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THERMAL PROPERTIES AND USE OF CLAY BRICKS IN LOW-COST HOUSING

Mufid A. SAMARAI*
Mowafaq AL-TAEY*
IRAQ

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1- Introduction

Clay is the first material used by man for building . From the begining of civilization building process with clay has been developed and civilizations of Mesopotemia and the Nile were among the first to use this material in developed forms. The name of (Al-Tob) was taken from the ancient Egyption name (Tob) which means the brick which was later derived by the west to "Adob".

Clay building is used in various geographic conditions and enviro ments to answer constructional, social and functional requirements. The various forms and techniques which could enhance its properties makes it more and more a demanded material for both low and normal cost housing. However, if clay material is used in its normal form it may provide good constructional material but its durability will not be suitable for modern requirements and demands for economical and durable materials.

This paper will review some historic uses of clay building in Iraq with different environmental conditions and present thermal aspects of clay bricks and recommends means of improving these aspects and presents some work which has been carried on soil stabilization in southern marshes of Iraq.

2- Historical Uses in Iraq

Archaeological villages located at the north part of Iraq are considered the oldest human settlements which related to the development of life of sensible man, from bringing up of animals to the first agricultural societies. Jarmo village near chamchamal east of Kirkuk city is the oldest human settlement. The period between Mesolini age and Neolini age (6750 B.C) . At this settlement were found 30 houses of mud which was built of Al-Toof (Al-Rahas) . After this style of housing there were the round style houses still used in the north of Iraq and Syria near Halab . The first sample of this type of house was found at hill of (Yarim Tapa) at Sinjar valley near Telafar which was Limited to period of Hassona age about six thousand B.C. There are also a type called Halaf period which used the circle figure added to it other figures. Building with mud was continuesly developed and sometimes placed on normal rock foundations in some cases houses were built of mud from bricks like cigars arranged in ranks three in length and three in width.

The roots of traditional rural building in Iraq is very old it refers to Mineral-Rock Age (5600 B.C.) . This was known

from the ancient archaeological village named "Tell Hassona" at Al-Shera district at a distance of 22 mile south of Mosul. Archaeological excavation showed houses in various historical stages of Mineral-Rock Age to Modern-Rock Age (3500-5600 B.C.) These houses were built of Altoof (Alrahas) made by mud placed in ranks of mostly 40 cm. height. Roofs the archacelogist (Eiton Luid) thinks have hump roof name in Iraq (Jamalon) derived rom hump of camel . Reeds and woods are also used in roofing and walls after coating it with mud mortar. Rains in the north of Iraq required hump roof but this tradition was less used in regions where there is lack of rain for easy construction depending on individual effort. The soil of Tel Hassona leads to good building concepts and developed modern constructional sense. As we found the roof covers five rooms of integrated constructional unit based on piles in the walls in spots bearing the roof. The method of using piles at walls are one of the developed solutions which are used to raise sufficiency of wall resistance to roof pressure, this solution is used in modern mud building throughout the world.

Tel Hassona shows a specific system in its plans, the rooms have an open spacing in the middle with oven, and there are pathways between rooms and this working area which provides the privacy for the rooms. This is the same style used across

ages in Iraq. The technique of building was altered after the period of Tel Hassona although the style of Altoof was still used in many cases of rural building of modern low housing, there was another important discovery near Samara city which was "Tel Alsawan" , dating to a period 1000-6000 B.C. Buildings with well planned lines within defence outside walls . The ceramic founded showed various muddy components with high technique where the clay contains mixes of other materials such as sand, lime, fine hay and grounded ceramic. Components of mud used in building was analysed and compared with the discoveries at other regions shows intial use of techniques in making mud where man leamed the manufacturing of (Libn), mud in wood moulds dried in sun, then placed in organized horizontal form, this is the constructional form for modern and old muddy buildings. The rare forms for historical muddy building is building of circle muddy piles covered with pointed mud or stone pins to give beautiful shapes. These forms also give strong roof and high resistance for loads which used in Euphrates river from Tel Menas in Syria to Alwarka near Alsimawa in Iraq. This type was known in specific historical period named Alwarka period (3700-3100 B.C.) In Alwarka at (Ay-Na) temple there is a clear sample for this well designed form of clay mud. This temple and these houses have other developed techniques which used limestone for foundations and mortar for walls (white of mud)

known as lime mud, Also used in Cyprus and Portugal and in other Arab states. Chemical components of clay of the temple were analysed and compared with other clay in Iraq. There is another rare types of buildings which is the Zikoras where mud used in form of (Libn) with reeds and ropes to strengthen the roofs of bricks which was positioned in layers either 8 or 12 and then a mat of reeds named Baria the ancient sumerian name used since Alwarka age about twelfth centrure B.C. like the system used in Agargoof Zikora near Baghdad.

After the period of Zikoras, mud forms and conical mosaic works which was known in that time disappeared, and the straight convexed alibunum forms took place which was arranged on one side in a form . . like fish bones which in spite of its important bonding shape caused by the difference in arrangement and entanglement, it insures stopping of ground water motion ascending by the capillary action. There is no mortar between the bricks, this also helps stopping water seepage. This arrangement is used in the lower places of the most modern buildings or the upper part of the wall to prevent seepage of water from the top of the wall to the other parts. The ideal example for this type of buildings was discovered in an important monumented hill near Baghdad called (Al-Khafafi Hill) which belong to (Musailam) era in the seventeenth century (B.C.) the building is distinguished

by its unique oval shape where mud flexible shapes are easy to make.

In Babylon the ideal models made of unpottered clay was observed. This city made use of all the old sources which was developed in clay building modifying it to modern methods in building such as the hollow clay. Bricks for them clay was a holy material and builts all the temples with clay which was protected by a cover of pottered brick called (kibso). The word casing was used in English and Arabic derived from the old Babylon word (Kibso).

In Babylons temples, we may find very unique methods for solving difficulties concerned with buildings with clay. Discharging of water, for examples is made by Furrows in the wall and pits in the ground obsorbing the surface water. These furrows are so many that it may increase the wall strength as well as giving good view for the wall with various geometrical ratios which may be compared by modern ratios and blocks in construction.

(Anmakh) temple the (great woman) was built by (Nabukhath Nesser), the great king of Babylon (562-604) B.C. This temple is agood example for (temple building) in old Iraqi . This temple is to be of rectangular shape with 52 m long and width of 35m. There is a slope in the walls measured as (5-7) cm per

metre to increase the bearing strength of the toe's wall under constructional loads. Sizes of the clay brick for this construction are ideal, with dimensions of 28 cm x 28m x 80cm with 2 cm allowance for the motar. This Technique was used all over Iraq even in places known before Babylon where the same style as that in babylon were used for building with clay, such as (Ur) or else.

Analysis made for unburned clay bricks formation in monumental building in the sedimentary plains in Iraq showed that the reasons for its durability is the gradual change in clay granular size and its chemical formation which consisted of materials which are not pure clay which ensured the durability of the buildings till now, also it contained some kaolonite and Montomorillonite.

Clay was agood material responding to all environmental requirements which gave some constructional solutions that enabled the using of this material not historically only but also on the modern.

Iraq has many geographical changes along its limited area. This environmental changes has direct effect on construction and its nature. Architecture is defined to many as an attempt made by mankind to shelter himself from the environment. And

so the present Iraqi people enhanced construction considerably so as to protect themselves from environment, and continued towards this trend derived from their ancestors.

The fundamental divisions in Iraq are:-

1- Southern Region:- with marshes

2- Middle region

3- Northern region

4- Dessert

1- Southern Area:

The weather in this area is known to be hot and dry , but due to the existance of the Arabian Gulf and the river (Shatt Al-Arab) and the marshes, the weather has changed and made different local weather. The eastern wind rises the humidity to an unbearable level accordingly the environmental demands in this region are too contradicting and occur in periodical successive times, daily and yearly. Therefore, the building reactions in this area was accordingly a combination of light Reeds Buildings with wide openings suitable for the hot humid climate and heavy clay houses with narrow openings suitable for dry and hot climate. The use of these buildings follows precise system in the daily use of these areas , where they were divided into limited spans used day and night, with special and common parts. But for the real occupation, light buildings closes its openings in the winter and opens them at summer .

These houses are to be distinguished by its pure geometrical shapes were the units are of pure cube rooms all arranged around a yard which is to be big or small according to the existing space. The yard is small when buildings are in between gardens, and are bigger in those located in open Agriculture land, and its the biggest for those near the desert. Palm trees usually makes an over shadow and releases the wind with an air movement into the yard. The mid yard is used in gardens during the day because clay walls absorb heat. But in the night, usually, the outside surounding roofs or Reed buildings are used where the clay walls reflects heat during the night and people gather in such places unless there is a wide yard with enough air draughts . The cubic rooms are the most adequate shapes than other shapes in hot region in addition to its pure shape and the possible varieties in reeds and clay buildings. The cubic shape rooms are considered to be the most adequate shapes suitable for hot regions where high rooms enables the hot air to remain up and cold air in the bottom and acurrent air in the center coming through some small opening in the bottom of the room and some wide ones up in the room. The Iraqi cubic style buildings didn't remain as it was. We may find agradution in the walls to its top. Walls in clay buildings are thick in the toe near the ground level were themoisture is high, ending with less thick walls in the top. This graduation in thickness is a good structural

Solution where the compressive strength of the wall exists in the toe and when the thickness reduces the load resistance and the moisture diminish. Shape and purpose were two reasons led to unique constructions all over the World, Arabic ones from south of Iraq to Morocco and internationally from Spain to Norther and southern of America. The roots came from south of Iraq, the land of civilization.

A clever heritage solution was used in the modern buildings on these bases, the cultivated building in the marshes were designed clay houses . However, we can see the diversification in the buildings whenever nearer to the marshes where clay building disappeared, and in stead of, the reed building, took place. Further away from the marshes clay building with greater middle area are seen. The clay Fence around the building is used, to make a clear bound, for the different part. Bonding all units together.

In southern area buildings with domes exist. Its usually Tombs like the grave of (Imam Ibrahim) In Iraqi Qurna city which is considered the town of father Adam. The Egyptions town Qurna took its name from the Iraqi Qurna this Egyption Qurna was connected with the first clay experiences like Mr. Hassan Fathy in Egypt.

Middle region

This area occupies the greatest part of Iraqi. Its well known that the weather in this region is hot and dry, but it changes to a cold dry weather in some of the winter months this clear contradiction in the weather leads to different solutions. Clay materials exhibit good insulation and offered a heat range suitable for the changing in weather between summer and winter, day and night. For this characteristics, the general shape for clay structure was concerned with the area, but by using small and regular more unit. The middle yard was used widely and the working places were seperated, and a good location were chosen for asite with the wind passing over the river and the farms then the yard then the rooms. In addition, the houses were to be on the roads to the village.

North Area

This area is classified into two primary Area:-

1- AL RAWABI Area: This area falls in the middle between middle area and the mountains. Day in summer is relatively good. The temperature never exceeds 30 c^{o} and the night are usually cold. Houses were distinguished with its mid yardand the holes on the surrounding fence to reduce erosion of outside walls.

2- Mountain Area: This Area is distinguished by its ideal mountain climate. In spite of the hot and dry weather in summer, the winter is too cold and with an average of rain fall of 370 mm. This is high value compared with an average rain fall in the middle region where its 125 mm. Iraqi mountain people adapted themselves for this rough nature by building a compound designed houses with limited yards and with a cieling providing protection of wall from direct effect of sun by providing canopies. Houses in the mountains used the rocks as a main building material in the construction. In the plains the clay is widely used and called in kurdish (Khashi Kal). Clay ceiling mixed usually with hay and a unique technique for preventing water leakageis used. There is a big and heavy cylindrical stone compactor called (Kirdin) used for compacting roofs after or before rain falls to prevent rain water leakage througth the ceiling to the room. Variations in plans are made in most of the houses in North villages . The most Ideal one might be of (Hiro) village which consists of two levels. The upper one is called (Sah-rikan) and the lower called (Zir-Kan) with a coridor dividing each floor called (hoywan) the house is distinguished by its perfect isulation from the suroundings through the balcony in the upper floor.

Ground floor is usually used as a shelter for the animals where roofs are pyramid or inclined in shape to discharge water or snow away. The house is considered as the main part of the village, which are designed clustered together to protect them from wind and erosion of the rain.

4- Desert Area-Desert is considered to be a very hot area with great dilherance between night and day, therefore a heavy building unit might be used to give agood temperature range. We may find different domes in the desserts and the house ensures aprotective environment not only consists of the living requirement but some plants and trees in addition. The outside walls of these cottages usually are regular in shape and with rounds in order to protect the walls from sand winds which is the main problem faced in the dessert. There are two types of the dessert cottages in Iraq: the first type with dual walls sometimes with basement which give the impression of the cave. The second type, the dispersed type with regular outside fence with rooms on this fence.

3- Clay Bricks in hot climates

As shown above many of the older houses built in hot climates are well adapted for the environment. This is because of repeated trials and errors and experience of generations of building techniques. However, these traditional method should be used but not copied for they might not be feasible for modern day requirement. And in spite of difficulties associated with high-rise building and the expense of skilled labour needed, brickwork is still much in demand because of its appearance and good surface weathering property.

Clay bricks may be classified according to clay type, place of manufacture, type of pressing process, type of surface or colour, type of firing process, or use.
Some of the most important properties required from clay brick is strength, low water absorption and low soluble salt content. Solid clay bricks are not considered good insulating materials by themselves and a 24 cm brick wall plastered on one face will not satisfy the thermal requirement this is why other measures should be taken to modify this property.

With steady conduction, constant temperature outside and inside , only the thermal insulation value of a wall is important . But this condition is never found. With changing

temperature the heat capacity of the wall, the amount of heat it can store, is of great importance both for comfort and and for the cost of temperature regulation. If inside temperature becomes approximately constant, the relative importance of the insulation value increases.

Heat capacity is proportional to the weight of the wall. The thermal insulation can, be said to be inversely proportional to the weight, when the thickness is given.
It seems therefore that a wall out to consist of two parts, a heavy part giving good heat capacity, and a light one giving a good insullation. However, there is tendency to improve the thermal properties of the bricks by the use of hollow bricks or lightweight bricks.

One of the most important terms used to measure the ability of a material to transmit heat in Thermal Conductivity(λ) and is expressed by Building Research Establishment (D108) as heat flow in watts per square metre of surface area for a temperature difference of 1 K per meter thickness and may be expressed as. W/m.k.

Table 1 below gives thermal conductivity of masonry materials. (BRE - Digest 108)

Table 1 Thermal Conductivity of masonry materials

Bulk dry density kg/m^3	Thermal conductivity W/(m.k) Brickwork protected from rain:1%*	Concrete protected from rain:3%*	Brickwork or concrete from rain:5%*
200	0.09	0.11	0.12
400	0.12	0.15	0.16
600	0.15	0.19	0.20
800	0.19	0.23	0.26
1000	0.24	0.30	0.33
1200	0.31	0.38	0.42
1400	0.42	0.51	0.57
1600	0.54	0.66	0.73
1800	0.71	0.87	0.96
2000	0.92	1.13	1.24
2200	1.18	1.45	1.60
2400	1.49	1.83	2.00

* Moisture content expressed as a percentage by volume

Moisture factors, for use with Table 1

Moisture content (% by volume)	1	3	5	10	15	20	25
Moisture factor	1.3	1.6	1.75	2.1	2.35	2.55	2.75

Some characteristic values for some common Building materials used in Iraq are given below

Material	Thermal Conductivity W/m.k	Density kg/m^3
Brick,well burnt	0.6	1460-1540
Brick, light	0.32	1000
Concrete	1.70	2300
Lightweight Concrete	0.60-0.14	----
Stone	1.60	2300
Mineral Wool	0.04-0.03	130-180
Pinewood	0.15	900
Mud	1.7-0.5	
Lime bricks (Thermostone)	0.23-0.13	700-800
Air/Atm.Pressure	0.10	
Gypsum	0.40	1300

The coefficient of heat transfer from inside to walls and roof is given to be 5-6.6 Kcal/m^2 h c^o and from outside, to walls and roof with a wind of 2 m/sec is given to be 20 Kcal/m^2h c^o

So it seems that the heat capacity of the usual heavy walls is more than sufficient, but the heat insulation values is insufficient, an ideal wall should have, say, half a brick on the outside, or one brick for structural and practical reasons, 5 to 10 cm. of rockwool or other highly insulating material, and a thin interior cladding of gypsum plates or similar materials; or an interior half-brick wall could be used. However placing insulation on the outside seems to be more efficient as can be seen from the following values:

Load Bearing Wall	Overall coefficient of heat transfer (U-value) $W/(m^2.k)$
20 mm gypsum plaster (inside) + 240mm clay brick	1.936
20 mm gypsum plaster + 360 mm clay brick	1.459
= = = + 200 concrete blocks	2.604
= = = + 240 mm thermostone	0.813
20mm = = + 240 clay brick + 20 mm cement plaster (outside)	1.834
= + 240 clay brick + 80 stone cladding	1.777
20 gypsum plaster + 240 mm clay + 50 mm mineral wool + 120 mm clay brick	0.526

4- Stabilized Soil Blocks

A vast programme has started in the marshland of Iraq as a regional scheme for the construction of low-cost housing, based on traditional structures and materials- cane, papyrus and mud for external walls, interior finishes such as plaster, fiberglass and Eternit . Part of the work demands the utilization of the clay of the region as a building material. The physical and chemical analysis of the marshes soil is :

Location	Max dry Density gm/cm^2	Optimum moisture content %	Total SO_3 Content %	Organic mater	Total Soluble Salts %	PH readi - ings
Naggara	1.69	18.0	0.06	0.47	0.20	8.2
CHIBAYISH	1.67	18.8	0.10	0.15	0.50	8.2
Hammar	1.89	14.2	0.92	0.30	1.93	8.2
Al-ISLAH	1.79	16.4	0.11	0.53	0.40	8.1

Natural earth despite its good insulating values, good compressive strength, it is necessary to improve its tensile strength, moisture resistance and durability in general. Stabilizing the clay to improve its properties has been a practice used in many localities. In the present case and in view of the analysis which was done on the collected samples, the application of a stabilizer seems to be indispensable.

The analysis done on size grading of clay and liquid limits, plastic limit, plasticity index and hydrometer analysis gave the general indication for the type of stabilizers to be tried, which were cement, lime and asphalt. Percentage of 4,6,8,10 were tried beeing tested at 38 day and some 90 days. Tests carried were dry compression, compression after immersion, water absorption and Erosion tests, BRE- Brepak block making machine was used.

The following comments are withdrawn from results

a) Satisfactory stabilisation procedure

Based on specified limits of dry and wet compressive strengths of 25 and 12 kg/cm^2 respectively the following stabilization procedures seem satisfactory for the walls.

1- Cement- 6%

2- Cement 3% + lime 3/%

3- Lime - 8%

The average dry compressive strengths for all the above soil stabilized blocks exceed the minimum strength of 28 kg/cm^2 which is specified in BS 6073 part I-1981 for precast concrete masonary units and also exceed the wet compressive strength of 12 kg/cm^2.

If cement is used for stabilization, precaution will have to be taken that all soil-cement mixture is compacted within ½ hour of adding water to the mixture.
Such a precaution is not necessary for lime-soil mixture.

Chemical analysis of hydrated lime shows that it contains about 75% Cao.

Test results also confirm the need for proper curing of stabilized blocks.

b) Water Absorption

Water absorption of the blocks made with various stabilizers are also shown in the Table. These values are more than 2.5 % limit suggested by the consultant in Note 16 (Programme of Tests). This limit of 2.5% appears to be based on the limit usually specified for asphalt stabilized blocks and for dense blocks and DPC bricks and is not specified for cement and lime stabilized blocks. Moisture absorption is rarely specified in U.K. except as a precaution against frost damage (BRE Note 184 Feb, 1980- stabilized Soil blocks for Buildings). Problems associated with frost are not existing in the marshes. Therefore, stabilization procedures mentioned above will be satisfactory for the marshes for walls above damp proof course level.

c) Morter for walls

Mortar need not be stronger than the blocks as a weak morter accommodates movements and so reduces the possibility of cracking of blocks due to drying shrinkage. Therefore, the same mixture as the blocks are moulded from may be used for morter.

d) Wastage

It is emphasized that proper care is needed in handling the blocks so that there is least breakage of blocks during manufacture, in transit or when building.

e) EROSION TEST

Erosion test compares and indicates relative durability against erosion of different stabilization procedures However, this test may be too severe for southern region of Iraq where the average rainfall is small (139 mm yearly in Basrah). This test was conducted with pumps available with pressure 0.8 bar. The pressure was lowered from 1.4 to 0.8 bar so the test was not as severe as it is for heigh rainfall.

We noticed the following points.

1- For lime and cement 4% rates leads to very bad results
2- From 6 to 10% cement stabilization leads to rather good results.
3- Lime results are difficult to forecast it's behaviour with the erosion (owing to the variation factor) but the 8 and 10% of lime rates are less good than those got with cement stabilization.
4- Lime 3 cement 3 rates results are less good than those got with higher rates of cement.

For all results the matter loss exceeds the approximative limit, and even with cement 8% or cement 10% we cannot speak of very good results, only of relatively good results.

As a precaution, it is suggested that walls may be shielded from erosion effects of rain by providing generous

roof overhangs especially in the direction of prevailing wind. Similarly, window cills should project a sufficient distance from the walls to prevent erosion by running water.

If rain water downpipes are fitted they should be kept well elear of the walls so that any water which overflows as a result of leaks or blockage is prevented from causing erosion of the wall by running water.

Rain splashing back from the ground into the base of the wall is a frequent cause of erosion. Since in the present case, due to excessive sulphates in the foundation soil, base of the wall upto DPC level has to be constructed with suitable class of concrete for protection against sulphate attack, the lowest course of stabilized block will be well above the ground level and will be well protected from rain splashing.

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"Thermal properties and use of clay bricks for low-cost housing"

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