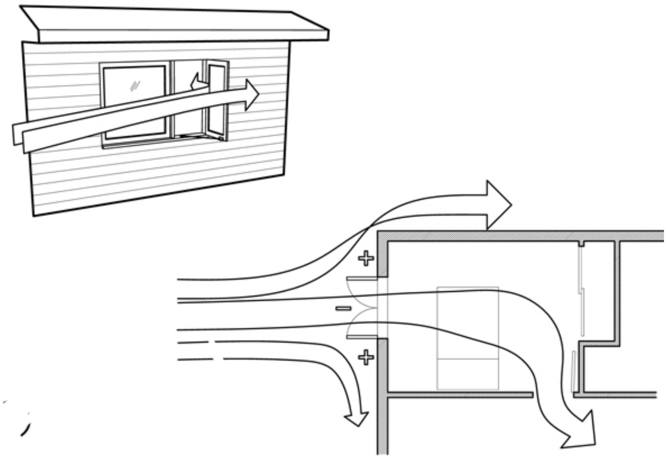


Fig 3.23

12) On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed.

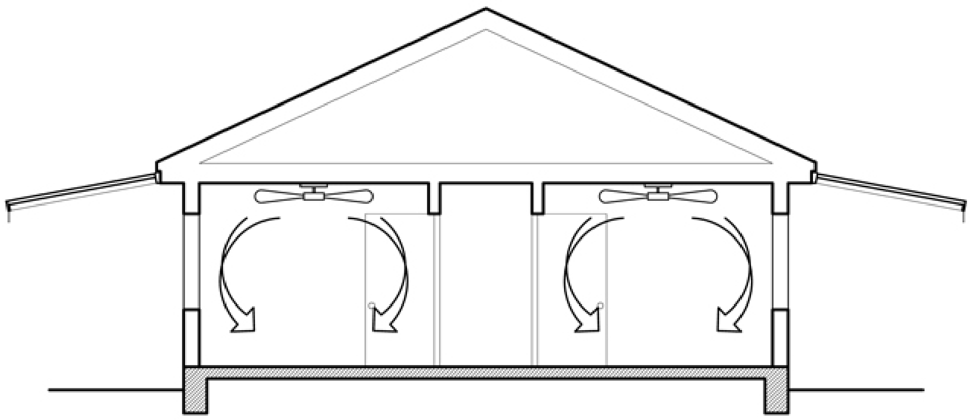


Fig 3.24

13) Long narrow building floorplan can help maximize cross ventilation in temperate and hot humid climates.
14) If soil is moist, raise the building high above ground to minimize dampness and maximize natural ventilation underneath the building.

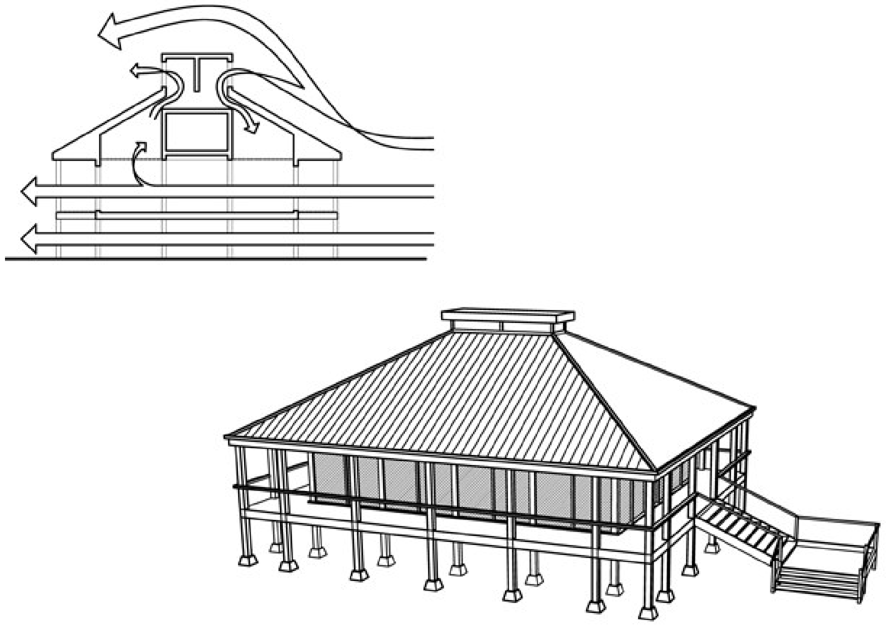


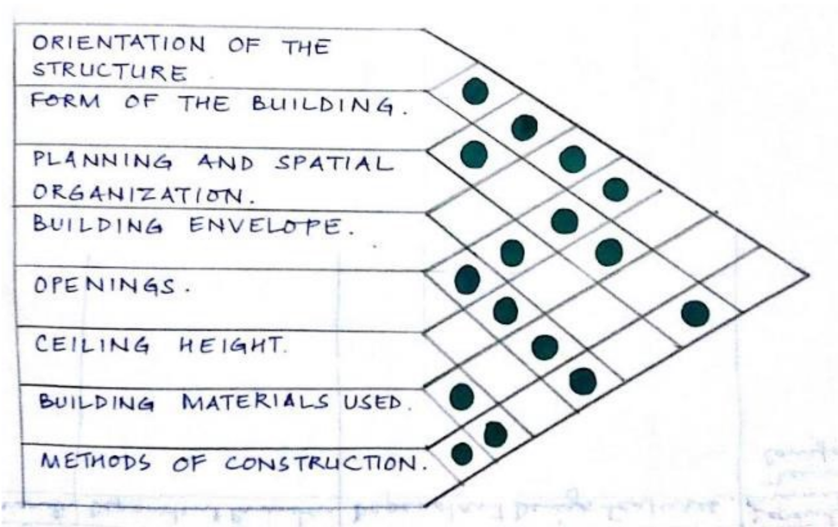
Fig 3.25

3.9 PARAMETER SELECTION AND RANKING

After going through a considerable number of literature on climate responsive architecture, including papers from MNRE and NBC, eight broad parameters were finalized.

- Orientation of the Structure
- Form, Planning and Spatial Organization
- Vegetation and Surroundings
- Building Envelope
- Openings
- Ceiling Height
- Building Materials
- Methods of Construction

This is as mentioned before, a "Broad" classification, with Specific Design Detailing discussed within each. Also, all these parameters are interdependent to each other, but the analysis is done giving each separate importance and value.



Interdependent Parameters

Fig 3.26

In order to rank these parameters and find their levels of importance in Architectural Design in the context of India, a questionnaire was prepared and an expert survey was conducted. This questionnaire was answered by architects and planners, practising as well as researching on sustainability, building sciences, energy efficiency and vernacular architecture. A total of 12 experts responded to this survey.

As a result of this survey, points were given to every parameter, and the total scoring was calculated in the end, thereby finding out which parameters are more important and which are not.

The entire analysis has been discussed below.

1. On a scale of 1-8, arrange the following parameters according to priority consideration in the design of a climate responsive structure, as per your opinion (with 1 being the most important).

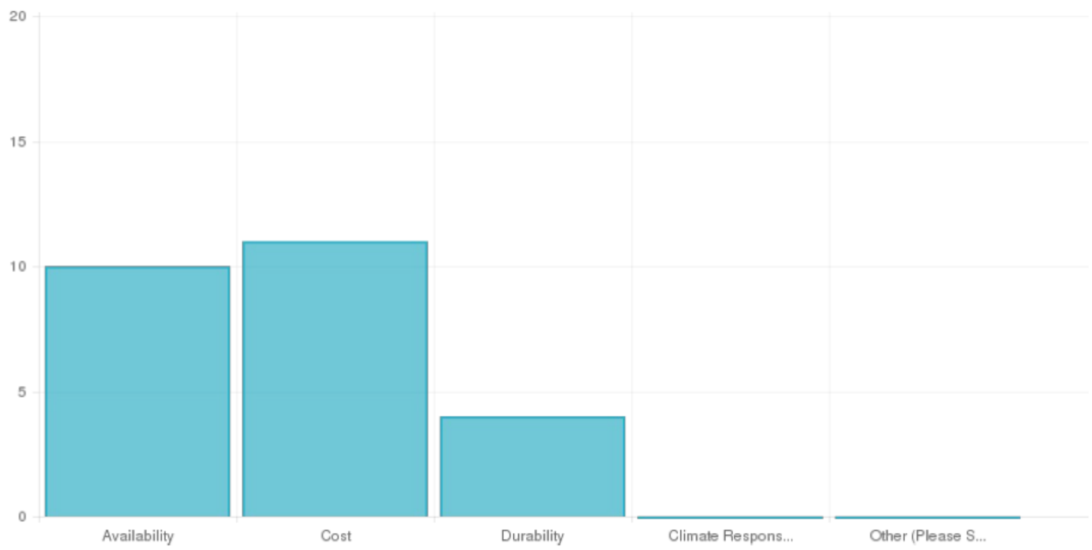
	1	2	3	4	5	Weighted Average	Score out of 8
Orientation of the Structure	0 (0%)	0 (0%)	2 (17%)	2 (17%)	8 (67%)	4.5 / 5	7
Form, Planning and Spatial Organization	0 (0%)	0 (0%)	2 (17%)	5 (42%)	5 (42%)	4.25 / 5	5
Vegetation and Surroundings	0 (0%)	0 (0%)	3 (25%)	4 (33%)	5 (42%)	4.17 / 5	4
Building Envelope	0 (0%)	0 (0%)	0 (0%)	5 (42%)	7 (58%)	4.58 / 5	8
Openings	0 (0%)	1 (8%)	1 (8%)	3 (25%)	7 (58%)	4.33 / 5	6
Ceiling Height	2 (17%)	1 (8%)	4 (33%)	3 (25%)	2 (17%)	3.17 / 5	2
Building Materials	0 (0%)	0 (0%)	0 (0%)	6 (50%)	6 (50%)	4.5 / 5	7
Methods of Construction	0 (0%)	1 (8%)	4 (33%)	5 (42%)	2 (17%)	3.67 / 5	3
						4.15 / 5	

Table 3.16

There is no 1 in the score because two parameters had the same score – Orientation and Building Materials, hence as per Rank to Score Methods, they are given the equal second highest point, and the last parameter gets a score of 2 instead of 1. Consequently, the scores of all other parameters in between, increases by 1 than the original rank.

2. Which of these factors primarily affect the building material used in the context of rural architecture in India?

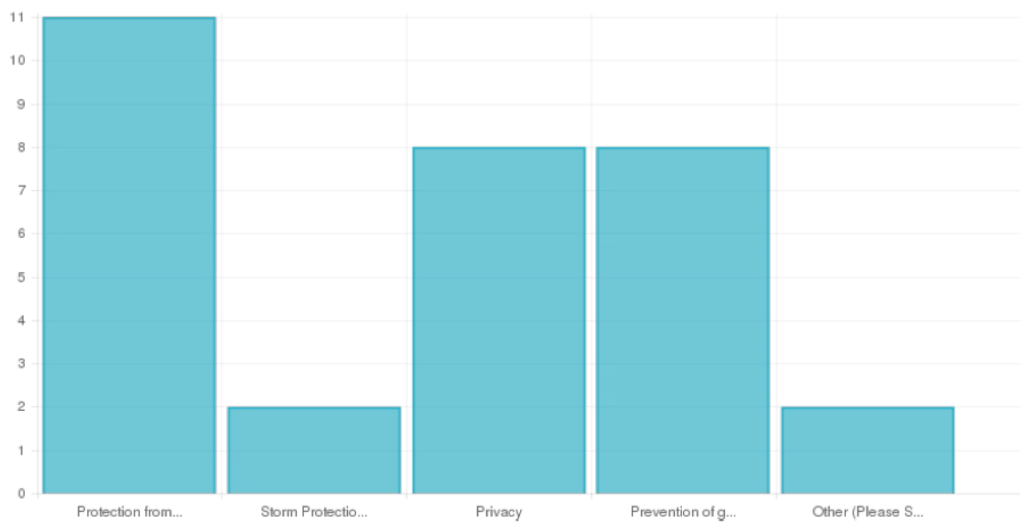
	Availability	Cost	Durability	Climate Responsiveness	Other (Please Specify)	Responses
All Data	10 (83%)	11 (92%)	4 (33%)	0 (0%)	0 (0%)	12



This result shows that Building Materials in India are majorly influenced by factors like cost and availability, and not on Climate responsive awareness and needs. Hence from Negating Theory, this parameter gets a score of (-1) while all others remain nullified.

3. What purpose do surrounding trees primarily serve in your designs?

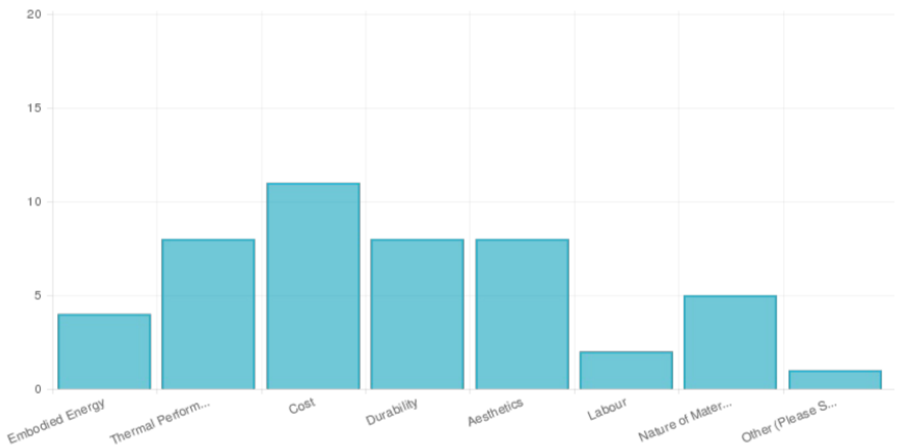
	Protection from Sun	Storm Protection	Privacy	Prevention of glare	Other (Please Specify)	Responses
All Data	11 (92%)	2 (17%)	8 (67%)	8 (67%)	2 (17%)	12



The result here indicates that surrounding trees i.e., Vegetation and Surroundings majorly protect from sun, and thereby prevent heat and glare, contributing to thermal comfort, and controlling the effect of climatic elements like solar radiation and temperature. Thus, from Positing Theory, Vegetation and Surroundings get a score of (+1) while other parameters remain nullified.

4. While constructing a home, which of these factors majorly influence the type of construction you choose?

	Embodied Energy	Thermal Performance (U-Value, R-Value)	Cost	Durability	Aesthetics	Labour	Nature of Material (Natural or Man made)	Other (Please Specify)	Responses
All Data	4 (33%)	8 (67%)	11 (92%)	8 (67%)	8 (67%)	2 (17%)	5 (42%)	1 (8%)	12



CLIMATIC FACTORS	SCORE	NON CLIMATIC FACTORS	SCORE
Embodied Energy	4	Cost	11
Thermal Performance	8	Aesthetics	8
Durability	8	Labour	2
Nature of Material	5		
	Total = 25		Total = 21

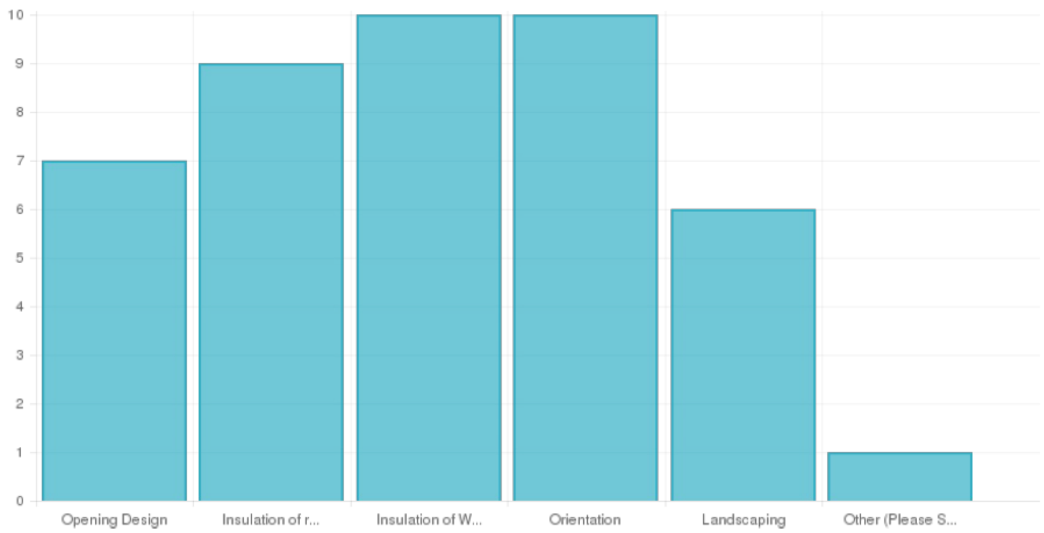
Here, the difference = 25 - 21 = +4

Table 3.17

Climatic Factors clearly dominate. Thus, both the associated parameters- Building Materials and Methods of Construction will have a score of (+4).

5. As an architect, which of the following strategies have you used in you previous design, that help reduce energy consumption?

	Opening Design	Insulation of roofs	Insulation of Walls and Floors	Orientation	Landscaping	Other (Please Specify)	Responses
All Data	7 (58%)	9 (75%)	10 (83%)	10 (83%)	6 (50%)	1 (8%)	12



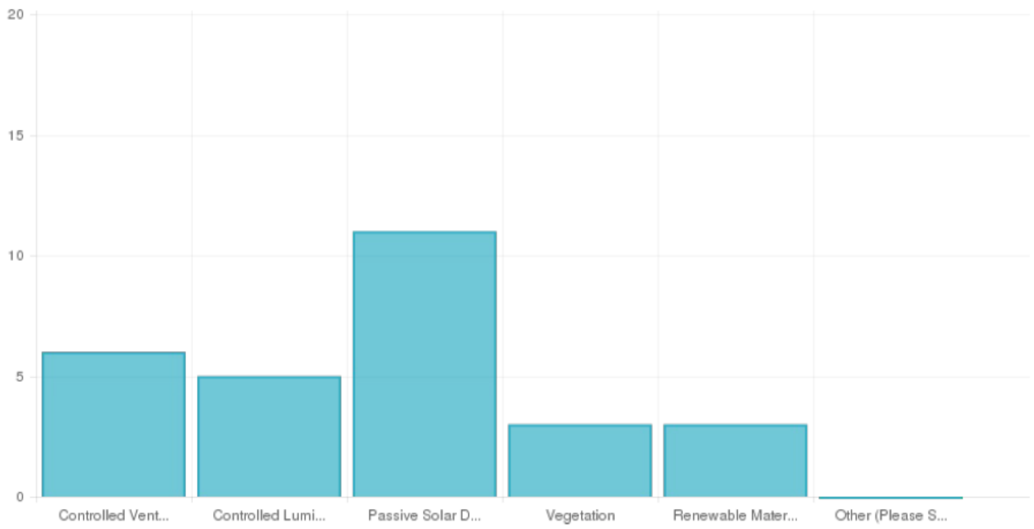
Factor	Parameter	Responses	Score
Opening Design	Openings	7	3
Insulation – Walls and Roofs	Building Envelope; Building Materials	9; 10	BE – 5; BM – 4
Orientation	Orientation	10	5
Landscape	Vegetation and Surroundings	6	2

Table 3.18

From Response to Score Method, the parameters Building Envelope and Orientation get the highest score of 5, while others decrease by 1. And the last parameter gets a score of 2 instead of 1.

6. Out of the following, which are the main climate responsive concerns you try incorporating every time in your design?

	Controlled Ventilation	Controlled Luminescence	Passive Solar Design	Vegetation	Renewable Materials	Other (Please Specify)	Responses
All Data	6 (50%)	5 (42%)	11 (92%)	3 (25%)	3 (25%)	0 (0%)	12



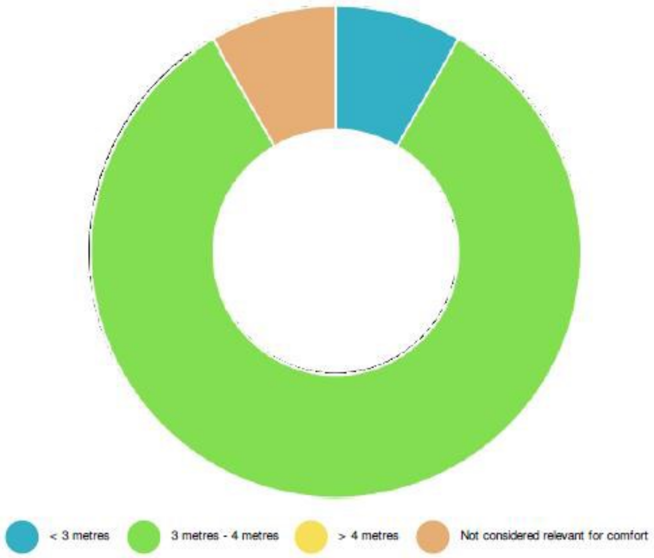
Climate Responsive Concerns	Parameters	Responses	Score
Controlled Ventilation	Openings; Orientation	6	OP -4
Controlled Luminescence	Openings; Orientation	5	OP -4
Passive Solar Design	Orientation; Building Envelope; Methods of Construction	11	OR -5; BE -5; MOC -5
Vegetation	Vegetation and Surroundings	3	VS -3
Renewable Materials	Building Materials	3	BM -3

Table 3.19

Again here the results are obtained from Response to Score theory, with the highest three parameters getting a score of 5 and the others decreasing gradually, with two parameters having a score of 4 and two having a score of 3.

7. What ceiling height do you usually give for small domestic structures to make indoor conditions comfortable?

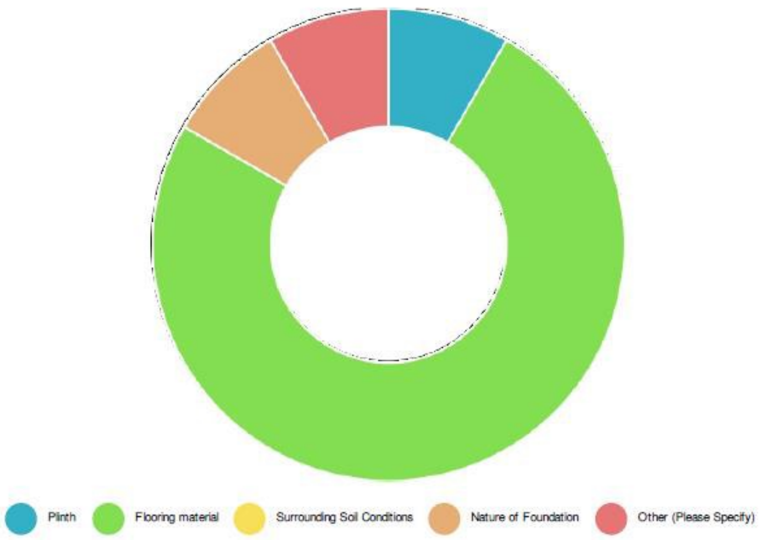
	< 3 metres	3 metres - 4 metres	> 4 metres	Not considered relevant for comfort	Standard Deviation	Responses
All Data	1 (8%)	10 (83%)	0 (0%)	1 (8%)	4.06	12



Avg. Ceiling Height preferred is 3m – 4m. Hence, the two Parameters associated get 1 point each – Ceiling Height and Method of Construction.

8. Which of these factors do you primarily keep in mind while designing flooring?

	Plinth	Flooring material	Surrounding Soil Conditions	Nature of Foundation	Other (Please Specify)	Standard Deviation	Responses
All Data	1 (8%)	9 (75%)	0 (0%)	1 (8%)	1 (8%)	3.32	12



Factors	Parameter	Responses	Score
Plinth	Methods of Construction	1	MOC -2
Material	Building Material	9	BM -3
Soil Conditions	Vegetation and Surroundings	0	VS -0
Foundation	Method of Construction	1	MOC -2
Material Availability	Building Material	1	BM -3
Insulation	Building Envelope	1	BE -1

Table 3.20

9. Out of 5, mark the following ancillary factors according to their level of significance in affecting the thermal comfort and indoor air quality, as per your opinion (with 1 being the least important).

	1	2	3	4	5	Standard Deviation	Responses	Weighted Average
Water Bodies	0 (0%)	1 (8%)	4 (33%)	6 (50%)	1 (8%)	2.24	12	3.58 / 5
Urbanization	1 (8%)	0 (0%)	2 (17%)	6 (50%)	3 (25%)	2.06	12	3.83 / 5
Altitude	1 (8%)	2 (17%)	2 (17%)	4 (33%)	3 (25%)	1.02	12	3.5 / 5
Ground Properties	4 (33%)	0 (0%)	3 (25%)	3 (25%)	2 (17%)	1.36	12	2.92 / 5
								3.46 / 5

Factor	Parameter	Score
Water Bodies	Vegetation and Surroundings	3
Urbanization	Form, Planning and Spatial Organization	4
Altitude	Vegetation and Surroundings	3
Ground Properties	Vegetation and Surroundings	3

Table 3.21

10. On a scale of 1-5, arrange the following factors affecting the building materials used according to their level of significance (with 1 being the most significant), in the Indian Rural context.

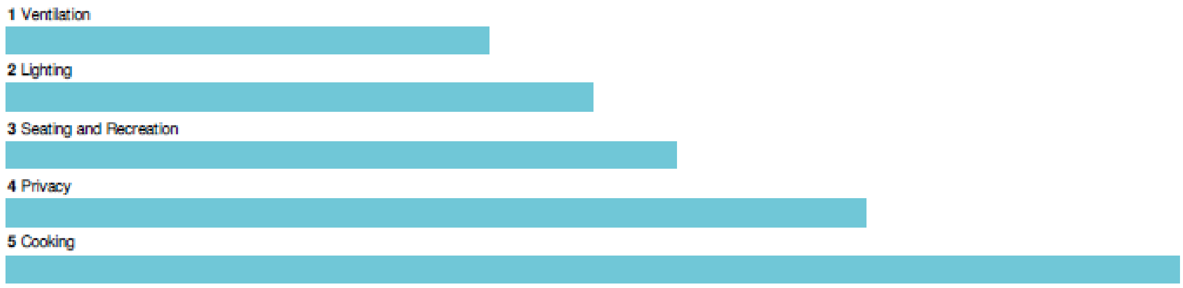
Climatic Factors	SCORE	Non Climatic Factors	SCORE
Longevity	3	Cost	4
Recycling Capacity	4	Availability	5
		Labour Skill	2
	Total = 7		Total = 11

Table 3.22

Here, the Difference = 7 – 11 = (-4)

Clearly, non-climatic factors dominate here. Thus, the associated parameter- Building Materials will have a score of (-4).

11. On a scale of 1-5, arrange the following uses of courtyards according to their level of significance (with 1 being the most significant), in the Indian Rural context.



Climatic Factors	SCORE	Non Climatic Factors	SCORE
Ventilation	5	Recreation	3
Lighting	4	Privacy	2
		Cooking	1
	Total = 9		Total = 6

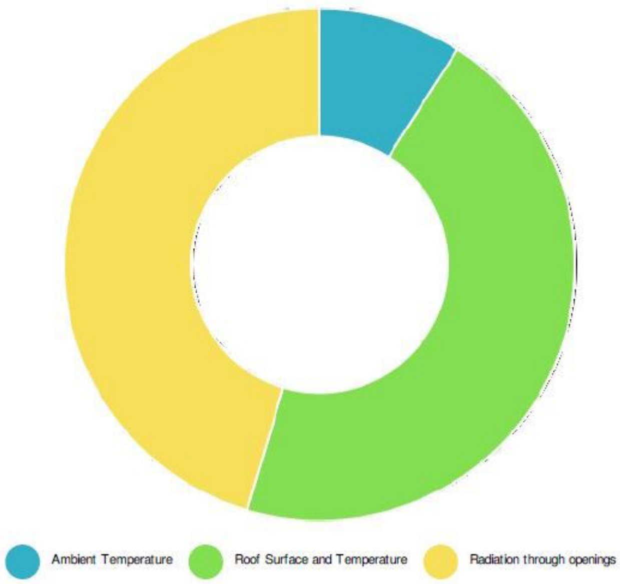
Table 3.23

Here, the Difference = 9 – 6 = (+3)

Clearly, the climatic factors dominate here. Thus, the associated parameters- Orientation, Openings and Form, Planning and Spatial Organization will have a score of (+3).

12. Luminescence affects the comfort conditions of a house in warm humid climate. Which of these variables get affected the most according to you?

	Ambient Temperature	Roof Surface and Temperature	Radiation through openings	Standard Deviation	Responses
All Data	1 (9%)	5 (45%)	5 (45%)	1.89	11



Factors	Parameter	Responses	Score
Ambient Temperature	Form, Planning and Spatial Organization	1	1
Roof and Surface Temperature	Building Envelope	5	5
Radiation through openings	Openings	5	5

Table 3.24

From Direct Response Method, the number of responses here are converted into scores, thereby giving the different scores to different parameters mentioned in the table above.

13. Out of 1-4, rank the following design strategies as per their effectiveness in managing excessive wind flow (with 1 being the most essential point of consideration).

Strategy	Parameter	Ranking
Opening Size	Openings; Building Envelope	2
Opening Cover	Openings	4
Orientation	Orientation	1
Barriers like vegetation and boundaries	Vegetation and Surroundings	3

Table 3.25

Thus,

Orientation Score = 4

Openings Score = 3

Building Envelope Score = 2

Vegetation and Surroundings Score = 1

14. On a scale of 1-5, arrange the following design considerations according to their level of significance (with 1 being the most significant), for the construction of openings in a warm humid climate.

Strategy	**Parameter**	Ranking	**Score**
Opening Size	Openings	2	4
Opening Filters	Building Envelope	4	2
Shutter Material	Building Material	5	1
Opening Orientation	Orientation	1	5
Position of other Openings	Form, Planning and Spatial Organization	3	3

Table 3.26

15. In your opinion, select the boxes in the columns of the parameters which are affected by lighting and ventilation mentioned on the left.

For e.g., if you think Lighting affects the selection of Building Materials, mark the matrix accordingly.

	Orientation	Form and Planning	Vegetation & Surroundings	Building Envelope	Openings	Ceiling Height	Building Materials	Methods of Construction
Lighting	○	○	○	○	○	○	○	○
Ventilation	○	○	○	○	○	○	○	○

	Orientation	Form and Planning	Vegetation & Surroundings	Building Envelope	Openings	Ceiling Height	Building Materials	Methods of Construction	Standard Deviation	Responses
Lighting	1 (8%)	**4 (33%)**	0 (0%)	3 (25%)	4 (33%)	0 (0%)	0 (0%)	0 (0%)	1.73	12
Ventilation	3 (25%)	3 (25%)	0 (0%)	0 (0%)	**4 (33%)**	2 (17%)	0 (0%)	0 (0%)	1.58	12

Parameter	Score For Lighting	Score For Ventilation	Total
Orientation	5	7	12
Form, Planning and Spatial Organization	7	6	13
Vegetation and Surroundings	0	4	04
Building Envelope	6	3	09
Openings	8	8	16
Ceiling Height	0	5	05
Building Material	0	0	00
Method of Construction	0	0	00

Table 3.27

16. In your opinion, select the boxes in the columns of the parameters which are affected by the factors of thermal comfort mentioned on the left.

For e.g., if you think Relative Humidity affects the design of Openings, mark the matrix accordingly.

	Orientation	Form and Planning	Vegetation & Surroundings	Building Envelope	Openings	Ceiling Height	Building Materials	Methods of Construction
Air Temperature	○	○	○	○	○	○	○	○
Surface Temperature	○	○	○	○	○	○	○	○
Relative Humidity	○	○	○	○	○	○	○	○
Air Velocity	○	○	○	○	○	○	○	○

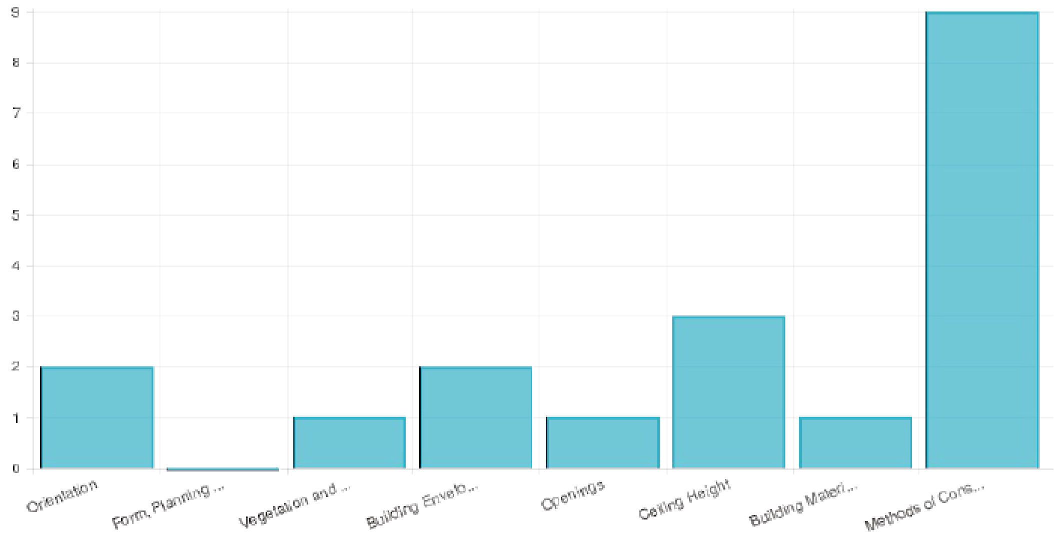
	Orientation	Form and Planning	Vegetation & Surroundings	Building Envelope	Openings	Ceiling Height	Building Materials	Methods of Construction	Standard Deviation	Responses
Air Temperature	1 (8%)	2 (17%)	0 (0%)	**4 (33%)**	4 (33%)	0 (0%)	1 (8%)	0 (0%)	1.58	12
Surface Temperature	0 (0%)	2 (17%)	1 (8%)	4 (33%)	0 (0%)	0 (0%)	**5 (42%)**	0 (0%)	1.87	12
Relative Humidity	1 (8%)	1 (8%)	3 (25%)	0 (0%)	**6 (50%)**	1 (8%)	0 (0%)	0 (0%)	1.94	12
Air Velocity	**4 (33%)**	3 (25%)	0 (0%)	0 (0%)	3 (25%)	2 (17%)	0 (0%)	0 (0%)	1.58	12

Parameter	Air Temp.	Surface Temp.	RH	Air Velocity	Total
Orientation	5	0	5	8	18
Form, Planning and Spatial Organization	6	6	4	7	23
Vegetation and Surroundings	0	5	7	0	12
Building Envelope	8	7	0	0	15
Openings	7	0	8	6	21
Ceiling Height	0	0	6	5	11
Building Material	4	8	0	0	12
Method of Construction	0	0	0	0	00

Table 3.28

17. Effective Temperature, defined as still saturated temperature, which would in the absence of radiation produce the same effect as the atmosphere in question, has its scale of measurement varying with temperature, humidity and air movement. Which of these parameters do not affect the Effective Temperature?

	Orientation	Form, Planning and Spatial Orientation	Vegetation and Surroundings	Building Envelope	Openings	Ceiling Height	Building Materials	Methods of Construction	Responses
All Data	2 (17%)	0 (0%)	1 (8%)	2 (17%)	1 (8%)	3 (25%)	1 (8%)	9 (75%)	12



Parameter	Score
Orientation	2
Form, Planning and Spatial Organization	0
Vegetation and Surroundings	1
Building Envelope	2
Openings	1
Ceiling Height	3
Building Material	1
Method of Construction	9

Table 3.29

Final Calculation

Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Total**
Orientation	7				5	5					3	5	4	5	12	18	2	66

Form, Planning & Spatial Organization	5								4		3	1		3	13	23	0	52
Vegetation and Surroundings	4		1		2	3			3			1	1		4	12	1	32
Building Envelope	8	-1			5	5		1				5	2	2	9	15	2	53
Openings	6				3	4					3		3	4	16	21	1	61
Ceiling Height	2						1								5	11	3	22
Building Material	7			4	4	3		3		-4				1	0	12	1	31
Methods of Construction	3			4		5	1	2							0	0	9	24

Table 3.30

Rank	Parameter
1	Orientation
2	Openings
3	Building Envelope
4	Form, Planning and Spatial Organization
5	Vegetation and Surroundings
6	Building Material
7	Method of Construction
8	Ceiling Height

Table 3.31

From the ranking hence obtained, the first five parameters are the most important, hence taken into account and further analysis of a vernacular structures will be done with these parameters in consideration. However, it is essential to note that the remaining three parameters fall into the selected five categories in some way or the other, and therefore, are not being ignored. The only thing is that they are not being taken into account separately with individual identities.

This ranking, along with the recommendations inferred from Mahoney Tables and Climate Consultant, will act as tools, and thereby, help in developing the inventory/ data sheet for the site visit and consequent analysis in terms of climate responsiveness of the vernacular structures.

3.10 PARAMETER ANALYSIS

Based on all the study conducted above, the following inferences were taken out about the eight design parameters selected. These conclusions intend to help in building an inventory for sample study on site.

Parameter	Dependent Parameters	Dependent Climatic Factors	Dependent Design Features
Orientation of the structure	Openings; Form, Planning and Spatial Organization; Vegetation and Surroundings; Building Envelope	Wind; Precipitation; Solar Radiation; Sky Conditions	• Design & Placement of Openings • Internal Planning • Form of Building • Overhangs
Openings	Orientation; Form, Planning and Spatial Organization; Vegetation and Surroundings; Building Envelope	Temperature; Humidity; Wind; Precipitation; Solar Radiation; Sky Conditions	• Size, profile and positioning of doors and windows • Ventilative Provisions • Overhangs • Verandahs
Building Envelope	Orientation; Vegetation and Surroundings; Openings;	Temperature; Humidity; Precipitation; Solar Radiation; Sky Conditions	• Light, insulated roofs • Protection from heavy rain necessary

	Building Materials; Methods of Construction		• Walls and Floors – Light, low thermal capacity • Roofs – Reflective surfaced, cavity
Form, Planning and Spatial Organization	Orientation; Vegetation and Surroundings; Openings; Ceiling Height; Methods of Construction	Humidity; Wind	• Spread out Plans • Courtyard Plans preferable • Form intended to channelize winds
Vegetation and Surroundings	Orientation; Form, Planning and Spatial Organization; Building Envelope; Openings; Building Materials	Humidity; Wind; Sky Conditions	• Effective shading for the walls and windows. • Ground cover by plants to reduce the reflected solar radiation
Building Material	Form, Planning and Spatial Organization; Vegetation and Surroundings; Building Envelope; Ceiling Height; Methods of Construction	Temperature; Solar Radiation	• Materials with low U values preferable to prevent the heat from entering inside • Smooth and light colour for exterior to help reflect the solar radiation
Method of Construction	Form, Planning and Spatial Organization; Building Envelope; Building Materials	•	-

Table 3.32

CHAPTER 4

- EVALUATION & CONCLUSION –

Recommendations for the five most important Parameters

Orientation of the Structure

Building orientation determines the intensity of solar radiation falling on the walls and roofs of the building, and the ventilative effectiveness of the building openings.

Optimal Orientation

Thermal Considerations -

For minimizing solar gains,

- Elongate North and South Walls, creating a prominent East-West Axis.
- East and West walls and glazing should be minimized, as they receive longer periods of and stronger radiations.

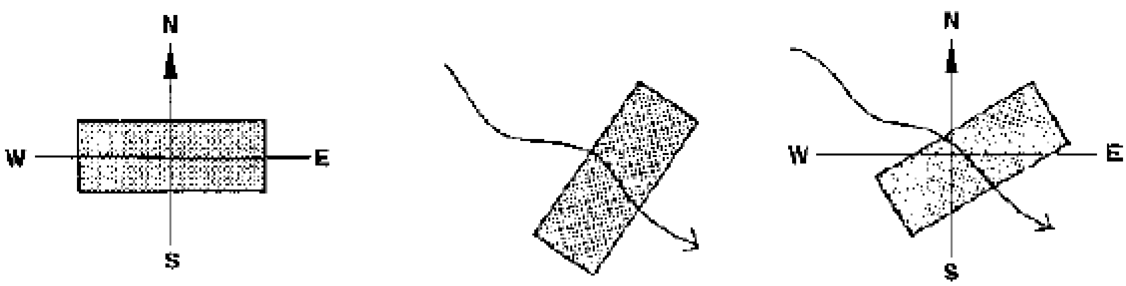
Ventilative Considerations -

To achieve highest avg room velocity in which air movement occurs in all occupied parts of the room,

- Largest pressure difference occurs when the building is perpendicular to the prevailing wind.
- One room deep plans are preferrable.

If a building is well insulated, light coloured and effectively shaded then the change in internal temperature is negligible. The ventilation would have a great effect on conditions. Inlets for natural ventilation can be designed more easily to accommodate for less optimal wind orientations than solar control devices.

For warm humid climates,



Sun Orientation | Wind Orientation | Compromised

Fig 4.1

Shading of the east and west elevations is difficult because of the low sun, and may require special devices; whereas the south and north

Thus the best orientation for protection from the sun is along the east-west axis.

Sides can easily be protected by an overhanging roof.

Poor orientation can be compensated partially by detailed design of façade and windows, as well as interior planning.

Where a predominant wind direction can clearly be identified, long-shaped buildings should be arranged across this direction.

Often the above two parameters are contradictory. In this case, a reasonable compromise should be made based on a detailed analysis of the specific situation, considering the possibilities for diverting the wind direction by means of vegetation and structural arrangements, such as parapet walls within the external adjoining space.

Openings

In warm-humid zones, openings should be as large as possible, and the view directed to surrounding grass or trees, with the sky blocked by roof overhangs or sun breakers. Air circulation should not be blocked by vegetation. An airtight construction is not needed.

Outlet openings should be located at high levels, where hot air accumulates.

Bedroom windows are best placed at the height of the bed or pivoted to direct the airflow towards the sleeping body. Louvres are a suitable accessory to assist the channelling of airflow. (In the hot period, windows must be protected from solar radiation and glare. In the cold season, however, solar heat gain through openings is desired. Hence, shading devices should be movable, which involves a somewhat complicated mechanism and also the attendance of the inhabitants.

Windows should be of medium size with openings on opposite walls for proper cross-ventilation during the humid period.

On the west and north side windows should be small. As a rule of thumb, the total window area should not exceed 25% of the floor area.

In upland areas, as many windows as possible should be located on the south side of the building to utilize the heating effect of solar radiation.

However, the glazed area should not exceed 50% of the south elevation because of extensive heat loss at night.

Excessive glazing can lead to overheating. This can be counteracted by

- The provision of adequate shading,
- The provision of ventilation,
- Sufficient heat storage capacity.

Windows should be equipped with tightly closing glazed panels, which provide protection against heat loss during the cold season and also against flow of heat and dusty air during the dry and hot season.

Protection against cold winter winds should be balanced by proper ventilation during hot and humid periods. Therefore, regulated air movement is a primary requirement. This can be achieved by well-planned openings with shutters.

Preferably, special openings for ventilation should be provided. Two small openings, one at a high level and one at a low level, or ventilating stacks may be solutions. The disadvantage of such special arrangements lies in the fact that they are often neglected by the inhabitants, with the result that warm or cold air enters the room at undesired times. The warmer the climate and the higher the humidity, the more important is it to provide cross-ventilation

Building Envelope

Walls-

Walls, both external and internal, should be as light as possible with a minimal heat storage capacity. These should obstruct the airflow as little as possible and should reflect radiation, at least in places where solar radiation strikes the surfaces.

The outer surface should be reflective, light coloured.

Walls should be shaded as much as possible. If, however, exposed to the sun, they should be built in the form of a ventilated double leaf construction, the inner leaf having a reflective surface on its outer side and perhaps with thermal insulation.

Light and thin materials such as timber or, even better, bamboo matting are recommended. Other materials forming light panels can be used, together with a frame structure to take care of the structural requirements.

The cooler the climate, the better the thermal insulation and air-tightness of the outer walls should be. A medium heat storage capacity of internal and outer walls is appropriate to avoid overheating in the daytime and keep the night temperature at comfort level.

Walls do not need extra shading devices in this type of climate, provided they possess reasonably good insulation and reflective properties.

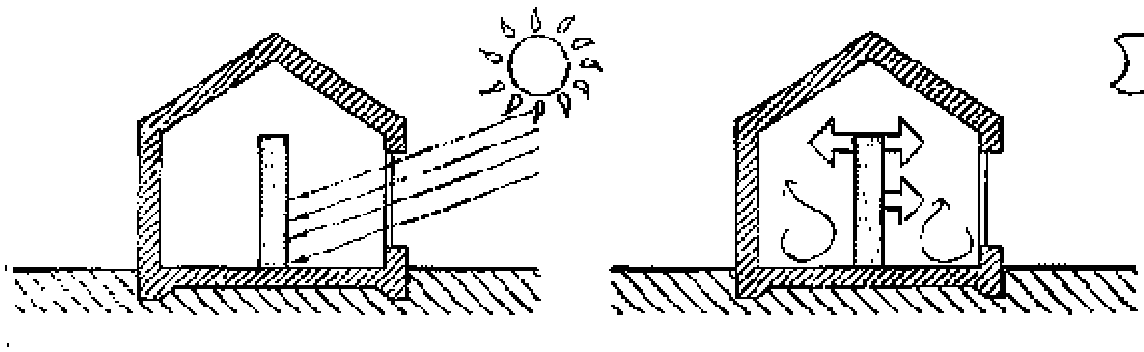


Fig 4.2: Internal walls as collector and heat storage mass

Floors-

Conduction is of practical importance in the choice of flooring materials, especially where people usually sit on the floor.

Basements and floors generally have a large thermal storage capacity and can therefore act as a climate regulating element. It depends on the specific climatic conditions, whether these properties are an advantage or whether the rooms have to be insulated against it.

Direct contact with the ground does not necessarily provide cooling because the temperature of the shaded surface is about equal to the mean air temperature. A certain cooling may only be possible by conduction for barefooted persons or persons sitting on the floor.

As a consequence, it is better to raise the floor and ventilate the space underneath. The floor should be of low thermal capacity (e.g. timber floor with void). The advantages are better ventilation due to the elevated space and maximum benefit of the slightly lower night temperature.

The floor may also be in direct contact to the ground, with medium insulation and thermal storage capacity. In upland regions, materials with low thermal transmission properties are suitable (e.g. timber). In addition, thermal insulation may be required. Floor areas receiving direct solar radiation should possess absorption properties and a heat storage capacity.

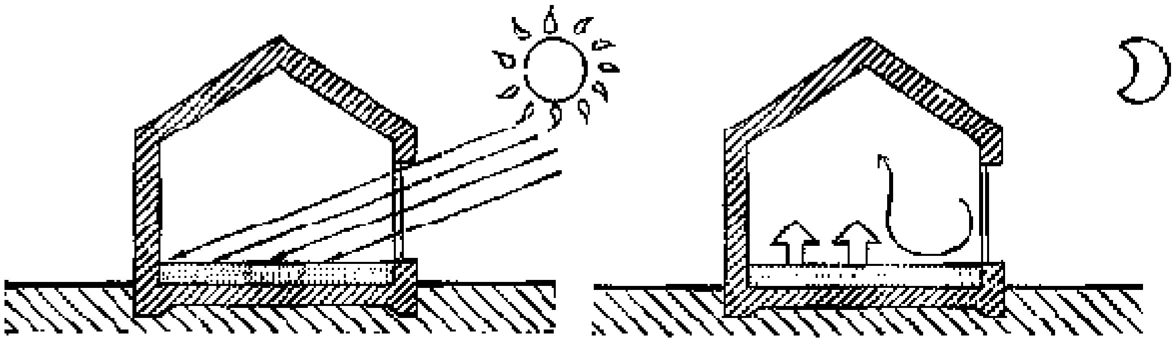


Fig 4: Floor as collector and heat storage mass

Roofs-

The design of the roof is of the utmost importance. The fact that the roof receives the greatest amount of solar radiation and re-radiates most at night is a further reason for the importance of roof design.

A typical example of the effect of the roof design on inside temperatures is the plain concrete roof slab under a tropical sun which can result in an unbearable indoor climate in the evening, with inside surface temperatures of up to 50 or 60°C.

The most important element is the roof because the strongest thermal impacts of heat loss and heat gain occur here. The roof is the part of the building receiving most of the solar radiation, and its shading is difficult. Therefore, this building part should be planned and constructed with special care. Naturally, this applies to single story buildings and to for the top floor of buildings only.

The thermal performance depends to a great extent on the shape of the roof and the construction of its skin, whereas the carrying structure has little influence.

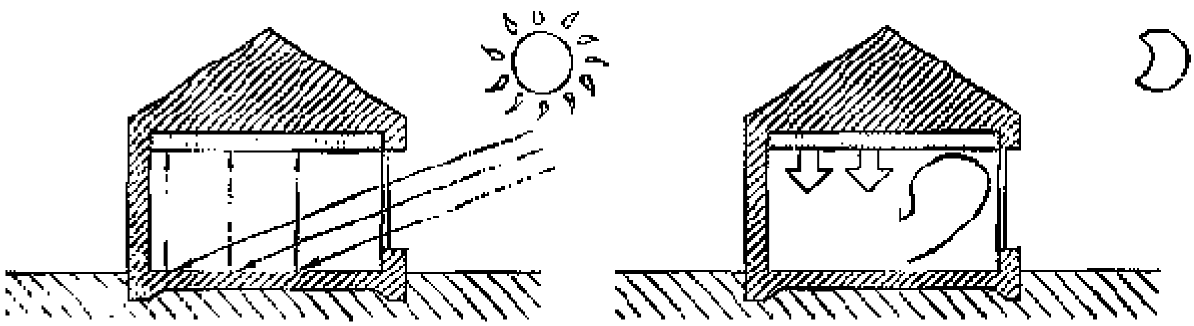


Fig 4.3: The ceiling as collector and heat storage mass

The shape of the roof should be in accordance with precipitation, solar impact and utilisation pattern (pitched, flat, vaulted, etc.)

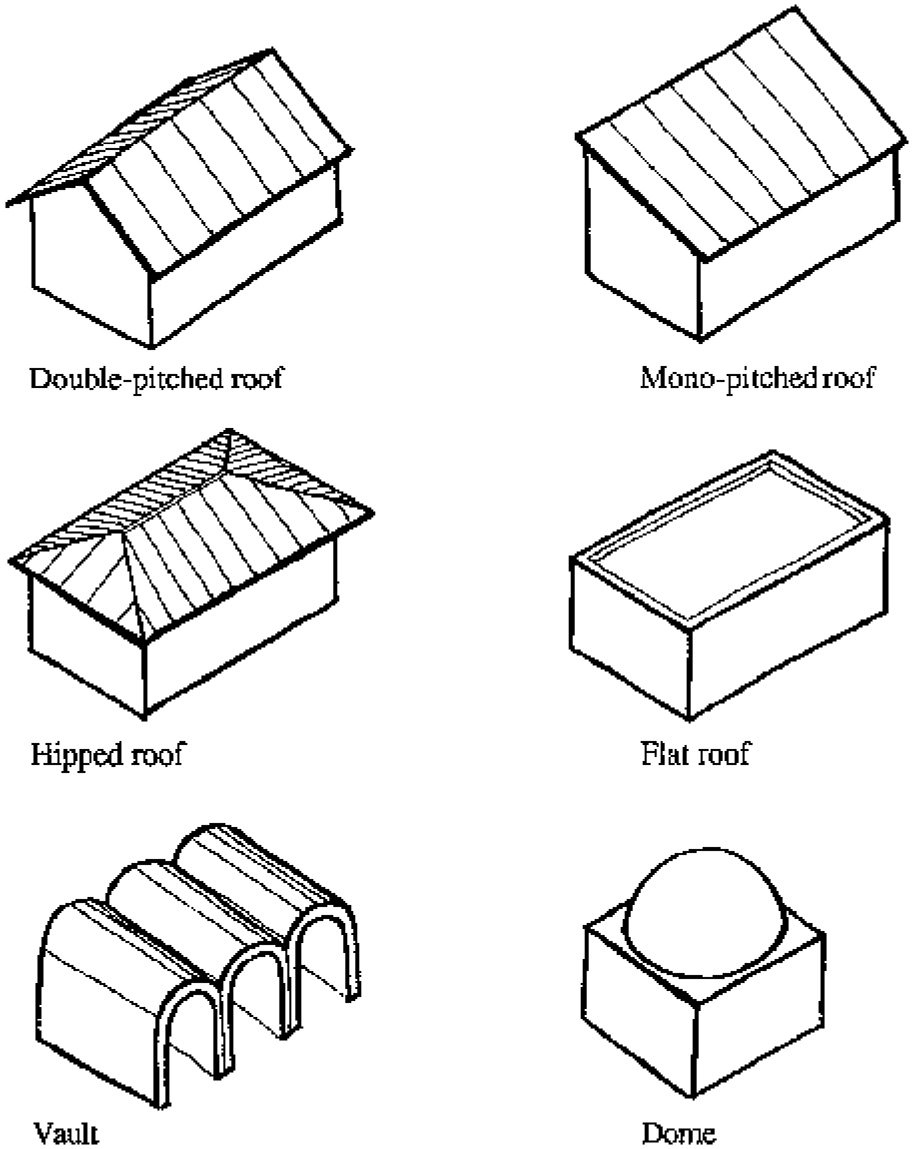


Fig 4.4: Types of Roofs

To keep roofs cool, they should be sloped towards the prevailing breeze and any obstructions which would prevent the airflow along the roof surfaces should be avoided. High solid continuous parapet walls around the roof would, for example, create a stagnant pool of hot air, and should, therefore, be avoided.

The appropriate design of floors, walls, roofs and openings varies greatly with different climatic zones. Solutions cannot therefore be generalised and have to be worked out according to the individual situation as well as to basic physical principles.

<u>Form, Planning and Spatial Organization</u>

The main design objectives which affect the form of the building are –

i. To provide maximum shade in summer and adequate heat gain in winter.
ii. To minimize reflection (indirect solar radiations) in sheets and open spaces.
iii. To plan narrow winding alleys and streets, which are shaded and relatively cool, and which break stormy winds but allow thorough ventilation and adequate sunlight and natural lighting.
iv. To design suitable building forms

Form cannot change the regional climate, but can moderate the area's microclimate and improve the conditions for the buildings and their inhabitants. Settlements in warm humid areas should be laid out to make maximum use of the prevailing winds. Buildings should be scattered, vegetation arranged to provide maximum shade without hindering natural ventilation.

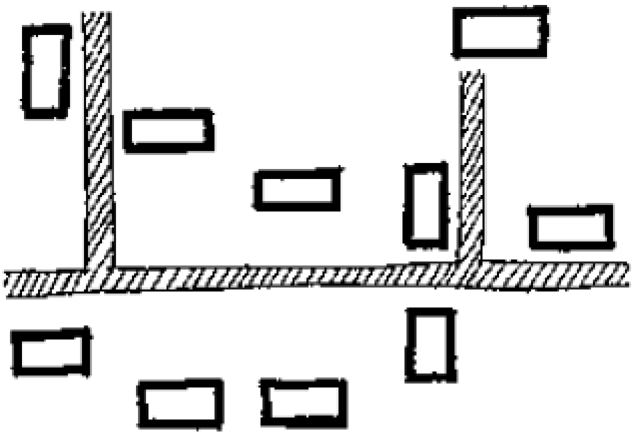


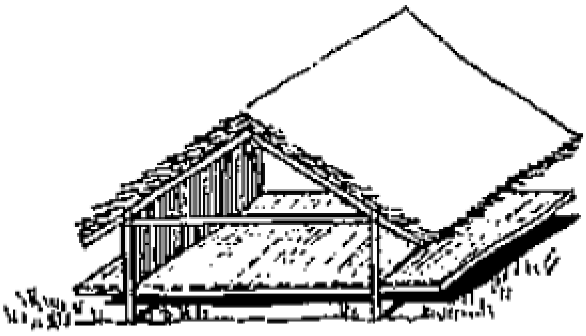
Fig 4.5: Typical settlement for warm-humid regions

Although modern requirements are often in contradiction to traditional patterns, their advantages should be adapted as far as possible.

In general, where little heat exchange between the interior and the environment is desired, the surface to volume factor should be small. The indoor temperature will be near to the average outdoor temperature.

Where heat exchange is desired, for instance to gain from cool nights in warm-humid areas, the surface to volume factor should be bigger. This also favours a higher ventilation rate.

The suitable form of buildings differs very much between the main climatic zones. Traditional regional dwelling types illustrate this clearly.



- Spread out forms
- Buildings preferably compact.

However, because of the conflicting climatic conditions, several solutions are possible, depending on local topographical conditions and functional requirements.

Vegetation and Surroundings

The properties of the ground surface cover also influence the climate. Bare or denuded surfaces store little or no humidity, but absorb solar heat radiation and heat up. Surfaces covered with vegetation heat up much less, and thus have a regulating effect on the temperature and increase humidity. The more intense the vegetation, the greater is its balancing effect.

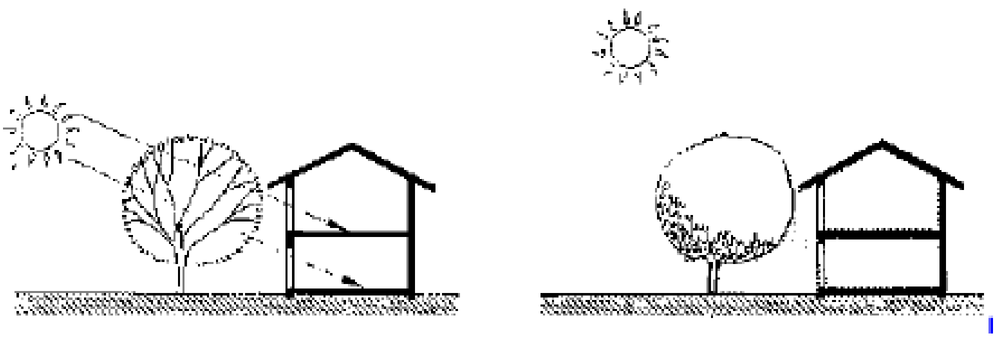


Fig 4.6: Deciduous trees provide access to winter sun but protect against summer sun

Designs using vegetation in the urban environment are of functional, aesthetic as well as climatic importance for its radiation absorbent surface and its evaporative and shade-giving properties. The vegetation in and around cities also has definite effects on air movement.

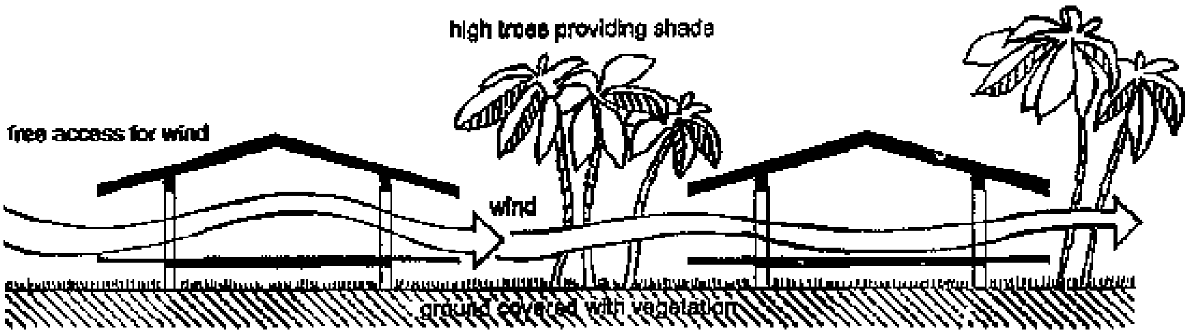


Fig 4.7

Vegetation is desirable both for providing shade, thus reducing the temperature in such shaded areas, and for reducing the effects of strong solar radiation on the walls of buildings and structures. Also, by forming a thick barrier of foliage, the velocity of strong wind is reduced. The foliage of different types of wooded land (e.g. hedges) acts as a filter and purifies the atmosphere by keeping down dust.

Advantages of vegetation

Landscaping using vegetation has many advantages:

• It improves the microclimate both outdoors and indoors.

• It checks hot and dusty winds in arid regions.

• Through the transpiration of leaves temperatures are lowered.

• Its shade lowers daytime temperatures and heat emission at night is also reduced, thus resulting in more balanced temperatures.

• It balances the humidity. During precipitation much of the free water is absorbed and during dry periods water is evaporated.

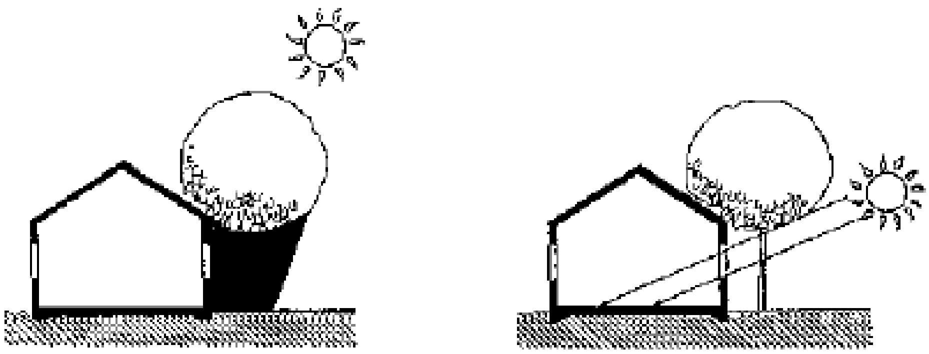


Fig 4.8: Tree close to a building

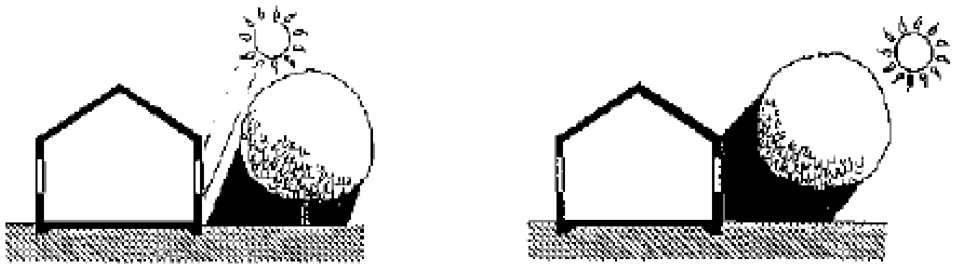


Fig 4.9: Tree far from a building

Conclusion

This entire analysis and set of recommendations is gathered and put down from different pieces of literature on the subject, to form a base for further study. It will help in creating an inventory and adding to its specifications and requirements.

Also, this ranking aims to help the researcher to understand the levels of importance of various parameters, and consequently, study them in reference to the site and the samples.

This research therefore deciphers and documents the various passive cooling techniques feasible in a specific climatic condition, namely Southern Bengal, and thereby identify optimal technologies and design solutions from vernacular architecture for a warm humid climate of the same kind.

A set of design parameters useful in achieving ideal comfort conditions within a building, have been fixed and ranked as per their levels of importance. Further this ranking will be used to analyse the possible design solutions in warm humid climate and check their practicability in terms of the climate of South Bengal.

The inferences from this research may help future researchers, historians, architects and planners to cope with and judiciously utilize the interaction between local architecture and energy conservation in the context of creating a successful building design.

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