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Energy Performance Evaluation of Rammed Earth Construction

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Abstract

Due to the increasing rate of energy consumption in the construction industry, designers have turned to construction methods that use less energy during construction by being more serviceable. Rammed-earth (RE) buildings are one of these ways because of the materials' availability, ease of preparation, and significant reduction in energy usage and environmental impact. When designed correctly, the thermal mass in the walls will maintain a stable internal temperature throughout the seasons. This reduces the need for power-based heating and cooling systems. In the current study, energy performance evaluation of rammed earth construction is done and compared to those of masonry walls. The thermal performance of rammed earth wall was experimentally measured by using thermal imager. West and south wall were taken to measure thermal performances. Similarly, computer based simulation software Ecotect was also used to carry out further analysis. The results illustrate the proper thermal performance of stabilized rammed-earth in comparison to the masonry materials.

Keywords

Construction Technology, Rammed Earth Construction, Thermal Comfort, Energy Efficiency, Thermal Performance, Masonry Construction

1. Introduction

The rise in the industrial development and population has resulted in the significant rise in the energy demand. In the year 2009 the building sector alone was responsible for the consumption of 40 percent of the energy in the United States and European Union [1]. Furthermore, the increase in the demand of thermal comfort has also tremendously contributed the use of energy. Thus, under this circumstance it is utmost necessary to use the material which can enhance thermal performance without being expensive.

Rammed earth walls are low carbon emission and energy efficient. Rammed earth is constructed by compacting the processed soil in progressive layers sometime stabilized by the use of cement or other binders. The primary constituents of rammed earth are clay (15–25 percent), sand (50–60 percent), gravel (15–20 percent), with/without a limited percentage of stabilizer such as cement (3–5 percent), and minimal water (8–12 percent), and finally tamping the mix in needed formwork using simple methods/tools, have clearly justified this construction as a low user of resources and energy compared to other constructions [2].

Due to its availability, low-cost advantages, auto-construction, and bioclimatic capabilities to withstand severe weathers, rammed earth has been used as a building material for centuries. In a study conducted in France, the use of locally sourced materials in rammed earth construction resulted in a substantial reduction in environmental effect as compared to a case where the construction material is sourced from afar and transported to the construction site [3]. When comparing a rammed earth house to a conventional concrete house, the energy used in transportation can be decreased by 85 percent. As compared to a reinforced concrete framed framework, the use of soil and cement to build unfired masonry blocks resulted in a 62 percent reduction in embodied energy (which is the energy used to manufacture a material or a product) and a 45 percent reduction when compared to burnt clay brick masonry and reinforced concrete [4]. The correct use of rammed earth can delay heat flow rate through external envelope, which can effectively reduce cooling and heating demand in the building. From the study it has also been found that the energy performance of rammed earth is better in tropical climate than in temperate climate. This study basically focuses on energy performance evaluation of rammed earth construction constructed in Kathmandu valley.

2. Methodology

This research uses post positivism paradigms. Both qualitative and quantitative data will be studied to carry out the research. Qualitative analysis will be carried out to review to build theoretical perception on rammed earth construction. Qualitative data will also encompass the individual perception on thermal comfort of rammed earth construction. Similarly, field based analysis will also be carried out the actual thermal performance of the case building. Thermal imager will be used to find out outdoor and indoor temperature difference of south and west wall. The data analysis was done taking seven days data as a base data. Finally, energy modeling with a simulation tool will be performed on the assessed structures. The methodology involves a residential building simulation that is based on quantitative and observable analyses.

Various scenarios are created depending upon the type of construction technologies used while constructing the building as shown below: Case 1- Base case scenario: In this case, the case building was simulated with the existing construction technology. The ground floor of the building is 2700mm.

Case 2- Improved scenario was created by modifying the internal planning of the building. The building was converted into one bed room apartment. Existing material of construction was used in this scenario

Case 3- In this case the building was simulated with a solid wall of 225mm thickness (outer) and 125mm thickness (inner wall)

3. Literature Review

3.1 Historical Background

The earth building techniques have developed differently in the different parts of the world. However, there are some common traits that are found everywhere. The subsoil required for the construction of earth building are found in many parts of the world. Earth construction are generally found in the areas which lacked timber and stone. Rammed earth construction dates back to the development of civilization. The development of agriculture practices beside major river led people to gather together around the towns. These fertile river valley civilizations provided the right types of soil for earth construction, and there is evidence for [5] development of earth building independently in the valleys of the Tigris and Euphrates, Nile, Indus, Jordan, Murghab and Yellow Rivers. The transition from hand-moulded to cuboid bricks occurred in Mesopotamia around 5000 BC, and that rammed earth was not found in South America prior to its introduction by Europeans [6].

3.2 Energy efficiency and Earth Construction

The construction of brick kiln contributes 500,000 tons of carbon monoxide per year, nitrogen oxide and sulfur dioxide, and 829 million tons of carbon dioxide [7]. Brick kilns have been a serious treat for human health and environment, due to emission of carbon monoxide and sulfur oxides. This is the reason why researcher are more focused on earth based construction as it is a low cost sustainable material which requires less than 10 percent of the energy input for manufacturing compared to fired clay and concrete masonry units. Earthen materials tend to have the ability to retain heat by both passive and latent heat storage mechanisms. As a result, this is the capacity to conserve and store heat throughout the day and then diffuse it as the temperature drops at night [8]. Rammed earth is one construction system that may have significant embodied energy savings, relative to comparable conventional systems [9].

3.3 Energy Performance of Rammed Earth

The building's high energy consumption has prompted the builder to concentrate on environmentally friendly and cost-effective construction methods that will have greater serviceability over its lifetime. The construction sector, which is responsible for the bulk of new buildings, now accounts for 36 percent of total energy usage and 51 percent of electricity consumption [10]. Thermal efficiency of rammed-earth materials stabilized with cement (time lag 14 63 min, R value 14 0.37 Wm K) was found to be superior to masonry materials (e.g., time lag 14 53 min, R value 14 0.10 Wm K) in the same analysis (ibid). SRE materials have a long-time lag and a low heat flux, indicating that they have good thermal mass (ibid).

Rammed-earth structures also found to be efficient in reducing the carbon dioxide emissions associated with energy consumption throughout the lifetime of the structure, as well as during construction [2]

3.4 Research Finding on Earth Construction

Study of indoor performances of a building using Rammed earth, Marrakech city, (Morocco) showed Rammed earth is an ecological, renewable and energy-saving building material. It fits perfectly into the energy efficiency approach [11].

Sustainability of compressed earth as a construction material. Wolverhampton, United Kingdom showed Embodied energy consumed by the rammed earth was found to be 5 to 20 kWh/m3 while the embodied energy consumed by the fired brick was found to be 1140kWh/m3. The embodied energy consumed by the cement is 2640kWh/m3. Rammed earth construction uses low embodied energy which results in saving energy and lowers CO2 emission [12]. Analysis of the Thermal Performance and Comfort Conditions of Vernacular Rammed Earth Architecture from Southern Portugal. [13] showed that by combining a number of passive strategies, such as passive cooling strategies in the summer, it is possible to achieve thermal comfort without using HVAC systems.

3.5 Sustainable theory on Earth Construction

The word ”sustainable” is often used to describe a technology that has a lower environmental effect on a particular environmental issue (e.g., climate change, water resource usage, etc.) and is often quantified in terms of reduced resource use or pollution emissions as a percentage or fraction. After the Rio Declaration on Environment and Sustainability was signed at the 1992 Earth Summit, sustainable development has gotten a lot of coverage. The initial definition of sustainability, which is about limited resources and reducing impact on the natural environment with a focus on technical issues such as materials, building products, construction technology, and energy-based design concepts, was undeniably influenced by most published works relating to the concept of sustainable building [14].

4. Bioclimatic Study

The boundaries for distinct passive and active design techniques will be determined using a bio-climatic chart. The comfort zone for Kathmandu's climate is between 22 and 26.8 degrees Celsius. Placing the calculated month (shown by lines in Figure 1) reveals that passive measures such as thermal mass effect and air movement may be effective ways to provide a comfortable zone within. Being in a humid climate, air circulation appears to be more important. Summer heat necessitates active cooling. During the winter, passive solar heating may be beneficial due to available sun radiation. The graph shows that even in the dead of winter, passive solar heating can be useful, whereas in the summer, direct and indirect evaporative cooling is required.

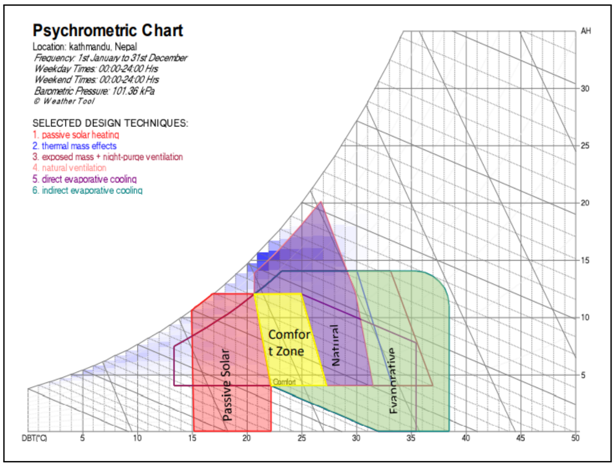


Figure 1: Bio-Climatic chart of Kathmandu

5. Simulation

The thermal performance of building is calculated by replacing rammed earth wall with solid wall construction. Various scenarios are created depending upon the type of construction technologies used while constructing the building as shown below:

Case 1- Base case scenario: In this case, the case building was simulated with the existing construction technology. The ground floor of the building is 2700mm.

Case 2- Improved scenario was created by modifying the internal planning of the building. The building was converted into one bed room apartment. Existing material of construction was used in this scenario

Case 3- In this case the building was simulated with

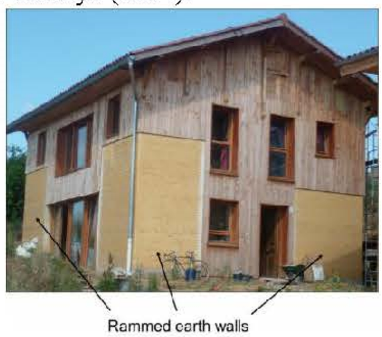
Case Study	Methodology	Findings
1. **South East France**	i. During the construction of the South/West wall, 12 sensors were mounted in 6 separate locations within the wall (in the middle and at 10 cm from both surfaces). ii. The sensors were mounted at a height of about 2 meters above the ground iii. Thermal behavior of the wall was studied	i. In terms of temperature stability and level, the house offers adequate comfort in the summer. Fig House in Saint-Antoine-l'Abbaye (2014). 
2. New South Wales Australia	i. The transducers were connected to Campbell Scientific data loggers and data recorded every 15 min	i. The east wall released as much heat as the west wall absorbed ii. During the day, the floor, ceiling, and other walls retain heat, which helps to keep the office cool.
3. Mato Ghar	i. The calculation of embodied energy and emissions has been calculated as follows: Embodied Energy= Quantity of Material x Embodied Energy Coefficient CO2 Emission (MT) = Quantity of Material x Carbon Emission Coefficient (Utama and Gheewala, 2009)	i. Mato Ghar 371,473.55 MJ embodied energy was obtained ii. 49,062.51 kg of carbon was emitted in Mato Ghar iii. Mato Ghar emitted 17.89 Kg carbon per square feet
2. Paudel Residence	Thermal Resistance (R) is calculated as: Total Resistance (Rt) = Rsi+ R1+ R2+ Ra+ R3+ Rso Where R1, R2 and R3 are the thermal resistance value of different layers of a surface and Ra is the air gap	i.Paudel residence; 508,240 MJ embodied energy was produced ii. 53609.3 kg of carbon was emitted in Paudel residence iii. Paudel residence emit 20.11 Kg carbon per square feet.

Figure 2: Literature case studies

a solid wall of 125mm thickness (outer) and 100mm thickness (inner wall)

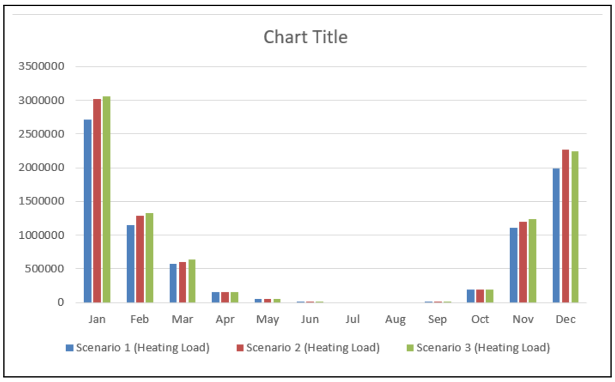


Figure 3: Comparison of heating Load in North Direction

Comparison of heating load in North Direction The graph above shows that the maximum heating load is in scenario 3, whereas the minimum heating load is in scenario 1 as per the data analysis of January.

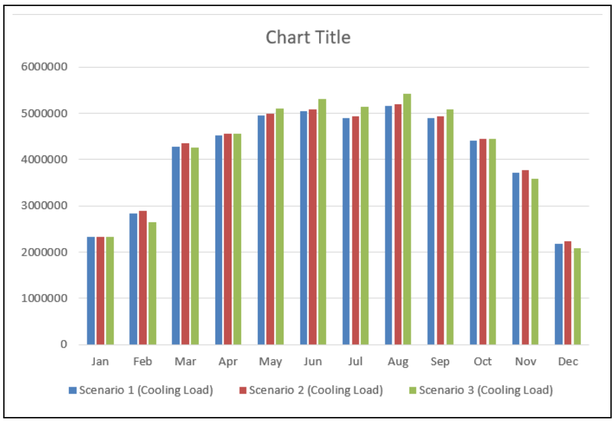


Figure 4: Comparison of cooling load in North Direction

The graph above shows that the maximum cooling load is in scenario 3, whereas the minimum cooling load is in scenario 1 as per the data analysis of August.

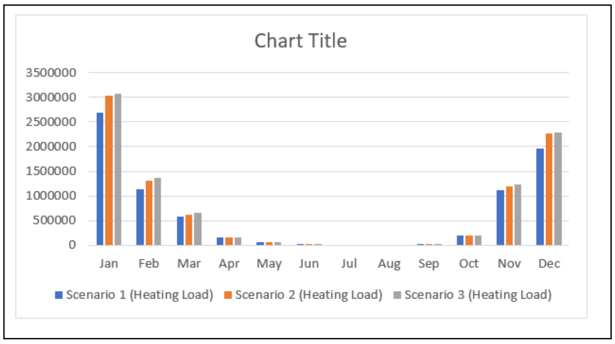


Figure 5: Comparison of heating load in south direction

The minimum heating load can be seen in base scenario i.e scenario 1.The maximum heating load can be seen in scenario 3 which is masonry construction.

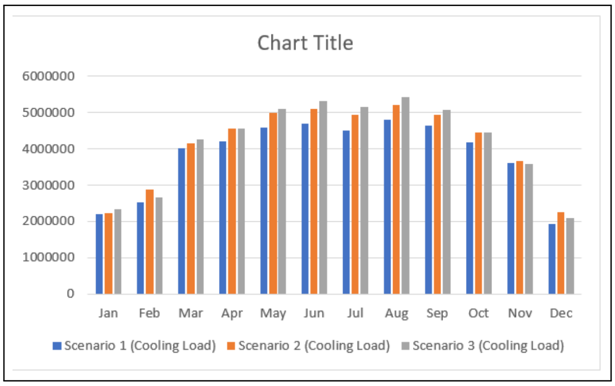


Figure 6: Comparison of cooling load in south direction

The maximum cooling load is in scenario 3 in the months of August. The minimum cooling load is in scenario 1, which is existing rammed earth construction in all the months.

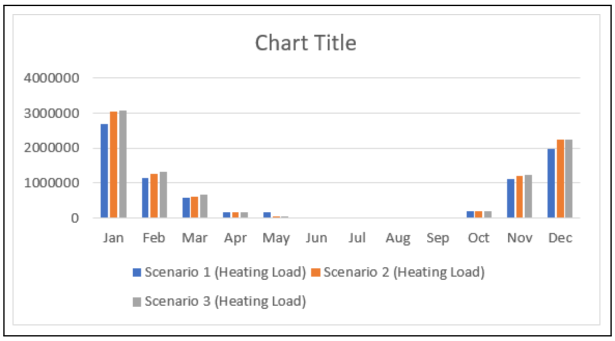


Figure 7: Comparison of heating load in west direction

Comparison of heating load in West Direction The minimum heating load can be seen in base scenario i.e scenario 1. The maximum heating load can be seen in scenario 3 which is masonry construction.

Similar result were obtained in the east direction when the building was simulated in ecotect.

6. Conclusion

Heating load is maximum in scenario 3 and minimum in scenario 1 in the months of January, when the building is oriented towards north direction. Cooling load is maximum in scenario 3 and minimum in scenario 1 in the months of August, when the building is oriented towards north direction. In the south direction, heating load is maximum in scenario 3 and minimum in scenario 1 in the months of January. Cooling load is maximum in scenario 3 and minimum in scenario 1 in the months of August. Similar result was obtained in the west direction for both heating and cooling load.

In the east direction, heating load is minimum in scenario 1 and maximum in scenario3. Cooling load is maximum in the months of July.

Simulation result obtained by the use of ecotect software also showed considerable amount of decrease in heating load as compared to masonry construction. The analysis of rammed earth construction and masonry construction in terms of monthly heating and cooling load discomfort also produced similar result. Thus, to conclude rammed earth can be an efficient energy saving building material if used properly.

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