Thermal Performance of Mud as Building Material in Composite Climate

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Abstract :

Among other things, indoor thermal comfort can be enhanced through careful selection of building materials. India has a wide range of weather extremes, ranging from hot and humid to cold and dry. A mixed climate prevails in a large part of the country, with a wide range of climate conditions. Twenty percent of the world's population lives in mud houses, and many rural people have lived in mud huts for generations which are an integral part of their culture. This research investigates rural indigenous mud-based construction, the characteristics of the soil and how well it performs thermally in India's diverse climatic conditions. The fundamental thermal properties of soil have been researched to establish its suitability and successful use in the seasonally fluctuating characteristics of a mixed climate. Ranchi, the capital of Jharkhand, has been considered as an example to demonstrate the performance in a typical mixed climate region.The construction of earthern houses has significantly declined in India and thus it is necessary to evaluate if they can make a valuable contribution to contemporary housing shortage. Therefore, an informal survey was conducted in India to understand factors favouring or limiting the construction and daily use of mud houses. The outcome of the survey suggests that 'Image' is the key barrier against a wide acceptance of traditional earthen houses which are linked to poverty. While modern earthen construction is desired, it is expensive for low-income households. The role of mud in addressing the contemporary housing shortage is analysed and suggestions are given for the implementation of modern mud technologies for low-cost affordable housing. Initiatives by middle-high income households, entrepreneurs and government can trigger a widespread interest in earthen construction. Successful demonstration of durable earthen structures at diverse locations and contexts can act as catalysts. We conducted Survey to understand factors favouring/limiting mud construction in India. We Study the Low societal image of mud as building material is a key barrier towards its acceptance. Compressed earthen technique (CSEB) has potential to improve image and acceptance for housing. Successful demonstration in diverse location needed to promote earthen construction.

Highlights:

- Survey conducted to understand factors favouring/limiting earthen construction in India.
- Low societal image of earth as building material is a key barrier towards its acceptance.
- Image of earth is strongly linked to poverty and intensive maintenance requirement.
- Compressed earthen technique (CSEB) has potential to improve image and acceptance for housing.
- The Climatic condition of earthern houses
- Successful demonstration in diverse location needed to promote earthen construction.

Introduction:

In India, there is a need for an affordable solution to cater for this shortage of housing. Construction with conventional materials such as concrete or fired bricks is often considered plausible due to their wide availability and standardization in use. However, the prices of these materials have risen significantly over the years and higher than the proportional rise in income. To meet the demands of low-income households, traditional and indigenous materials could be re-considered as interesting alternatives. Local construction materials and building practices that are tailored to rural lifestyles, topography, climate and resistance to natural calamities have the potential to offer solutions to the shortage of housing in rural India. Traditional building materials are inexpensive, readily available and require minimal processing before use. Furthermore, the labor involved in the construction process is also sourced locally, often limited to the household, the extended family or members of the local community, thus saving on labour costs. Earth or mud is one of such abundant resource that has been used as a construction material for over 9000 years. Even today, one-third of world population is estimated to live in houses that are at least in part made of earth. In developing countries, this number is estimated to be much higher. Earthen houses are considered environmentally friendly and affordable as compared to houses built with concrete or fired clay bricks, for a multitude of reasons, for example earthen houses are known to improve the indoor air quality and thermal comfort they consume minimal energy for material production and the transportation costs are reduced due to local resource utilization. In recent years, the increasing price of building materials has resulted in revival of interest in earthen construction globally which puts forwards an important question ‘‘Can earth be a solution to housing shortage in India”.

Gernot Mink (2005) suggests that mud block construction was a popular practice in regions with dry, hot, subtropical and moderate climates and it is still a convenient, inexpensive, straightforward and environmentally beneficial building material for many indigenous rural buildings. According to the 2011 census (Census, 2011)1, mud walls still exist in more than half of Indian houses. According to Dr. B. B. Puri (2003), more than 1/3 of the world's population lives in mud huts. The following characteristics, which are most prevalent in rural areas, have a major influence on the indigenous architecture of that region. · Climatic conditions

· Locally available building materials

· Local building techniques

· Social customs and traditions (Susilo, 2007)

It is clear from the above that in areas where clay/earth is available in abundance, mud is the most accessible, cost-effective and practical building material for rural housing. This study examines how mud works as a building material in the diverse environments of rural India, focusing on its thermal properties. Many tribes in eastern, northeastern, and central India have mud huts as part of their cultural history. For India's rural population, it is important to improve them by enabling better thermal comfort indoors. Since they are readily available, inexpensive, and relatively simple to work and construct, mud and straw are some of the oldest building materials in human history. Mud's plasticity and versatility have enabled it to be used in the construction of a variety of structures in different terrains, from desert huts to multi-storey houses.

According to ancient architecture and contemporary technologies, earthen building is essential for sustainable future society (Hassan, 1973) According to Dr. B.B. Puri (2003), there are two general groups of earthen buildings: buildings built using traditional methods and buildings built using modern methods. Most traditional rural houses are built using the following traditional techniques:

1. Sun-dried brick or adobe
2. Rammed earth building
3. Wattle and daub

Building Modern methods include:

1. Compacted earth blocks
2. Stabilized, compacted earth blocks
3. Stone facades and compacted earth blocks
4. Earth blocks with chemical stabilization
5. Pneumatic ramming of soil

of all the techniques and methods described above, the rammed earth technique is effective in both traditional and modern methods. Rammed earth building was first used in India in 1948, when 4000 houses were built in Karnal (Haryana). People have been living in these houses for more than 50 years now. With a comprehensive analysis through trial and error, vernacular architecture often expresses an ideal form, which is highly responsive to the environment and materials at hand (Cooper, 1998). With a comprehensive analysis through trial and error, vernacular architecture often expresses an ideal form, which is highly responsive to the environment and materials at hand (Cooper, 1998).The following paragraphs present some facts that Thermal performance of mud walls, which are frequently used in the construction of rural mud houses in Ranchi, Jharkhand, located in the mixed climate zone of the Indian subcontinent.

Key Feature of Composite Climate :

According to NBC (National Building Code, 2005) India has 5 distinct climatic zones which are hot-dry, hot-humid, temperate, mixed and cool (see Figure 1). The mixed typology combines the influences of hot and humid and hot and dry.

The mixed climate exhibits distinct characteristics throughout the year, cycling between short periods of heavy rainfall and high humidity and extended periods of intense heat and dryness. There is a third season, winter, which consists of cool nights and dry, sunny days.

The central region of India falls under the mixed zone. New Delhi, Kanpur, Ranchi and Allahabad are some of the cities that have this type of climate. In summer, during the day it can be very hot, between 32 and 43 °C, and at night, it is warm, around 26 to 32 °C. In winter, it gets cooler, nights are cold, between 3 and 10 °C, and daytime temperatures range from 10 to 25 °C. In dry and wet periods, the relative humidity ranges from 20 to 25% and 55 to 95%, respectively. In this region, the annual rainfall ranges from 500 to 1300 mm. During the monsoon, the region is subject to strong winds from the southeast and dry, cold winds from the northeast.

The state of Jharkhand, which is located in the eastern region of India, has Ranchi as its capital. The latitude and longitude of Ranchi are 23.3* north and 85.3* east. The Ranchi Plateau is located at an average altitude of 900 meters above sea level, which is a fairly high altitude. According to the 2011 census (Census, 2011), Jharkhand has a large tribal population and 75.9% of its residents live in rural areas. According to the 2011 census (Census, 2011), 58.5 percent of housing units in Jharkhand have mud walls and 53.4 percent have clay tile roofs. Throughout the year, the city receives high rainfall.

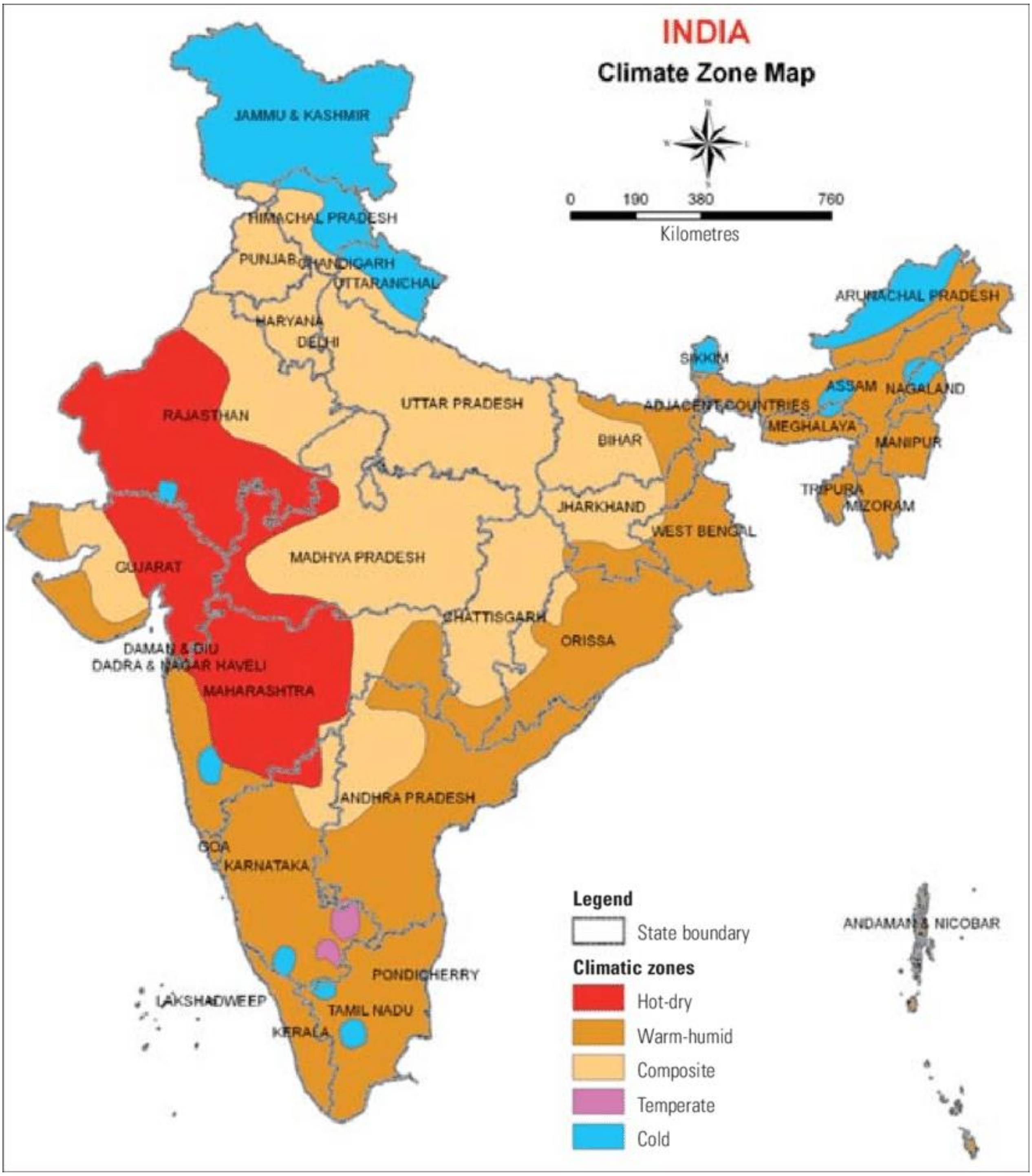


Fig. 1: (National Building Code, 2005) Classification of Climatic zones

Literature Study

Traditional Mud-based materials for building walls.

Mud is used frequently throughout India to build clay walls because it can be used in a variety of ways and in combination with other materials.

Table 1 lists some of the possible combinations that can be employed with other materials. Construction methods found in central India such as Madhya Pradesh, Chhattisgarh and Odisha in the east and also in some northeastern states include daub (mud mixed with bamboo framework), mud walls and cob walls (built layer by layer). Most rural houses in these areas are made of mud walls and thatched roofs. The seven sisters, or northeastern states of India, use clay, wood and bamboo. Clay bricks and tiles are used for construction in rural areas of some northern and central states. In the southern part of India, clay bricks are used in many parts of Kerala and clay bricks are commonly used in Pondicherry.

The following table shows the various methods used for construction of mud-based walls mostly found in rural dwellings:

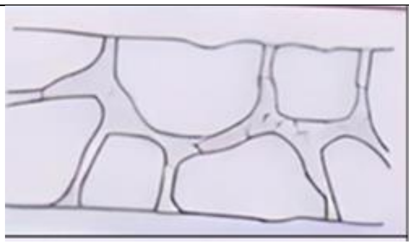
Combination Of Materials Used	Graphical Representation
Cow Dung Slurry with Compacted Earth	
Stone Masonry Made with mortar of Mud	
Mud Mortar Coating On Poles and Twigs	

Table 1: Overview of Wall Building Materials Found in Composite Climate Zone of India (Bansal, 1988)

Knowing Mud as a building material and its Thermal Properties in detail.

Understanding the material under different environmental conditions is important to understand its thermal performance. This section examines the work already done to describe the specific thermal properties of soils and their expected effects on the thermal performance revealed so far.

A study looked at people living in traditional mud huts and their attitudes towards thermal comfort. According to their survey, 90.6% of people living in mud houses say they are comfortable without artificial cooling or ventilation

(Cooper, 1998). According to Matthew Hall and David Allinson (2008), rammed earth generally has a low thermal conductivity, measured between 0.6 and 1.0 W/mK.

The following table (Table 2) lists the thermal conductivity (k values) of some commonly used building materials at moderate temperatures.

S.N.	**Building Material**	**Thermal-Conductivity(k) (Watt/Metre Kelvin)**
I	Brick	0.811
II	RCC (Mix 1:2:4 by weight)	1.582
III	Cement Mortar	0.951
IV	**Mud**	**0.6**
V	Brick Tile	0.681
VI	Cement Plaster	0.721
VII	Window Glass	0.815
VIII	G.I. sheet	60.47
IX	Thatch	0.35
X	Cellular Concrete	0.188

Table 2: Thermal Conductivity (K Values) of Common Building Materials at Moderate Temperature (Verma, 2004)

According to Gernot Mink (2005) the U value (thermal transmittance) of a 300 mm thick rammed earth wall reaches 2 watts/m² Kelvin, which is also called its "thermal mass". It has a very large thermal mass and a great capacity to store heat energy (Madhumati, Vishnupriya, & Vignesh, 2014).

This means that they naturally regulate the internal temperature of a building. Although they cannot easily prevent the passage of heat energy, they can absorb and store it due to their high density. On the other hand, due to its density, rammed earth acts as a poor insulator. The internal relative humidity of the house is automatically controlled by rammed earth, leading to better air quality. During summer, the increased thermal mass prevents heat from entering and transfers thermal lag (Narayan, 2009). Insulated rammed earth walls provide excellent thermal resistance and are superior to solid rammed earth buildings in terms of thermal mass. High thermal mass and low thermal conductivity can be achieved by using rammed earth and rigid insulation. Combining low thermal conductivity with high thermal (White, 2009).

Enhancing Mud's Insulation.

To increase the thermal insulation of soil-based materials, consider incorporating porous elements such as seaweed straw and lightweight plant-based materials. Insulation can be improved by adding plant-derived materials, natural and chemically produced mineral particles such as slag, expanded clay, pumice and manufactured glass. In addition, some waste products, such as wood shavings, grain husks and sawdust, make them less effective as insulators due to their high density. Increasing the porosity of the material increases both its lightweight properties and thermal insulation. Notably, insulated rammed earth walls outperform solid rammed earth buildings in terms of both thermal resistance and thermal mass (Fix 2009). By building high thermal mass and low thermal conductivity from soil and rigid insulation within a composite envelope, the U value5 of these walls can be reduced to 0.33 watt/m² Kelvin and 0.24 watt/m² Kelvin, respectively, by using only 50 mm thick or 75 mm thick insulation (stone, 2013)

Combining Mud and Bamboo.

One of several methods of building mud-integrated bamboo walls, wattle and daub involves covering the bamboo structure with more soil than necessary, thereby increasing the insulation capacity of the soil and promoting thermal comfort inside. (See Figure 2)

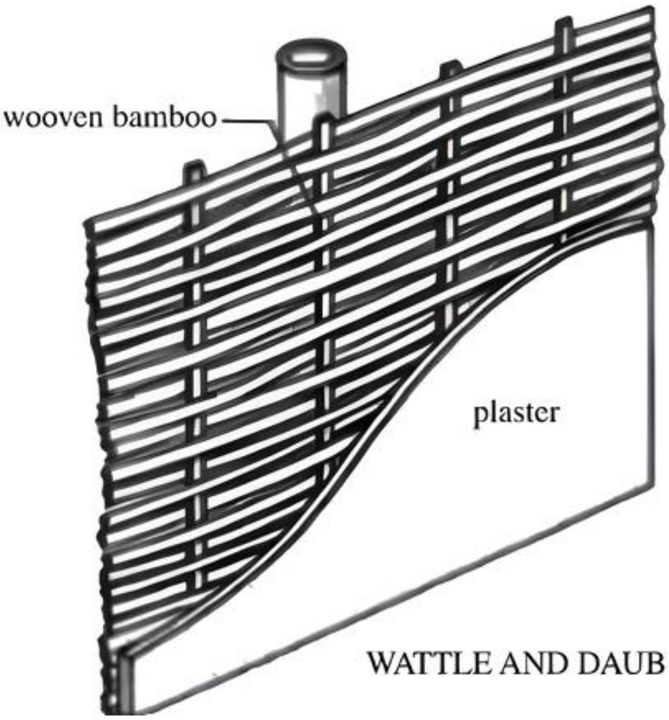


Fig 2: Wattle and Daub (Socrates, 2012).

Mud walls strengthened with bamboo provide insulation from heat and cold. The walls of traditional buildings were more than 50 cm thick, but these days mud walls are thinner as they are strengthened with bamboo stems that are properly split into quarters and heated to bitumen. The horizontal and vertical bars of the reinforcing mesh are properly secured at the crossings using wires. A mixture is made by kneading rice husk, mud, ash, a little lime and water. This mixture is applied layer by layer while the bamboo mesh is placed in between.

Discussion:

Thermal Performances in Studied Mud-Dwelling.

Typical mud homes in Mhow near Indore feature walls that are 450 mm thick, constructed using the cob technique. This method entails applying layers of mud one over the other, gradually building up the wall's thickness (Fig. 3, 4, and 5).

The following images show contextual examples and schematic sections:

Fig 3: Square Dwelling Unit 1. (Plan and Photograph).

Fig 4: Mud wall 450mm thick. (Source: Clicked by author).

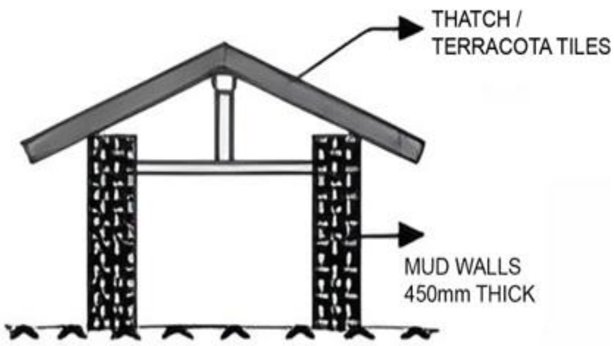


Fig 5(a): Typical mud huts in the studied area.

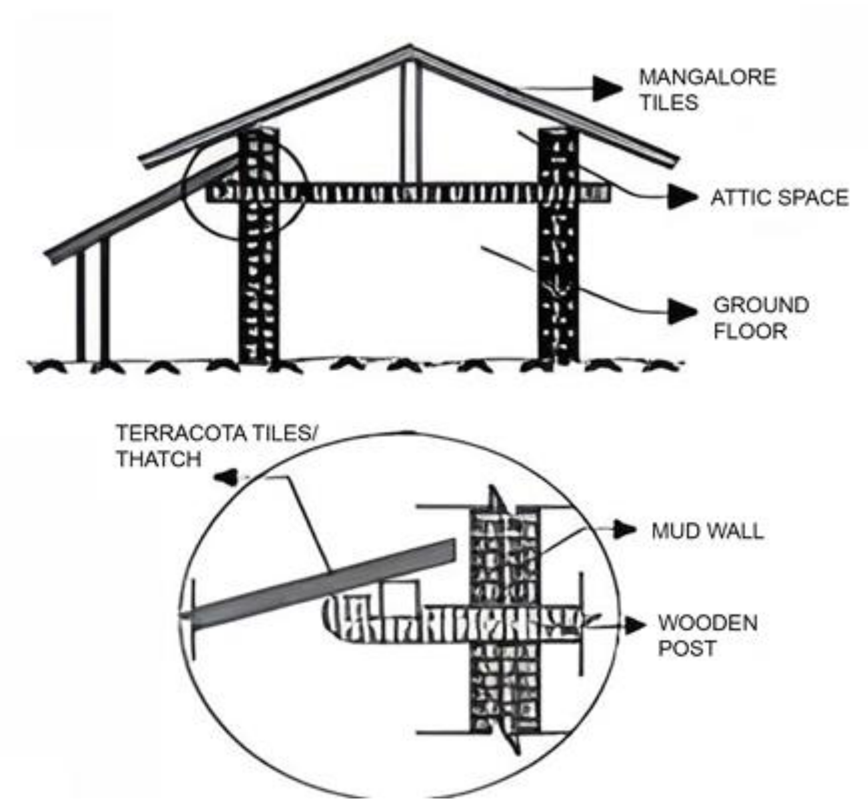


Fig 5(b): Typical mud huts in the studied area.

Observation: Fluctuations in temperature when studied for over 24 hours.

The authors performed temperature measurements ,including the hottest and coldest seasons determined from historical climate data. These measurements were made inside sample mud huts to understand how mud walls interact thermally. The internal and external temperatures of the traditional mud house prototypes were measured and the following observations were made:

1. In summer and during the daytime, the thermal behavior of the mud wall proved to be an advantage. But as night falls and the temperature drops, the temperature inside the hut remains high. When the outside temperature reaches 42 degrees Celsius during summer, the temperature inside all the buildings averages around 35 degrees Celsius. Even though the outside temperature drops to 27 degrees Celsius, the night temperature inside the hut is still high at around 35 degrees. The mentioned fact underlines the need to reduce the thermal mass in mud walls during hot months to increase cooling through nighttime ventilation.

2. The internal thermal characteristics of soil, which allow thermal lag inside the soil dwelling, are useful in winters as they maintain the night temperature above the cold outside temperature. Due to the thermal time lag factor, the internal temperature does not decrease to that level. When the outside temperature drops to 3 to 4 degrees Celsius during winters, the temperature inside remains around 13 degrees Celsius. Overall, it can be inferred that the thermal characteristics of non-stabilized compressed mud blocks should be thoroughly investigated and reported in ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and Indian Building Codes. IS: 2110-1980 Bureau of Indian Standards (BIS) talks about building cement soil walls in rural areas. Hence under BIS, further regulations need to be introduced for the use of compressed earth blocks and rammed earth walls for rural houses, to establish uniformity in earthen building processes across the country and to make traditional earthen architecture functional and modern.

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