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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 envelope was 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 envelopes, which has raised concerns about their thermal energy performance and long-term sustainability. This study presents a comparative analysis of the 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 a model building. The model building was simulated in SketchUp with the OpenStudio plugin software to evaluate and compare the thermal performances of these materials used in the building envelope. The simulation results obtained are analyzed, compared, and discussed in the subsequent sections under Results and Discussion.

Keywords: Efficiency, energy, building, heating, cooling, demand, comfort

INTRODUCTION

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

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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, most significantly, optimizing the building envelope [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, much of the literature shows that building envelopes are ranked among the most effective energy efficiency strategies. A well-designed and constructed building envelope can reduce heat loss or gain, thereby 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 infill walls.

In this study, a simulation was carried out in SketchUp with the OpenStudio plugin software on the existing building with brick infill walls and traditional rammed earth to compare 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, simulations were carried out on an existing building with envelopes made of cement-based material and mud-rammed earth.

METHODOLOGY

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 Figure 1.

Location and Climatic Condition

The location of the model building is in Bongdey, a small town in the Paro District located close to Paro International Airport. The GPS coordinates of the city are 27.400°N and 89.420°E, with an elevation of 2,235 m above sea level. The temperature varies from -6°C to 27°C, with a harsh, cold winter and a warm summer. The city falls under ASHRAE climatic classification Zone 7, corresponding to a calculated 1,288 Heating Degree Days [4]. The climatic information for the city is shown in Table 1.

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

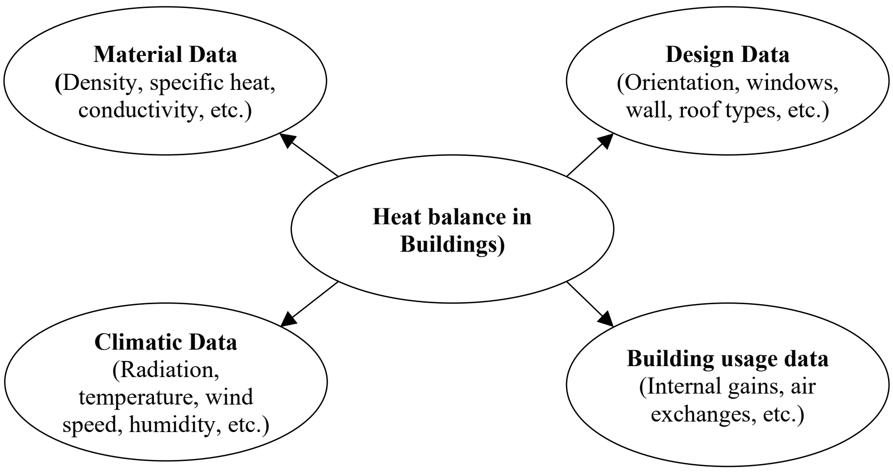

Figure 1. Thermal simulation flow path.

The building has two units on each floor and is used as apartments. Each apartment is a three-bedroom unit with a kitchen (3BHK). In total, it has four units, and Figures 2 and 3 show the building's perspective view and layout.

Description of Model Building

The building has a total volume of 1,274.88 m³ and a floor area of 360.24 m². Almost 74% of the total volume may require heating, since the location falls under a high number of heating degree days and a low number of cooling degree days, equivalent to 1,288 HDD and 366 CDD, respectively.

Table 1. Climatic information.

Altitude	2235 m
Mean Temperature	13.20°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 %

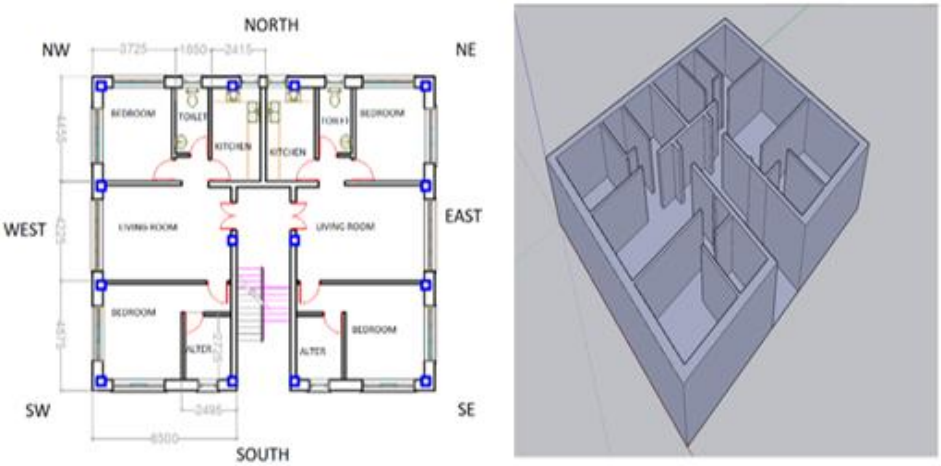

Figure 2. Model building views.

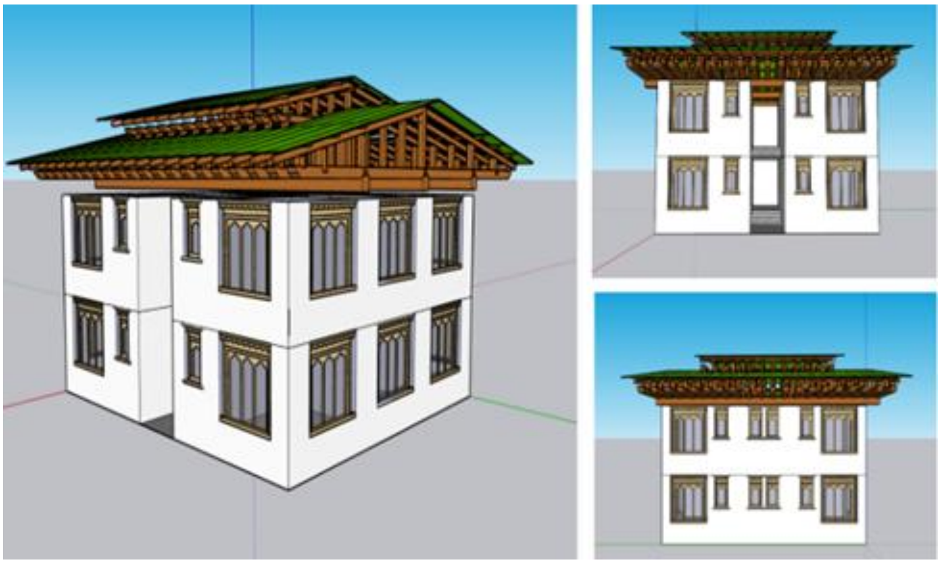

Figure 2. Model building views.

The building is an RCC structure with brick infill walls and a plaster finish. No insulation was used, and the windows have standard 5 mm thick glass.

Building Modelling Parameter

The modelling parameters considered in this research are as follows:

Model

The model building geometry was developed in SketchUp, and the energy simulation was performed in the OpenStudio plugin. The actual building's dimensions, architectural details, orientation, and other site conditions were also considered. The developed model building exactly represents the existing building, which is an RCC structure with infill brick walls (modern building).

The same model was converted to a traditional building by replacing the brick walls with mud-rammed walls. A building simulation was performed on both models in SketchUp with the OpenStudio plugin simulation software. For a realistic prediction of thermal performance, indoor comfort, energy demand, and other associated parameters, different forms of rendering were carried out, as represented in Figures 4 (a, b, c, d, e, and f).

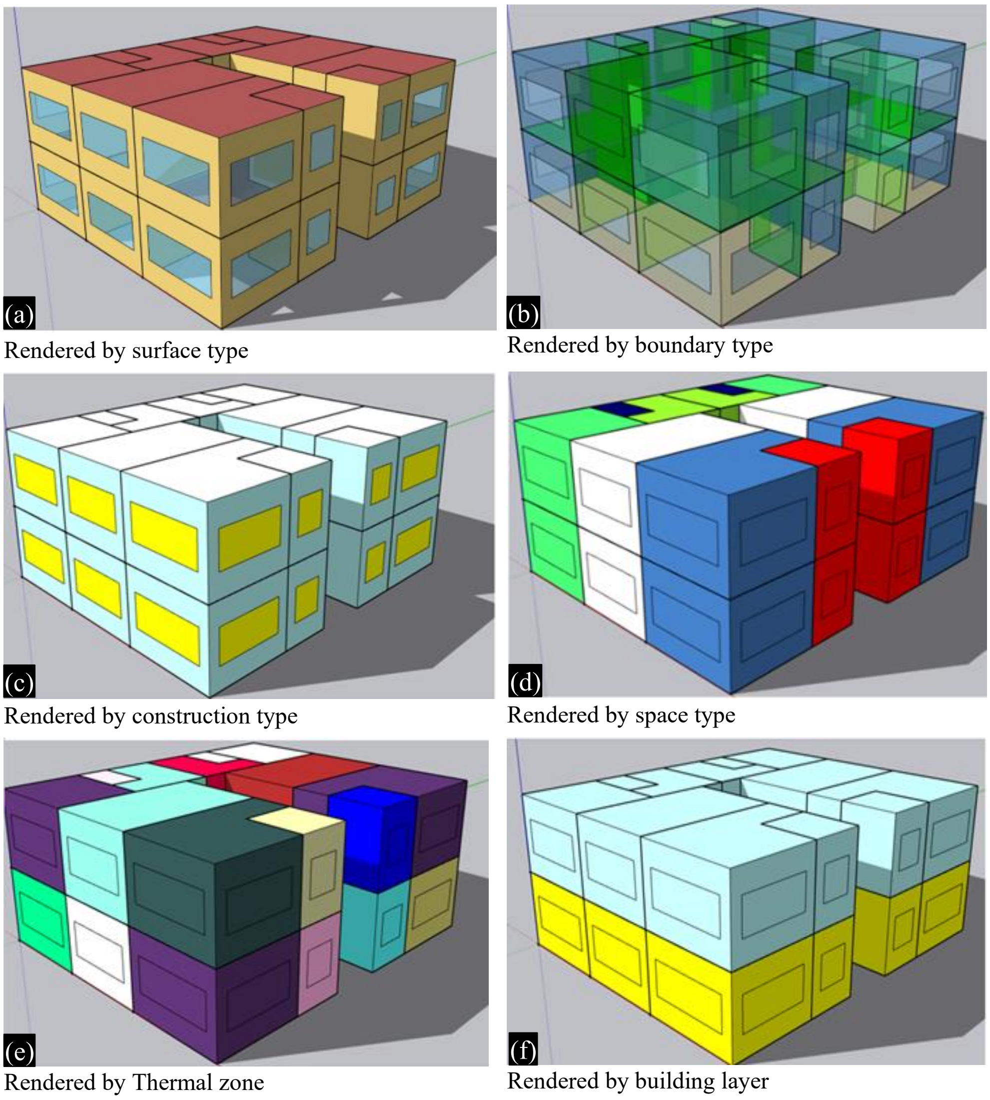

Figure 4. (a–f).

Thermal Zoning

The model building has four identical apartments, two on each floor. Each apartment is divided into six thermal zones, making a total of 24 zones. The zone division was done according to the rooms within each apartment. The zones of one unit/apartment are shown in Table 2.

Internal Loads and Occupancy

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

RESULTS AND DISCUSSION

This section presents the outcomes of the simulation carried out to compare the thermal performance of modern concrete buildings and traditional mud-rammed buildings. The results indicate that traditional mud-rammed buildings have significant energy-saving potential.

Thermal Load on the Building

Figure 5 clearly indicates that the thermal load required by both buildings is for heating during the winter seasons, especially for the peak winter months of January, February, November, and December. Another indication is that the energy requirement for the traditional mud-rammed building is lower compared to the modern concrete building, resulting in an average energy saving of 12% over the year.

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

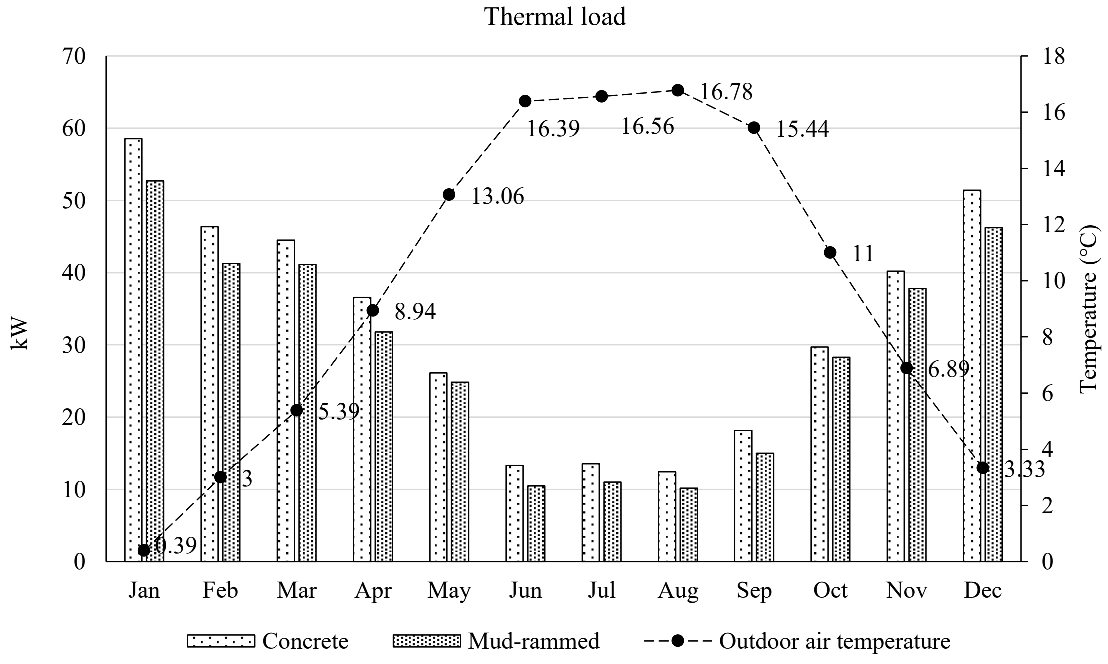

Figure 5. Thermal energy demand w.r.t abmient temperature.

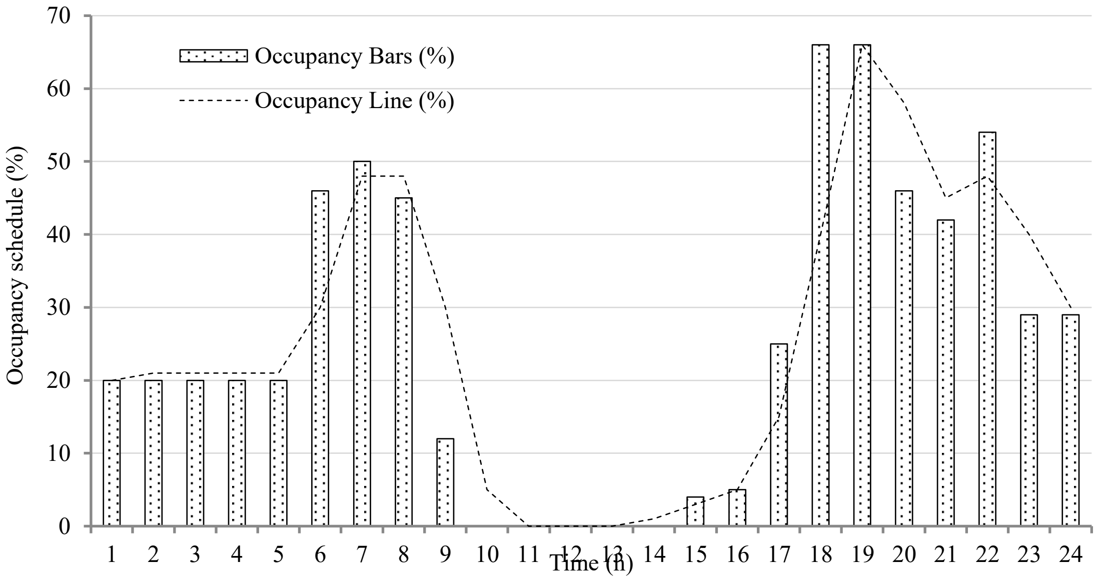

Figure 6. Occupancy schedule pattern.

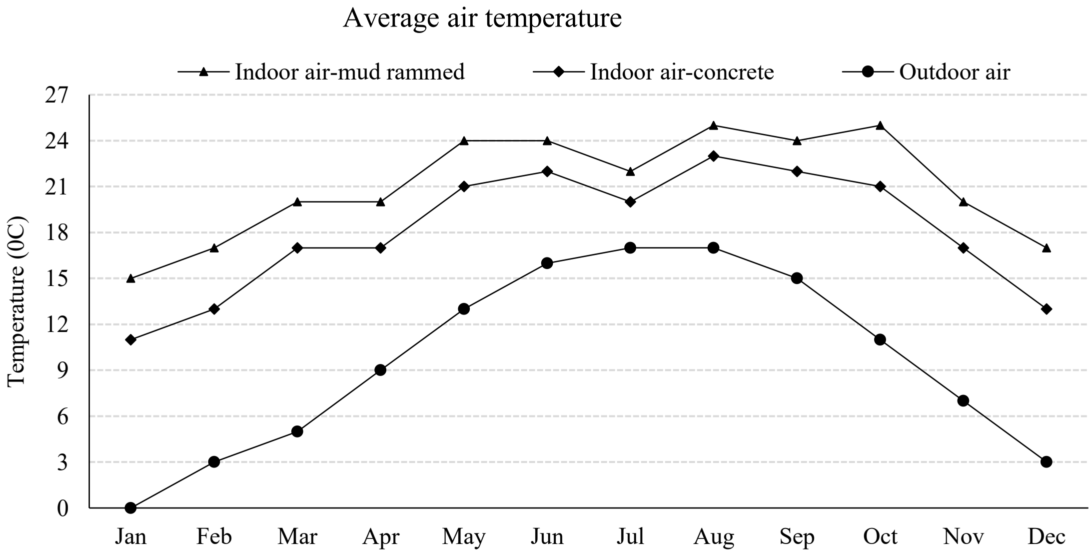

Figure 7. Indoor and outdoor temperature.

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 Figure 7 shows the indoor air temperature of buildings with respect to outdoor air temperature.

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 Figure 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.

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 Figure 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.

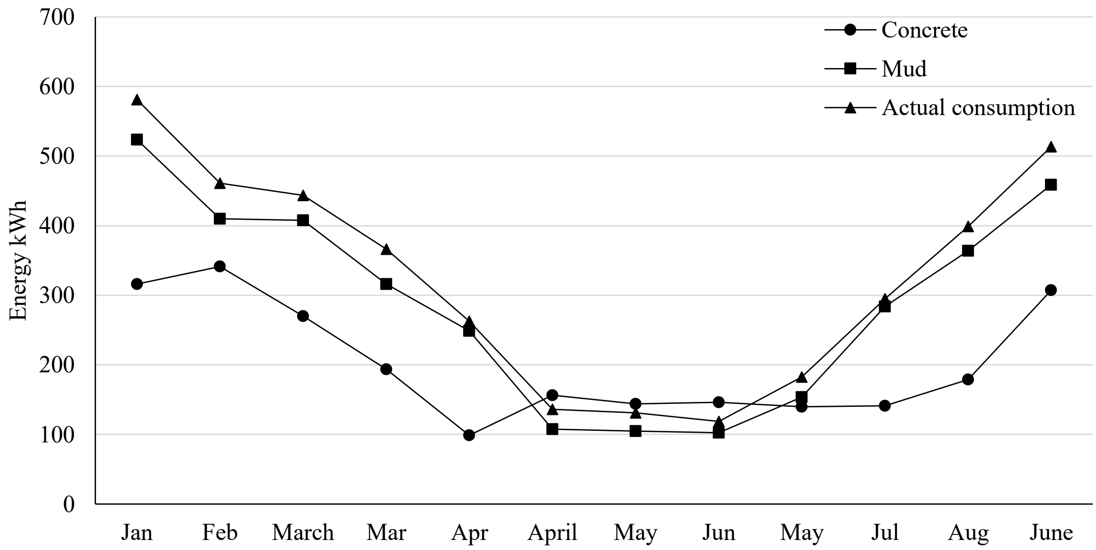

Figure 8. Energy demand and acutal consumption

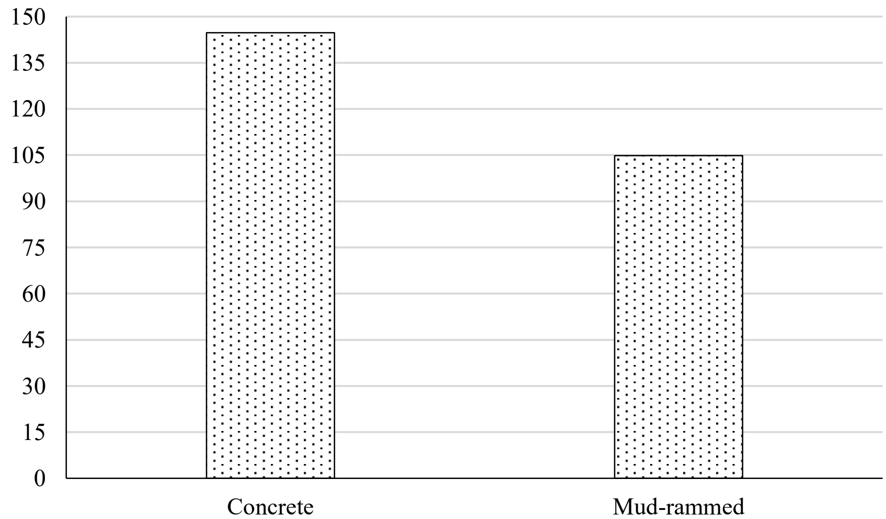

Figure 9. Annual heat energy demand

CONCLUSION AND RECOMMENDATION

Globally, energy demand in the building sector has consistently been among the highest, and there has been a continuous striving toward more energy-efficient and sustainable buildings, and energy-saving strategies. Bhutan, despite being a small country, experiences diverse climatic conditions due to variations in elevation, a factor that significantly influences 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 reaffirm 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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