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Assessing Thermal Performance of Mud House Using ECOTECT Analysis - A Case of Vernacular Architecture in Northern Bangladesh

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Abstract

Mud is one of the predominant vernacular building materials in rural settlements in Bangladesh, especially in the northern region because of its unique thermal performance. Mud being a very cheap, abundant, and environmentally friendly building material, is used extensively for building construction in the subcontinent. Mud as a building material has high heat capacity and low thermal conductivity which enhances the thermal stability of earthen building compared to other materials. This paper aims at analyzing the thermal performance of residential earthen buildings in northern Bangladesh and providing a basis for designing mud houses in rural Bangladesh according to environmental considerations. The resultant data from thermal simulation conducted in 'Ecotect Analysis' software shows that mud houses keep the indoor environment comparatively cooler than the outdoor warm environment during summer and the opposite during winter season which results in proper thermal comfort for the inhabitants.

Keywords: Mud House; Vernacular Architecture; Thermal Performance; Passive Solar Design; Thermal Comfort.

1. Introduction

Adobe is one of the oldest materials that has been extensively used for construction since Neolithic times. Mud-house is made of a mixture of mud, clay, sand, water, and rice husks or straw as binding materials. Most of the ancient civilizations have used it in some form as it was abundant, cheap, and strong. Constructing with adobe required only simple technology.

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In Egypt, the grain stores of Ramesseum which was built with adobe in 1300BC still exist. Again, the Great Wall of China has over 2000 years old predominant sections built in rammed earth. Mud construction is generally found in relatively dry places. Vernacular architecture in Bangladesh results from the philosophy of living in tune with nature. Mud construction for housing can be found mainly in the rural areas of the country. Mud houses are most favorable in the northern parts of Bangladesh because of several climatic reasons. This region consists of areas that have hot and dry climates. The lands are suitable for mud house construction as the lands are normally above the flood level. Though modern construction materials such as fire burnt brick, Concrete, steel are emerging, people here still prefer mud as the construction material for building houses because of its abundance and affordability. Walls and floors made of thick mud control the indoor thermal environment while maintaining hygienic. Moreover, this type of construction has very low maintenance. Mud houses slowly dissolve in the ground when they are abandoned without hampering the environmental damage.

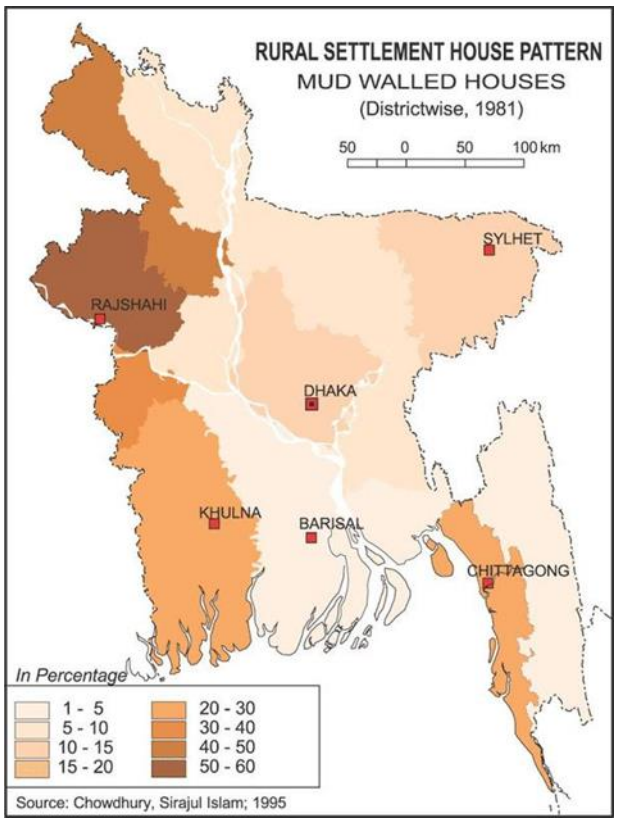

Figure 1: Mud-house distribution in Bangladesh [1].

Mud absorbs sunlight and warms the building over the course of the day which is called passive solar heating and it will keep the inside of the building warm in the winter and cool in the summer [2].

2. Study Area

Mud houses are seen all over Bangladesh though it is more popular in the northern region of the country because for climatic suitability. A long patch of landform running from Dinajpur, Bagura to Jessore, and some parts of Khulna following the western side of the country have a distinctive characteristic of mud-walled houses [1].

Oblong-shaped mud-walled houses with a thatched roof are common in Rajshahi, Bagura, Pabna, Kushtia, and Jessore [1]. In Chapai Nawabganj, the roof of the mud-walled house is molded by brick-dust mixed with lime, which is peculiar to only this area and in the region from Bagura to Kushtia, mud-walled houses with CI sheet or kerosene tin roof is another common type [1]. This paper aims at studying the rural mud houses in Rajshahi and Bagura in case of functionality and construction and analyzing their thermal performance. The dominant climate in Bagura and Rajshahi is the warm humid climate, the main characteristic of which is mild winters with very hot summers. This region has a humid atmosphere during most of the year for being at the bank of Padma and Brahmaputra river and low diurnal temperature range.

	January	February	March	April	May	June	July	August	Septem-ber	October	November	December
Avg. Temperature °C (°F)	17.8 °C (64.1) °F	20.9 °C (69.7) °F	24.9 °C (76.8) °F	27.1 °C (80.8) °F	27.7 °C (81.9) °F	28.2 °C (82.7) °F	28 °C (82.4) °F	28 °C (82.4) °F	27.4 °C (81.4) °F	25.7 °C (78.3) °F	22.4 °C (72.4) °F	19.2 °C (66.6) °F
Min. Temperature °C (°F)	11.9 °C (53.3) °F	14.5 °C (58) °F	18.5 °C (65.3) °F	22.4 °C (72.3) °F	24.1 °C (75.3) °F	25.5 °C (77.8) °F	25.7 °C (78.2) °F	25.6 °C (78.1) °F	24.9 °C (76.8) °F	22.1 °C (71.8) °F	17.1 °C (62.8) °F	13.6 °C (56.5) °F
Max. Temperature °C (°F)	23.9 °C (75) °F	27.3 °C (81.1) °F	31.2 °C (88.1) °F	32.5 °C (90.6) °F	32.1 °C (89.8) °F	31.8 °C (89.3) °F	31.3 °C (88.4) °F	31.4 °C (88.6) °F	30.8 °C (87.5) °F	29.8 °C (85.6) °F	27.9 °C (82.3) °F	25.1 °C (77.2) °F
Precipitation / Rainfall mm (in)	12 (0.5)	22 (0.9)	44 (1.7)	137 (5.4)	326 (12.8)	400 (15.7)	361 (14.2)	302 (11.9)	280 (11)	152 (6)	17 (0.7)	7 (0.3)
Humidity(%)	67%	60%	56%	70%	80%	84%	84%	84%	86%	83%	71%	68%
Rainy days (d)	1	2	4	10	17	19	21	20	18	10	1	1

Figure 2: Yearly Climate Data of Bagura [3].

	January	February	March	April	May	June	July	August	Septem-ber	October	November	December
Avg. Temperature °C (°F)	17.9 °C (64.1) °F	21.3 °C (70.3) °F	25.9 °C (78.6) °F	28.7 °C (83.6) °F	29 °C (84.2) °F	28.9 °C (84) °F	28.1 °C (82.7) °F	28.1 °C (82.6) °F	27.7 °C (81.8) °F	26.2 °C (79.1) °F	22.8 °C (73) °F	19.4 °C (66.8) °F
Min. Temperature °C (°F)	12.2 °C (53.9) °F	15.1 °C (59.1) °F	19.4 °C (66.9) °F	23.4 °C (74.2) °F	25 °C (77) °F	26.1 °C (78.9) °F	25.9 °C (78.6) °F	25.8 °C (78.5) °F	25.2 °C (77.3) °F	22.7 °C (72.8) °F	17.8 °C (64.1) °F	14.1 °C (57.3) °F
Max. Temperature °C (°F)	23.6 °C (74.5) °F	27.3 °C (81.1) °F	32.2 °C (90) °F	34.6 °C (94.3) °F	33.7 °C (92.6) °F	32.5 °C (90.6) °F	31.3 °C (88.4) °F	31.4 °C (88.5) °F	31.1 °C (88) °F	30.1 °C (86.3) °F	28 °C (82.4) °F	24.8 °C (76.7) °F
Precipitation / Rainfall mm (in)	10 (0.4)	22 (0.9)	29 (1.1)	75 (3)	205 (8.1)	318 (12.5)	316 (12.4)	261 (10.3)	252 (9.9)	118 (4.6)	15 (0.6)	9 (0.4)
Humidity(%)	67%	60%	52%	61%	74%	82%	85%	85%	85%	80%	69%	68%
Rainy days (d)	1	2	3	7	13	17	20	20	17	8	1	1

Figure 3: Yearly Climate Data of Rajshahi [4].

3. Literature Review

A typical mud house in Rajshahi or Bagura is generally three to four meters wide and five to six meters long. These houses vary in size concerning economic conditions and family size. There is a considerable number of larger houses as well that extend up to twelve to fourteen meters in length and eight to nine meters in width.

These huts are arranged in a linear pattern along the cross streets which are connected to the main street of a village amidst agricultural fields and rocky spur [5]. In rural areas, one family has at least five to eight members. One family possibly with a married son and his wife typically occupies one house [6]. These houses are generally east-west elongated in order to maximize cross ventilation and ensure optimum solar exposure [7].

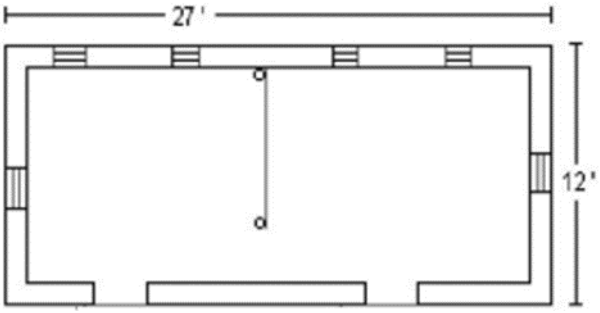

Figure 4: Plan of a typical Mud house [6].

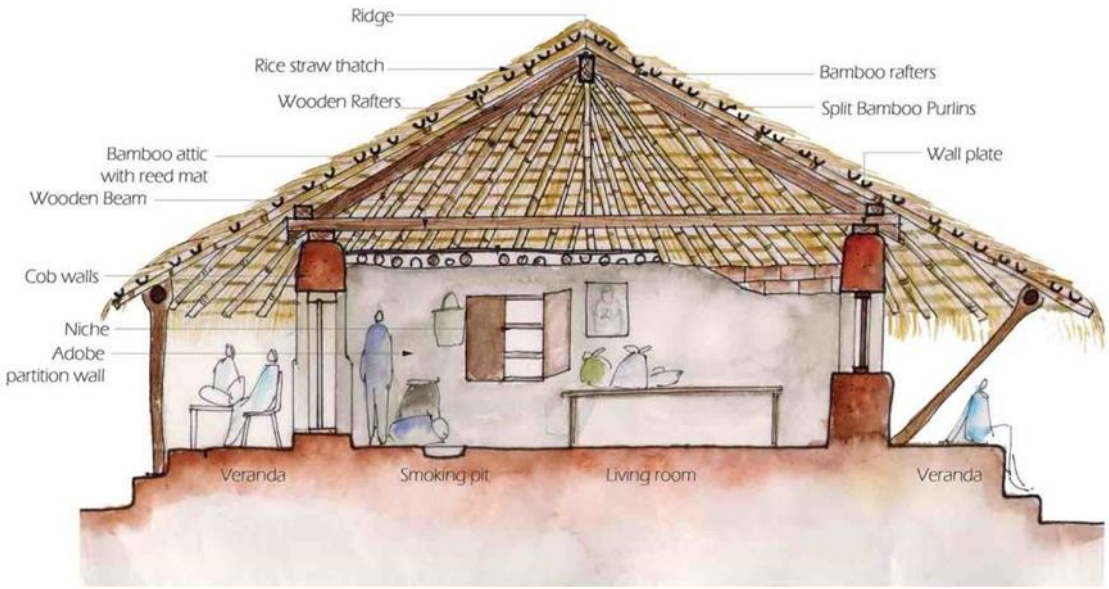

Figure 5: Section of a typical Mud house [8].

3.1 Construction Technique

Mud houses require a very unique construction technique. The foundation of a mud house is an earthen one in which the mud is pressed enough till it reaches up to the plinth [8]. The foundation is generally one meter deep and a little thicker than the walls. A veranda runs throughout the periphery of the mud house which has a shallow foundation of mud-built in a similar way [8]. The walls of a rural mud house are made of cob which is a mixture of locally available soil and a paste made with rice husk. These walls are generally one ft thick. Rice husk acts as fiber for providing tensile strength to the cob.

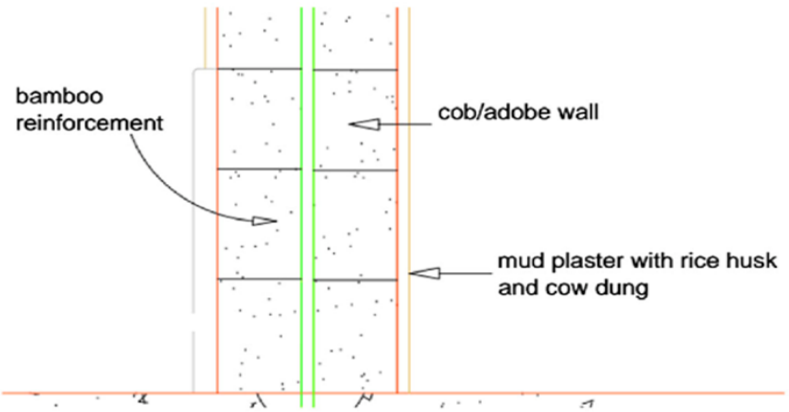

Figure 6: Wall Section of a typical Mudhouse in Bangladesh [9].

4. Research Methodology

Various approaches have been undertaken worldwide in order to assess the energy performance of houses. At Kerala in India, an in-situ measurement method has been used to assess the thermal environment in a house [10]. Findings from this method revealed the cooling technologies for a traditional mud house. It shows that the earthen floor, thatched roof, and natural ventilation are the most efficient and effective vernacular way to achieve interior cooling. This study attempts a similar kind of approach in which the climatic data analysis and thermal performance analysis of mud houses are done by 'ECOTECT Analysis' simulation software and the resultant data is investigated in-situ in the summer and winter period. This study explores how the traditional vernacular construction techniques in the Rajshahi and Bagura are conducted that can be used in modern constructions as well.

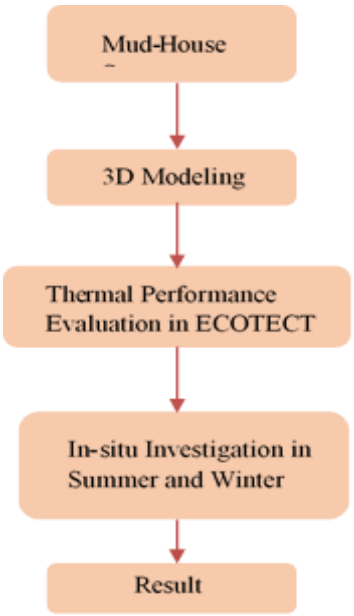

Figure 7: Assessment process of Thermal Performance of mud-house in Rajshahi and Bagura (Drawn by Author)

5. Result and Discussion

The total surface area of the studied mud house in 3D modeling is 173.80 square meters. The total floor area is 50 square meters. In warm-humid climates, the prime concern is creating airy spaces [11].

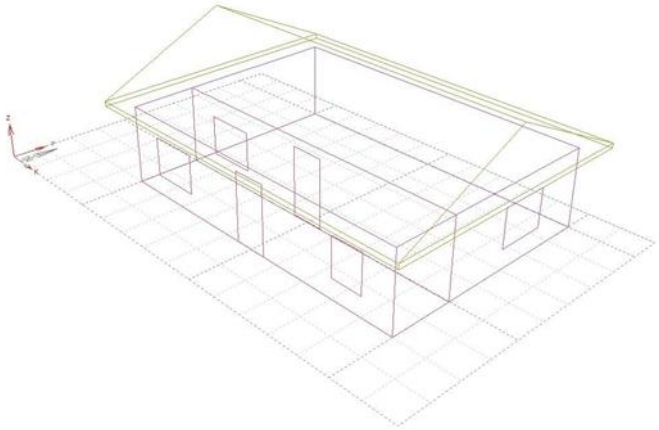

Figure 8: 3D Model of mud-house in Rajshahi and Bagura (Drawn by Author)

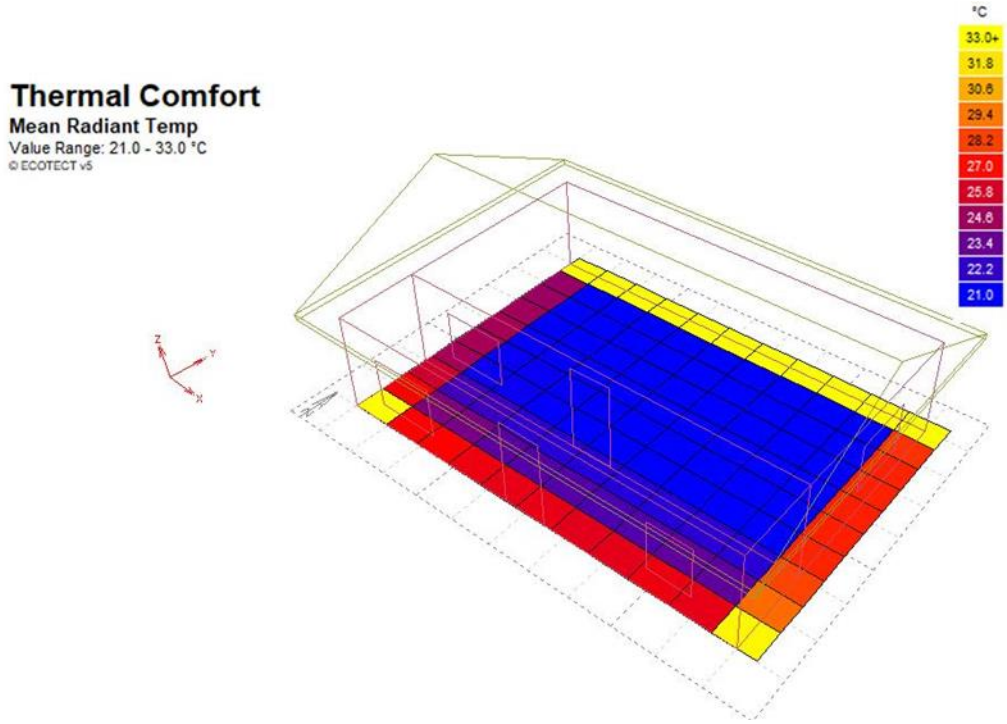

Figure 9: Mean Radiant Temperature inside living area (Drawn by Author)

Mud-house ensures thermal comfort inside the living area. Figure 09 shows the simulated thermal performance of a mud-house in summer. It reveals that the veranda zone is cooler than the outside where the living zone remains the coolest among them. In this case, the outside temperature is 33.0 degrees Celsius. The mean radiant temperature in the veranda zone remains within the range of 27.0 degrees Celsius to 23.4 degrees Celsius. This

zone is the thermal barrier between the outdoor and the living zone. Hence, the temperature in this zone remains within the range of 21.0 to 22.2 degrees Celsius which falls in the thermal comfort zone.

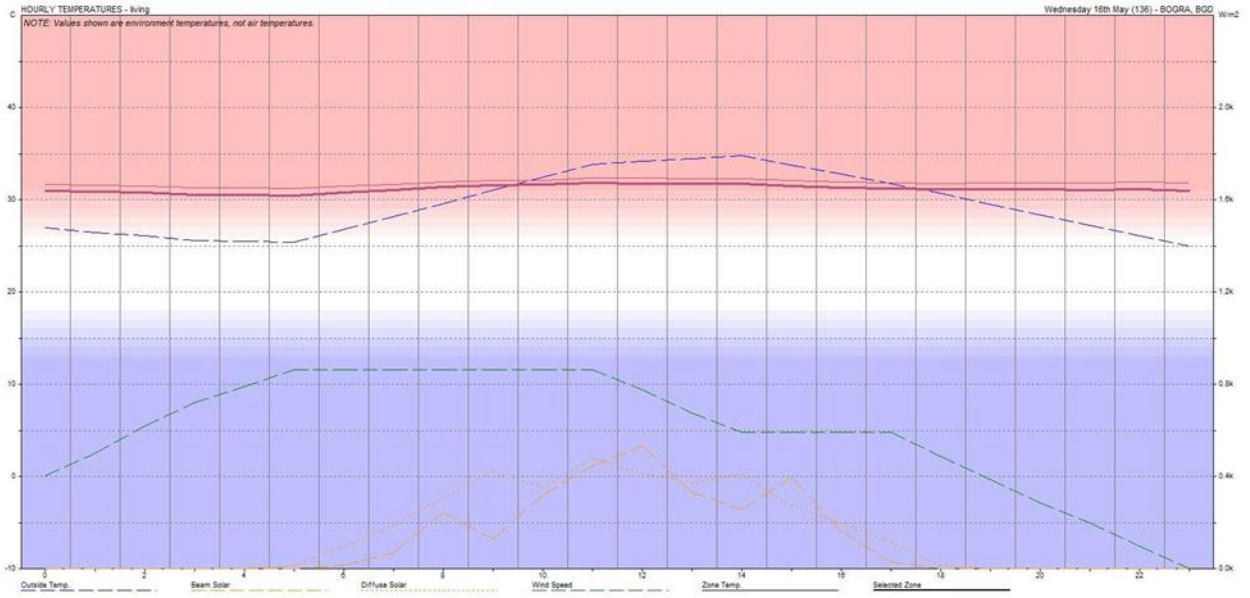

Figure 10: Thermal Performance of mud-house at 16th May 2020 (Drawn by Author)

Figure 10 shows how mud-houses in northern Bangladesh perform in summer. It retains interior temperature from rising so much that it can cause discomfort for the inhabitants. It occurs due to the low thermal conductivity of the adobe. On the other hand, in winter, the interior space remains warmer than the outdoor area. It ensures a constant thermal comfort condition for the inhabitants.

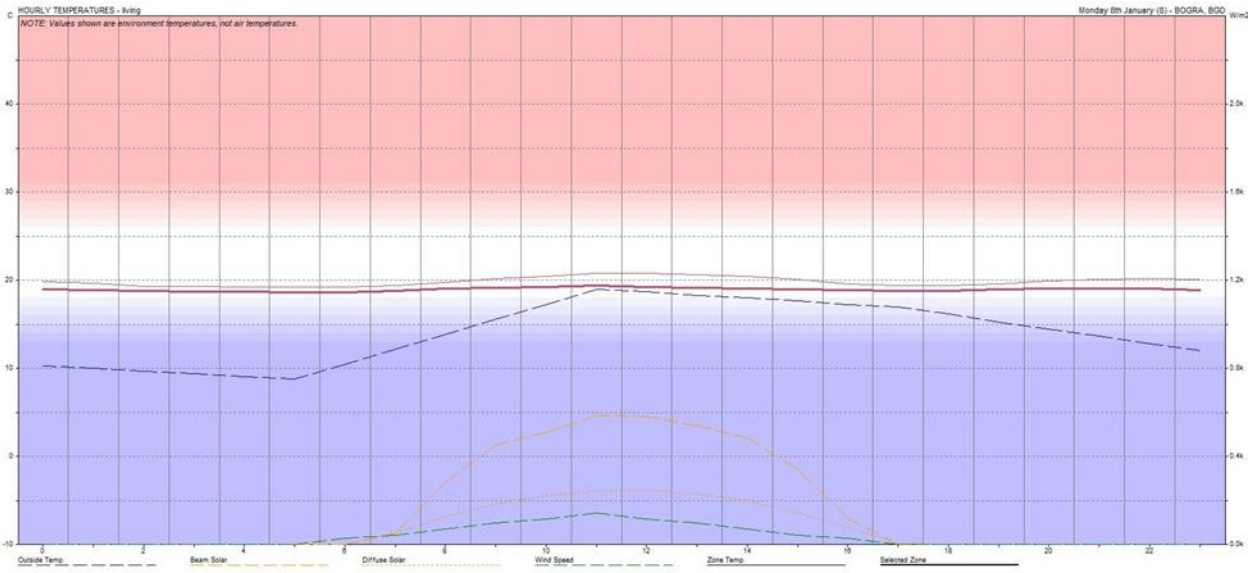

Figure 11: Thermal Performance of mud-house at 8th January 2020 (Drawn by Author)

Figure 11 shows the thermal performance of the mud-house on 8th January 2020 which was the coldest day of

2020 in Bagura. On that day, the outdoor temperature fell as low as 8 degrees Celsius but the indoor temperature remained at a constant 19 degrees Celsius which is within the comfort condition. Hence, this mud house is a sustainable and environment-friendly option for housing particularly in the rural areas of northern Bangladesh as it can ensure comfortable thermal conditions without much investment for mechanical cooling or heating. For minimum heat gain, the ratio of surface area to volume ratio of mud-houses should be as low as possible.

5.1 Impact of the Study

The findings from this simulation will help architects to determine some design factors which are the followings:

- Orientation of a mud house for this tropical climate should be East-West elongated in order to maximize cross ventilation.
- Mud walls should be at least 10 inches wide in order to utilize their thermal benefits.

5.2 Limitation of the study

The study was conducted in terms of thermal performance on two particular days. Only the extreme thermal conditions were taken into consideration. Simulation on other days might have alternative results. However, only one mud house was selected for simulation, other houses might conclude alternative results.

6. Conclusion

The constant and continuous process of improvement of traditional built forms has been developed out for more perfect solutions. Vernacular architecture thus gives us efficient and sustainable solutions with minimum adverse impact on the environment. It provides the most energy-efficient built environment. Mud is one of the most popular indigenous materials for building construction in the northern region of Bangladesh because of its abundance and thermal performance. Mud absorbs sunlight and warms the building over the course of the day which is called passive solar heating and it will keep the inside of the building warm in the winter and cool in the summer [12]. Mud houses are generally built almost entirely from natural and clean materials, unlike conventional homes which are normally constructed with synthetic or industrial-foamed material. Hence, mud houses are very environment-friendly and their usage should be uplifted to rejuvenate both environment, tradition, and culture.

7. Conflict of Interest

The author declares that he has no conflicts of interest.

8. Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article. All data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable

request.

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