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Comparative Analysis of Thermal-performance of vernacular dwelling in Arid climate of India

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ABSTRACT

The thermal characteristics of dwellings such as external and internal walls, slab with flooring directly affect the energy uses and thermal comfort. Building materials respond to climate differently. This study aims to analyze the naturally ventilated Bhunga dwelling with walling material mud and stone wall in Bhuj region. The study mainly focuses on rural area considering construction techniques and energy-patterns. The inter-zonal heat gain, the mean temperature of the radiant heat, and the degree of comfort in the home were the parameters under examination. Analysis is done Bhunga house form with traditional stone and mud wall and pitched roof made of thatch. Comparative study and discussion are done on the thermal performance, comfort, and energy usage patterns of mud and stone walls. Using graphic depiction, it has been shown how a building envelope responds to environmental factors, and it has also been shown by using Ecotect Software.

Keywords: Vernacular Architecture, Simulation Study, Thermal-performance

1. INTRODUCTION

The passive architectural design is used to provide comfortable living with little to no additional building budget requirements. It takes advantage of renewable resources like wind and solar to adjust buildings to the climate [1]. Traditional buildings in Bhuj, Gujarat, are regarded as good examples of hot and dry climatic zone dwellings that are flexible to the local climate and well suited to the locally available materials. As societal changes occur, architecture will play a significant part in Bhuj's future growth. Although the society of Bhuj is still deeply ingrained in culture and customs, this attracts tourists, and tourism is therefore increasing significance. With the course of time, locals began building their dwellings using mud, and following mud, stone is being employed for more rapid construction. The temperature issue was mostly ignored in this procedure. Therefore, the goal of this study is to determine the thermal performance of naturally ventilated stone and mud homes, which are prevalent in Bhuj, Gujarat, villages. And the research will help to recommend better building materials by considering the comfortable living circumstances of locals as well as tourists, as well as the percentage of openings that may be offered in such climatic conditions.

This research paper analyses the thermal efficiency of stone and mud dwellings in Bhuj in order to ascertain if mud homes are more suitable for naturally ventilated rural residences and create a more comfortable living environment than stone walled homes.

1.1. Research Question

1. Which of the following is a better insulator: stone or mud?

2. LITERATURE REVIEW:

Thermal efficiency of mud house buildings measured and evaluated with help of a different form of building (a stone structure). A wall and roofing material act as a thermal mass that determines how well it can retain temperature, hold it, and then either let it go internally or outside. When the outside temperature is much higher, thermal mass can prevent heat from transferring through a building's exterior to interior and thus helps in keeping the interior cool all day [2].

Thermal mass collects temperature from inside sources when subjected to the interior, reducing the intensity of the inside temperature change.[3].
This is useful because it absorbs the day's internal heat gains in hot climates, limiting a significant temperature rise and reducing the possibility of excessive heat. [4]. Due to the temperature difference between the outermost layer (radiant) and interior air, a structure with a lot of thermal mass may soak up heat and provide a cooling effect. Szokolay[5] claims that absorptance/reflectance will have a major impact on solar heat absorption. Reardon [6] and Szokolay [5] both acknowledge that the thermal mass effects of porous materials with low specific heat are minor.
According to C.V. Coffman et al [7] mud house architecture aligns with nature by keeping interiors cooler during day time and warmer during night and offers a natural air-cooling effect. As R.J. Duffin et. al stated in study that the use of mud as a wall material to regulate the temperature of rooms in buildings. The most popular type of passive solar architecture uses thick walls to stabilize internal temperatures. This kind of architecture is used to create Yemen City's famous mud dwellings. Both residents of cold developed nations like Europe and America as well as those in hot developing nations find the use of mud as a building material to be a major point of concern.
Engineers from affluent nations have recognized the unique characteristics of mud as a building material. Due to its unique qualities, such how the mud habitat fits a variety of climatic and geographic circumstances since the temperature within the mud structure remains temperate throughout the year, mud construction is used more frequently in desert and hot places. [9]. H Algifri et al. [10] examined the possibility for using mud as a building material for passive homes to save energy by analyzing the thermal behavior of a Yemeni adobe home to that of a modern concrete structure.

3. METHODOLOGY:

Computer modelling was utilized in the study to determine the overall thermal resistance of the system by using the known thermal resistance values of the various building material layers. Hourly measurements of ambient temperature, mean radiant temperature, and incident and diffuse solar radiation were utilized to model inter-zonal heat gain. The simulations were done using meteorological information for Bhuj, Gujarat. For this purpose, the test unit, a mud wall and stone wall building, was first modelled in ECOTECT (Autocad and Sketchup are used first, and then the Ecotect software is stimulated), and then the thermal characteristics of the constructional aspects were modified to see how these changes affected the thermal comfort of the occupants. It should be highlighted that all materials used in this simulation study had walls that were 30 cm thick. For better outcomes, the model is considering traditional Bhunga house form. The model is made up of a square with a side of 3.3 meters and a circle with a radius of 3 meters, with the front side facing south. Pitch roof made of CI sheet is the roofing system considered. The eastern and western walls are where the openings are located. To determine the results, all factors were held constant with the exception of the kind of wall material.

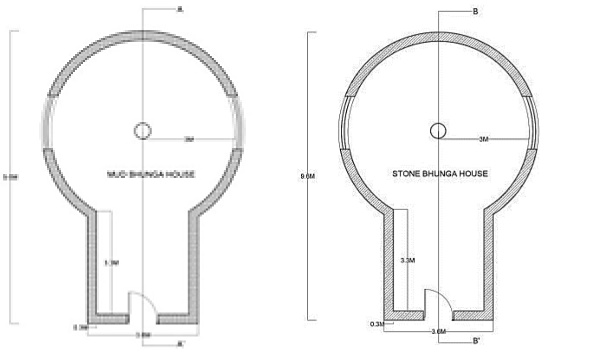

Fig. 1 Plan of study models with mud wall (left) and stone wall (right side).

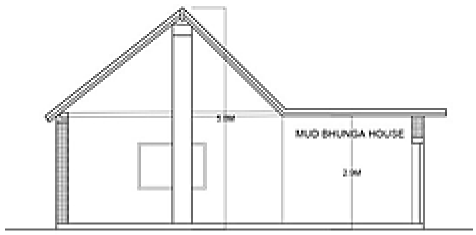

Fig. 2 Section of model with mud wall

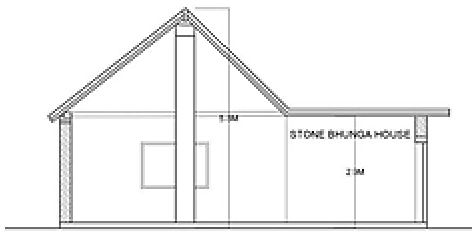

Fig. 3 Section of model with stone wall.\

3.1. Mud and Stone Construction in Bhuj

Prior to 2001, brick that had been fired or burned rather than mud or unburned brick was more frequently used to construct walls in rural areas. Burnt brick is currently the most extensively used walling material in metropolitan India, but since there are more and more high-rise buildings, concrete is gaining popularity [11]. As "sustainable" building materials, rammed earth and straw bales are usually recommended in addition to mud and stone construction. Their embodied energy is one factor that supports a theory that these materials are sustainable. Rammed earth and mud brick contain an embodied energy of about 0.7 MJ/kg when made locally lesser than 20% of lightweight aerated concrete blocks and

30% lesser of clay bricks (other than stone) (2.5 MJ/kg). But many publications regularly overstate the thermal conductivity of these materials. Because of their thickness, earth walls are said to provide "superior insulation," giving "excellent protection from climate extremes" and minimizing heating and cooling costs.
A mud home is one of the traditional building styles used in rural regions and also on fringes of villages in Bhuj, Gujarat. Bhunga structure normally one or two floors tall with primarily utilized for single-family homes. House as a load bearing structure consists mud walls of 500 mm thick and support the roof load. Roofing materials include clay tiles, thatch, and CI sheets. The usage of these materials is determined by their local availability and the capabilities of the homeowners.

Fig. 4 Mud wall Bhunga house Location: Regenta Resort, Bhuj

Fig. 5 Different roofing materials of Bhunga house Location: Regenta Resort (left) and Hunarshala (right), Bhuj

Fig. 6 Coursed rubble masonry, Stone wall Bhunga house

According to Amrita Das et.al , houses are mainly of rectangular plan with lengths ranging from 20 - 30 feet and widths ranging from 10 - 15 feet [12]. The major structural elements are mud walls that support the roof. The opening area accounts for approximately 30% of the entire wall area. But in recent years, buildings made of brick, mud, and stone with thatch roofs have become increasingly common. More people are drawn to stone houses as a result of economic prosperity in rural areas and the perception that stone walls are more durable. However, in the climatic environment of Bhuj, stone walls with Mangalore tile roofs can generate overheating and unpleasant living conditions.
Mud is beneficial to the ecosystem. In extreme weather, it functions as a heat sink due to its high thermal capacity. An agricultural by product called straw can also be utilized in construction. Traditionally, it has been used with soil or clay to create mud brick. Additionally, it has superb insulating qualities. Utilizing mud walls' thermal mass can drastically reduce a building's energy requirements. Heat-gain modulation can be carried out by efficiently applying the thermal mass of the structure to capture and retain heat throughout the day and emit it to the environment after a few hours.

4. Data Analysis:

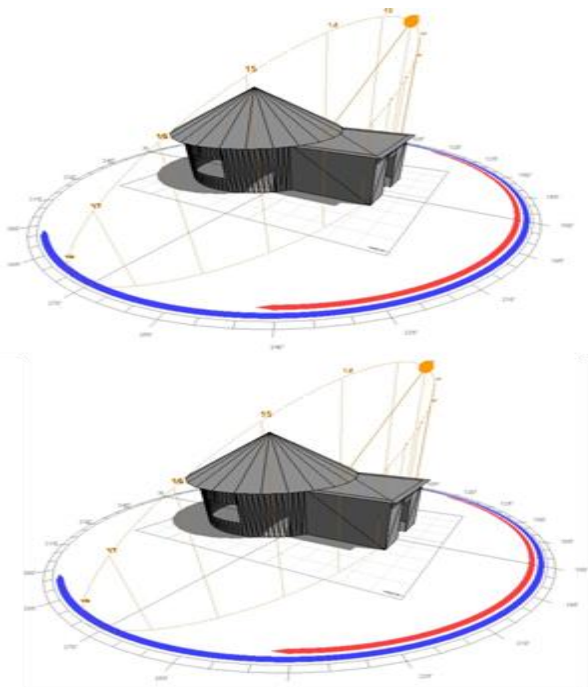

Fig. 7 Study model with mud wall (above) and stone wall (below) in ECOTECT

ECOTECT simulates the mentioned model as a summer for the month of march, monsoon for July, and winter for December, The following section discusses the findings' comparative analysis.

4.1 Comparisons between an hourly temperature and the MRT (Mean Radiant Temp.):

Inside temp. in the designated zone is indicated by the MRT simulations. By comparing the material with the simulated results, we may determine whether it effectively creates comfortable interior conditions at a specific time of day.
With three zones (Shahed) and hourly lines (brown, dark blue & green) on the comfort graph / zones (blue means cooler zone, white means comfort zone, and red means warmer zone). The roofing temp data is represented in brown dark blue represent data for outside dry bulb temp. and the green line represent as inside temp.

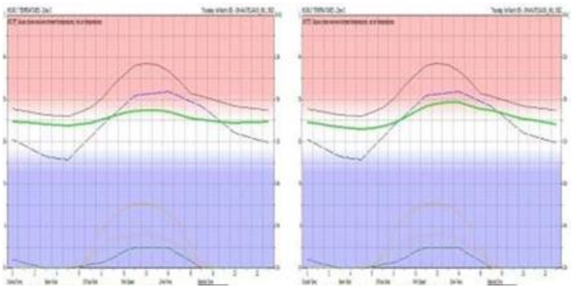

Fig. 8 Hourly temperature for mud wall (left) and stone wall (right) (1st March)

The hourly temperature and mean radiant temperature graphs show that for a mud-walled dwelling in the month of March, the inside temperature remained lower than the exterior temperature in the comfort zone (white shaded).

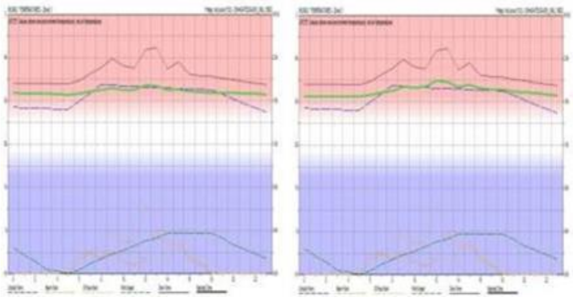

Fig. 9 Hourly temperature for mud wall (left) and stone wall (right) (1st July)

For mud-walled house the MRT and hourly temp. data analysis show that the indoor temperature remains lower than the outdoor dry bulb temp but that it occasionally exceeds the comfortable range (between 11 am and 2 pm), as compare to high difference in stone-walled house.

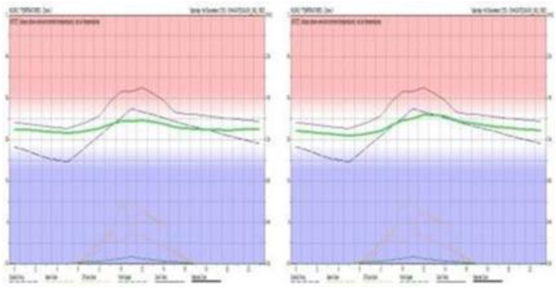

Fig. 10 Temp. analysis for mud wall (left) and stone wall (right) (1st December)

According to the diagrams and graphs above, both mud and stone walled houses keep the internal temperature within a comfortable range. However, the hourly temperature graphs reveal that the mud walled building has less instability in indoor temperature than the stone house.

4.2 Comfort Zone

The thermal comfort range is affected by a variety of elements such as humidity, wind speed, sun radiation, and individual differences. Keeping these parameters in mind, the comfort zone for 70% humidity and 0.5 m/s wind speed is set between 18.0- 26.0 ^{o}C[13]. The following results were obtained by performing comfort simulations in ECOTECT.

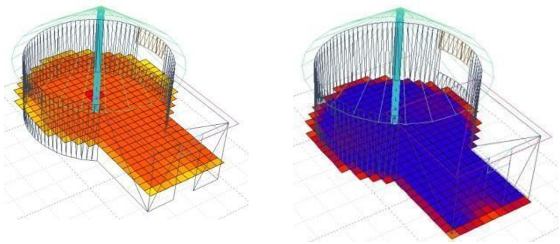

Fig. 10 Study model while running comfort

Table 1 Outcome of comfort simulations in ECOTECT.

Mud wall	Stone wall
Operation: Weekdays 00-24, Weekends 00-24.	Operation: Weekdays 00-24, Weekends 00-24.
Comfort Band: 18.0 - 26.0 C̊	Comfort Band: 18.0 - 26.0 C̊
In Comfort: 3911 Hrs. (44.6%)	In Comfort: 3625 Hrs. (41.4%)

As a result, the internal temperature in a mud walled house will be more comfortable than in a stone walled house.

4.3 Passive gains or losses:

ECOTECT was used to analyze passive heat acquisition or loss in order to determine how changes in wall material affect the amount of heat gained or lost.

The figures clearly demonstrate that a house with a stone wall will experience significantly higher passive heat gain than one with a mud wall. Even in a difficult area, like the arid terrain in our example, a Bhunga's interior conditions can be enhanced by reducing its temperature in the summer and providing moderate temperature gains in the winter. The performance of the home was evaluated through the evaluation of indoor air temperature readings to thermal comfortable standards established by dynamic comfort studies [14].

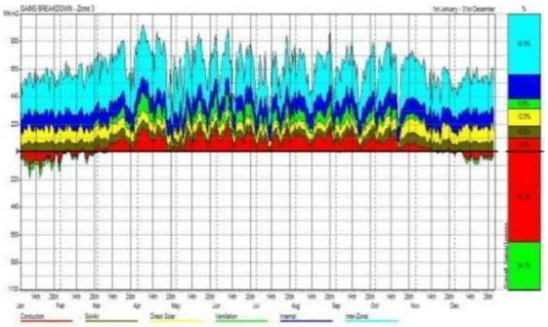

Fig. 11 Heat gain/ loses graph for house with Mud Wall

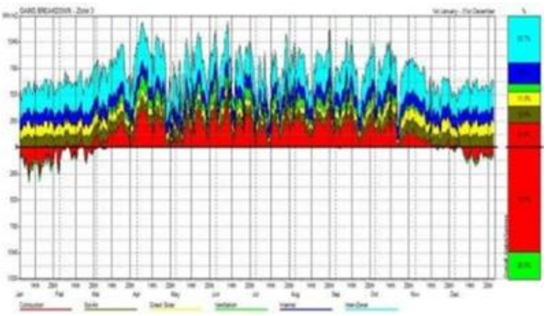

Fig. 12 Heat gains or loses graph for house with Stone Wall

5. RESULTS AND DISCUSSION

An experimental analysis has shown that houses with mud blocks performed better than in a Stone walled house in our desert climate [15]. The quantity of passive heat uptake in a stone walled house is substantially more than in a mud walled one.

According to the statistics, the Mud house had a lower temperature than the Stone house. The Mud house has a longer time lag, which might lower cooling loads. The study focused solely at dwellings with thatch roofs. Further research may be carried out to determine the effect of roofing material on inside temperature and whether the circumstances in the Mud home can be improved further by using different types of roofing. Lowering the interior temperature can result in reduced energy use and lower carbon emissions. We may develop a sustainable living environment and decrease thermal stress by employing mud or earth as a construction material.

6. CONCLUSION

In comparison to stone walls, mud walls make the interior of the construction or bhunga home cooler in summer and warmer in winter. As a result, mud may be a preferable alternative for both visitors and locals in Bhuj, Gujarat. However, careful design considerations can increase the cooling impact of these traditional mud dwellings as well as the thermal comfort conditions within the buildings.

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