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Climate Responsive Vernacular Buildings in Hilly Regions, Tamilnadu, India

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The evolution of the poombhari settlement is distinctly referred to the timeline where occupants settled down orienting their habitat with response towards climate, context and materials. In this study the Bioclimatic Principles at the settlement level and Climatic design principles were identified in various housing typologies through study, documentation and analysis. The dwellings comprise of thick walls, sloping roofs, smaller openings and building typologies adopted passive design strategies. These traditional typologies were documented based on passive features like spatial planning, Orientation, Materials and Construction techniques, with respect to climatic design principles. This study analyses the architectural typologies and its elements in order to establish the relationship between the site context, dwelling units, materials and climate. Furthermore, the study identifies the Architectural style of hilly region and calls for the norms and practise of traditional ones rather than modern construction as many of the building are replaced by modern architectural techniques.

Keywords: Building Envelope, passive design strategies, bioclimatic principles, cold climate, hill settlement, Vernacular architecture

1. Introduction

Energy consumption in buildings is the highest challenge faced in India. Most of the buildings consume more energy since they are not responding to local climate and context. The skins of the buildings look similar in their visual Language irrespective of the context they are designed. The contemporary buildings designed in Hilly regions are highly challenging due to

contours, terrain and contrary climatic conditions. From the Literature it was found that the vernacular buildings designed in hilly regions of India are Environment friendly and in current scenario the contemporary buildings are designed with latest Construction materials and are contextually inappropriate and causes damage to the Surrounding Environment. Several scientific studies have established that by passive strategies Vernacular Architecture across all climatic Zones has achieved better thermal performance (11-14). In India, the traditional construction practices were forgotten due to modernisation and the need for fast construction of buildings with latest technologies and materials for the growing population without considering Environmental conditions. Subsequently, the rural houses and the Environmental Knowledge systems are vanishing and there is a need to study and document the construction practices. The major challenge found is that the professionals and builders need to understand importance of Context Specific sensitive development in Hilly regions and try to integrate the Sustainable Principles in Hilly regions. Maria Philokyprou et. al (2017)(1) assessed the Environmental design approaches of rural settlements and the vernacular dwelling typologies as a representative case study in the various contextual regions of cyprus. The Environmental design strategies like building typology interrelationships, hierarchy of semi open and open spaces configuration, materials and construction techniques were studied in all climatic zones. the results showed that bioclimatic design features used in the vernacular dwellings acts as a model for sustainable Approach in each climatic zone. Ashwani Kumar et. al (2013)(2)stressed the need for formulating appropriate building regulations for hill settlements by adopting the vernacular principles which has a greater potential for contextual and sustainable development. Susanne Bodach et. al (2014)(3) reviewed and analysed the bioclimatic principles of Vernacular Houses and its building elements across varied climatic zones in Nepal qualitatively. Vissilia Anna-Maria (2009)(4) studied, documented and analysed the Greek Vernacular Settlement, Sernikaki focussing on Bioclimatic Design Principles. The aim of the paper is to study, document and analyse the Vernacular Settlement and the various built typology in the hilly region of kodaikanal focussed on its Bioclimatic Principles. This paper discusses the sustainable principles observed in the study area in two major sections- Section I of the paper deals with bioclimatic concepts found in the settlement and street level and the second part deals with passive design principles observed and studied in varied building typologies like Building materials and construction techniques, planning concepts with respect to climate.

2. Literature Study

Several vernacular practices and architectural styles have evolved over the years in designing communities and constructing buildings for local people, utilizing locally available and environmentally friendly materials through indigenous building construction techniques. The objective of these local practices and styles aims to provide protection against weather condition and natural disaster. The vernacular settlement in hilly areas is designed to accommodate the unique topography, climatic condition and locally available materials specific to their regions. Ashwani Kumar et. al (2013) stressed the need for sustainable development of hilly settlement requires utilization of local materials, emphasis on thermal comfort, environmentally sensitive design, reduced spatial footprint, and contextually appropriate development. Kishan Data Bhatta et al. (2023)(5)documented and analysed

significant changes in the vernacular settlements of the Rana Tharu in Far Western Nepal, including shifts in settlement patterns, housing forms, construction materials, and architectural details. They emphasize the need to raise local awareness about cultural and architectural identity. Stakeholders, including local governments, should focus on studying vernacular architecture and promoting the use of indigenous technologies and materials to preserve and enhance local architectural, artistic, and cultural identity.Kadek Merta Wijaya et al 2021(6) reviewed the architectural orientation of the vernacular settlement as a literature review in the highland, coast, mount/highland context of Indonesia. The settlement reveals a diverse range of orientation and spatial planning influenced by contextual factor and cultural significance. These orientations carry dual meanings of logic and symbolic representing the practical consideration of context, climate and sustenance of economic activity and connection to god. These findings highlight the spatial awareness of the local people that benefits them in fulfilling fundamental human and economic needs. M.K.Singh et al 2014 (7)carried out a study in vernacular architecture of Northeast India to find out different solar passive features that exist in various bioclimatic zones of the region. The Bio climatic features like built form, orientation, Built Envelope, shading, openings, Spatial organisation and activity pattern were studied in all bioclimatic zones. The results shows that all the bioclimatic zones of the region serves as a best example for bioclimatic design and demonstrates an optimal balance between local Context, Climate, materials and Construction techniques. Utilizing local materials offers advantages such as climatic adaptability, extended life span and economic benefits while also providing environmental benefits in maintaining comfortable indoor environment, reduces energy consumption, low production impact and improved seismic resilience. These practices were inherited by the local builders of the region for providing thermally comfortable indoor spaces and to improve energy efficiency of the building.The comprehensive review done by S.S Chandel et al 2016 (8) in review identified an emerging Architectural Style for the Himalayan region by incorporating passive solar features, building materials and construction techniques and the study highlighted the appropriateness of using vernacular materials and styles in Modern Buildings for achieving Thermal Comfort. Agugilaro et al 2015 (9) extensively studied the bio climatic characteristics of traditional architecture across various climatic regions and its unique approaches to design, planning and spatial organization. Ngygen et al 2011(10) examined the climatic design strategies of Vietnam's vernacular architecture highlighting their effective adaptation to the local climate. Six traditional houses from three distinct climatic regions were examined for analysing bio-climatic strategies and the study found that the natural ventilation, building orientation, shape and solar shading were the most effective strategies for passive indoor thermal comfort in Vietnam. The study emphasized implementing bio climatic guidelines will enhance the indoor comfort and reduce energy consumption for heating and cooling of the building. Currently, Hill Settlements are facing tremendous pressure for development. The quality of the living environment has deteriorated due to unsuitable modern practices for quick construction by neglecting the importance of traditional practices and methods. As a result, environmental knowledge practices and system are disappearing. However, carrying out the study to document and analyse the bioclimatic principles with various building typologies and materials at kodaikanal can suggest the advantages of vernacular settlement and importance of climatic factor while designing houses in context of hilly settlement of the region.

3. Methodology

In the first stage of the Study the authors documented and analysed the Bioclimatic principles like hierarchy of streets, Spatial Planning, degree of Enclosure at the Settlement level of the village and the second stage deals with documenting and analysing the passive design principles of various Building Typologies like Orientation of the buildings, Building Envelope, Openings, Construction techniques and spatial planning(Figure -1).

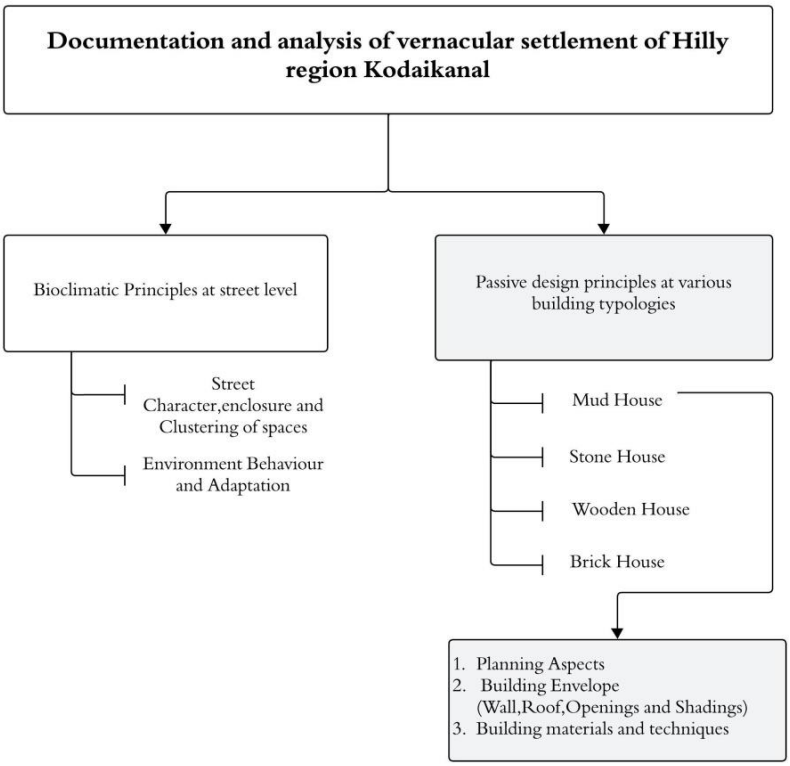


Figure 1. The research methodology adopted

Poombharai: A vernacular settlement in Kodaikanal, Tamilnadu

Location and History

Kodaikanal is a hill station situated in the Palani Hills at an average elevation of 2100m at 10degree 14'N, 7729'E. Human habitation in the Palani Hills is believed to date back to 3000BCE. Villages around Kodaikanal such as Poombharai, Vilpatti and Mannavanur are all older than the Town of Kodaikanal itself. Poombarai village is located in the heart of the Palani Hills which is around 18kms from Kodaikanal. The settlement pattern reflects a precolonial style of communities segregated by streets. The village entry is emphasized by two long narrow stone pillars with a horizontal slab across the top. The entry to the Village has breathtaking views and vistas of the valley and the village surrounded by sloped farming, colors of the soil, forest and vegetation, water falls, natural patterns created by the terraces and

contours were found to be most attractive elements of this Hilly region. Agriculture is the occupation for the people of Poombarai. Garlic is the main crop and the farmers store these crops inside the ceiling of their house.

Hill Settlements in Kodaikanal

The settlements are located in Southern slopes to receive maximum radiation and protection from cold winds. The settlements are designed with response to the context and lies in harmony with the contour. The Traditional settlements follow linear pattern of streets designed on the contour with row type houses with sloped roof facing the street with wall-to-wall construction. These buildings also have lower footprints with less ground coverage and the buildings are oriented to receive maximum radiation and minimum cold winds. The buildings are mostly rectangular in shape and constructed with vernacular materials like Mud, Stone, Wood and Brick. The Spatial pattern of settlement and street along contour, Planning and Organisation of houses to receive solar exposure, Low footprints and ground coverage, Locally available materials and construction technology and development according to site and surroundings will lead to contextual appropriateness of the settlement.

Climatic Analysis

According to Climate Classification of India, the climates are normally designated as hot dry, warm humid, moderate, cold and composite. Kodaikanal comes under Cold Climate and the below table gives maximum and minimum temperature and Humidity. Table 1 shows a maximum temperature of 27degC and a Minimum of 18 deg C during summer and a maximum of 22deg.C and minimum of 15deg.C during winter and relative Humidity varies from 60% to 80% (Table-1).

	J	F	M	A	M	J	J	A	S	O	N	D
Dry Bulb Temp(average monthly) °C	19.4	21	22.7	23.8	23.8	21.5	21	20.8	20.8	20.2	19.4	18.9
Minimum Temp °C	14.5	15.4	16.7	18	18.5	18.2	17.8	17.4	16.9	16.8	16.3	15.1
Max Temp °C	23.7	25.6	27.6	28.4	27.8	26	25.4	25.4	25.6	24.5	23	22
Relative Humidity average monthly) (%)	72	64	63	68	77	83	83	81	82	82	81	80

Table -1 Weather Data

Present day scenario

Today, the settlement of Poombharai has undergone various transformations. The prototype houses studied, i.e., mud, stone, and wooden houses, are the outcome of traditional knowledge and practices designed to perform with respect to the climatic condition of the region. The spatial planning of the houses studied was designed as per passive design techniques, but in the last few decades, the spatial form of Poombharai has undergone fast transformation. High thermal mass materials are replaced with lighter construction to enable quick construction and reduce space. Currently, the walls of the newly built house are 230 mm thick or much lighter with cement mortar. The roofs are either R.C.C. 150mm thick without any insulation on the top or galvanized iron sheets. Moreover, the sizes of the windows are becoming larger, allowing cool breezes to enter the house and increasing heat loss from the building during the

night when the outside temperature drops. Few of the newly constructed houses are built with little consideration of climatic aspects, but they highly depend on mechanical systems or electrical control for providing thermal comfort. The occupants living in concrete roofed houses and galvanized iron sheets experience higher thermal discomfort. The local construction techniques are replaced by modern construction due to the reduced workmanship of vernacular practices. As a consequence, thermal comfort is diminishing, and the buildings have become lighter. The consideration of specific guidelines, regulations, and codes for preserving and restoring vernacular settlements has to be precisely set. However, in addition to the construction of traditional dwelling units, restoration and extension of existing units with proper guidelines must be established to avoid disuse and decay. The architectural practices of the settlement need an understanding of traditional architecture by incorporating guidelines that provide recommendations on orientations, building envelopes, size of openings which serves as an example of Bioclimatic principles.

Poombharai Settlement

Poombharai has architecturally evolved in terms of its vernacular style by using locally available resources and skilled craftsmanship. One of the key considerations in the design and site planning of the settlement has been protecting the building from cold climate, The Village poombharai has developed according to the natural setting of the contour. The Spatial organisation of various spaces has shaped uniquely over the generation of user due to the caste-based influence of the settlement pattern. Each street is defined by the Unique entrance Gate made of Stone or wood. The streets of the settlement play a significant role due to the interaction spaces at the entrance created at each house. The linear clusters are one of the interesting characters found with open and closed spaces of the streets. In terms of spatial character and evolution the first settlement existed in the highest point of the valley which is the periyar hamlet near nedutheru. Later after the establishment of the temple streets the layout of settlement evolved connecting the temple as a nuclei. Recently, housing expansions is found around the temple premises and are oriented towards the natural contour setting.

The spatial organisation defines a clear visual connectivity with stepped stairs which acts a pedestrian to reach the subdivided streets of the settlement from the main street. The entire streets of the settlement open up to the agricultural field. The streets and buildings are designed as per the human scale. In order to maximise heat gain the entire settlement is exposed to solar radiation which is incorporated at street level and building level.The prominent activity of the settlement is agriculture and the entire area is characterised by vegetation. The settlement maintains a uniform skyline along the street where the height of the building is too small in relation with the width of the street in order to avoid mutual shading. The design strategies of Cool climate were followed in the settlement to provide comfort to the users by preventing heat loss from the buildings and the vernacular typologies were designed to receive maximum solar heat gain and the fenestrations were designed to prevent heat loss. The settlement was found to be compact in nature and the dwellings connected by narrow pathways and located above the contour.

Streets, Enclosure and clustering of Spaces

The street of Poombharai acts an open court where majority of the activities like washing utensils, drying clothes, interaction, cooking, recreational and of such kind happens as the

street is exposed to sun's radiation. Each street is defined by an entrance with doors which acts as threshold between public and private spaces. The street edges are designed by the raised platform called thinnai which acts as a sun space where people gather for socialising and interaction. The villagers had in depth knowledge about the existing natural resources and the building were constructed without affecting the environment by following sustainable design principles and practices. The main circulation spine of the settlement is defined by an entrance and the pathway leds to the stepped stairs due to the natural contour and topography. The secondary spine branches out from the main primary spine which has a unique defined entrance to all the streets. Primordial consideration in development of the street and building is to protect the people from winter cool breeze. The street was oriented along east west direction where most of the building has their longer axis facing the eastern direction. As Poombharai is located in a colder region the horizontal shading is not essential to enable various activities to be conducted in the streets. The entrance of all the houses were opened to streets without the high compound walls in order to receive the maximum solar radiation. The settlements were compact in nature with high density and row typologies were identified without setbacks and wall to wall construction of houses were observed in the streets to prevent the heat loss. Streets in poombarai acts as a main living space where all the household activities like washing vessels, kids bathing spill over the streets due to solar exposure (Figure-2 and 3).

Environment Behaviour and Adaptation

The people of Poombarai adapted well to the existing context and climate. The people spent most of the Time outdoors in order to receive the solar radiation which is needed in cold climate. The people wear two layers of clothing due to cold winds and mostly move to sunny region when they are not comfortable and the occupant open and close the doors and windows based on their comfort during day and night. Most of the occupants sit in thinnai (raised platform) in front of their house and all the household activities happen in outdoor for their thermal comfort. They are adaptable and balance all activities indoor and outdoor based on climatic characteristics they experience. For example, the occupants sleep in ground floor or

Fig 2 and Fig 3: Overview and Plan of the settlement

First floor based on the Environmental characteristics which gives them thermal relief during Cool season

Study and Documentation

Mahoney Table: Design Recommendations based on Cold Climate

Poombharai Vernacular habitats are evaluated based on Mahoney's design variable which supports the development of climate responsive buildings. One of the Main criteria which were analysed were building envelope which includes wall construction, thickness of the materials, roofing detail sand the spatial layout of the building. Using Mahoney table the climate data are incorporated which provide preliminary climatic design strategies. They are categorised under eight headings layout, spacing, air movement, openings, walls, roofs, outdoor sleeping and rain protection. Recommendation for Poombharai is as follows i) Layout: The layout Orientation of the building as per east-west axis ii) Spacing: Compact planning to prevent from hot and cold wind iii) Air Movement: Permanent provision for air movement with single banked rooms vi) Openings: to be provided as very small opening of 10-20% of wall area v) Heavy external and internal walls for the wall plane vi) Roofs: Light, insulated roofs vii) No space for outdoor sleeping viii) Rain Protection: From heavy rain is required.

Typologies of houses

In poombarai varied typology of houses were identified based on the principles of Spatial Planning and organising, sociological and cultural aspects. Each typology is unique with respect to planning aspects, materials and technology, decoration and style and the architectural detailing of each house varied with respect to the sociological and cultural aspects. The house plan lies in synchronisation of varied activities of the occupant. Each street and houses has certain symbolism and decoration to identify them. Four varied typology of houses were found in Poombarai like stone houses, Mud houses, Wooden Houses and Brick Houses. The construction of the houses was categorized as kucha, semi pucca and pucca. Of the representative samples chosen 24% of the households had kucha houses and the semi pucca houses were as high as 59% and only 17% of them were pucca houses. The houses were well maintained structurally as it could be seen as high as 59% of them were of good condition and 41% of them were of average condition. The interiors of the houses are designed to support the daily activities of the people of Poombarai. It is sequentially arranged to their activities with respect to time. Since the people of Poombarai are agriculturist space to store the resource like a rice barn, small air tight shelves are seen. The house plan in the settlement varied in its details and spatial functions. Maximum all the houses in poombharai incorporated local vernacular style of architecture to suit the user's requirements made with local materials, climate efficient and is economical in nature. The Physical form of the houses are influenced by social, economic aspects which are mostly climatic responsive (Table-2).

	Mud House	Stone House	Wooden House	Brick House
Type of settlement/ pattern	Linear pattern of settlement	Linear pattern of settlement	Linear pattern of settlement	Linear pattern of settlement
Layout	Compact	Compact	compact	Row
Building Shape	Rectangular shape	Rectangular shape	Rectangular	Rectangular
-Planning	One room all activities – cooking, eating and dining	Ground Floor is used for ccoking, eating. First floor – Sleeping, storage Wooden stairs leads to first floor	One room all activities – cooking, eating and dining	Ground Floor is used for ccoking, eating. First floor – Sleeping, storage Wooden stairs leads to first floor
Building Orientation	EW	EW	EW	EW
Number of stories and height	1 2.4m	2 5.5m	1 3.5m	2 5.3m
openings	Small wooden windows in the entry	Minimal openings	Very less openings	Average window openings

Ceiling	Low	Low	Double wooden ceiling	Low
Solar Shading	Less	Not available	less	Less
Natural Lighting Techniques	Poor	poor	poor	poor
Sun Spaces	Veranda / streets	Present -front verandah	Veranda and streets	Veranda , streets
Wall Material and thickness	Mud Wall of Abode and 40 to 60 cm	Stone wall – 45 -50cm	Thin wall	Brick wall – 45cm
Roof material and Thickness/ roof overhang	Single Pitched roof/ less projected eaves	Single pitched roof/no eaves	Single pitched roof/small eaves	Single pitched roof/large eaves
Floor and Ceiling openings	Low ceiling/Very small	Low ceiling /Very small	Low ceiling /Very small	Low ceiling /very small
Color	Natural color of Mud	Natural color of stone	Natural color of wood	Natural color of Brick
Aspect Ratio	1	1.3	1.4	1.5
Passive Techniques Heating Strategies	Compact Building Configuration -Protects from lower temperatures and cold winds during winter Very Small openings to avoid heat losses- prevent the infiltration of cold air in indoors Verandah and Balcony acts as sunspaces Very less projected roof eaves to exploit Solar radiation Single banked/Double banked room Thick walls - store heat energy during day and release it back to spaces during nights			

Table 2. Vernacular Houses in Kodaikanal – Varied typologies and Characters

Mud House

The dwelling under study is a compact structure consisting of a ground floor and a first floor, featuring an extended covered front yard known as "Thinnai," which overlooks the streets. The centrally placed doorway leads to the larger section of the house, where most household activities occur. The extended space on the ground floor connects to a smaller unit used as a workspace and the first floor is provided by wooden stairs. The doors, windows, and columns are constructed from timber, which not only resists cold weather but also acts as an insulating layer. The spatial organization ensures comfort for occupants both indoors and outdoors. These walls serve as effective insulators due to their substantial thermal mass, which absorbs heat during the day and releases it at night when the outside temperature drops. The interior walls are either plastered with lime or mud mortar to enhance the room's internal reflected component, providing subtle tonal differences within the interior. The local builders have adapted their construction techniques to the cool climate by using high thermal mass materials to maintain higher time lags and provide insulation. The mud walls typically of 450 mm thick are reinforced with mud mortar. The mud is mixed with lime and straw and reinforced with reeds. To strengthen the mud wall construction, wooden posts with a diameter of 200 mm are used at the corners. The internal walls are often left unplastered. This construction method addresses both climatic conditions and social needs, using locally available and traditional materials such as mud, thatch, straw for binding, wood posts for columns, and horizontal supports. Roofs were traditionally laid with local straw but are now often replaced with curved clay tiles or machine-made tiles. The single-pitched roofs have slopes less than 30° and are supported by wooden trusses and rafters, with decorative motifs typically placed on the ridge. These roofs are usually double-tiered, with the first layer acting as a wooden false ceiling and the top layer consisting of principal rafters covered with clay tiles. The triangular shape of the roof is sometimes utilized for storage, holding wooden logs for cooking and providing a sleeping zone accessible by wooden stairs. Permanent windows are provided along the main entrance, with a minimal percentage of openings to reduce the entry of cool breezes. The windows are strategically placed to maximize solar radiation without shading devices, based on considerations of topography, views, and sun direction. Most windows face northeast or

southwest, with the latter absorbing the maximum amount of heat. In row-type dwelling units, fenestration is typically placed on the front or rear sides. The doorway design, common in Tamil Nadu, consists of vertically placed flat wooden planks secured by solid horizontal panels. Some doors feature an engraved panel above the frame. In response to the extremely cold temperatures, local builders in Poombharai have incorporated thick mud walls reinforced with wooden sticks plastered with mud. This construction method effectively endures the weather conditions and supports the community's social structure (Figure -4, 8(a) and b).

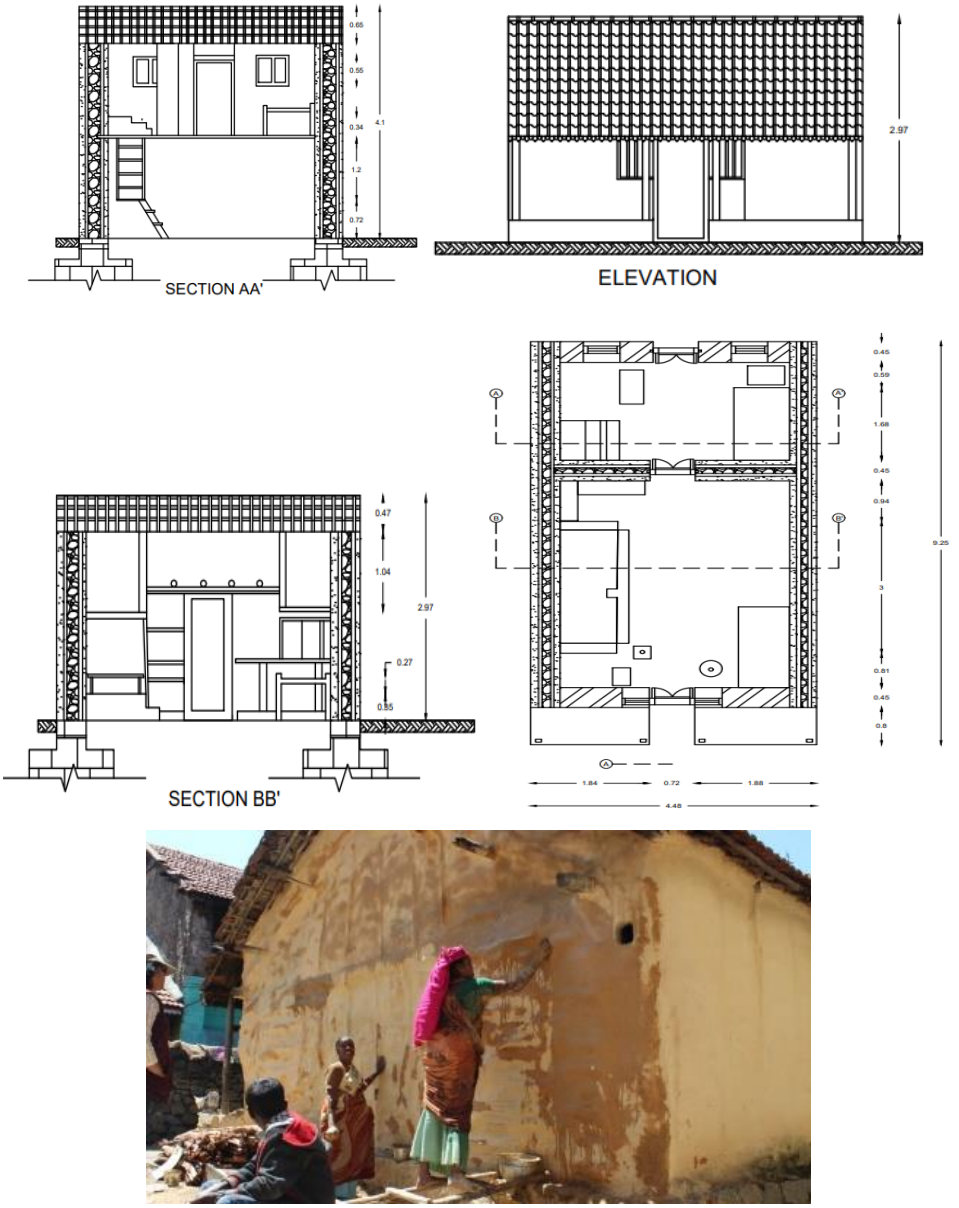
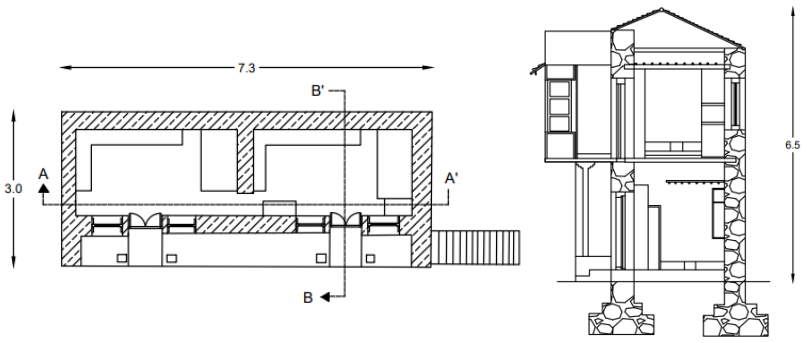


Fig 4: Floor Plan,Section and elevation of Mud house of Poombharai

Stone House

The dwelling features a rectangular plan with a front verandah known as Thinnai. The two-storey house is accessed by a stone staircase located in the exterior of the building. Unlike many traditional buildings, it does not share walls with adjacent structures. The primary living activities occur on the ground floor, while the second floor is designated for sleeping. This stone house exhibits a spatial organization with a central axis, aligning the entrance doorway and windows. Timber is used for doors, windows, and columns to accommodate the climatic conditions. The first floor's built envelope consists of stone walls and large glazed windows, which contribute to potential storage of heat gain due to its thermal mass. A sunspace on the first floor embodies passive heating techniques, utilizing the large glazed window facing south. This spatial planning and construction technique exemplify the climate-responsive design of traditional Poombarai houses.The construction materials, primarily stones collected from fields and stream beds are bound with mud, while locally available stone with lime mortar is used for walls and plastered with lime mortar. Both internal and external walls are plastered with lime mortar. The outer wall of the first floor features timber with large glazed windows. Single-pitched roofs are constructed to manage frequent precipitation in the mountainous region. The roof structure rests on wooden rafters and tie beams with clay tiles available in square or rectangular shapes, serving as the roofing material. Decorative motifs are often found on the roof ridges. In Poombarai village, doors and windows are oriented southeast to maximize solar exposure during winter, with no openings on the rear side. The windows on the main entrance façade are small to minimize the intrusion of cool breezes, and their shutters are fully closed during the night and cold seasons.Local builders in Poombarai extensively use locally available materials, such as stones and wood, for walls and roofs, chosen for their thermal mass properties suited to the cold climate. Pitched roofs are commonly covered with tiles or slates to reduce heat loss. The internal spaces are vertically organized to create a thermal buffer for the ground and first floors. The settlement demonstrates an adaptation to the cold climate, emphasizing the importance of design strategies that include massive construction, compact planning, the presence of solariums, and the absence of shading devices to maximize heat gain (Figure -5).



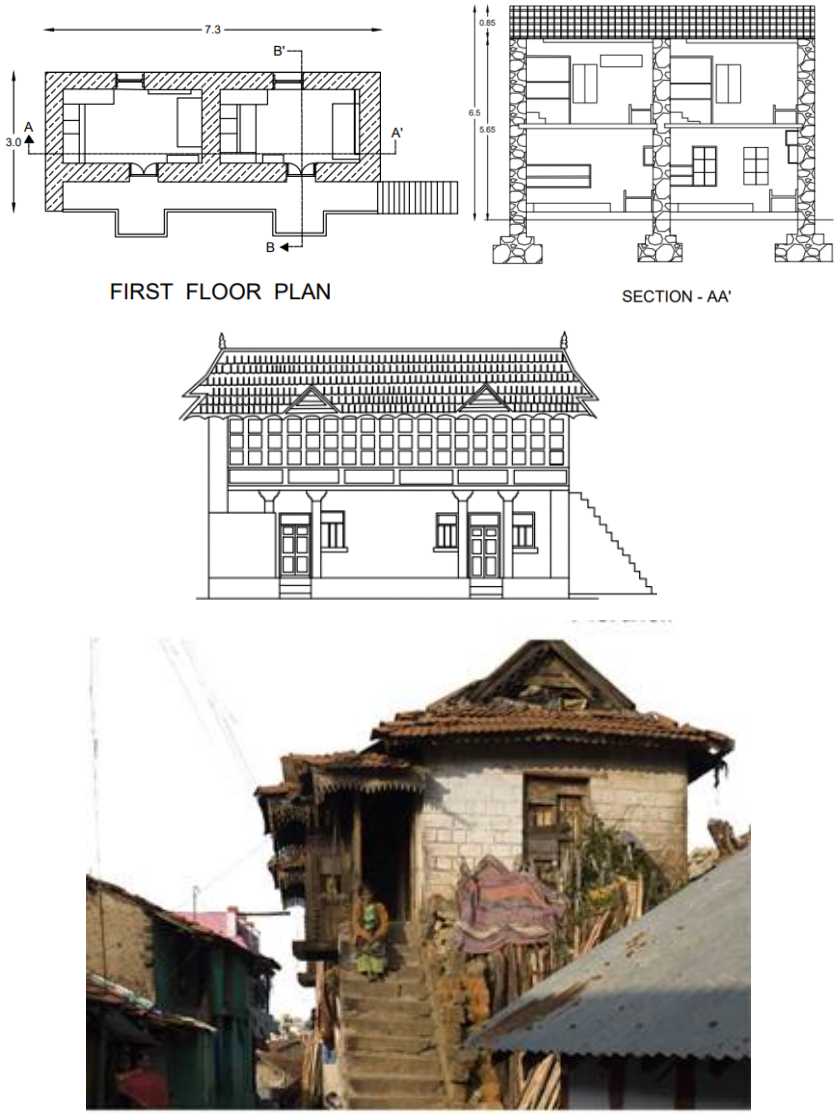


Fig 5 : Floor Plan,Section and elevation of Stone house of Poombharai

Wooden House

The house under study follows a common layout with an elongated plan of typical vernacular architecture designed for cold climates. This dwelling unit is oriented along east-west axis, facing south to maximize solar radiation. The elongated plan is symmetrically divided into twin houses sharing a common wall with Both houses are single-banked, with major activities such as living, cooking, and working occurring on the same floor. The compact profile of both houses minimizes external surface exposure. The planning layout is indicative of climate-sensitive design, aimed at trapping heat during winter while blocking direct sunlight to provide internal shade during summer. Wooden houses are highly effective thermal insulators and have lower greenhouse gas emissions. The wooden walls provide excellent heat insulation, ensuring

a comfortable living environment. Internal partition walls are light in construction, consisting of a narrow wood frame placed horizontally with interlocking joints. Wall construction involves laying two longitudinally placed wooden beams. The roof is single-pitched, supported by wooden beams, followed by purlins and rafters. Clay tiles are commonly used as a roofing material. Openings in the house are smaller in size and symmetrically placed to optimize views, topography, climatic aspects, and sun angle. These openings are provided along the length of the building, while openings along the shorter side are avoided to enhance seismic performance. No shading devices are provided to maximize thermal gain for indoor spaces. Vernacular practices predominantly use locally available materials that are easily workable and renewable. The use of stone and timber not only contributes to good seismic and thermal performance but also adds aesthetic value. Doors and windows are smaller in size to minimize the intrusion of cool breezes (Figure-6).

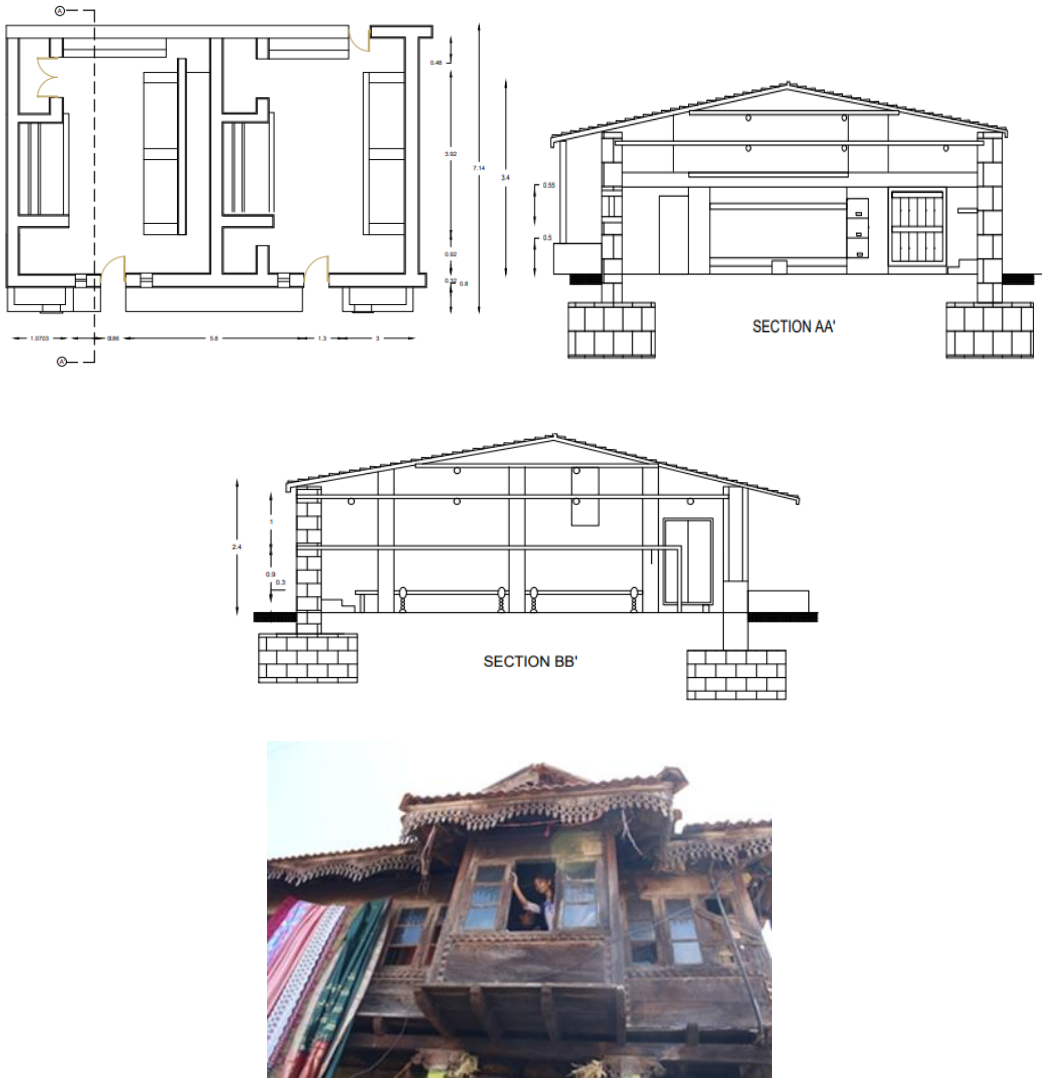


Fig 6 : Floor Plan,Section and elevation of wooden house of Poombharai

Brick House

The house is an outcome of latest change in usage of material as a contemporary approach of building construction but compact spatial planning have been adopted. The house has an extended covered front yard known a thinnai at one end and an external staircase at the other side to access the first floor.The performance of the brick house is less as compared to stone or brick because of its less conductance of heat. The spatial form of the house is rectilinear and hence symmetrical. The house is two storeys and the first floor is accessed by stair located in the outside of the building. The primary living activity happens in both the floors and the first floor is accessible by stairs located in the outside of the building. Although the brick house is constructed through modern technique the spatial planning of the house minimizes external surface exposure. The roof of the brick house is pitched of slope <30° supported by wooden trusses and rafters. Locally available timbers are used for roof trusses constructed by the local carpenters. Thick stone wall plates are often provided to support the roof trusses and the triangular space of the roof is used for storage without any false ceiling. The openings of the brick house are oriented as per the climatic consideration. The size of the windows is very small and mostly found absent in few smaller houses to prevent the heat loss. The windows are placed in such a way it provides maximum utilisation of solar radiation. To conserve heat, the height of the habitable rooms is kept below 3 meters. Although the vernacular houses in poombharai were built using mud, stone, wood but the use of brick and concrete are increasing in the area. Due to the change in building construction and techniques the buildings have become lighter (Figure-7).

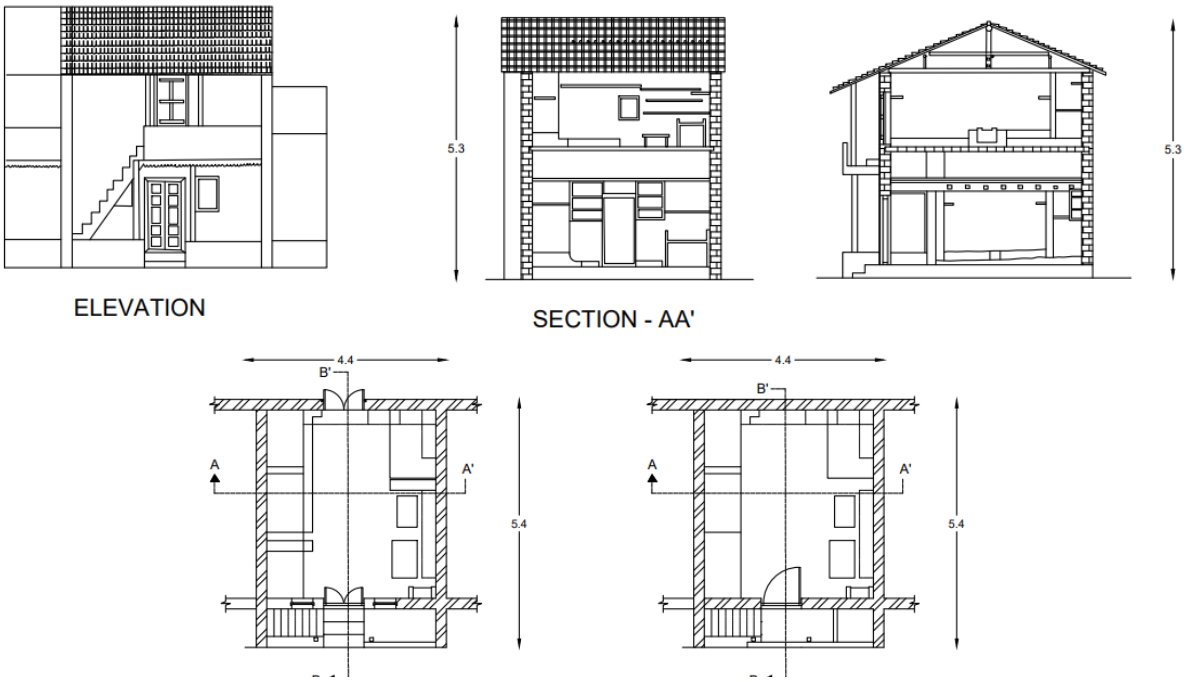


Fig 7 : Floor Plan,Section and elevation of Brick house of Poombharai

Figure – 8(a) Storage Space (b) Mud Plastering

4. Conclusion

Vernacular architecture of hilly settlement of poombharai set as a good example of bioclimatic concepts and passive design principles. The existing prototype studied represents a great balance between local climate condition, geographical setting, use of locally available materials, building techniques, socio-cultural and economic aspects.The use of locally available materials in the area create a great advantage of climatic adaptability, resilience and have longer lifespan. Most of the vernacular techniques of the dwelling units were learnt by local builders from former gnerations.The housing typologies of mud, stone and wooden houses incorporated passive design strategies like building envelope, orientation, Materials and Construction techniques and spatial organisation. These types of spatial form are simple, economical and satisfy socio-cultural aspects with major consideration of climatic requirements. The prototypes of the various building typologies studied are represented through plan, section and elevation to understand the spatial function and its architectural characteristics. Moreover, the houses have significantly incorporated passive techniques which are used to control the indoor temperature due to the existing climatic condition of the region.

In this present study on vernacular architecture of mud house, the building envelope is massively constructed by locally available material for ensuring comfort for the occupants. Overall the entire structure of the building is oriented to receive maximum radiation and protection from prevailing cold winds. Sloping roofs are doubled tiered to prevent heat loss. Generally the Ceiling of the house is used as an attic space for storage or sometimes used as a sleeping zone. The height of the room is kept small to conserve heat inside the building. The doors and windows are strategically placed to increase solar radiation with less percentage of opening to minimize the entry of cool breeze. One of the significant building construction techniques of the mud house is the reinforcement with wooden sticks which endures weather conditions.

The study on stone house has high thermal mass concerning the prevailing cold climatic consition.The windows on the main façade are kept small to minimize the intrusion of cool breeze. The room dimensions and arrangements are determined by their functionality. However, the spatial planning of ground floor and first floor satisfies the resident's requirement and designed as per climatic consideration. In cold climate compact planning,

presence of solarium and massive construction plays a vital role.

In cold climate, wooden house serves as a good example of dwelling unit as wood is highly effective thermal insulator and provide comfortable living environment.The house is symmetrically divided into twin house with elongated plan and the functionality are based on the occupants and shows better thermal performance. The house is symmetrically divided into twin house with elongated plan and the functionality is based on the occupants and shows better thermal performance. It is also important to mention the house was strategically designed in accordance with climate sensitive design and use of locally available materials that are workable and renewable. The study of vernacular house of mud, stone and wood suggest that all three typologies are in response to climatic condition than the Brick house. This paper has studied documented and analysed the bioclimatic strategies at settlement level and passive design principles at building typology level which indicates sustainability with reduced ecological footprint and make settlements culturally significant and habitable. Therefore it is important to understand the unique environment of hilly settlement of cold climate where building regulations have failed to address the unique conditions as they lack the context. Hence new building regulation considering the construction techniques and materials, climatic aspect, architectural features and aesthetical significance along with maps of landuse, topography, slope, potential hazard mapping to be prepared which will play a vital role in understanding the importance of sustainable development.

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