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The Inherent Thermal Comfort Provision in Mud Houses Regarded as Climate Responsive Vernacular Practice of Village Mawna at Gazipur District, Bangladesh

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Abstract: *The study is aimed to analyze the thermo climate analysis in different mud houses of village Mawna at Gazipur district near the capital city of Dhaka. For case studies, four different mud houses were selected while thermal comfort has constituted the results of the paper. A micro-climatic survey technique was used to simulate the temperature comfort level for inhabitants while human interaction with surface-atmosphere in the rural environment was considered meticulously. By using the thermal comfort indexes like PMV (predicted mean vote) and MRT (mean radiant temperature) of previous theoretical assumptions, it has revealed that the thermal comfort of mud house displays that the PMV values are close to a comfortable level; surely better than any dwelling units in the city. This analysis of thermal comfort and the wind flow also showed how influential was the local environment to incorporate the climatic responsiveness of such architectural feature. To realize the core idea for thermal controlling through the approach of traditional technique, the whole construction process and the spatial quality of mud architecture was revaluated to find out which decisions had driven the local wisdom for the material selection and space organization in this particular way. For this, an elaborate literature review has been done to learn and figure out the possible role of architects or other building professionals on the further development of indigenous techniques and also include these outcomes in academic curriculum.*

Keywords: *Vernacular architecture, Mud Houses, Design decisions, Climatic responsiveness, Thermal comfort, Thermo models*

1. INTRODUCTION

Vernacular architecture is a culture and region specific social product which overcame the constraints of daily life for its thousands year practice thus treated as a vehicle of cultural identity. It is said that mud architecture of Bangladesh is a synchronized expression of this land, water, geography, climate and people where nature and life, all have created an unparalleled relation together which eventually resulted as a distinct vernacular style for any particular region (Doza, 2008). In addition, different types of traditional houses were possible to be evolved from different climatic zones for their quest of better solution to solve the environmental problems. These types are also not independent from the questions like availability of materials and structural techniques. Additional factors of climatic disasters such as flood, cyclone, hailstorm etc. are also considered to form the specific styles of traditional architecture. Thus, the native wisdom lies behind every sphere of any rural homestead, from its construction technique, planning organization to the inherent qualities like climatic responsiveness, cost effectiveness and durability. These principles are usefully to be understood as timeless guidelines for

the future as well as descriptions of the past (Rudofsky, 1964). Due to the rapid aggression of modernity and urbanization, the existence of vernacular architecture is declining without any proper substitution. Blind acceptance of western trend is nothing but a denial of the adherence to long carried traditions. This practice eventually led us to less growth of our knowledge and thereby there is no potentiality for its development over time (Denel, 1990). For centuries, these houses have been using locally available materials to ensure micro climatic comfort in built-environment under the guidance of local builders. The planning decision and all the details are come from their experience to shape the users' necessity in reality. Here both the builder and the owner could be a single person but the knowledge is collective (Ahmed, S., at el., 2014).

Acknowledgements

This research is the outcome of an academic report on "Traditional mud house of Gazipur" prepared by the 14th batch students of Department of architecture, Bangladesh University. The course was Housing design under the curriculum of "Design studio 10". The author is acknowledging their contribution and also thankful to the house owners. Without all of their help and participation, the study was not possible.

1.2 Objective of the Study

a) To explore the existing vernacular architectural practice of Gazipur and its development pattern of the study area.

b) To study the effect of spatial configuration and structural as well as material selection.

c) To investigate the thermal environment of mud houses.

1.3 Scope and Limitations of the Study

1.3.1 Scope of the study

a) The study would present the practical scenario of vernacular architectural pattern in an organic planned rural area in the present context.

b) The thermal effect of spatial configuration and structural pattern has also been analyzed.

c) Extensive study can be done based on this study which can eventually guide to generate some sustainable principles to modernize the traditional practices without doing any harm to its aesthetics.

1.3.2 Limitations of the study

a) The thermal comfort level in any particular environment was identified under broad category, detailing of individual comfort was ignored in the study due to limitation of time.

b) Only the selected segment of village was taken into consideration, other potential areas were excluded from the study.

c) Only the simple tools and portable equipment for example, thermometer were used for temperature recording. More modern and précised equipment will give exact situation for the research which needs not to tell more explanation.

d) Different time of the different seasons might give us more précised overview of the study. We have only prioritized the summer time.

Topics like thermal comfort, eco-architecture, and green buildings are not discussed here just to avoid further expansion of the literature review.

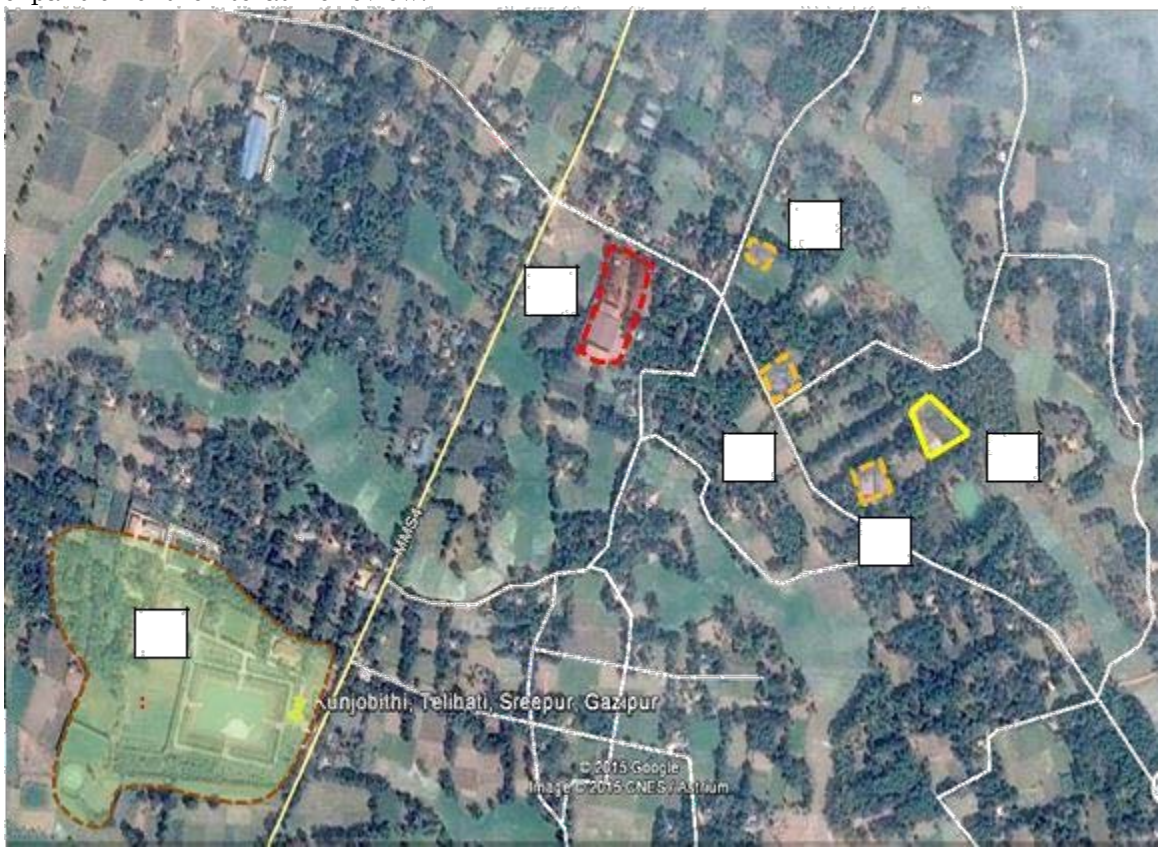


Figure 1: The four surveyed mud houses marked in yellow line, A is Dhaka Feed poultry food industry and B is tourist spot Kunjabithi

2. Methodology

The intention behind the paper was to document the thermal comfort features of the vernacular architecture of village Mawna at Gazipur. Thus, concentration over a field survey on both single and the double storied mud houses of Mawna has been carried out by following steps:

2.1 Selection of the study area:

The study focuses and appreciates the mud architecture found in Gazipur, the closest district of capital city Dhaka which tends to stretch toward its direction. Thus, research team selected a distinct part of village Mawna which is known as the core rural area while the surroundings are on a phase of that rapid urbanization.

2.2 Collection of Data:

In this research, user involvement tool is incorporated with data collection as participating users in the prearranged context should be the main source of information (Groat et al., 2001). This Data collection process includes two steps: User perception Investigation and Literature survey.

2.2.1 User perception Investigation:

Total 4 houses were surveyed during this research period. Users were interviewed with some thermal equipments. The survey included such questions dealing with construction history, occupational information, legal issues of ownership, use pattern, climatic comfort, and sociological aspects and other issues related with

living environment. The collected data from climatic survey were accumulated to have a brief understanding of the prevailing context on which condition this specific housing style emerged.

2.2.2 Literature survey

For Lacking of modern thermal apparatuses, literature survey did play an effective role in this research. Some legal documents were collected to know the weather data and for thermal comfort, mathematical equations provided by scholars of previous studies were followed by temperature recording and its analysis.

2.3 Physical Survey of site and structures:

Site survey and documentation of structures were carried out by a team consisting of housing design studio students (4^{th} year 2^{nd} semester) of architecture. The intension of the site survey were to find the physical features of built form and find the determinants which shaped the form-space as influential factors for thermal comfort. The structures were also assessed to know their preserving condition and possible threats.

2.4 Analyzing Data:

All the data collected from climatic survey were analyzed to make this study report which documented and revealed this particular vernacular architecture from a view point of thermal comfort.

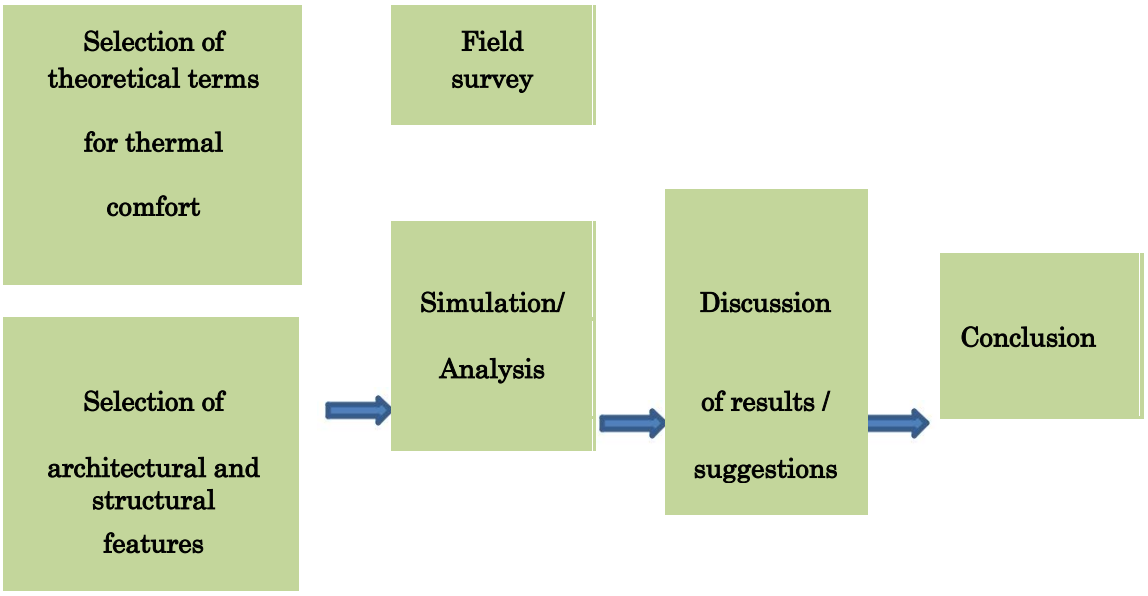


Figure 2: Diagram for the research design and approach of the study

3. Literature review

Air flow and ventilation are the most important facts for thermal comfort and heat balance. Interior spaces are very important at the typical city dwelling units for micro climatic considerations as daily activities take place there. But due to congestion of the buildings in the haphazard urban fabric and buildings also constructed with hard and heat generating materials like bricks and concrete, this cannot be achieved. The prevailing wind direction is also not effective enough in many cases (Hendron et al., 2008). For direct solar radiation associated with sol-air-temperature and heat gaining by built materials, temperature raises high above the comfort level in the interiors of dwelling units, especially in the daytimes of summer. The effects get more complicated after sunset when the structures lose heat by long wave radiation to the environment. For the periodic heat flow, the interior space becomes warmer and the people feel discomfort till mid night. Thus radiant heat loss may occur in both day and night but the radiant balance is negative only at night. Therefore, the study concerns the periodic heat flow effect on the ambient air temperature and ambient thermal comfort.

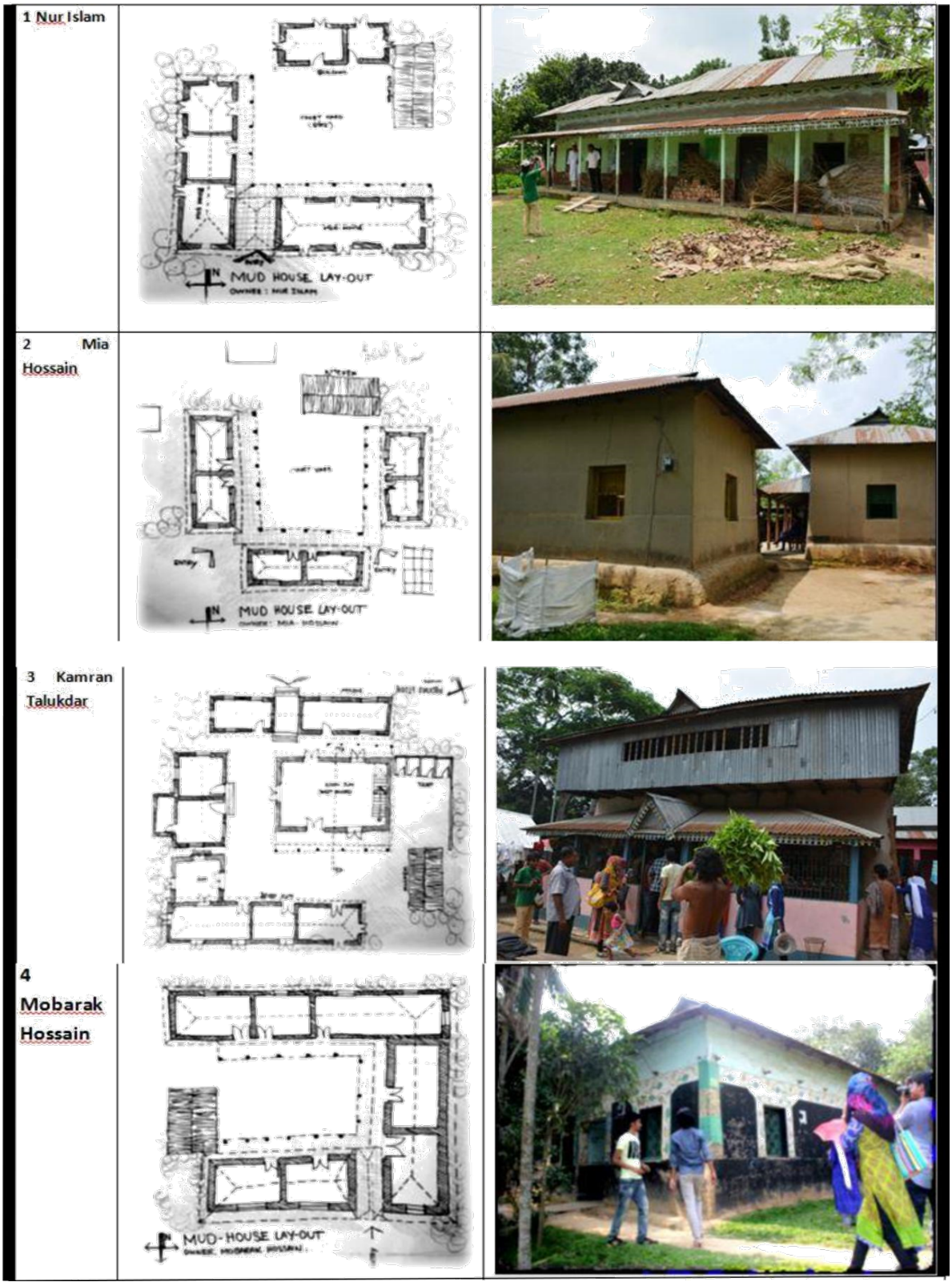


Figure 3: The surveyed houses in a sequence: owner's name, plans in sketches and exterior view

The evaluation of comfort level is directly based on the analysis of the found values for air temperature and relative humidity. Ambient air temperature for human comfort is within the range of 24°C & 32°C while the range of relative humidity is within 50% to 95% (Mallick, 1994). This statement does require some conditions like no air movement, people wearing normal summer clothing and engaged in normal household activities in indoors and having normal metabolisms. When air is still, people feel uncomfortable when the humidity is generally high for most of the time in a year. With the introduction of air flow, relative humidity rises up to 90% which is tolerable. Little or slow air movement up to 0.15 m/s makes a little difference in temperature in the terms of comfort. The mean comfort temperature for this range is 28.9°C and for higher velocities of 0.3mps to 0.45 m/s; the upper & lower limits of comfort temperature increases only within 2°C to 3°C and mean comfort temperature increases up to 31.2°C (Szokolay, 2010). Summer comfort value for Bangladesh is going to be derived from the above findings, which should incorporate the climatic features like air temperature, relative humidity & air movement of a given circumstance.

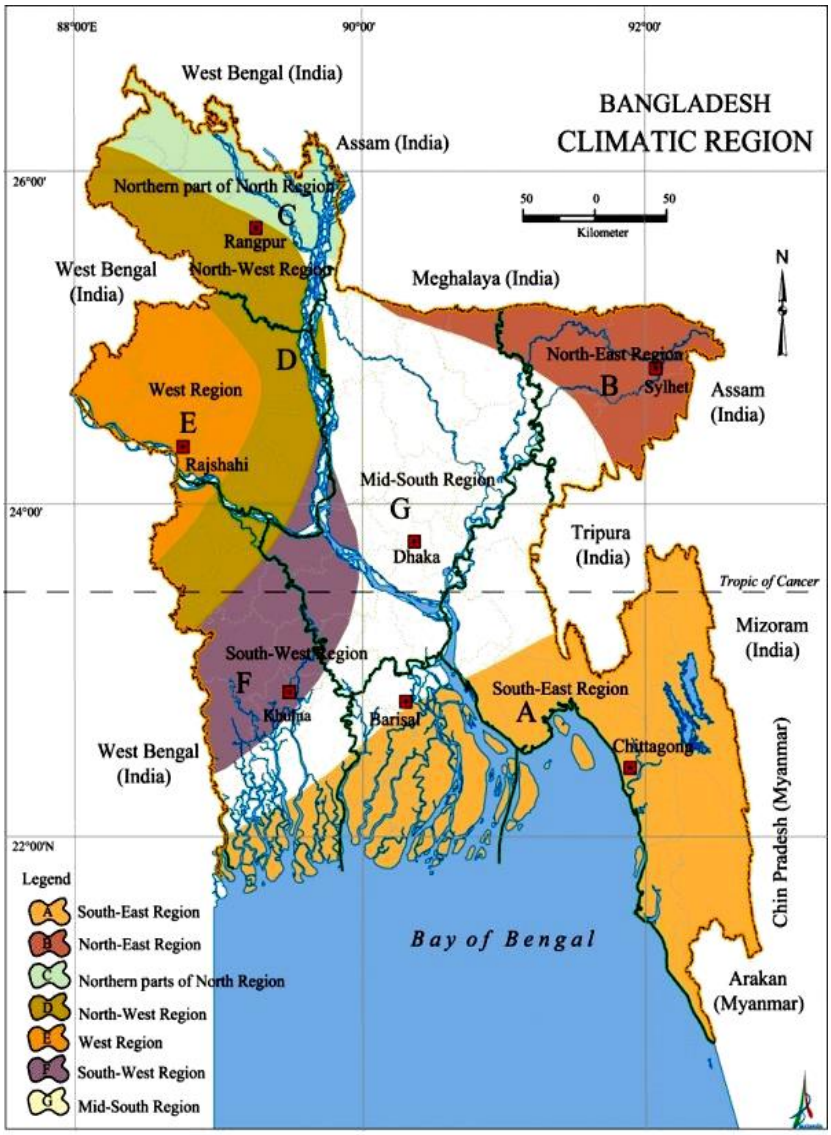


Figure 4: The climatic zones of Bangladesh, encyclopedia of Bangladesh

4. Climate of the study area

Bangladesh is located in the subtropical monsoon region. On the basis of the entire climatic condition, Bangladesh can be divided into seven distinct climatic zones (Haroun, R., 1991). This climate is considered to be Aw² according to the Köppen-Geiger climate classification. Direction of Wind comes from south while 32% wind from south and 20% wind comes from south-east. Average wind velocity is 5 kilometer per hour (Library of Congress Country Studies, 1988).

The district Gazipur is situated in the Madhupur Tract and it is at the south-central climatic zone G. This zone comprises greater Dhaka division and parts of adjacent districts of Khulna division. Our study area Shreepur is the one of the driest area in this region where annual rainfall is generally 2036 mm and humidity is approximately 78% during summer. It has an average temperature of 25.8 °C. Temperatures are the highest on average in May, at around 28.9 °C. Mean summer maximum temperature is over 33.4°C and the highest precipitation rate is 388 mm in June (Climate-Data.org., 2016).

6. Functional decisions to arrange Architectural Spaces

Space could be defined as the three dimensional extension of our visible world around us - the intervals, relationships and distances between people to people, people and objects and also object to object (Rapaport, 1977). The daily activities of dwellers and their inter action with the neighbors have been imitated in space order of vernacular architecture. Degree of privacy in any single homestead also paves the way to maintain their socio-cultural balance for the whole rural community as a continuous chain. This means a contextual appropriateness is required as common indoor and outdoor activities are essential for such agricultural society. As we know that homestead is nothing but an amalgamation of indoor and outdoor spaces (Kabir et al., 2009). However, the main function areas of a typical mud house of village Mawna are-

Figure 5-9: At the middle, the scale of entry of case study 4, right: the open entry at corner in case study 2, above and left: the storage at separate roofing system of entry corridor at case study 4

6.1 Corner foyer and entry

Foyer is not that usual but functional here. It is somewhat corner entrance with distinct architectural character with low and intimate scale to create an inviting approach. The simple walls in crosswise direction create sense of enclosure.

6.2 Uthan or the courtyard

Almost similar morphological characteristics of Bengal to have a central court and all the household activities are arranged around it (Hassan, M., 1985). The courtyard is such multipurpose space which

witnesses birth, marriage and death. The length and width of the Uthan vary from 10 to 20 feet as it is square. There were no trees in the courtyards.

6.3 Toilet and bath space

Toilet and the bath space are usually grouped together at one corner near the tube well. It is also made of mud blocks.

Figure 10: The corner mud walled toilet at case study 2

6.4 Kitchen

Usually kitchen is integral part of courtyard surrounding built form and it is open toward the court (Ahmed, I., 1997). The kitchen in all surveyed mud house is low by height and mud wall or screens made of bamboo or wood is usually erected on sides and upper portion of it is used as store. All four walls of the kitchen are constructed with bamboo weavings of different density and carefully placed according to the position of the stove and the direction of wind.

Figure 11-13: Kitchens open to courtyards in all cases. Images are in a sequence from left; case study 1, 2 and 4

6.5 Semi outdoor space

There are similar semi outdoor spaces used as circulation in the ground floors of the mud houses that is found all over Bangladesh. Usually it is a space out of the main structure of the house facing to the courtyard and has a different leveled roof shade (Mowla et al. 2000).

6.6 Bedrooms

In every vernacular pattern, bedrooms are usually arranged in a single built form of nearly 15 feet high (Hasan, M. et al. 2000). If it is two floored, then the bedrooms of the lower floors are a bit smaller (nearly 1feet on each side) due to the tapering mud wall. But Height in the upper floor rooms is less than the lower floor rooms. These rooms are arranged at the north south direction for the convenience of ventilation and lighting here in Gazipur for optimizing the cross ventilation.

6.7 Cantilever Verandah (if double heighted)

It is first floor verandah with very intimate scale of joyous linear space. Usually, it has highly decorated and colorful wooden railing. This verandah has versatile roles like gossiping, playing cards, resting place during the summer etc. additional living room for its low lying eaves.

Figure 15: The cantilever veranda at first floor of case study 3

6.8 Kar or Attic, a loft room (if double heighted)

Figure 16-17: Details of roof structures at case study 2 and the attic at case study 3

6.9 Other Services

It is one of the unique features of the Mawna double storied mud houses. The spare space between the pitch roof of CI sheet at the top and the ceiling of the ground floor is used as a storage facility. This space is linked by a stair from ground floor. To

accommodate the purpose of Kar, the height of the pitch roof is more than that of one storied mud houses.

Cow shed, Tube well, wooden fuel store all are detached from main spatial organization of homestead and usually set at a distance on diagonal axis of courtyard.

7 The whole construction scheme for the mud house

7.1 Material Selection and preparation:

Muds from all area are not suitable for erection of a house. Local people look for that kind of crop fields where red particles and gravels are found more than other soil. Then, it is mixed with water to make clay and knead properly to make it suitable for construction. Additional materials like husk, cow dung, various kinds of grasses, chopped straw, paddy chip, jute fiber, dust etc. also added to increase tensile strength of the wall. The basic materials for structure like bamboo, wood plank; jute ropes etc. are found and processed nearby (Muktadir et al., 1985). Two timbers are widely used as structural member, Supari tree and palm tree. Plum tree is available in the area and it is strong enough to continue its durability as a structural element nearly for 70 years. Supari tree undergoes with some treatment process. Two weeks before installment, the workers use cows' urine with submersible pump to achieve its desired durability of 35 to 40 years. Both timbers cost 68 taka per square feet which means it is inexpensive than other types of wood. Having the structure of palm pile; these mud houses can get an extreme quality of durability. A century life span of any mud house is quite common here.

Figure 18-19: Above: placement of mud blocks of case study 2 and palm leave thatching at case study 4

7.2 Steps of construction

7.2.1. Time period: Mainly mud house constructed in dry season (November to February) and it takes 3 or 4 months to complete a mud house.

7.2.2. Excavation for wall footing: Soil dig up to 1.5 feet to 2 feet deep on the site for the foundation. It is excavated along the marked lines generally at a width of 3ft. The excavated ditches are dried in the sun for 2-3 days.

7.2.3. Foundation: The raw mud mixed with straw, paddy chip, dust and jute fiber put into the layout to make a foundation "bed" up to plinth level. During mud processing period, the foundation bed is covered with mat.

7.2.4. Mud wall:

7.2.4.1. Building material: mud blocks are laid into the excavated cavity space in a number of layers one after another and rammed around that foundation bed and dried well in the sun. Then workers start to build up the walls slowly by placing the mud humps one over another. The rectangular mud block is generally 20 inch high and 20-30 inch in length. The upper ones are smaller in size then the lower ones and walls are constructed in a tapered way. After completing each layer, the walls are coated with clay by hand in interior for reducing the cracks and perforations and it is done regularly to make the house much more durable. The clear height of the wall is around 10-15 feet. This newly erected wall needs to be dried immediately to prevent cracks. Thus long splotches by trowel placed arbitrarily in the wall to dry its inner side so that the moistures come out and wall loses extra weight due to water in it. When it is dried up perfectly, then they start the shading work (Rashid R., 2007).

Figure 20: The different layers of bitumen. rice husk and paint over mud blocks of case study 4

7.2.4.2 Finish material: the mixture they use to plaster the both sides of the wall is comprised of clay and husk, average thickness of its layer is 1.5 inch. This Coating of straw, husk on exterior facade is to protect it from the decay due to monsoon water. When it is dried up, it is colored either by tar (for black appearance) or lime (for the white) for exterior beautification and to protect it from the decay due to water. Usually, paints like distemper can be used over earthen wall. But use of color gradations of pale earth on wall and yellow plinth color is to create a contrasting pattern.

7.2.5. Plinth: The plinth is made by earth filling in between the walled space. The earth is rammed well to make the plinth a hard surface and clayed to make it smooth. The plinth level varies 6 inches to 12 inches.

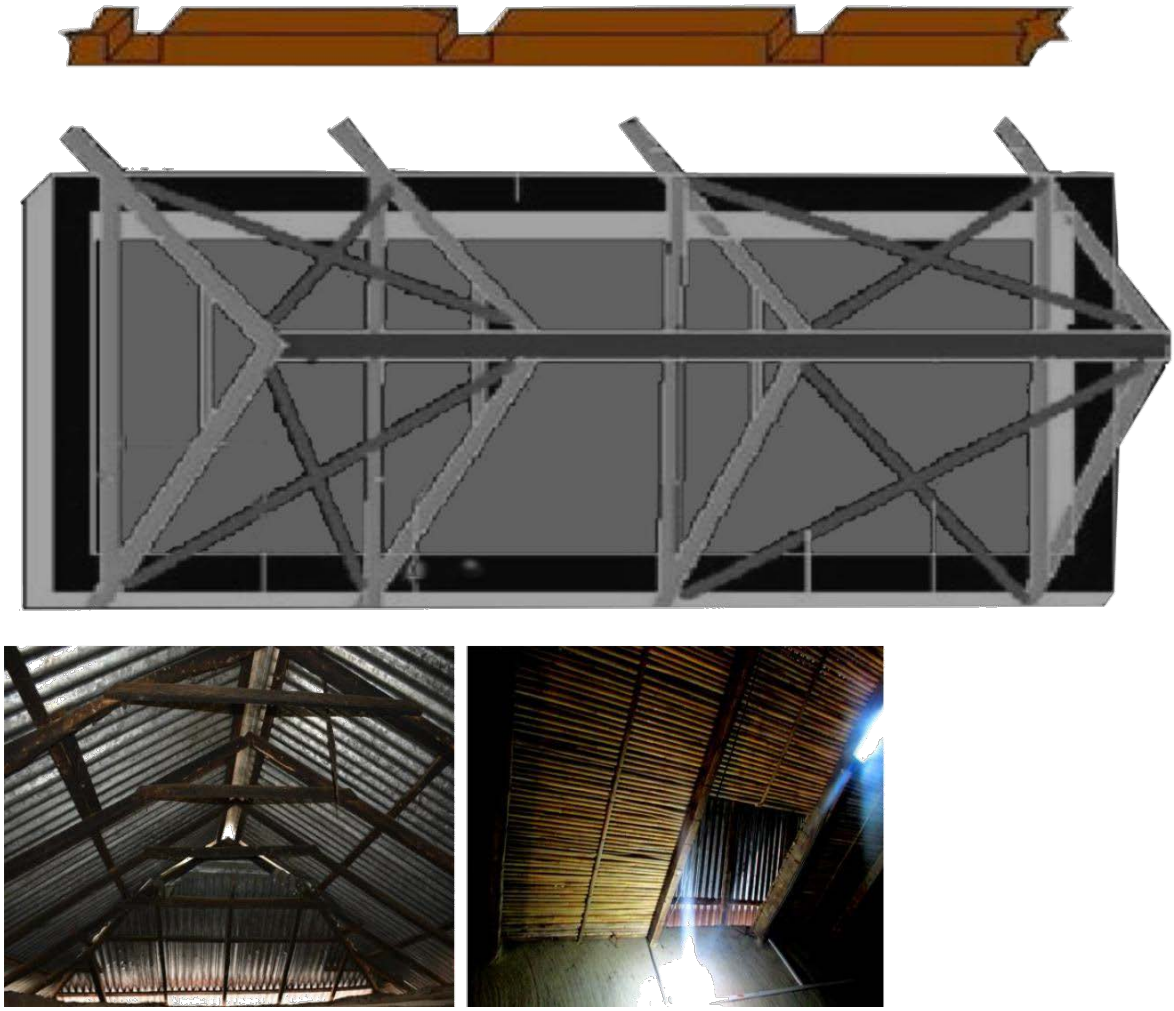


Figure 21-24: Above: 3d modeling of grooves for the placement of rafters in ring beam. Middle: 3d model of diagonal braces in-between rafter, left below: use of collar beam at case study 3 and ceiling made of bamboo weaving over palm wood beams at case study 2

7.2.6. Shed Making: To make the shade of mud house today they use
CI sheet. But traditional practices
for roofing are available. And cheap
materials like thatching of straw, and various kinds of dried tree leaves such as date, coconut, and palm are in that area

7.2.7. Ceiling: The ceiling of the ground floor has three layers: wooden planks of seasoned palm or coconut tree which work as the beam, bamboo layer placed perpendicular to the wooden planks and in close proximity leaving least gaps in between the bamboos and then tied well with jute ropes to keep them in stable position

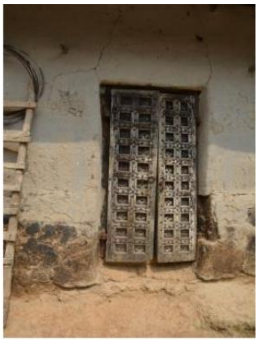



Figure 25-26: Left: palm plank for lintel at case study 2 and wooden frieze at case study 3

7.2.8. Roof: The walls at the edges are constructed to 2-3 feet high from the final ceiling level and over this part the pitched roof with wooden truss is installed. The space between the ceiling and the pitched roof is used as storage.

7.2.9. Fenestration: Rectangular voids are kept during the process of wall construction. The lintel is a supported bamboo or wood plank. No frame is visible around the void. The short jambs are installed beside just to hold the wooden planks.

7.2.10. Details for double height mud houses



Figure 27-29: Above: cantilever verandah interior view and its construction system,

Below: wooden stair from ground floor to attic.All three pictures are from case study 3, which is a double height mud construction

7.2.10.1 Cantilever verandah: It is basically an extension part of the upper level floor having full height wooden fencing at the edge line which also works as railing.

7.2.10.2 Stair: The stair is nonstructural and only supported on its resting edges, one with mud walls and another on ground floor. Steps and railings both are made of wooden planks, bamboo or iron bars. Risers are usually 8 to 10 inch while the treads are about 9 to 10 inches.

8 Outcome of Survey:

Our study area, Gazipur is comparatively high land and composed of agriculture based Neolithic villages, where mud house bears the transformed heredity of nearly 25,000 years from its early settlement. As the ground level is relatively free from flood prone area and the earth is of grayish red tone; thus, it is proved as ideal for erecting variety of mud houses (Hossain, I., 2013). Besides, relatively less rainfall, dry climate and lateritic soil are the main reasons behind choosing the mud construction for households in this region (Sultana, 1993).

Case studies	Interior wall temperature	Exterior wall temperature	Temperature difference
1 Nur Islam	34.6°C	35.6°C	1°C
2 Mia Hossain	34.4°C	35.3°C	0.9°C
3 Kamran Talukdar	33.6°C	34.7°C	1.1°C
4 Mobarak Hossain	34.6°C	35.8°C	1.2°C
Average	**34.3°C**	**35.3°C**	**1°C**

Table 1: The recorded temperatures for each of the case study

Our study area village Mawna is only 1.5 km away from its townscape and famous for the construction of generic type of mud structures. We were able to know that all these households belong to Muslim farmers and most common feature is homesteads built around a large courtyard being open towards the south east corner. Only the double height structure is oriented in the north south direction and accommodates a loft space which makes it higher than the other structures. Here is the chart for the surveyed houses showing the temperature readings which we will use for the thermal model indexes next.

8.1 Operative temperature: This value attempts to combine the effects of air and mean radiant temperatures into one metric. From the recent climatic data of Gazipur, the average wind speed is 5.4 k/h or 0.15m/s during the month of May. If the air speed is less than 0.1m/s, (as is typical in interiors) radiation heat and convective heat transfers may be the similar value, and so the equation for operative temperature can be simplified as:

$T_o = (T_a + T_r)/2$ where T_a = Temperature of surrounding air of any occupant, T_r = mean radiant temperature (Designing Buildings Wiki, 2014).

For the simplicity of calculation, we took the highest air temperature for Gazipur in May that is 32°C as air temperature and mean radiant could be the lowest air temperature 26°C of the region for an assumed thermal balance. As air dry-bulb we could not use in the survey, the weather data was used for reference. It is assumed that air temperature and mean radiant could be equal for buildings with low thermal mass (Matzarakis at el., 2008).

$T_o = (32°C + 26°C)/2$

$T_o = 29$ °C

8.2 Thermal Neutral model: The relationship between the neutrality temperature and the monthly mean outdoor temperature is known as thermal neutral model proposed by researchers like Nicole and Humphreys (Athienitis at el., 2002). The equation for this model is:

$T_n = 17.0+0.380 * T_m$ where T_n = Neutral temperature when the occupant will not feel any cool or hot and T_m = Mean outdoor temperature.

For the same month (May), the monthly average temperature is found 28.9°C on Bangladesh weather chart which is also the highest for the whole year, thus we can use this value as monthly mean outdoor temperature to decide thermal neutrality of studied area.

$T_n = 17.0+0.380* 28.9°C$

$T_n = 27.9 °C$

For information, solar radiant heat loses by periodic heat flow at interior after sunset. This causes a discomforted condition for a longer time in the city dwelling units. Sometimes this discomfort state may continue from 6pm of evening to 11pm of midnight during summer. Because then we have longer daytime as a result of radiation and higher angle of incidence. In this study, the comfort condition exits in the experimental mud walled rooms with gentle air velocity.

PMV scale	state
+3	hot
+2	warm
+1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold

Case studies	PMV
1 Nur Islam	+1 = slightly warm
2 Mia Hossain	+1 = slightly warm
3 Kamran Talukdar	-1 = slightly cool
4 Mobarak Hossain	+1 = slightly warm

Table 2: The PMV vote for four case studies of mud house in Gazipur

8.3 The Predicted Mean Vote (PMV): It is developed by P. O. Fanger, making use of heat balance equations to define comfort level. Comfort zone in building interior depends on ASHRAE 55 standard which states a predicted mean vote in-between -0.5 and +0.5 for built interiors while occupants metabolic rate is between 1.0 to 1.3 met and clothing between 0.5 clo to 1.0 clo for thermal insulation (Autodesk sustainable workshop, 2011). For surveyed mud houses the predicted, mean vote (PMV) could be calculated as (+1+1-1+1) /4 as well as + 0.5, ranges between neutral to slight warm level. In experiment, we used portable handheld Anemometer (model LAC-EA3010). Its temperature ranges from 29.9°C to +59°C and accuracy is +/- 0.1°C. Owners were asked to puff on anemometer's fan to decide their comfort level by metabolic rate.

8.4 Climatic responsiveness of Mud houses

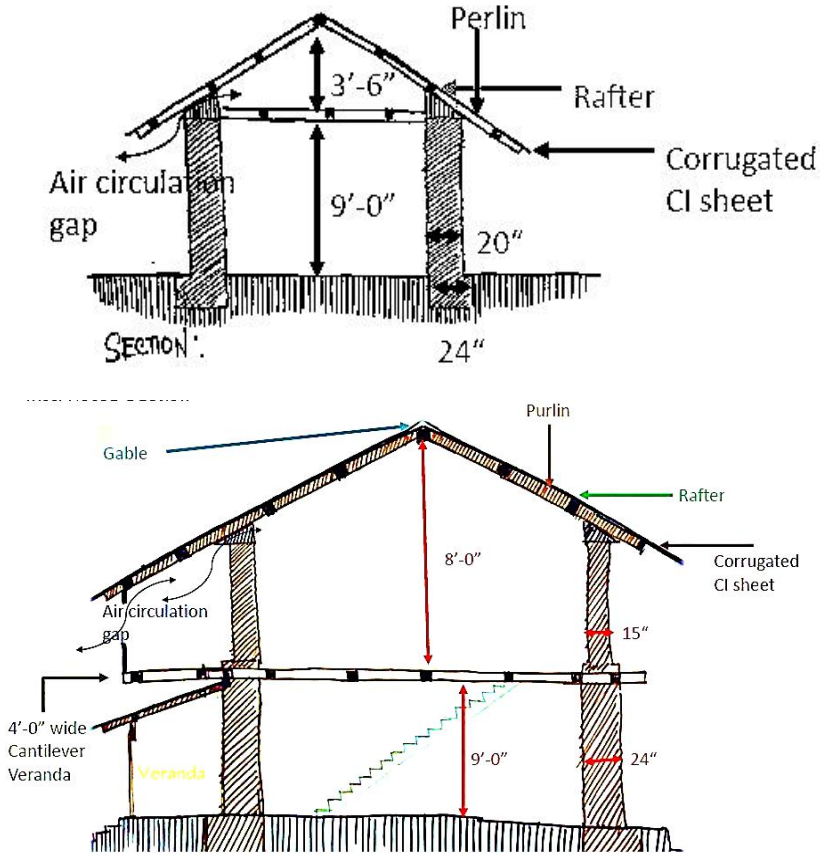


Figure 30, 31: Sections of single and double heighted mud houses with dimensions and natural airflows

8.4.1 Diffused daylight: The wide verandah which wraps around the house is used for various activities during the day time has ample diffused light. This also gives the interior spaces a modest visibility throughout whole day. The courtyard works like an effective light well.

8.4.2 Ventilation and cooling: All the rooms are cross ventilated for the narrow air channel of semi-outdoor between interior and courtyard. The mud walls allow passive cooling in the interior rooms and the air trapped at the bamboo weaving of loft"s false ceiling become condensed, thus kept for storage area of raw materials like potatoes, rice etc. The courtyard with walled enclosure creates a super climatic shell by playing the lead role for cooling to ensure human comfort. For information, the mean average temperature is 35°C in this hot dry region. The massive thick walls work as great insulators to control the thermal comfort at indoor spaces and thus during the summer the interior remains cool. On

the other hand, during the winter, interior remains warmer than the outdoor environment, while the courtyard becomes lively with the glow of shiny sun beam in the mornings, which is pleasant for inhabitants. The loft space of double height mud house is separated by a system of false ceilings made of wooden planks which act as storage space and also an effective passive cooling device.

8.4.3 Reduction of heat gain: The use of mud walls acts as non-transmitting material for heat. Besides, the extended roof overhanging cast shadow on wall surface which helps to reduce heat gain to a minimum level. The courtyard is shaded by large trees or bamboo bush from the west corners so that the long period of west side sun is also avoided.

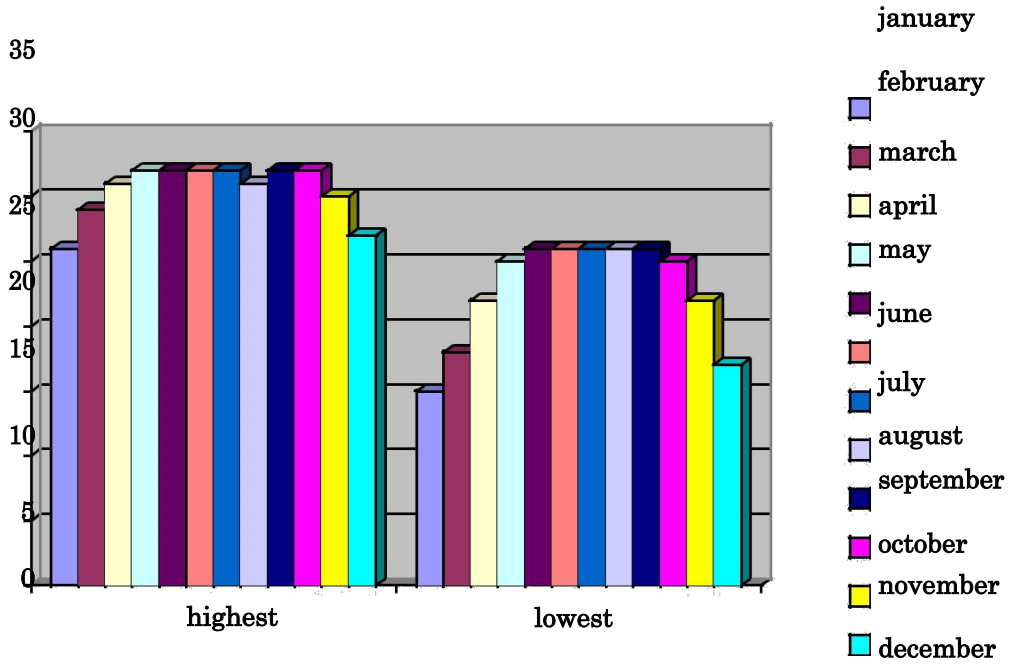
8.4.5 Prevention of the sun glare: To reduce glare, the window is generally sunken into a deep distance from façade, about 10 inches deep which require some additional treatments again. This is achieved either projection from the overhang eave or a thatched screen.

8.4.4 Rain water absorption: The pitched roof is comprised of two tiers thus completely protects the walls from rain water. The walls are finished with a mixture of mud and rice husks which eventually results as a smooth and water repellant finish material. In monsoon, the projected eves of the slope help to protect it from the driving rain and the sharp pitched roof help the rain water to run quickly. The thickness of wall up to window‟s seal level is 30 inches so that it can absorb the sprinkled rain water from ground. The wood panels in the windows are set obliquely so that the rain water falls down quickly. It saves the interior surface of the mud wall to get wet and also acts as sunshade for the windows.

9. Analysis of results

From the mathematical equations, we get that operative temperature is 29 °C which means the indoor environment is balanced at this temperature. The interior wall temperature found lowest at the double height mud house of case study 3, which is 33.6°C and with a difference of just 4°C from operative temperature. It means the double height mud house interior is much cooler because air is just trapped on it if the wind velocity is minimal. Again, the value we found for thermal neutrality is 27.9 °C and people don‟t feel just uncomfortable on that state. This is an “ideal” situation which cannot be achieved in practical environment by any cooling device but we can compare it in that way as the temperature of exterior air in the pleasant season like late winter or beginning of spring (mid-February to mid-March) is around 25-28°C. As the interior temperature is always around 2°C less than the exterior surface, we can say at that season people enjoy more similar interior of thermal neutrality. Besides, it is really surprising that this survey was conducted in the hottest month of summer but the Predicted Mean Vote (PMV) is still +0.5 for all the 4 owners of these mud houses. We acknowledge that a large number of people should go under the test but we are sure that the vote will surely be at a range of -0.5 and +0.5 or even better. We can say that our result is just on the range of desired prediction of PMV scale which is quite desirable at this region for a hot month like MayTo prove the climatic responsiveness of mud house, we will focus the thermal conditions, humidity and rainwater as some critical factors. The average interior wall surface temperature (assumed as interior temperature) is 34.3°C and the average exterior wall surface temperature is 35.3°C and also the average difference between interior and exterior is 1°C, which is really significant for this study because no additional device is used here to reduce the heat gain. So, naturally heats are controlled in the interiors of mud house by its entire structural and physical system. This is just because heat loss in summers is promoted by courtyards and trees around the homestead although there is no water body beside them as the locality struggles for water scarcity as well as underground water level is also beyond normal level. We know that ponds play good role in cooling and other vernacular patterns of the country includes pond always at east side. The reason is buildings in warm and humid regions need maximum cross ventilation to carry through the evaporated contents of air to cool the environment and by doing this air decreases humidity level. Being deprived from such “blessings” from water bodies, this type of vernacular pattern has achieved a satisfactory level for the burning question of thermal comfort; which is extraordinary detection of this

survey. Rain in this area is the lowest among the whole climatic region and thus existing condition of mud houses are adaptive and had well coped with traditional rain water controlling system.



Graph 1: From the district data of Bangladesh weather board the graph showing highest and lowest monthly temperature of Gazipur.

10. Suggestions

It is claimed that there are some aspects of vernacular architecture cannot provide healthy environment with its age-old traditional technology (Denel, 1990). In this study, the appreciation for Mud houses as a vernacular practice is not to oppose the modernization or any kind of uplifting of rural life style (Filippi at el., 2005). Again, scientific knowledge to improve any permanent solution for the treatment and process of natural materials requires less maintenance but provides better thermal performance. These opportunities do exist in local wisdom but is not used just for our ignorance (Kabir et al., 2005). But it is surprising and significant that 100 years earlier local masons built such houses entirely made of mud, wood and bamboo, are still in practice. Thus Workshops could be arranged for local masons, so that the knowledge can be transferred in both ways: learning and reviving traditional techniques for today's practitioners and also for local masons who will get adequate encouragement to use the modern knowledge to enrich their indigenous wisdom (Filippi at el., 2005). Some additional suggestions are mentioned below stating how small things can bring a noteworthy progress on the basis of more durable structure and thermal comfort:

10.1. Suggestions regarding Thermal comfort

10.1.1 Introduce some critical shading devices

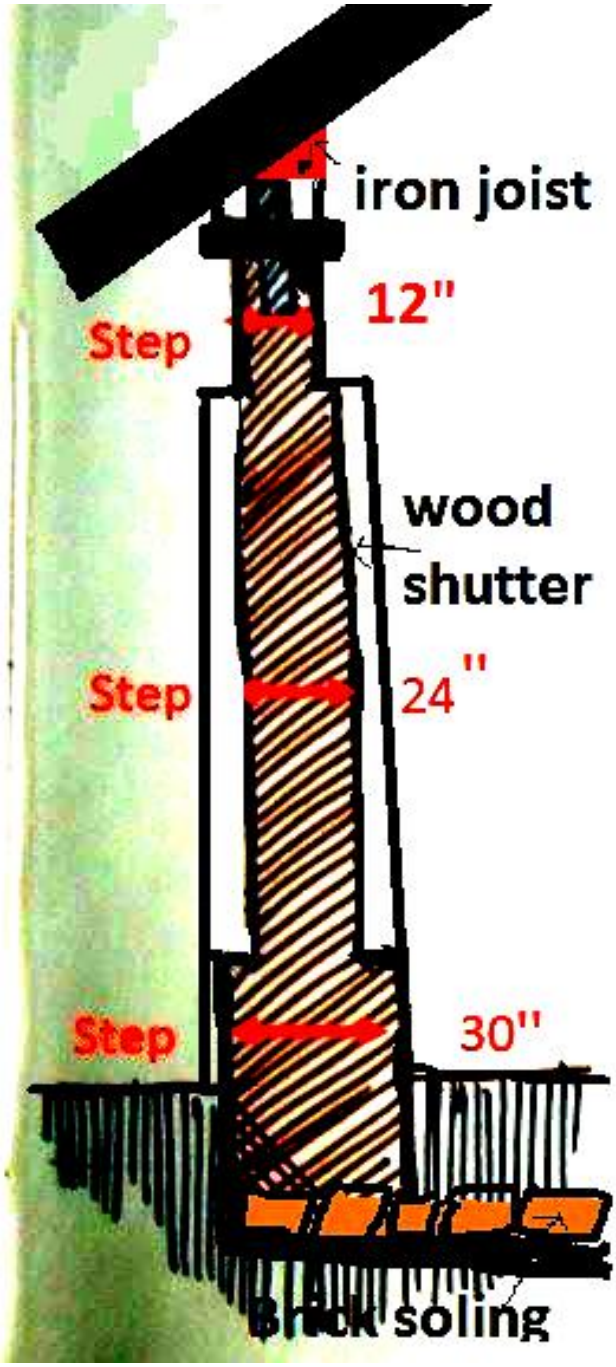


Figure 32: Section of a mud wall with some proposed structural elements

The total mud house complex is shaded in a number of layers with pitched roof. The distance between two layers of shade should be calculated. The lintels could be extended or boxed around the openings such that it can cover the rest of the mud made facade after the extended slopes of pitch roof during the rainy season. Buildings having longer-axis in west direction could be treated with cavity walls and roof/wall insulation may perform better for thermal comfort. Adequate shading and external reflective surfaces on western sides are recommended to project the sun of west.

10.1.2 Acquaint with some additional openings if more cooling is needed

High-level windows are preferred on both shorter facades of any rectangular room whereas low windows could be kept at the interior walls adjacent to the plinths of verandahs and can be faced to the courtyard. But we can also take the advantage of mud wall as it naturally regulates moistures like a perfect humidifier.

10.2. Structural suggestions

This section is postulated to enhance the three mottos: how to protect and keep the wall, the ground floor and adjacent plinth foundation dry from capillary system of earth without weather coating or stabilizers. Secondly, stretched canopy system is required. And finally the erosion control over mud wall surfaces.

10.2.1 Formulate a brick soling beneath mud foundation

If brick soling is introduced over the rammed earth foundation, then the load carrying capacity for whole structure will increase. For cladding of plinth, cement can be mixed with mud clay as a more sustainable solution to prevent decay due to the horizontal drifting rain. Speed breakers like bamboo strips, husk in layer, rope and hole perforation could be introduced to restrict or slow down the rain water which come down fast over wall. Brick columns can also be introduced.

10.2.2 Preparation of mud

Naturally the earth is mixed with organic constituents that later help the weeds to grow on wall over the porosities and cracks. Thus before erecting a wall, the soil should be fined enough and checked properly. Some chemicals like Barium sulfate ($BaSO_4$) could be mixed with mud which is odorless and insoluble in water and also not harmful for human. Mud blocks which are damaged could be replaced by new blocks and the damaged blocks will be recycled to nature for a super environmental performance from such low-tech material.

10.2.3 Introduce shuttering at corners and openings

As corners and the joints are the weakest points of the mud wall, cracks start to develop from there. Where any void for opening is made, pealing of wall surface and efflorescence are also some common problems we noticed. To solve these, wooden shuttering in the corners and around the openings can be used to support the wall, which may be hidden from the surface with mud cladding of left as an expression of the treatment for decoration over elevation.

10.2.4 Bonding modification for cladding

Due to different moisture content of the materials, the unsealed or improper bonding between mud and structural members like wood, pile, bamboo, palm plank etc. cause cracks at any conventional mud structure. Again, wood rafters, piles and the bamboo get rotten for the contact with moisture of mud if they are not sealed meticulously and thus termite begins. This study proposes wooden structure and the enclosure of mud must be separated. Filler materials can be introduced between structure and mud wall as a layer. Cement blocks between two types of materials can fragment the wall into small parts without doing any harm to its aesthetics. As Cracks always develop in huge volume; thus, fragmented wall would prevent the crack which is more sustainable as a solution.

10.2.5 Improvement of joints and fastenings

Traditionally bamboo joists are tightened together with jute made rope which is not durable. Metal wires and clamps can be used for more structural stability. This study also wants to educate Bangladesh's

architects who overlooked mud for the excuse of modernity. Prefabrication technique for rammed earth block and electrical fittings can be layered in multistoried buildings within scale. So, mud could be an excellent alternative for the alarming heat gain and trapped heat of cityscape of Dhaka where concrete consumes energy and causes carbon emission. **Conclusion**

Today, the awareness of green buildings is increasing as we are facing a lot of adverse effects of global warming. While any modern green built environment incorporates with more and more complexities in technical aspects, our vernacular practice along with its conducive and indigenous intelligence behind it, out of scare resources and minimal energy; is quite approved and effective for the questions of cost and sustainability. Although, recent researches present temperature variations from 5-15°C; but it should be considered here that this study is to explain an existing situation. Mud architecture is more economical than typical brick or concrete construction in the cities by several ways. It does not involve any machinery and has low labor cost as all the materials are available in the surrounding nature and needs no transportation which has reduced the material and transportation cost remarkably. They need not to carry out maintenance in a long run as mud in this area is extremely durable which means the maintenance cost low as well. It is also cost effective regarding the electricity consumption as its adaptive capability for thermal comfort has reduced utility cost. Hence, this study suggests that elaborate study must be done on the indigenous materials and the structural system of all vernacular types of Bangladesh in a scientific way, using the best and appropriate modern technical knowledge, so that all the scopes and limitations can be revealed. This particular section of knowledge must be included on the learning curriculum at graduate levels of architecture schools to educate future architects to design with more sustainable initiatives. If such architects could contribute to take these things a step ahead in future, the gap between education, practice and research could be bridged. In addition, concerned authority should focus on professional training on sustainability, research publications and preparing regulatory guidelines or building codes for different climatic zones of Bangladesh to suit their respective regions using updated climatic data. Eventually, by saving our cultural identity and its continuity; Mud house may assist us to open our eyes for an alternative and ecofriendly architectural design solution to resist the effects of global warming.

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