

Sustainability of traditional rural mud houses in Tamilnadu, India: An analysis related to thermal comfort

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Abstract— Energy consumption in the buildings sector is very high and is expected to increase further due to improvements in living standard and increase in the world's population. With the energy crisis deepening, the role of the built environment becomes more significant. Incorporating appropriate solar passive features in climate responsive buildings are good options for energy conservation. This paper aims to assess passive solar design techniques and the extent to which they promote high thermal comfort in a vernacular mud houses in the Madurai, Tamilnadu in India. These houses were constructed, without any mechanical means, in such a manner as to create micro-climates inside them to provide high thermal comfort levels. The study of this rural mud house provides an insight for designing an energy efficient houses that provides thermally comfortable conditions, as well as leaving behind a very low environmental footprint. The various parameters which are considered in the study of the existing rural house are – orientation, plan-form, building exposure to sun, surface-volume ratio, openings, shading, building envelope material and ventilation. As a tool for studying the thermal comfort conditions inside the vernacular rural house and in order to simulate different thermal conditions, the software 'Autodesk Ecotect Analysis sustainable design analysis' was used. On-site measurements were used to validate building simulation results and to draw some inferences about the thermal behavior of dwelling units.

Keywords— Mud architecture, Passive Design strategies, Thermal Comfort, Environment Friendliness

I. INTRODUCTION

Before the advent of the industrial age, and the invention of mechanical heating and cooling, bi-climatic means were exclusively used to achieve moderately comfortable climates inside buildings. Today, active heating and cooling devices ensure interior comfort, but require major energy inputs. However, given the dual challenge of a growing fuel crisis and concerns of global warming, the amount of energy used to provide thermal comfort levels will become unsustainable. Sustainable, ecological, and climate-adaptable architecture offers possible

solutions to these challenges. Many architectural publications advocate that traditional and vernacular homes form the basis of environmentally conscious design [1]. Design lessons learned from traditional and vernacular architecture can help in designing an eco-friendly future. Ancient Indian buildings use the environment, climate responsive design, and local and sustainable materials in their design and construction. Once built, these buildings form embodied an important strategy of environmentally friendly homes: minimal use of energy [2].

India has as per the 2011 census, 51.55 % of its total population living in rural areas, with very low economic status and it is in this context that the development of proper rural architecture is important. With the energy crisis deepening, the role of the built environment becomes more significant. Madurai is known as the Athens of the East, Madurai is a place of great historical and cultural importance. It is the oldest city in Tamil Nadu and Madurai lies on the banks of the River Vaigai. Madurai is located at 9.93°N 78.12°E. It has an average elevation of 101 meters. Madurai is surrounded by several picturesque villages with rich archaeological history. The study area Meenakshipuram is one such village located in the eastern part of Madurai. Meenakshipuram is a famous Heritage spot with four different caves which acted as ancient Jain beds and six bhrami inscriptions.

The village Meenakshipuram, Madurai is a classic example of traditional vernacular settlement which has sustained through the ages. The site of Meenakshipuram is valley lying on the foothills (Figure 1). The water flowing from the hills form a channel which forms the major water resource of Meenakshipuram (Figure 2). Dense clusters of small and compact tenements configured organically along the narrow streets and alleys form a major part of the settlement. The form and structure of vernacular settlement of Meenakshipuram are a result of centuries of evolutionary process and knowledge transfer, reflecting a set of varying physical and nonphysical determinant forces such as climate and geology, religion, socio-cultural values, economics, technology and administrative factors. It is a closely knit fabric of small clusters of dwellings comprising of thick mud walls, thatch roofs, small openings and narrow streets. The house plans essentially remains same in size, shape and detailing, and their climate

sensitivity. The aim of this paper was to evaluate the vernacular settlement of Meenakshipuram, in terms of its climate appropriateness of various features of the building and the settlement. The evaluation of the settlement and houses was carried out keeping in mind the environmental elements such as heat, humidity, air movement and light and the general activity pattern of the residents. Design strategies for improving thermal comfort levels are also suggested.



Fig.1. View traditional hut at the foot hill



Fig. 2. Water Channel, communal water body of Meenakshipuram

II. METHODOLOGY

Various approaches were employed in the literature. Dili et al. used in-situ measurement method to evaluate the thermal environment in a traditional building in Kerala, India [3]. Shaghayegh Mohammad and Andrew Shea in their study used computer simulation models by means of Design builder software to evaluate the performance of Modern Building Thermal Envelope Designs in the Semi-Arid Continental Climate of Tehran [4]. In an intensive study in Japan, Hiroshi et al [5] researched four traditional farmhouses using both in-situ measurement and computer simulation on a model house. Their findings revealed that cooling technologies for traditional buildings, such as solar shading by a thatched roof, earthen floor and natural ventilation as

criteria effective for interior cooling. The present study uses a similar approach in which the climate analysis and building performance analysis were done by ECOTECT simulation software and the thermal performance of vernacular settlements were also analyzed by in-situ investigation in the summer period. The present study also explores the ways in which the traditional construction techniques in the experimented settlements can be used in modern constructions.

III. STUDY AREA

The dominant climate in Madurai is the warm humid climate, which is characterized by very hot summers with mild winters, with high humidity during most of the year and low diurnal (day/night) temperature range. Table 1 display the climatic characteristics of the study area. The heat gain in the indoors is of major concern in the warm humid climate especially in summer as the outdoor air temperature is higher than the occupants' body temperature for a larger period of the time. The days are hotter and the air temperature drops down only in the night, a few hours after the sunset. Thermal insulation of the building envelope can be achieved by appropriate use of building materials and by employing suitable techniques of insulation [3]. The hottest months in Madurai are from March to July. Madurai experiences a moderate climate from August to October, tempered by heavy rain and thundershowers, and a cool and climate from November to February. The average annual rainfall in the Madurai district is about 85.76 cm. Temperatures during summer generally reach a maximum of 40 °C and a minimum of 26.3 °C, although temperatures up to 42 °C are not uncommon. Winter temperatures range between 29.6 °C and 18 °C. Table 2 gives the climate modification strategies for warm humid regions.

An average hut measured approximately 5 to 6 meters long and 3 to 4 meters wide (Figure 3). The huts vary in size. There are also a considerable number of the larger huts that extend up to 12 to 14 meters in length and 8 to 9 meters in width. These huts are arranged in a linear pattern along the cross streets which are connected to the main street of a village (Figure 4), amidst agricultural fields and rocky spur. The houses are normally detached and a very few row houses with common walls are also found. A typical hut usually consists of a multipurpose space and a kitchen with storage space in the front (Figure 6). Most day to day activities occur in outdoor spaces (Figure 7). The water bodies present in the foothills serves as the source of water for drinking, bathing, washing, and cooking. Very few houses have newly constructed bathrooms. The houses are often on a raised platform made of compacted earth called as Thinnai (Figure 5). The high thermal mass helps to keep the house cool in the evenings in the summer, which makes it pleasant for people to rest in the evenings. The huts normally have minimal openings. Often the only opening on the external walls is the main door.

TABLE1-CLIMATE DATA FOR MADURAI, INDIA

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature Average high °C (°F)	30.6 (87.1)	33.2 (91.8)	35.8 (96.4)	37.3 (99.1)	37.7 (99.9)	36.8 (98.2)	36.0 (96.8)	35.7 (96.3)	34.8 (94.6)	32.7 (90.9)	30.6 (87.1)	29.7 (85.5)	34.24 (93.64)
Temperature Average low °C (°F)	20.1 (68.2)	21.1 (70)	23.0 (73.4)	25.4 (77.7)	26.1 (79)	26.1 (79)	25.6 (78.1)	25.3 (77.5)	24.3 (75.7)	23.6 (74.5)	22.6 (72.7)	21.1 (70)	23.69 (74.65)
Relative Humidity in %	66	60	54.5	61	56	56	56	56	65	68	78	71	62
Precipitation mm	7.4	11.8	14.1	37.1	72.6	32	83.2	80.3	146.9	159.4	140.3	53	838
Avg. precipitation days	0.9	1.1	1.1	2.4	4.4	2.0	3.6	4.1	7.8	8.1	6.3	3.4	45.1

Source: Indian Meteorological Department Mean data from 1971–2000

TABLE 2-CLIMATE MODIFICATION STRATEGIES AND BUILDING TACTICS FOR WARM-HUMID CLIMATE TYPE.

Climate Type	Adverse Climatic Elements	Climate Method	Response Strategies
Warm-Humid	High heat, High humidity Insolation Small diurnal variation	Minimize heat gain Maximize ventilation Maximize shading	<ol style="list-style-type: none"> 1. Thin bar building with an east-west axis. 2. Cross ventilation 3. High ceilings 4. Ventilated roof 5. Window shading all the year 6. Shaded Veranda

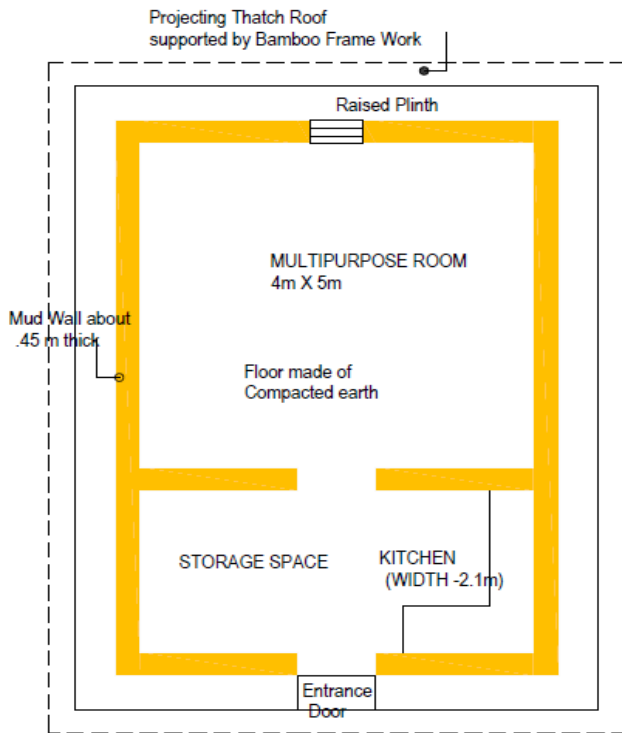


Fig. 3. Plan of a typical hut



Fig. 5. Raised Plat forms -Thinnai



Fig. 6. Kitchen space in the hut



Fig. 4. View of hutments in Meenakshipuram



Fig. 7. Outdoor utility Areas

The type of mud-house construction employed in Meenakshipuram, Madurai is Rammed Earth in which damp earth lay between the formwork and molded and compacted by ramming. The huts were made of local materials like timber, bamboo, clay, straw, cow dung, and a special variety of grass called nanal were used to build houses. The walls were made of mud mixed with cow dung and chopped straw to make the raw material for the walls. The walls are approximately 450 mm thick (Figure 8). These houses were mostly self built by family members, sometimes aided by neighbors. Traditional architecture developed its individuality by tapping nearby resources and exploiting them to confront the problems posed by the local environment [6]. The roof rested on wooden posts erected rows, purlins support the roof structure. The huts usually had a thatched roof (Figure 9). Bamboo sticks formed the mullions to support the thatch. The thick thatch used as roofing material prevented rain from entering the house and at the same time provided insulation to the building. The Experimented Thatch roof consisted of layers of Palm reeds, Bamboo reeds, Thagavai reeds and layer of Nannai straw. All these materials were locally available in the agricultural fields surrounding the village. The average life time of the thatched roofs in Meenakshipuram is about 90 years.

In order to study and analyze the thermal performance a typical hut is chosen for the simulation study. Its dimension is 8.5 meters in length by 5 meters in breadth (Figure 10). The Model House under study has been divided into two zones – the west-zone and the eastern zone for more specific study. Also, for further detailed study, one room in the west zone, which is used as a sleeping room at night, is subjected to further detailed study to analyze its thermal behavior.

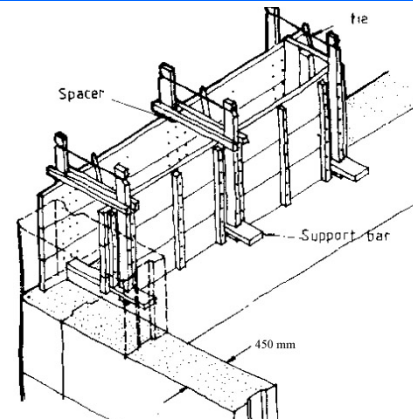


Fig. 8 Schematic section of Rammed Earth Wall

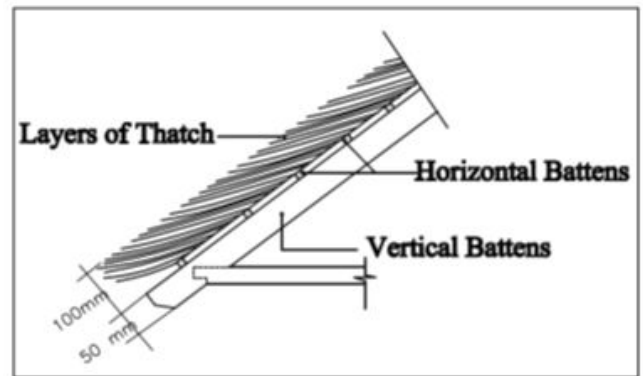


Fig. 9 Schematic section of Thatch roof

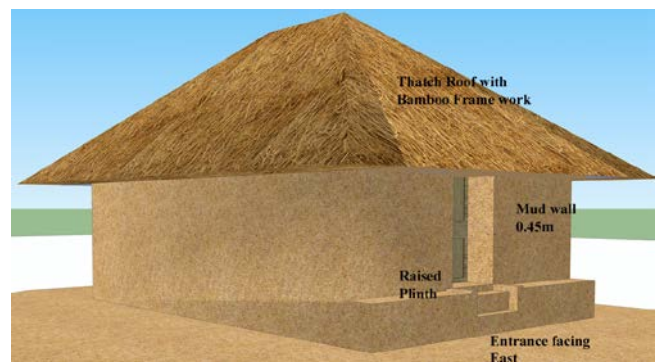


Fig. 10 Digital recreation of study hut

IV. RESULTS AND DISCUSSION

A. Surface area to volume ratio

The total surface area (excluding ventilation opening & including roof area) is 136 square meters in mud hut studied. The total volume is 70 meter cube. The ratio comes to be 1.93. In warm-humid climates the prime concern is creating airy spaces [7]. The annual heating and cooling energy saving potential of mud-house was determined as 1500 kWh/year for warm humid climate. The total mitigation of CO₂ emissions due to both heating and cooling energy saving potential was determined as 6 metric tons/year.

B. Orientation of the houses

The mud house has its longer side oriented along North-South Axis. The main door is placed in the

eastern side. The solitary small void like opening is placed on the western wall. Most of the houses were located in the same orientation. The east and west walls is completely shaded by the projecting eaves of the roof. They were also located in clusters which enabled mutual shade of the houses and the open spaces within the cluster were also shaded which acted as open utility spaces. Ecotect software analysis of simulated study-hut shows that the Mean radiant temperature (Thermal Comfort) inside a mud hut at 12Noon, 15th April on the west zone is about 32°C and the east zone is about 36°C which is very low compared to any other modern building materials (Figure 11).

Thermal improvements were observed when the built form is one side longer than the other is the long

sides facing the South- East and North-West direction, making an angle of about 72.5 degrees from North, rather than the longest side of the building aligned along the proper North-South Axis as done in the mud house studied.

Direct solar radiation to the walls can be further avoided by increasing the width of the raised plinth (Thinnai) from 450 mm to 750 mm and the eaves can be projected to 900 mm, instead of 500mm in the east and west direction. Ecotect software analysis of simulated study-hut for the above conditions showed that the Mean radiant temperature (Thermal Comfort) inside a mud hut at 12Noon, 15th April on the west zone is about 31.2°C and 24°C in the raised plinth which makes the Thinnai more suitable for outdoor activities (Figure 12).

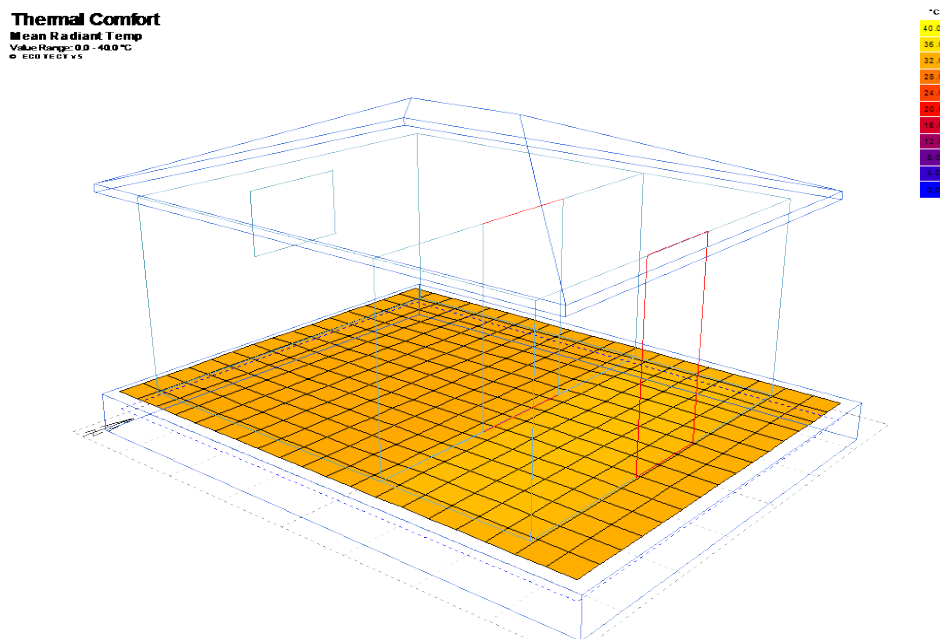


Fig. 11. Ecotect software analysis of simulated study-hut - Mean radiant temperature (Thermal Comfort) inside mud hut at 12 Noon, 15th April, 2013. East-West Orientation of the house, void (window like smaller opening) on the west wall

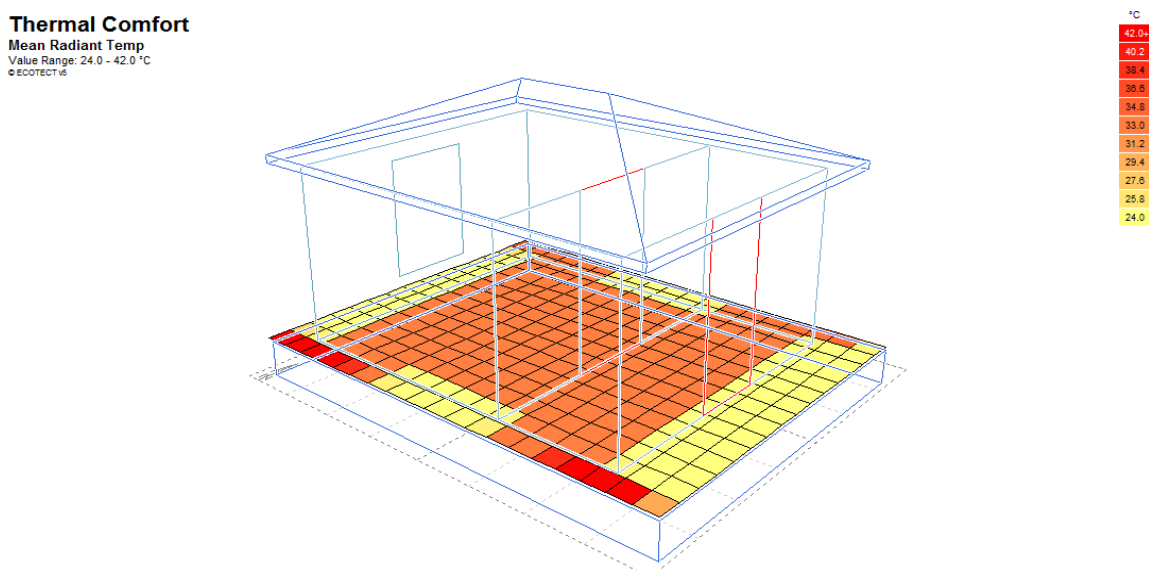


Fig. 12. Ecotect software analysis of simulated study-hut – Mean radiant temperature (Thermal Comfort) inside a mud hut at 12 Noon, 15th April longer side orientated along NW-SE direction, at an angle of 72.5 degrees to the East-West Axis eaves are projected 1m

Prevailing Winds

Wind Frequency (Hrs)

Madurai - IND

Date: 1st January - 31st

Time: 00:00 - 24:00

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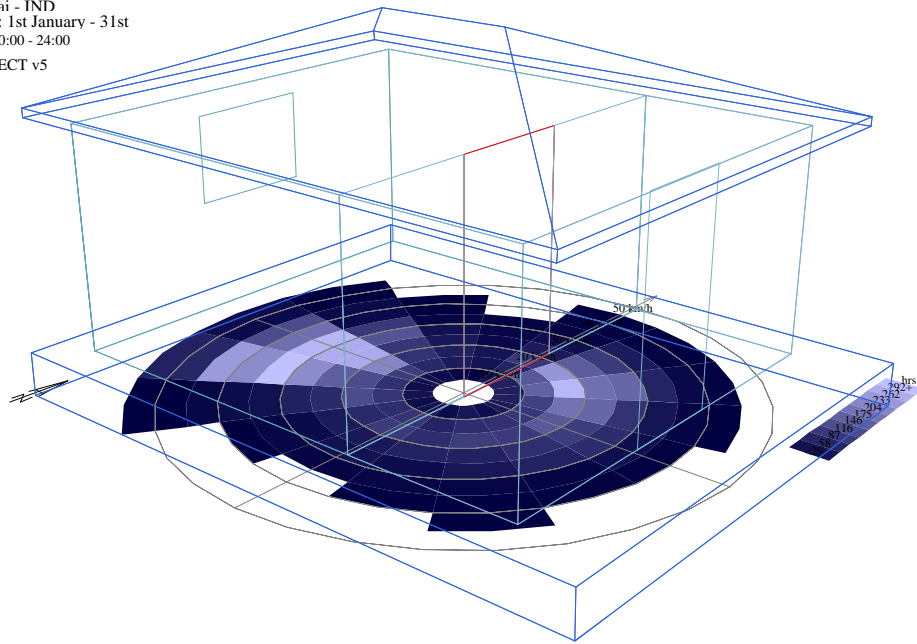


Fig. 13. Prevailing annual wind direction and wind velocity within the hut

C. Ventilation

The air velocities inside the house were measured at different time of the day using a handheld anemometer. The indoor air velocities were between .5 and 1 m/s. The ASHRAE Standard 55-2004 specifies that the occupants would feel comfortable at 27°C operative temperatures and 75% relative humidity (with 0.27 solos and 1 Met) if the air velocity was at least 1 m/s. Warm humid climates report comfort at air velocities above 1.5 m/s, when air temperature is well above the skin temperature and humidity is high [8]. The Ecotect analysis of the existing hut shows that the openings are arranged according to the prevailing wind direction (Figure 13). However the portion through which cool air at night could come in at the top portion of the roof and through which warm air can go out by convective process has been blocked in this particular hut due to rain water coming inside the hut during the rains (Figure 14). This causes lack of ventilation in summer and convective air flow at evening and night. A probable solution is to let the openings remain and cover them by bamboo mesh like surface to stop rain water coming in the monsoons (Figure 15).



Fig. 14 Lack of air outlet at ceiling level in existing hut



Fig. 15. Extended Eave projection and bamboo meshing to prevent rain ingress and allow ventilation

D. Building envelope materials

The Thermal Transmittance value (U) indicates the total amount of heat transmitted from outdoor air to indoor air through a given wall or roof per unit area per unit time. The lower the value of U, the higher is the insulating value of the element. The value of the overall heat transfer coefficient for the Rammed earth wall is 1.9 W/ m² K and for Thatch roof is 0.35 W/ m² K, which is considerably lower than the suggested value of 3.5 W/m².K for walls and 2.33 W/m².K for roofs [9] which indicates that both Rammed earth wall and Thatch roof are good insulating elements. Mud has a number of properties which make it a perfectly suitable material for constructions which aim at achieving thermal comfort at

a low cost. Rammed earth walls have a very high capacity to store heat energy – commonly referred to as 'thermal mass'. The high thermal mass of rammed earth walls means they act to naturally regulate the internal temperature of a building [10]. They do not readily prevent the flow of heat energy, but, owing to their high density, they can absorb and store it. The energy required to both heat and cool the building can be greatly reduced, which further reduces the CO₂ emissions of the building. Rammed earth naturally regulates the internal relative humidity of the building, producing an improved air quality [11]. Rammed earth is perfectly able to act as load bearing members within a structural system.

Rammed earth is an ancient building method that has seen a revival in recent years as people seek more sustainable building materials and natural building methods by which such alternative construction techniques can be widely used in all types of construction. Traditionally for Rammed earth wall construction the earth is mixed thoroughly with water to get a homogeneous humid mix. This humid earth is poured into a form in thin layers and then rammed to increase its density. The increase of density increases as well the compressive strength and the water resistance. They can be labor-intensive to construct without machinery. In modern variations of the method, rammed-earth walls are constructed on

top of conventional footings or a reinforced concrete slab base. Where blocks made of rammed earth are used, they are generally stacked like regular blocks, but are bonded together with thin mud slurry instead of cement. Special machines, usually powered by small engines and often portable, are used to compress the earth into blocks. Modern version of Rammed earth wall when built with 4" of rigid insulation hidden in the center of the wall the U value is brought down to 0.65 W/m².K.

In modernization of Rammed earth wall construction the traditional wooden rammer has been replaced by pneumatic rammers. Heavy wooden formworks evolved into light composite ones, made of plywood, wood and steel or sometimes aluminium.

Compressed Stabilized Earth Block is another sustainable technique invented which requires less skilled workmanship compared to Rammed earth technique. The soil, raw or stabilized, for a compressed earth block is slightly moistened, poured into a steel press (with or without stabilizer) and then compressed either with a manual or motorized press. CEB can be compressed in many different shapes and sizes. Compressed earth blocks are stabilized with cement or lime. The input of soil stabilization allowed people to build higher with thinner walls, which have a much better compressive strength and water resistance

Thatch is a natural insulator, and air pockets within straw thatch insulate a building in both warm and cold weather. A thatched roof will ensure that a building will be cool in summer and warm in winter. Their thermal insulation value is high, so thatch roofs are comfortable in warm climates. In the past, the biggest disadvantage of thatch roofing was its flammability, but today's thatched roofs include a fireproof barrier base, such as Rockwool, that protects the underside of the thatched roof from spreading fire. The thatch itself is sprayed with a fireproof material to resist flames. Modern day thatch treated and improved industrially can also be used for mass use in rural areas, being low cost and having very good thermal properties.

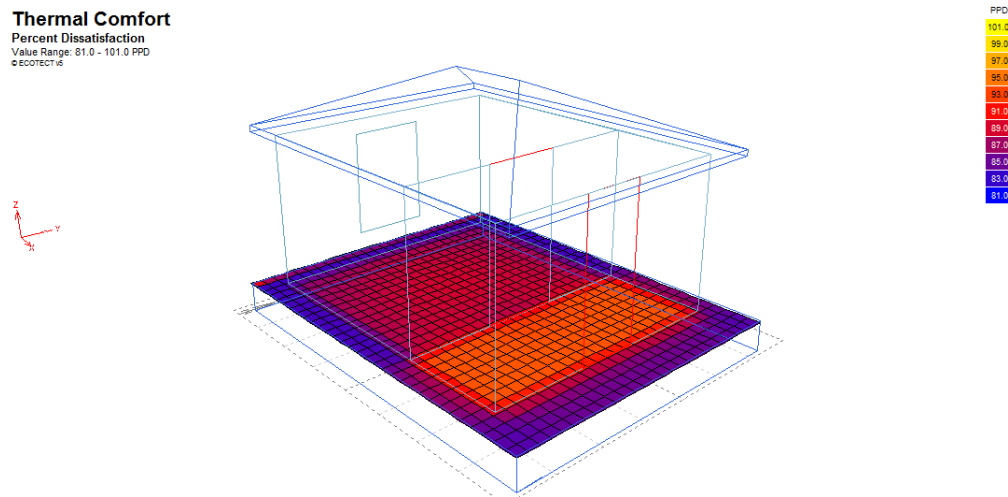


Fig. 16 Thermal comfort at 12 noon, 15th April (Ecotect simulation)

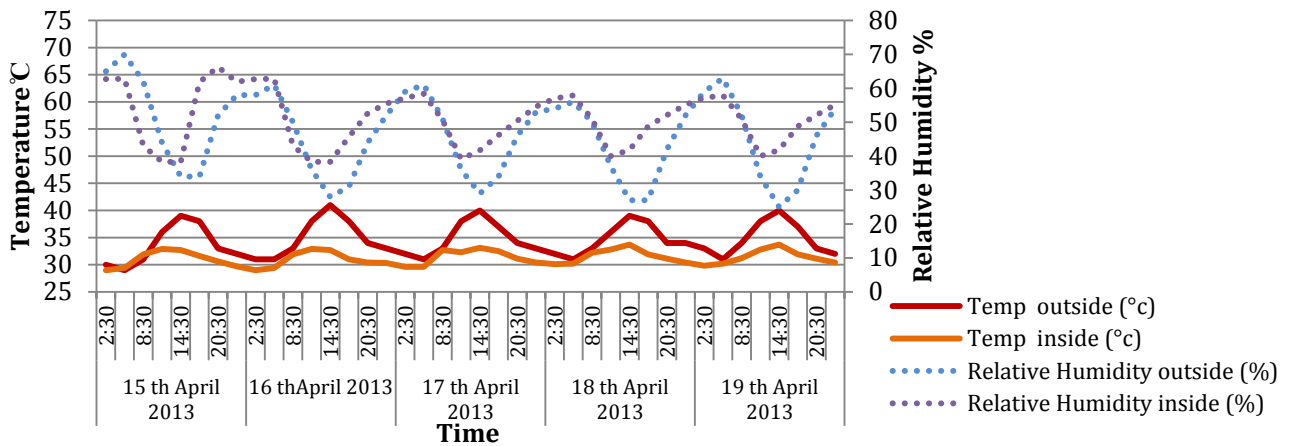


Fig. 17. Temperature /Humidity Graph Hourly Inside and Outside, measured in the west zone room from April 15th to 19th

The Predicted Percentage Dissatisfied is calculated for the existing hut using Ecotect analysis (Figure 16). Predicted Percentage Dissatisfied - PPD - index is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment. The ECOTECT analysis of PPD index of the hut shows discomfort is minimum in Thinnai spaces because of air movement and maximum in west zone (sleeping space) because of more direct solar radiation in west side. If shading is increased by having greater eave projections and also sunken window or chajjah then heat gained can be considerably reduced.

E. Thermal comfort measurements

The on-site temperatures inside the mud house are taken, on the hottest days inside West Zone Room–April 15th to April 19th, 2013 (Figure 17). This is done to study the thermal conditions inside the dwelling unit. The room chosen for taking temperatures is the sleeping room in the west zone of the hut. Digital Temperature Data Logger is compact equipment used for calculating temperature and humidity level at continuous intervals. An anemometer is an instrument that measures wind speed. This type of anemometer has a spinning wheel.

In summer, inside remains cooler than outside during day-time. This can be attributed to thermal time-lag of heat-conductivity of mud. The mud stores the heat gained during day-time and dissipates it gradually after 8 PM at night, after getting heated from 7 AM to 5 PM in summer (with peak heat gain during

10.30 AM in the morning to 3.30 PM in late afternoon). Inside Temperature is less than the outside temperature from 8 AM in the morning to 7 PM, during the night hours the inside temperature is almost equal to outside temperature.

Mean air temperature inside the hut during summer remains at constant between 31.7 to 32.9 degrees Celsius. The above data taken is compared with the ASHRAE 55 standards of Adaptive comfort zones (Figure 18). The purpose of ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy, is “to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space” [12]. ASHRAE 55 compares thermal comfort parameters of the outdoors and gives the indoor comfort temperature for each month. The indoor temperature average for the month April (32.3°C) measured within the hut matches with the ASHRAE 55 standard (32.2° C).

The monthly Discomfort degree hours in the West zone room, based on the ECOTECT analysis for April, is 11327 Hrs (89.2%).

distribution for the hut is about 89.2 %. The annual comfort when calculated for a conventional building of the same size with a brick wall and concrete roof is only about 55%, which proves the traditional huts in Meenaksipuram are more efficient in providing thermal comfort.

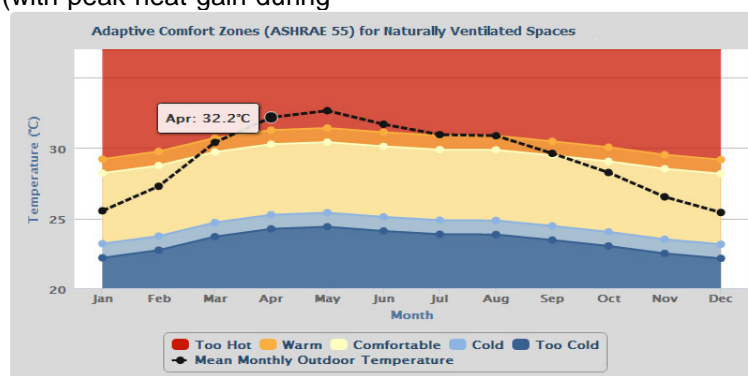


Fig. 18. Adaptive Comfort temperature for the month of April calculated from ASHRAE 55

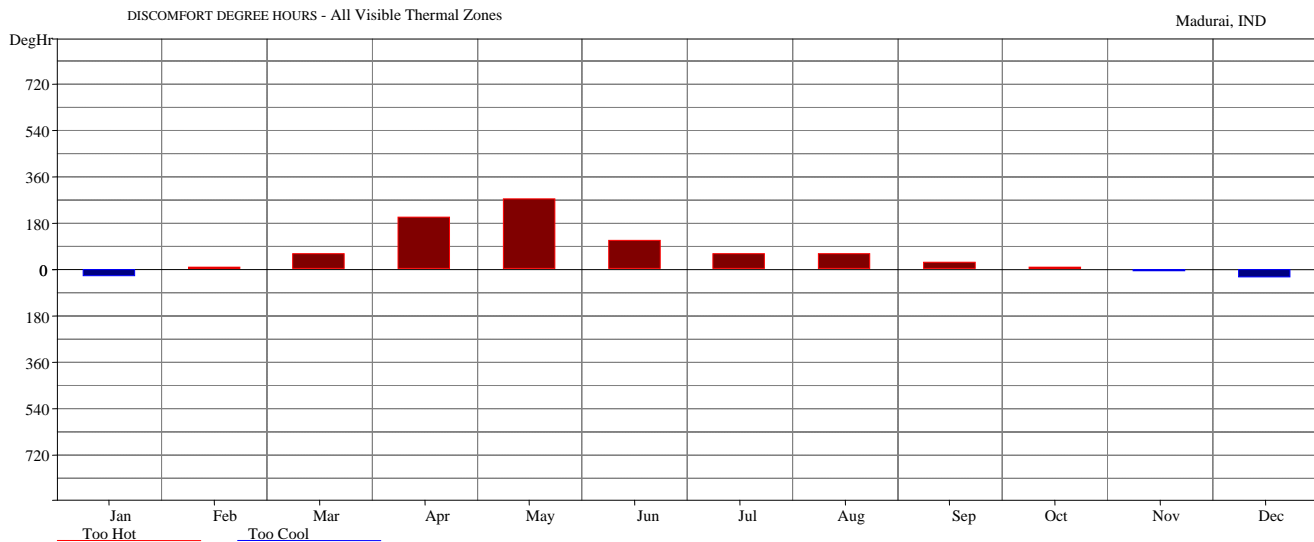


Fig. 19. Monthly load discomfort of the hut; Discomfort Degree Hours too hot = 818.5, too cool = 74.3; total discomfort = 892.8; Annual Comfort Distribution 8687 Hrs (89.2%)

V. CONCLUSION

Principles of Vernacular Architecture can be applied to modern architecture and offer improved adaptation to a particular climate. The Mud house studied reinforced the fact that mud and thatch used in building envelope keeps the inside of the hut cooler in summer. Mud and Thatch are the locally available materials in Madurai Region. Use of locally available building materials has certain advantages for example, since the material is from same climatic conditions, it shows more adaptability, longer lifespan and better economic. From environmental point of view this has added advantages such as: (a) low environmental impact in production, renewability and even natural dissolution (b) significant reduction in energy involved in processing and transport. It has also been found that some solar passive techniques are used in these houses to control the indoor environment and address the existing climatic constraints. However the cooling effect of these traditional mud houses can be further improved and living conditions inside the huts improved by proper design considerations like proper building orientation, surface-volume ratio maximization, projecting eaves of roofs and having proper openings in roof which guard against water ingress of huts to facilitate nocturnal ventilative cooling, use of shading devices being properly used and proper building material selection which can be economically viable for rural areas as well as have proper thermal insulation properties. Modern day industrially improved thatch can be used with all the good thermal properties intact and the disadvantages of thatch gone. Presence of entire village with Vernacular character without any modern development is a rare phenomenon nowadays. Preserving the architectural character of the village would add heritage value of the Meenakshipuram village which has other interesting tourist attraction also. Use of rationalized traditional technologies would help in improving the sustainability

of the hutments, easy maintenance and help improve the indoor air quality of the huts. It would be a great boon to the vast rural populace of Tamilnadu if they could see their modest mud-house being improved by the use of rationalized traditional technologies and if they could be given an easily constructible prototype mud-hut. These can be systematically being made available to the rural poor through awareness and government initiatives and loans/grants.

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