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Evaluation of Thermal Performance of Rammed Earth in Warm-Humid Climate:

A Trivandrum Case Study

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ABSTRACT: *Stabilized Rammed Earth (SRE) is considered as the material having the lowest environmental cost and low embodied energy. Using material that is available locally means considerably reducing the energy consumed for manufacturing and transporting, which accounts for 29% -40% of the total embodied energy of that material.Earth has excellent ability to maintain interior air humidity level and thermal mass superior to other alternatives. This research focuses on thermal performance of rammed earth wall in warm- humid region taking case of Thiruvananthapuram.*

KEYWORDS: *Stabilized rammed earth, Humidity, Thermal performance, Insulation types.*

1. INTRODUCTION

"Rammed earth is a longstanding construction technique where natural aggregates – gravel, sand,silt and clay - are compacted into a formwork creating monolith building structure. Among other forms of unbaked earthen construction, such as mud brick, moulded earth and compressed earth blocks, rammed earth is one of the most widespread building forms in the history of our planet. Estimations indicate that nowadays more than one third of the world's population lives in buildings made of earth (Birznieks, 2013).Rammed earth is experiencing a rise in demand. There is a growing demand to select materials which are sustainable. The adoption of green certificates for buildings has increased. There is concern of using materials which contribute healthy indoor air quality. Desire to reduce energy consumption led to increased use of rammed earth. (Windstorm, 2011)

2. THERMAL PROPERTIES OF RAMMED EARTH

2.1. Thermal mass

Thermal mass can reduce the size of the energy wave once heat has moved though the walls, which is known as 'decrement factor'. Due to these properties of thermal mass, temperature swing of the rammed earth wall houses can be smoothed out and energy input for space cooling can be reduced. Temperature profiles in a wall are functions of the inside and outside temperature. It also depends on the thermo-physical properties of the materials. Heat wave on the outer surface of the wall travels through the wall and its deformation depends on the materials properties. Heat wave reaches the inner surface with small amplitude after certain time. Time taken for heat wave to pass through the materials is "time lag" and ratio of the two amplitudes is called "decrement factor". Heat storage capacity of materials depends on time lag and decrement factor. Thermal mass of a material depend on its ability to store and release the heat in interaction with its surroundings. Parameters used are diffusivity and emissivity of materials. Rammed earth has been used successfully in moderate to hot climates as the thermal mass effectively moderates the daily temperature swings, creating a comfortable living environment. Yet RE has a low thermal resistance and tests have determined its R-value to be only 0.4/inch. (Hall, 2005)

2.2. Thermal resistance

Thermal mass effect of the external wall can only reduce and delay indoor extreme temperature. In winter, thermal mass effect can be used for heat storage to absorb and store solar heat during the day will be released back in to the house at night reducing the heating load. Thermal performance of buildings in cold climates is mainly determined by thermal resistant capacity (r-value) of the building envelope.

Source	Thickness	R-value m^2 k/w
Bulletin 5 (Middleton)	300	0.391
HB 195 (Walker et al 2002)	300	0.35
CSIRO press release (Clarke 2010)	200	0.4

Table 1 Thermal resistance of rammed earth

2.3. Thermal conductivity

Thermal performance of rammed earth largely depends on its density. For un-stabilized earth thermal conductivity (k-value) is typically in range between 0.5- 1.2 W/mK. (Hall, 2005) Rammed earth is a better insulator than concrete and brick. Thermal resistance of a 200mm thick rammed earth wall slightly below 0.4 mK/W. This is comparable with the overall thermal resistance of 220 mm bricks with density of 1280 kg/ m3, or 200 mm concrete blocks with density of 2210 kg/m3 and little higher than the resistance of 250 mm concrete wall with density of 2240 kg/m3. (ASHRAE, 1997)

2.4. Emissivity and diffusivity

Thermal diffusivity is defined as the ratio between thermal conductivity and the product of the density with the thermal capacity. Thermal diffusivity represents the ability of the material to transmit temperature variations. It represents the speed of calories displacement. Lower diffusivity, higher the effect of the materials

$D=\lambda/\rho Cp$ with:

k [W/ m K]: thermal conductivity, q [kg /m^3]: dry density,

Cp [J/ kg K]: thermal capacity at constant pressure.

Thermal emissivity is defined as the square root of the product of the thermal conductivity, density, and thermal capacity. It is a measure of the ability of the materials to exchange energy with its surroundings and to absorb heat; higher diffusivity indicates how quickly the materials absorb heat without temperature rise at its surface.

$$E=\sqrt{\lambda\rho C}$$

3. OBJECTIVES

- To find out whether Stabilized Rammed Earth (SRE)

  suitable in warm-humid climate.

- To investigate the thermal performance of SRE wall system comparing to other wall predominantly seen in warm-humid climate.

- To analyze the thermal performance of SRE with different techniques in SRE construction.

4. To find out the effect of u-value and thermal mass in SRE wall system by calculating conduction heat gain.

5. SCOPE AND LIMITATIONS

- Influence of water content in rammed earth has effect on thermal properties such as diffusivity and emissivity which as to be further researched.

- This study intends to explore the potential of rammed earth wall in humid regions.

- This study helps for the further investigation of thermal performance of rammed earth in humid regions.

- The study is limited to a comparative analysis of materials predominately used in warm-humid climate.

6. INSULATION IN STABLIZED RAMMED EARTH

Thermal performance of stabilized rammed earth can be improved with insulation. By nature, rammed earth is hygroscopic. When the walls are clad externally, cladding materials and finishes must be vapour permeable to allow evaporation. It is important for un-stabilized rammed earth walls. Stabilizing agent will impair breathing through the wall. But it wise to consider vapour permeable solutions for both the instances to avoid issues associated condensation. Vapour permeability of the wall is less important when considering internal insulation in rammed earth, when moisture is encouraged to evaporate externally. Specification for internal insulation is lot more flexible than for external insulation. Application of insulation directly on the surface of the wall should be avoided.

7. METHODOLOGY

The research is focused on identifying the characteristics of rammed earth wall. A comparison study is used for analyzing the potential of rammed earth in humid regions. A base model is created, and through simulation, performance of rammed earth is compared with other conventional building materials prevailing in warm-humid regions. Research is carried out during the summer month of March.

For the identification of the parameters, factors were categorized into dependant and independent variables. Ten wall systems are identified for the comparative study. Each wall systems is compared with the performance of stabilized rammed earth of different wall thickness of 250mm, 300mm and 400mm and with the insulated typologies of rammed earth with different insulation techniques. In the phase 2 of the research comparative study of the results is done by taking a peak day in the month of March.

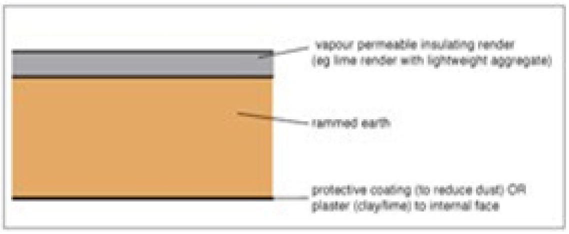


Fig.1 External insulation, Source:www.greenspec.co.uk

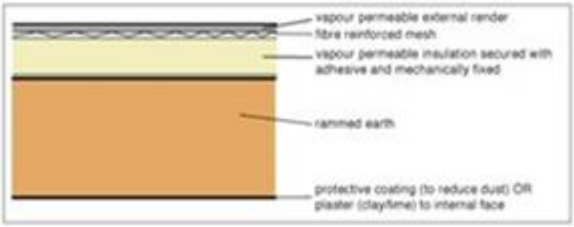


Fig. 2 External insulation-Insulation board and render

Source: www.greenspec.co.uk

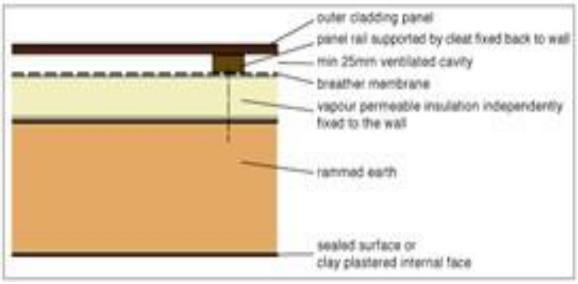


Fig. 3 External insulation-Insulation board and render

Source: www.greenspec.co.uk

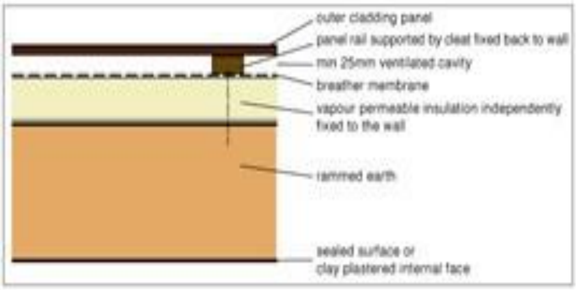
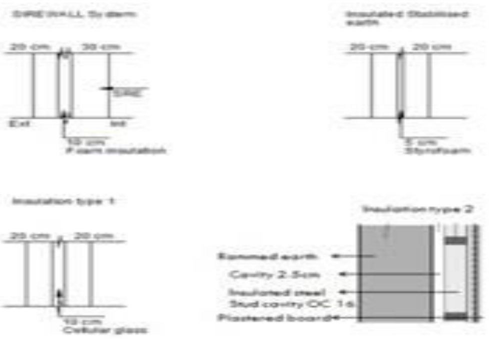


Fig. 4 Internal insulation- Free-standing studwork with infill insulation, Source: www.greenspec.co.uk

- The parameters taken for this stage of the study were as follows: __
- Comparative study of heat gain/heat loss through the wall system (one dimensional steady state flow method considering the effect of direct radiation).
- Comparative study of mean radiant temperature experienced in the base case room with different wall systems.
- Comparative study of moisture content and relative humidity.



7.1. Climatic condition

Thiruvananthapuram belongs to warm-humid region comfort requirements differ according to the climate conditions. A building in warm- humid region has to resist heat gain by decreasing exposed surface area and increasing thermal resistance.

In December, temperature reaches to the minimum, and in March, temperature reaches to the maximum. Relative humidity stays almost same throughout the year though precipitation rate is different. It affects the overall air temperature of the selected months. Diurnal variation range is very small in Thiruvananthapuram. Thermal mass of the building mass is to store the heat and release it in the night. Since, the variation in diurnal temperature is small; the effect of material with high density and heat capacity is subjected for study.

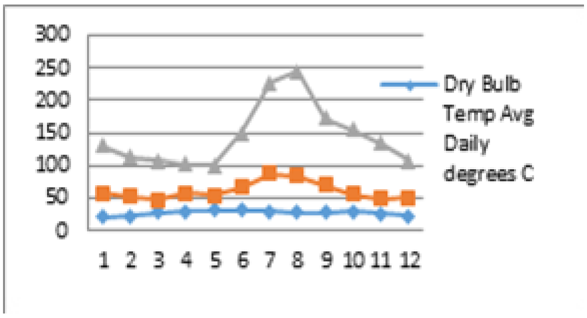


Figure 5 Relationship between DBT, RH and diffuse radiation

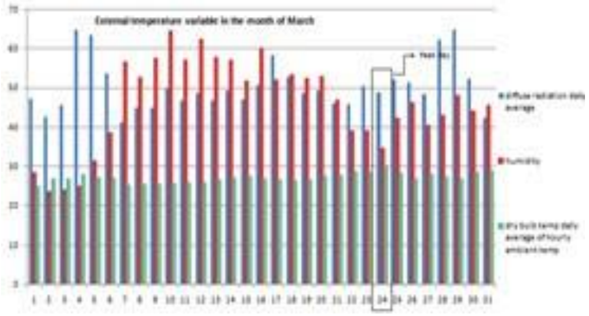


Figure 6 Peak day in the month of March

Peak day is selected from the summer month to understand the mean radiant temperature experienced inside the base case model with different types of wall systems. 24th of the March experiences the highest value of dry bulb temperature and moderate value of relative humidity.

7.2. Insulation in rammed earth wall

Figure 7 Insulation in rammed earth wall.

For the purpose comparing rammed earth with different insulation techniques in rammed earth, few types of insulation methods are selected. Four such insulation typologies are compared with stabilized rammed earth with different thickness of 250mm, 300mm and 400 mm and other conventional materials.

Overall ten materials are selected for the comparative study of thermal performance in warm- humid region. U – value of these materials are denoted in the graph. U-value is calculated for the composite wall systems. From the Fig 8, insulation typologies have the lowest of the U-value and AAC (Aerated Autoclaved block) has the lowest in the conventional building materials typology. Highest value of U-value

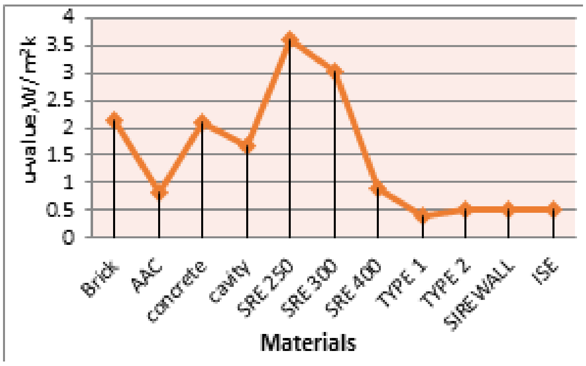


Figure 8 U- value of materials

is of stabilized rammed earth of 250 mm thickness, having a U-value of 3.6 W/m^{2}k.

7.3. Characteristics of base model

Bedroom 1 is selected for the initial results. Two fluorescent lamps are given in the bedroom, along with a ceiling fan. Occupancy is given as two.

For the purpose of simulation, West wall of the base case model is given different wall materials and simulated with the condition of the peak day, which is 24th of the month of March.

Parameters	Descriptions	Thickness	U-VALUE
Floor area	9m^2	-	-
External wall height	3m	-	-
External wall area	18m^2	-	-
Area of the openings	1.8m^2	-	-
Roof	Reinforced concrete	150mm	2.78W/m^{2}k
Floor	Insulation-RCC-Cavity-Chipboard flooring	268.2mm	0.22W/m^{2}k
External window	Outer pane-cavity-inner pane		1.6W/m^{2}k
Door	Plywood	37mm	2.199w/m^{2}k
External wall	-	-	-
Internal partition	-	-	-

Table 2 Characteristics of base model

For the purpose of simulation, West wall of the base case model is given different wall materials and simulated with the condition of the peak day, which is 24th of the month of March. Roof of the base case model is given reinforced concrete of 150 mm thickness and floor is given insulation RCC cavity chipboard flooring of thickness 268.2mm. External window which is 10% of WWR is outer pane cavity inner pane of U-value 1.6W/m^{2}k. There is only one door with is internal made of plywood of thickness 37mm having a U-value of 2.199W/m^{2}k.

8. RESULTS

Simulated results are generated from IES VE software, in which the west is given the different wall materials to see the effect of the wall system in mean radiant temperature inside the room. Wall materials include brick masonry, AAC(Aerated autoclaved cement block), concrete block, cavity block, stabilized rammed earth of 250mm,300mm and 400mm, SIREWALL, ISE insulation type, Type 1 and Type 2 insulation wall systems. Heat gain /heat loss is calculated manually and mean radiant temperature experienced in the room is simulated through the IES VE software.

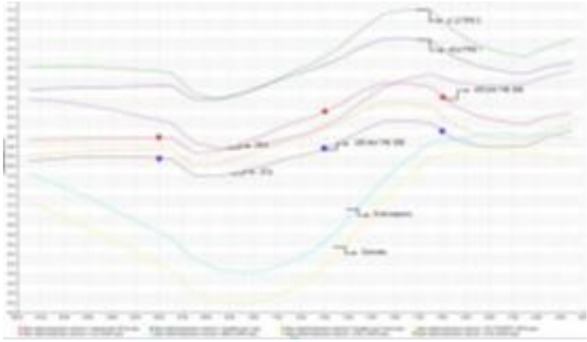


Figure 9 Mean radiant temperature in the base case model with different wall systems in the peak day, 24th March

Mean radiant temperature in 250 mm thickness, stabilized Rammed earth is lesser than 400mm thickness SRE, Fig 9 Time lag of 250mm SRE is lesser than 400 mm thickness SRE. Lowest Mean radiant temperature is experienced in concrete wall and in brick masonry. Highest MRT is experienced in insulation type 1 and insulation type 2. Highest MRT reaches 38.6 and SRE400 39.8 and in SRE250 reaches 38.9. In morning MRT goes to 36 in brick meanwhile its 37.8 in SRE 250 and 38.4 in SRE 400.

By middle of the day, mean radiant temperature in the room with brick masonry and concrete falls below than the exterior DBT. Brick masonry and concrete wall systems are the only two wall systems fall below the dry bulb temperature inside the room. Rest of the materials shows sharp rise of temperature inside. Temperature experienced inside SIREWALL systems shows the highest of mean radiant temperature.

For the understanding the thermal properties of the materials, heat gain/heat loss calculation is done and compared with stabilized rammed and other materials with the same internal indoor temperature. While calculating the heat gain/heat loss direct radiation is considered falling on the west wall. From the Fig 10 brick masonry transfers the highest of heat gain. Type 1 conducts the least of heat through the wall. Within the variations of rammed earth with various thicknesses, 400mm thick rammed earth conducts the lowest and 300mm thick rammed earth conducts the highest.

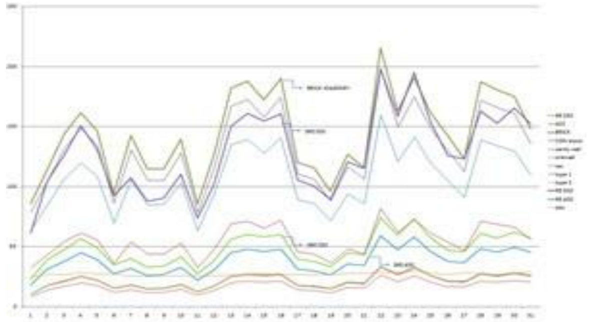


Figure 10 Conduction through different wall systems

Lowest heat gain is from type 1 Insulation and highest is from brick. U-value of brick is W/M^{2}k and type 1 insulation having a U-value of 0.409 W/M^{2}k which is the lowest among the materials. Fig 11shows that brick wall conducts highest of the rest of the building materials and rammed earth of 300 mm thickness comes second and concrete wall comes third. Type 1 insulation conducts least and SIREWALL come second last.

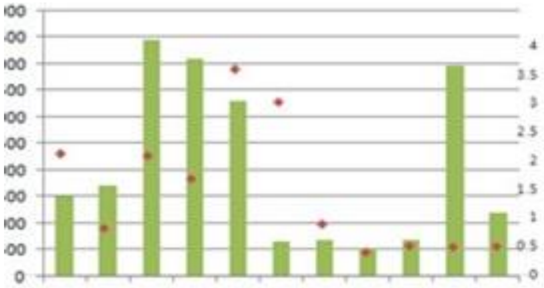


Figure 11 Monthly average of heat gain v/s u-value

In the case of 250 mm rammed earth has the U-value of 2.4 W/m^{2}k and density of 1500kg/m and AAC has a U-value of 0.7 W/m^{2}k which is lesser than RE 250 but has slightly lesser denser than AAC. In the case of concrete wall, it has U-value of 2.6 W/m^{2}k and high density.

Highest MRT value is experienced in modified SRE wall types, but their respective u–value and thereby heat gain is lower. Lowest MRT is experienced in concrete wall room following brick. In the case of SRE types, lowest MRT is experienced in SRE 250 mm, followed by SRE 300mm and SRE 400 mm.

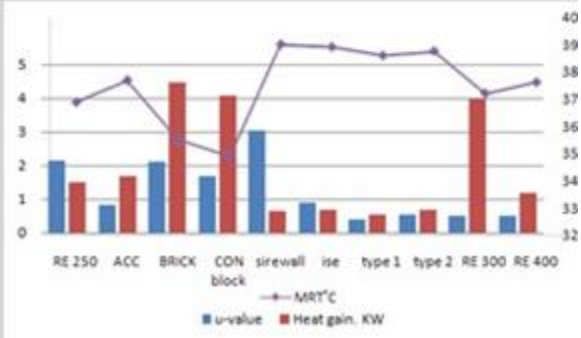


Figure 12 Daily total heat gain and density comparison

9. CONCLUSIONS

The objective of the research on the thermal performance of rammed earth in warm-humid climate is to find whether the stabilized rammed earth suitable for the warm-humid climate in terms of Mean Radiant Temperature (MRT) and heat gain through the building materials which are commonly on the climate of warm-humid climate. Internal relative humidity experience inside the room with different wall materials is also analyzed. The research is intended to understand whether any variants of stabilized rammed earth suitable for the warm-humid climate. Comparing to the prevailing materials in the warm- humid climate, brick masonry performs better than SRE and among the different types of SRE, 250mm SRE perform better than the other variants.

Contrary to the popular belief that rammed earth will reduce indoor temperature in warm-humid climate and the reduction of humidity in interiors is found not justifiable from the results of the research. Brick and AAC block performs better than rammed earth in warm-humid climate and influence of natural ventilation is understated.

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