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Comparative Study on Thermal Performance of Mud Rammed and Concrete Residential Building Envelope in Paro - Bhutan

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Abstract— A key factor in assessing the total energy efficiency of a building is the thermal performance of the building envelope. In Bhutan the building energy sector accounts for 15% of the total domestic electricity consumption out of which 50 to 60% accounts for space heating in the temperate region [1]. Previous research findings and data also indicate that heat loss or gain through the building envelop were the most significant contributor accounting for 40 to 70% of the total heat losses [2].

Bhutan is a country known for its traditional architecture, which makes extensive use of locally sourced natural materials. Mud rammed walls have been a defining feature of Bhutanese construction for centuries due to their durability, availability and excellent insulation properties. However, in recent years, there has been a notable shift towards concrete-based building envelope, which has raised concerns about their thermal energy performance and long-term sustainability.

This study presents a comparative study on thermal performance of traditional and modern wall materials used in Bhutan. The modern materials considered are red bricks, cement-stabilized earth block (CSEB) and autoclaved aerated concrete (AAC), while mud walls represent traditional construction. A residential building in Paro, Bhutan has been used as model building. The model building was simulated in SketchUp with OpenStudio plugin software to evaluate and compare the thermal performances of these materials used in Building envelope. The simulation results obtained are analyzed, compared and discussed in the subsequent sections under results and discussions.

Keywords— efficiency, energy, building, heating, cooling, demand, comfort.

1. Introduction

Building thermal energy refers to the energy required to maintain indoor temperatures within a comfortable range for occupants [1-3]. Globally, Buildings accounts for a significant share of total energy consumption. Therefore, optimizing building thermal energy performance in buildings are essential for reducing overall energy consumption.

To improve building thermal energy performance, various strategies can be implemented, such as improving insulation, using efficient HVAC systems, optimizing building orientation, implementing energy efficient lighting and the most significant one being the optimization of building envelop [4]. The building envelope plays a crucial role in regulating the transfer of heat and moisture between the interior and exterior environments, which affects the building's thermal energy performance. Moreover, many literatures shows that building envelopes is ranked one amongst other available energy efficiency strategies. A well-designed and constructed building envelope can reduce heat loss or gain, resulting in lowering energy consumption.

Bhutan is a country known for its traditional architecture, which incorporates the use of locally sourced natural materials. Mud rammed earth walls have been used in Bhutanese buildings for centuries due to their excellent insulation properties, durability and availability of raw materials. However, in recent years, there has been a shift towards the use of concrete buildings with brick fill walls as materials.

In this study, simulation is carried out in SketchUp with OpenStudio plugin software on the existing building with brick fill walls and tradition rammed earth for comparing their thermal performances.

This research aims to quantify the thermal benefits of traditional mud rammed walls compared to contemporary brick walls, providing empirical data to support sustainable building practices in Bhutan. To evaluate and compare their thermal performance, simulation were carried out on an existing building with envelopes made of cement –based material and mud rammed.

2. Methodology

2.1. Research design and simulation tool use

A comparative simulation – based design was employed to evaluate thermal performance of the two types of building envelope. The types are RCC structure building with brick infill and a traditional mud rammed house. The primary software tools used are sktchUp for geometric modeling and the OpenStudio plugin for detailed energy analysis. OpenStudio plugin runs on the EnergyPlus simulation engine, widely accepted and validated for whole-building energy simulation programs.

The thermal simulation flow path as for simulation is adopted shown in the Fig. 1.

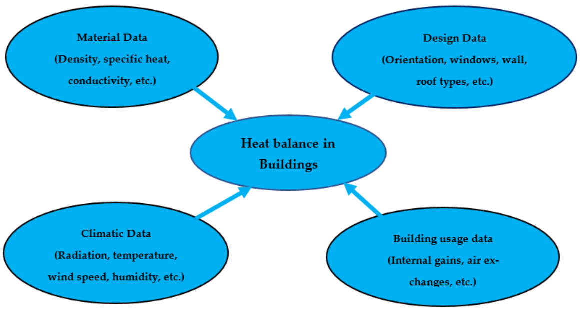


Figure 1: Thermal Simulation flow path

2.2. Location and climatic condition

The location of model building is in Bongdey, a small town under Paro district located closer to Paro International Airport. The GPS coordinates of the city is 27.40^{0}N and 89.42^{0}E with elevation of 2235 m above sea level. The temperature varies from -6^{0}C to 27^{0}C with harsh cold winter and warm summer. The city falls under ASHRAE climatic classification of zone 7 inferring to calculated Heating Degree Days of 1288 [4]. The climatic information of the city as shown in the Table 1.

Table 1. Climatic information

Altitude	2235 m
Mean Temperature	13.20^{0}C
Global Horizontal Radiation	144.75 kWh/m^2
Direct Normal Radiation	143.67 kWh/m^2
Diffused Radiation	59.33 kWh/m^2
Wind speed	3.0 m/s
Relative humidity	69.79 %

2.3. Description of Model Building

The model building used for case study is a two storey Bhutanese residential building that represents the traditional Bhutanese architecture with modern design and construction techniques. It also meets the requirement for modern amenities and comfort while retaining the aesthetic look and features of traditional

Bhutanese buildings. The building has two units on each floor and is used as apartment. The apartment is of three-bedroom house with kitchen (3 BHK). In total, it has four units and Fig. 2 and 3 shows the building's perspective view and layout.

The building has total volume of 1274.88 m^3 and floor area of 360.24 m^2. Almost 74% of the total volume space may require heating, since the location falls under high heating degree days and low cooling degree days, equivalent to 1288 HDD and 366 CDD respectively.

The building is of RCC structure with filled brick walls and plaster finish, no insulation used and the windows with normal window glass of 5 mm thick.

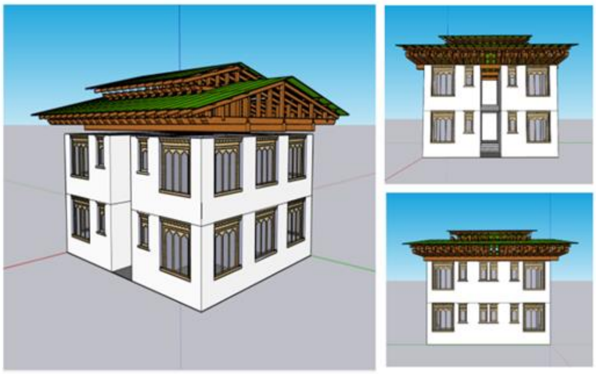


Figure 3: Model building views

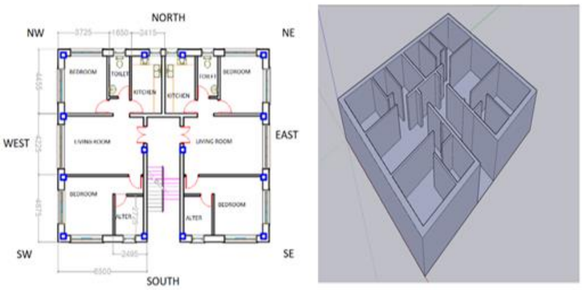
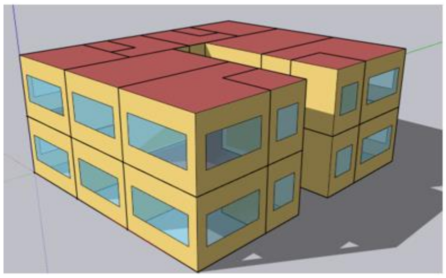


Figure 2: Model building views

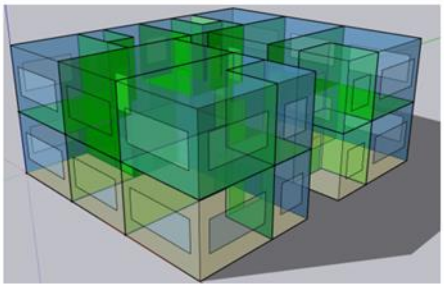
2.4. Building modelling parameter

The modelling parameters considered in this research are as follows:

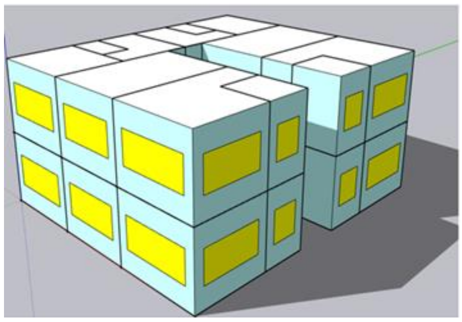
2.4.1. **Model:** The model building geometry is developed in SketchUp and energy simulation is performed in OpenStudio plugin. The actual building's dimensions, architectural details, orientation and other site conditions are also considered. The developed model building exactly represents the existing building of RCC structure within fill brick walls (modern building). The same model is converted to tradition building just by replacing brick wall with mud rammed walls. Building simulation is performed on both models in SketchUp with OpenStudio plugin simulation software. For realistic prediction of thermal performance, indoor comfort, energy demand and other associated parameters, different forms of rendering has been carried out, as represented in Fig. 4 (a, b, c, d, e, f)



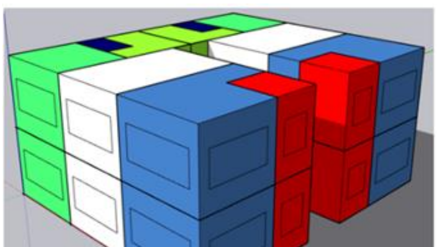
a. Rendered by surface

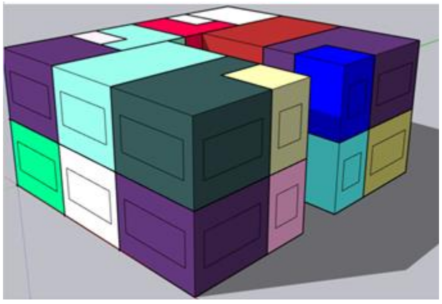


b. Rendered by boundary

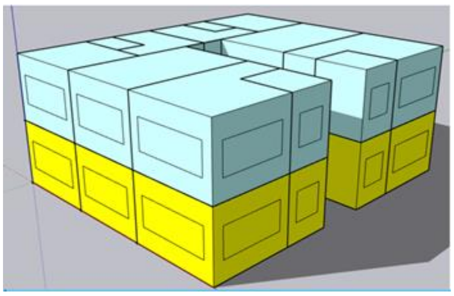


c. Rendered by construction





e. Rendered by Thermal



f. Rendered by building

2.4.2. Thermal zoning

The model building has four identical apartments, two on each floor. Each apartment is divided into 6 thermal zones making total of 24 zones. The zone division is done as per the rooms in it. The zones of one unit/apartment is as shown in the Table 2.

Table 2. Thermal zone for one apartment

Zone name	Zone area (m^2)	Zone volume (m^3)
Living room	27.29	95.52
Master Bed room	23.41	81.94
Bed room	16.28	56.98
Kitchen	12.28	46.48
Rest room	6.48	22.68
Alter	4.32	15.12

2.4.3. Internal loads and Occupancy

One of the important factors in building energy simulation is building occupancy, lighting and equipment schedule. The Fig. 6 shows occupancy patterns which were based on the typical pattern of officer goer residents.

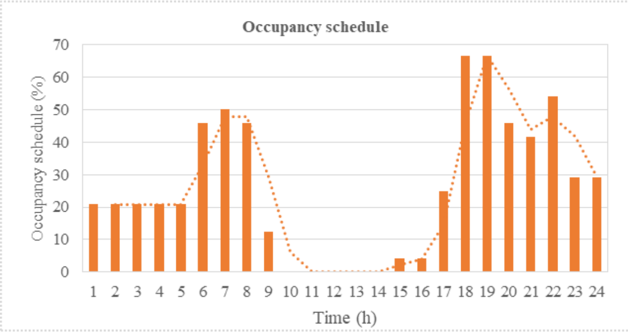


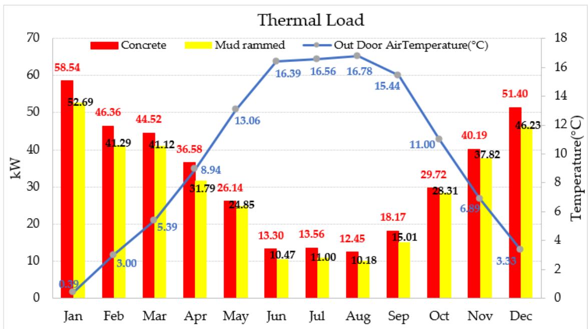
Figure 6. occupancy schedule pattern

3. Results and Discussion

This section presents the outcome of the simulation carried out for comparing the thermal performance of modern concrete buildings and traditional mud rammed buildings. From the results, the traditional mud rammed building can be one of the options for building energy saving potential.

3.1 Thermal load on the building

Fig. 5 clearly indicates that the thermal load required by both buildings are for heating during the winter seasons, especially for pick winter of the month January, February, November and December. Another indication is that energy requirement for Traditional mud rammed building is lower while comparing to modern concrete building and there is energy saving of 12% on



average over the year.

Figure 5. Thermal energy demand w.r.t abmient temperature

3.2 Indoor and outdoor air temperature

Since temperature is considered as one of the important measures for the build environment when considering the thermal comfort for occupants and in the design of the building service systems.

While comparing the indoor air temperature between two types of buildings, the traditional mud rammed has higher indoor air temperature. This leads to reduction of heating energy demand during the winter seasons, and the contrast is that it may demand energy for cooling during pick summer season and Fig. 7 shows the indoor air temperature of buildings with respect to outdoor air temperature.

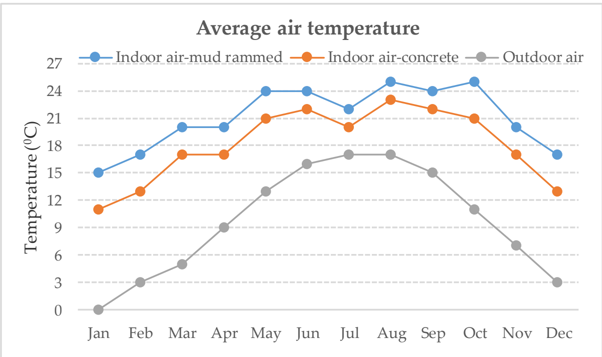


Figure 7. Indoor and Outdoor temperature

3.3 Energy demand and actual consumption

The heating energy demand request from the two buildings are compared with the actual electrical energy consumption. The energy demand request is obtained from simulation, whereas electrical energy is based on the energy consumption bill issued by Bhutan Power Corporation.

The Fig. 8 below indicates that energy demand from the building is higher during the winter month of January to May and October to December. Similarly, during the summer month of June to August the actual consumption is higher than the actual demand from building.

Since the building does not have any insulation, the building's energy requirement is influenced by the outdoor condition. Therefore, the building requires more heating energy during winter months, and it is compensated by local heating system called Bukhari. Whereas during summer, actual consumption is higher than demand and is the result of energy used for cooling during summer.

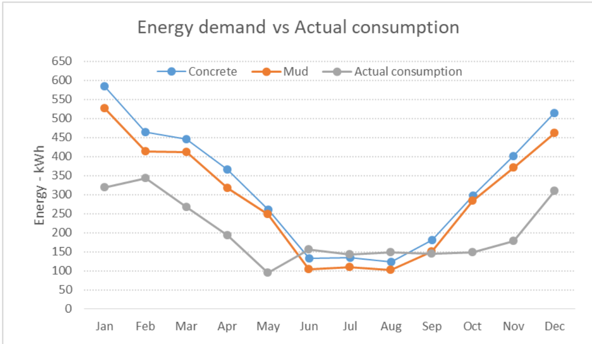


Figure 8. Energy demand and acutal consumption

3.4 Annual energy demand for heating

The traditional mud rammed building will save annual heating energy by 27.41% while comparing to concrete building as shown in the Fig. 9. Therefore, buildings with mud rammed façade will bring down the energy requirement with no additional cost on the construction. The façade of brick or concrete wall can be replaced by mud rammed walls to improve the building energy efficiency and maintaining the thermal comfort at required scale.

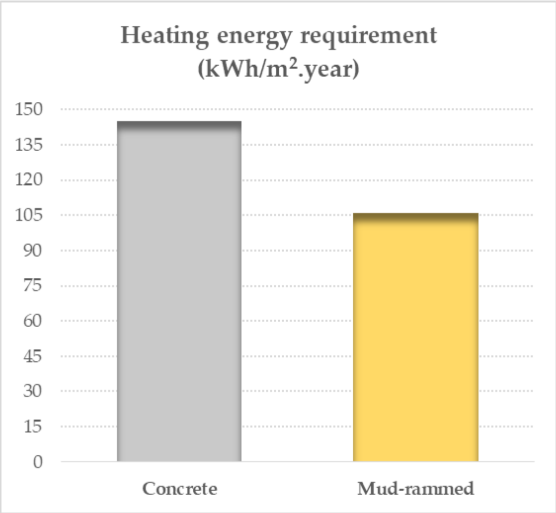


Figure 9. Annual heat energy demand

4. Conclusion and Recommendation

Globally energy demand in the building sectors have consistently been among the highest and there has been a continuous strive toward more energy efficient and sustainable buildings and energy saving strategies. Bhutan, despite being a small country, experiences diverse climatic condition due to variations in elevations which significantly influence building design requirements to ensure occupant safety and thermal comfort.

Recently, the transition from traditional mud rammed buildings to modern construction materials such as concrete has raised concerns about long-term sustainability in Bhutan's built environment. Traditional structures are often better adapted to local climatic conditions, while modern materials may lead to higher energy demands for heating and cooling. Therefore, this study highlights important insights for promoting energy-efficient construction practices that align with Bhutan's national vision for sustainable development.

The results reaffirmed that traditional mud rammed walls outperform concrete walls by requiring approximately 27% less heating energy annually. This underscores the critical importance of considering thermal performance when selecting building materials and retrofitting existing structures to enhance energy efficiency and sustainability.

Considering these findings, it is recommended that the government develop policies to promote energy-saving measures within rural communities and encourage the adoption of renewable energy technologies. Immediate actions could include formulating energy-efficient building codes and regulations, thereby supporting sustainable and economically viable building practices in Bhutan for the future.

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