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A COMPREHENSIVE STUDY OF RAMMED EARTH FOR THERMAL COMFORT AND ENERGY CONSUMPTION OF A BUNGALOW

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Abstract: Thermal comfort and energy consumption of a single storied house has analyzed in this paper. The building has designed using rammed earth in the exterior surface for architectural purpose and thermal comfort in summer season. The climate of Dhaka can be characterized as tropical wet and dry, so the challenge of providing comfortable living with minimal energy consumption is considerable. This paper describes an evaluation of the building in terms of measured thermal comfort and energy use. Using DesignBuilder (energy simulation software) a model has developed of the structure and different energy parameter has analyzed. Simulation output revealed that the increase of rammed earth thickness further decrease the energy consumption. Three different types of rammed earth thickness used in the simulation. The validated model has been used to investigate key building parameters and strategies to improve the thermal comfort and reduce energy consumption in the building. Simulations showed that improvements could be made by design and using different thicknesses of rammed earth properly and efficiently.

1. INTRODUCTION

There are different building enveloping materials are available for cladding and partitioning, but new designs continue to be introduced. Rammed earth is a form of unbaked earthen construction material used as an exterior envelope of building. They can reduce energy demand and as a result decrease in greenhouse gas emissions (Peter et al. 2005). It is, along with other alternative materials such as mud bricks and straw bales are often promoted as 'sustainable' building materials. One aspect that makes these materials perceived to be 'sustainable' is their embodied energy (Veronica Soebarto, 2009).

Traditionally thermal comfort has been achieved at the expense of significant energy use for heating and/or cooling. However, a well-designed building should be able to provide good thermal comfort, while simultaneously having low energy consumption. The main objective of the study was to establish:

A. Whether the bungalow building provides a satisfactory level of thermal comfort
B. If this building uses significantly less energy, and thus generates less green- house gas emissions

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2. METHODOLOGY

DesignBuilder integrated energy simulation software (a product of DesignBuilder Software Ltd. UK) was used to develop a model of the rammed earth bungalow and different energy parameter has analyzed. The building had an estimated area is approximately 280 square meter. The single story buildings rendered view has shown in figure 1.

Figure 1: 3D view of single storied Rammed Earth Low Cost House in Bangladesh

3. CASE STUDY AND CLIMATE DATA

The single storied bungalow building in Purbachal, Dhaka has been used as the case study which contrasts sharply with a typical residential building in almost every feature (Figure-2).

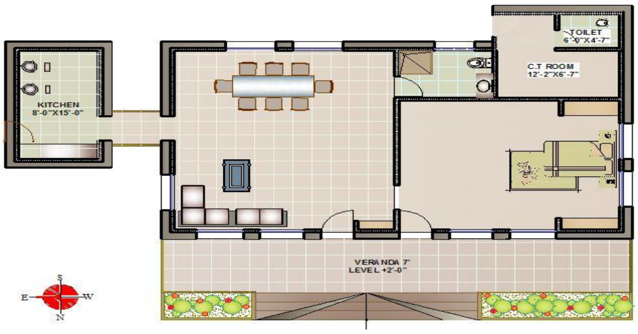

Figure 2: Plan View of Rammed Earthen Bungalow

It is single storied building with beam column framing with roof steel truss and the external walls are covered by 200mm thick rammed earth blocks. Roof ceiling is covered by coco coir. There is a living cum dining room, one bed room, two toilets, one caretaker room, one kitchen and a large veranda with a total estimated floor area of280 m^2. The house is located in the Purbachal area of Dhaka city of Bangladesh (23.8458° N, 90.4974° E). Purbachal, Dhaka has a hot, wet and humid tropical climate. Minimum temperature has seen in 2015 in the Purbachal area is 15°C in the December and the maximum temperature 33.5°C in the April (BMD 2015). The window glazing of the north wall is 6% of the north wall area, while the window of the south bedroom is 12% of the south wall area.

4. ENERGY SIMULATION OF THE BUNGALOW

The bungalow geometry was modeled based on the available architectural plan and construction drawings, confirmed or modified based on-site measurement and observation. Existing vegetation and other shading devices such as curtains and blinds were included in the simulation models. The bungalow was modeled as having several zones so that the spaces being monitored could be examined separately, whereas other spaces not being monitored (such as toilets) were lumped together as long as they were in the same orientation toward the sun and had the similar use patterns. The elevation view of rammed earth wall has shown in figure 3.

Figure 3: Elevation View of Rammed Earth Bungalow

In these simulations, different variation of rammed earth thickness was simulated. The concepts of envelope thermal transfer takes into consideration three basic components of heat gain: heat conduction through opaque walls, heat conduction through glass windows, and solar radiation through glass windows. The maximum permissible ETTV is set as 50 W/m^2 (BCA 2004).

The ETTV formula is given as follows:

$$ETTV=12(1-WWR)U_w+3.4(WWR)U_f+211(WWR)(CF)(SC) \quad (1)$$

Where

ETTV : envelope thermal transfer value (W/m^2)

WWR : window to wall ratio (fenestration area / gross area of exterior wall)

U_w : thermal transmittance of opaque wall (W/m^2 °K)

U_f : thermal transmittance of fenestration (W/m^2 °K)

CF : correction factor for solar heat gain through fenestration

SC : shading coefficient of fenestration

Comparison was made in the basis of different thickness of the rammed earth on the exterior wall (100-200mm thick) for the single story bungalow building. In order to provide a common basis for comparison, the building materials used for the wall , roof , floor and ceiling , infiltration rate, lighting requirements , occupancy schedule of the building and the air conditioning system, etc. were the same throughout the simulations. The R-value rammed earths of different thickness are shown in Table 1.

Table 1 Detailed calculation of R-values of different rammed earth thickness

Rammed Earth Thickness (mm)	R value of Rammed Earth (W/m^2)
100	1.53
150	1.84
200	2.51

The estimation of equivalent R-values of rammed earth wall was based on data collected in the field measurements on a rammed earth wall of a high-rise commercial building in Gulshan; Dhaka named SPL Tower in February 2016. (Figure-4)

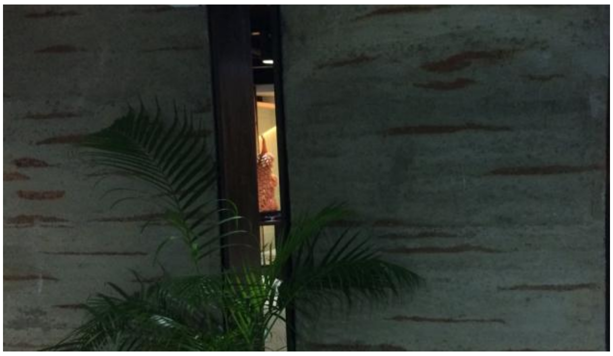

Figure 4: The rammed earth wall of the high-rise building

The measurements were carried out on both interior and exterior rammed earth wall, and then surface temperature measurements were implemented in the interior and exterior environments respectively. All parameters were measured and recorded at 30 min interval.

The thermal properties of the material are shown in the Table-2. For the calculations, rammed earth density 1500 kg/m^3, conductivity 1.2 W/m/K and specific heat 1250 J/Kg.K were used.

Table 2 Thermal properties of wall materials of the case study bungalow buildings

Rammed Earth Thickness (mm)	U-Value (W/m^2.K)	Solar Absorptivity
100	4.11	0.5
150	3.52	0.5
200	3.17	0.5

General dimensional and operational parameter used in the simulations has shown in the Table. 3

Table 3 Dimensional and Operational Parameter Used in Simulation

Building Zones	Description	Area(m^2)	Volume (m^3)
Bungalow	Single Storied	280	1120
External East Facing Wall		50	
Internal West Wall		48	
Structural Element	Beam, Column, Roof Truss		
Floors	125mm thick rcc slab		
External Wall	200mm thick rammed earth		
People	4 people		
Lighting	use of daylight		

5. DATA ANALYSIS AND SIMULATION

5.1 Comparison of thermal comfort results for different rammed earth thickness

Thermal comfort is a subjective measurement. Thermal comfort is defined by as “that condition of mind that expresses satisfaction with thermal environment” (ASHRAE 2004). One way to measure thermal comfort levels is simply to ask building occupants how they experience a building in terms of their temperature sensations. A good measure of thermal comfort is room temperature and relative humidity.

To assess the thermal comfort a comparison of the room temperature between the different thicknesses of rammed earth layer from 100 to 300 mm was carried out and the results are shown in figure-5. This simulation result shows that, a reduction of 4.5% (for 100mm thick rammed earth) to 13.5% (for 200mm thick rammed earth) of temperature was observed.

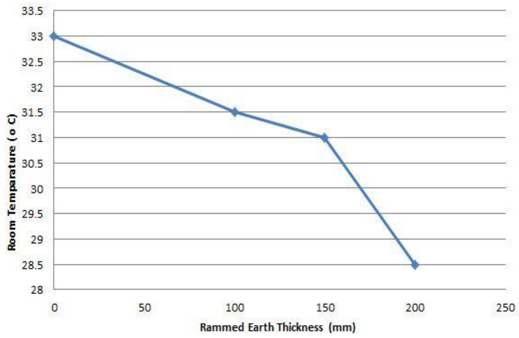

Figure 5: Comparison of Room Temperature for Different Rammed Earth Thickness

Another comparison of the relative humidity between the different thicknesses of rammed earth layers from 100 to 200 mm was carried out and the results are shown in the figure -6. Simulation results show that, a reduction of 5.5% (for 100mm thick rammed earth) to 22% (for 200mm thick rammed earth) of relative humidity was observed.

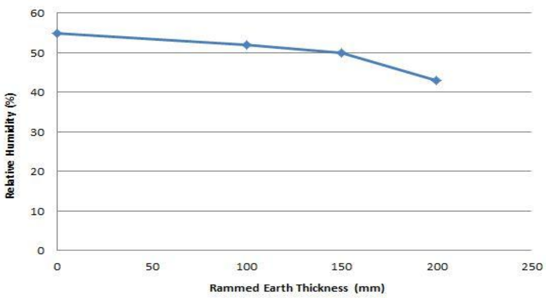

Figure 6: Comparison of Relative Humidity for Different Rammed Earth Thickness

5.2 Comparison of energy consumption results for different rammed earth thickness

A comparison of the annual energy consumption between the different thicknesses of rammed earth from 100 to 200 mm was carried out. From the simulation it has shown that, increase in rammed earth thickness has significantly reduced the energy consumption of the building. A reduction of 0.5 MWh (5%) for 100 mm thick rammed earth to 2.8 MWh (28%) for 200mm thick rammed earth was observed. Simulation result has shown in figure 7 .

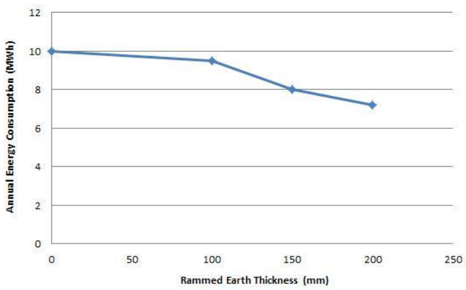

Figure 7: Comparison of Annual Energy Consumption for Different Soil Thickness

The installation of envelope like rammed earth has significantly reduced the peak heat transfer through ETTV. As shown in Table 4 and Figure-8.

Table 4 Comparison of peak RTTV to Different Types of Vegetation

Thickness of Rammed Earth	Covered Area (m^2)	Peak ETTV (W/m^2)	Reduction (%)
Typical 125mm Wall	170	12.3	-
100 mm Rammed Earth	170	11.7	5
150 mm Rammed Earth	170	10.2	17
200 mm Rammed Earth	170	9.8	20

The use of rammed earth external wall as envelope has significantly reduced the envelope thermal transfer value (ETTV). A reduction of 5% (100mm thick rammed earth) to 20% (200mm thick rammed earth) was observed.

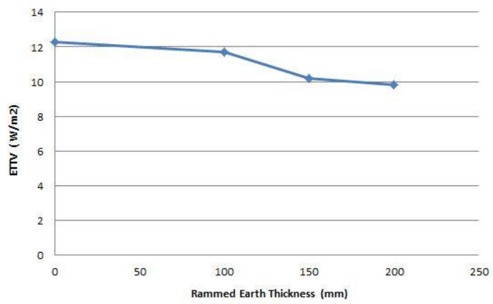

Figure 8: Comparison of ETTV to Different Rammed Earth Thickness

6. CONCLUSION

This study shows that the use of rammed earth in a single storied bungalow building at Bangladesh could result in a saving of 5 to 28% of total annual energy consumption.

The research also shows that an optimum reduction of 4.5 to 13.5% on room temperature , 5.5 to 22% on relative humidity with different rammed earth thickness of 100-200mm as a measure of thermal comfort. The envelope thermal transfer value (ETTV) reduced by 5 to 20% due to the application of different thicknesses of exterior rammed earth wall.

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