Thermal Properties of Mud Bricks: the Example of Gypsum-Stabilized Adobe

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1987

1. Introduction

This paper is a part of a research carried out by the members of the Building Materials Department of the Faculty of Architecture of the Technical University of Istanbul. During the first stage of the project, the qualities of adobe were improved in order to make it an adequate building material for contemporary necessities. The stabilization of adobe with gypsum - a material for found abundantly in Turkey and easy to use- proved to be successful. The gypsum-stabilized adobe has been given the name ALKER, and it has been produced on site and used for the construction of a test building. The building has been used as a nursery for the children of the faculty members for the last three years. This paper is based on the observations and measurements taken on this building. Asst. Prof. Dr. Erdal Gürdal and Asst. Bilge Işık have assisted in the preparation of this paper.

2. Definition of the project

It is established fact that to try to solve housing and nutrition problems in developing countries by importing methods from developed ones present major difficulties in terms of implementation. Solution must be found that make use of the local resources and potential. The points to be considered while selecting the method, can be stated as follows:

- The amount of energy needed for the construction and operation of the building must be reduced. That is, the energy spent in the production and

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transportation of materials and elements of building, and the energy spent for heating, repairing and service life of the building must be as low as possible.

- Regional resources such as materials and labor force must be utilized.

- The technology of construction must not be alien to the region. It should be based on regional technology, that is, a developed model of it that can be learned and applied by the local population.

- Saving measures should be implemented while, at the same time, it should be possible to produce large amounts of material in a relatively short time.

Clearly, the material that would fulfill the conditions best stated above while providing bio climatic comfort conditions must be earth-based. By choosing earth-based materials, the appropriate technology can also be found. In this sense, earth can be considered as a contemporary building material. Once its qualities have been improved, earth has been shown to be an adequate material for the social economic conditions for our day and which can help to solve the housing problems of many developing countries.

After outlining the studies carried out to improve the properties of earth as a building material, we shall concentrate on our main subject and present the findings and evaluations of the thermal properties of earth-based materials.

The reasons for the use of gypsum to produce improved earth are as follows:

- Its abundance in Turkey;
- The techniques for its production and use are well know by the rural population;
- Its production is simpler and easier than cement;
- The amount of energy consumed during its production is less than in the production of cement;
- Its helps to improve the performance of buildings.

During the first stage of the research, an examination was made of the conditions required to obtain a mixture of earth and gypsum possessing the qualities needed for construction. After obtaining positive results in the laboratory, ALKER was produced on site and use for the construction of the test building.

3. Gypsum-stabilized adobe, ALKER -adobe with improved properties

(a) Definition of ALKER

Materials used in ALKER production

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The first step to produce a good mud-brick is to choose the appropriate type of earth. The granulometric structure of earth samples is important in this choice. Figure 1 shows the ideal granulometric curve /1/ and the curves of the samples used in this study. The gypsum used for the stabilization process is $CasO_4$ 1/2 H_2O, which is produced in the first stage of gypsum processing at 160^0-200^0 C. The material-know as simple gypsum in standards-fulfills the requirement for ALKER production. It was found that the addition of 10 per cent (dry weight) of gypsum was sufficient achieve the improvement. The amount of water to be added was determined in accordance with the plasticity limit of the mud. Its was also found that the addition of 22.5 to 5 per cent of lime slightly decreased the pressure resistance. Depending on the amount of gypsum and lime in the moisture, the drying period may take up to 20 minutes.

Structural properties of ALKER

Mechanical and physical properties of adobe are improved considerably when gypsum is used as stabilizer.
Very small pores homogeneously distributed and fine capillary vessels constitute the structure of ALKER. This structure can be explained as follows: after the gypsum has been mixed with earth of an appropriate granulometric composition, its forms a rigid homogeneous skeleton within the mud which still maintains its plastic condition. The clay that fills this skeleton would tend to shrink but the skeleton reduces the extent of the shrinkage. Thus, while good non-stabilized clay present 5 to 6 per cent of shrinkage, ALKER shrinks by only 2 per cent. At the same time, unit weight decreases from 1.7 kg/ Lt. to 1.5 kg/ Lt. Inner tensions are formed in the structure of the material. The interaction between the shrinking of the clay and the rigid gypsum skeleton explains the increase in pressure resistance and the decrease in the unit weight. The increase in water resistance can be explained by a chemical reaction that takes place as result of mixing clay, gypsum and lime.
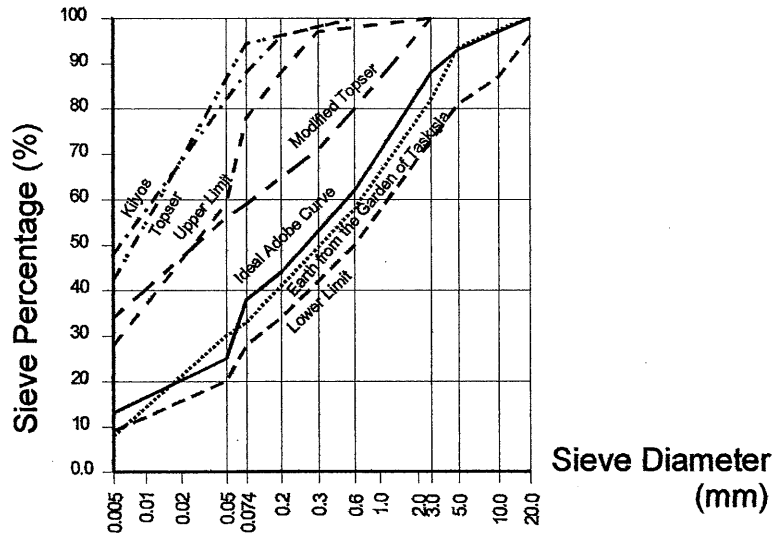
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Fig. 1. Granular composition of soils suitable for manufacture of adobe
1. Kilyos clay
2. Topser clay
3. Improved Topser clay
4. Clay from the garden of Taşkışla

(b) Mechanical properties of ALKER

The mechanical properties of the material were determined using samples produced in the laboratory and on site. Some of the results obtained with the addition of gypsum have been stated above. It was observed that the addition result in increases in pressure, rigidity and in the module of elasticity, as well as a decrease in deformation. By adding 10 per cent of gypsum, a pressure resistance of 4.5 MPa was obtained. The bending resistance also increased by 300-800 per cent.

(c) Physical properties of ALKER

<u>Unit weight</u>

It was found that earth samples with earth samples with granulometric composition close to the ideal show a decrease in unit weight and that the addition of gypsum also contributes to this decrease (see figures 1 and 2). The main reasons for the decrease in weight are structural changes and decreased shrinkage of the new material. ALKER presents the lowest heat permeability when compared with other materials of similar unit weights i.e. 1.4000-1.500 kg/m^3. Thus, an shrinkage, and an increase in porosity.
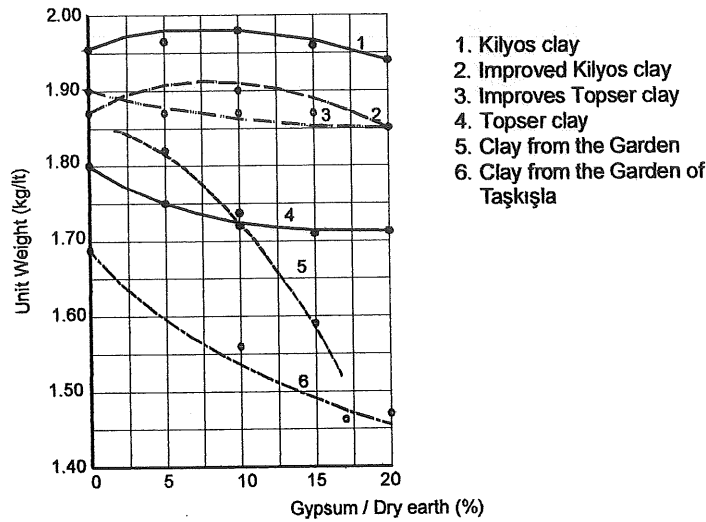
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Fig. 2. Unite weight of soil used for the tests and the changes after gypsum was added

Shrinkage

The extent of shrinkage in natural clay is considerably high, especially in clay with fine grains. Shrinkage decreased in those samples with granulometric composition suitable for the production of mud-bricks. Figure 3. shows that the addition of gypsum decreases shrinkage considerably in relation to the granulometric composition of the earth samples. Changes in scale and deformation are also greatly reduced.

Moisture permeability

It was indicated above that ALKER has a structure with open pores and capillary vessels and thus it is vapor permeable. Test result showed that samples with 10 per cent of gypsum have a vapor permeation resistance factor of $\square$=13 which forms a balance with the heat conversion property of ALKER. The ability of material to diffuse vapor in short periods of time makes it possible to keep the desired level of humidity in the interior of the building.
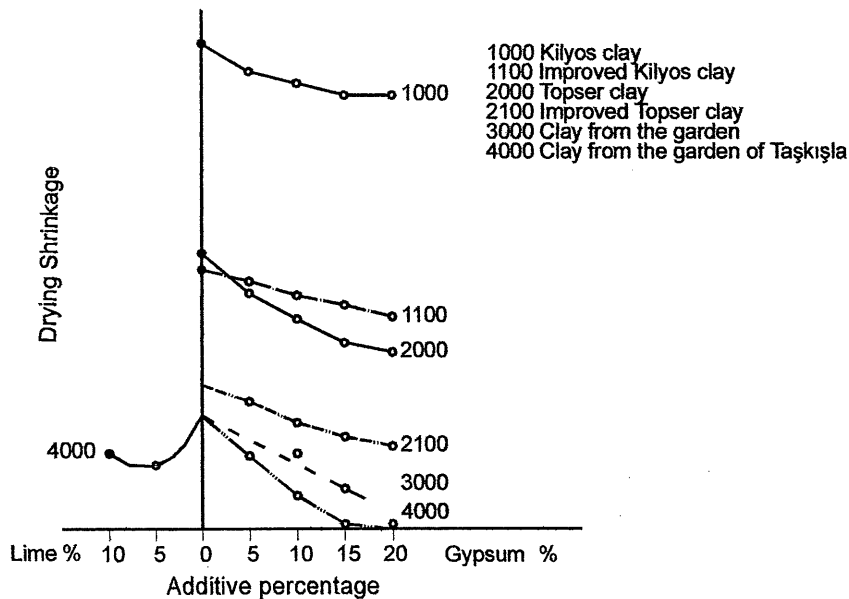
1000 Kilyos clay
1100 Improved Kilyos clay
2000 Topser clay
2100 Improved Topser clay
3000 Clay from the garden
4000 Clay from the garden of Taşkışla

Drying Shrinkage

1000

1100

2000

4000

2100

3000

4000

Lime % 10 5 0 5 10 15 20 Gypsum %

Additive percentage

Fig. 3. Result of shrinkage tests

<u>Water absorption</u>

Owing to its structure, ALKER can be absorb water faster than regular adobe For this reason, ALKER walls should be situated on the foundation walls to guard them against moisture from the ground.

It was observed that samples with 10 per cent or more of gypsum showed no trace of dissolution but regular adobe samples completely dissolved in water within four hours.

Tests for rain resistance showed that samples with 5 per cent gypsum or no gypsum at all loose around 3.3 per cent of weight and wearing out of corners and the surface of blocks was observed. On the other hand, samples with 10 per cent gypsum and 2.5 per cent lime showed almost no signs of wear. A sample with 10 per cent gypsum and no plaster was left outdoors for four winters and no deterioration was observed.

<u>Heat transfer value</u>

Experiments for heat transfer value could not be carried out efficiently in our laboratories. Some experiments ware conducted with specially made samples one cm in width. The heat transfer value of these samples was found to be λ= 0.40 kcal / mh^{0}C or 0.46 W / mK. This value was for used for the planning of the test building. In previous publications, the same value is given for straw-added adobe. However, as is shown below, the thermal properties of the test

house, electricity consumption and heating measurement calculation seem to indicate that the real value is lower than the one obtained from the experiments.

Specific calorific value

The specific calorific value used for used for measuring the heat accumulation capacity of the material and the heat differences of the walls could not be calculated trough experiments. The previously accepted value of 0.30 kcal/kg^0 C (1.254.kj / kg^{0}K) was used.

Expansion and effect of heat

Experiments in the laboratory were carried out at temperatures ranging from 20 to 500^{0}C. Around 160^{0}C some shrinkage was observed but at 280^{0}C, the samples expanded to their original size. As the temperature approached 500^0 C, the samples without gypsum continued to expand while those with 10 per cent of gypsum kept their original size. Shrinkage was observed in samples with 15 to 20 percent of gypsum.

Evaluation of the thermal properties of ALKER

The physical structure of the material is similar to that of a good handmade brick because both have fine capillary vessels and open pores and, therefore, their reaction to physical effects are also alike. However, heat accumulation and heat transfer values of handmade bricks are considerably higher. Heat transfer values of earthen materials are generally lower and the addition of straw in traditional adobe decreases these values and the unit weight even further but it also results in a vapor diffusion resistance value of four. This situation affects the balance between heat diffusion and moisture diffusion and, at the same, time decreases the resistance to pressure and increases sensitivity to moisture.

ALKER overcomes these disadvantages to a great extent. The homogenous pores in the structure bring the unit weight close to that of hollow bricks while decreasing the heat transfer value. A wall ca n be built with a thickness of up to 50 cm for a very small increase in cost, thus creating the possibility of keeping heat accumulation value and phase differences at the desired levels with no significant extra expense. Among the building materials for walls such as bricks, concrete, lime and sand stones, ALKER is only one with a unit weight of 1.400-1.500 kg/m^3 heat transfer value of 0.40 kcal / mh^{0}C or 0.46 W / mK and a vapor diffusion resistance factor 0f 13. In addition, the production technique is very simple. Other points which have to be considered are: all materials other than ALKER have to be produced in factories
And therefore, require time, capital and a great amount of energy for production and transportation.

4. The ALKER test building

After obtaining positive results in laboratory experiments on ALKER, it was decided to continue the studies on site. A rural house of 80 m2 living room, two bedrooms, a kitchen, a bathroom and an entrance was designed (see annex I for and sections).

(a) Construction possibilities with ALKER and description of the test building

A series of experiments were carried out in order to determine methods for the production of ALKER on site and the properties of the resulting blocks.

It was found that several variants may be introduced, such as the use of manual and/or mechanical mixing and pouring. The method used will depend on site condition, number of buildings planned and the quality of the project. In order to make various evaluations, different methods were used in the construction of the test house: block of 45 cm wide, in situ pouring with intervals, and continuos in situ pouring (see figure 4, 5 and 6).

The roof and the ceiling of the building were made together. Ready-made blocks of fired earth were placed between the reinforced boards of the roof; a 3 cm thick layer of concrete was poured over it, and this was covered with a 2.5 cm thick insulation of Heraklite and corrugated asbestos-cement plates (see figure 7).
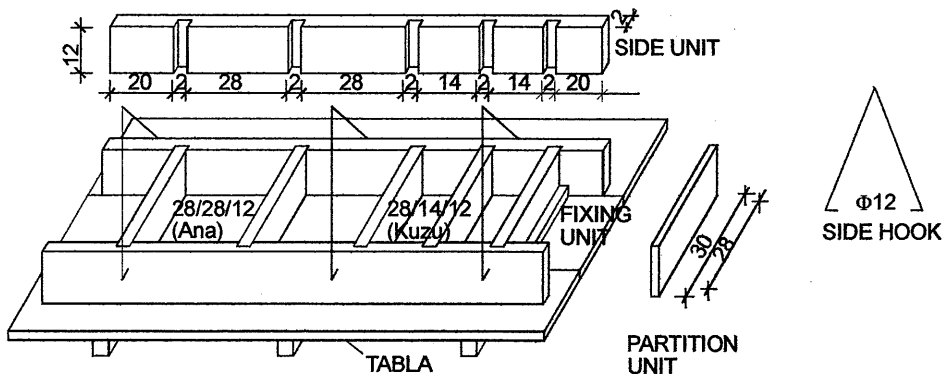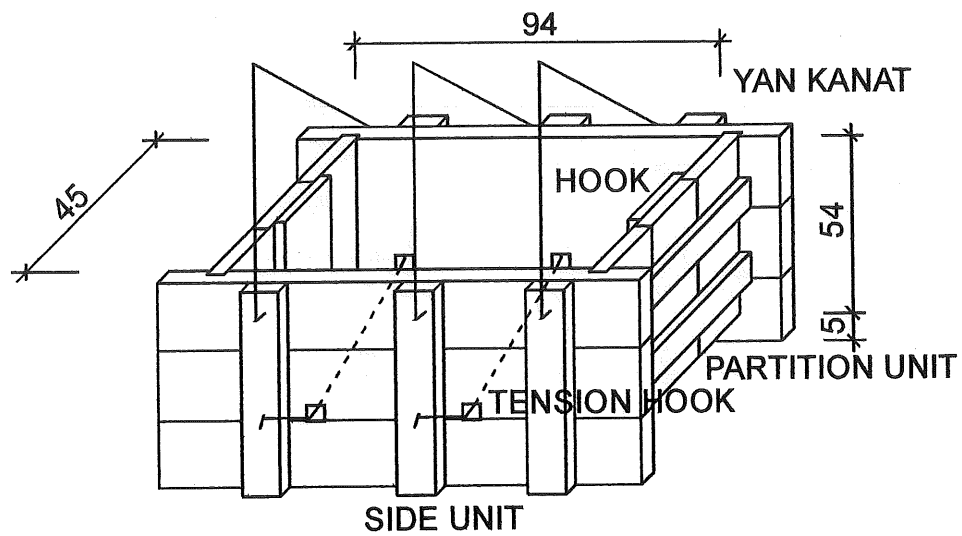

Fig. 4. Mould used for making blocks
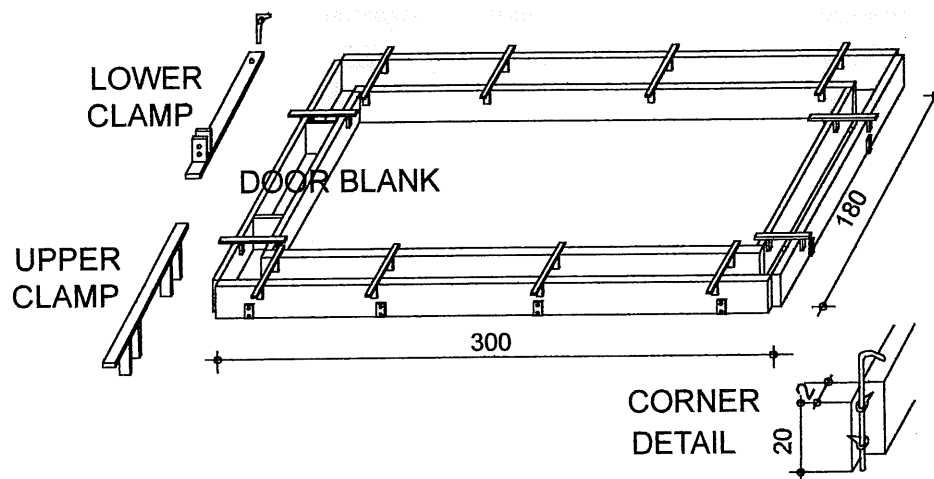
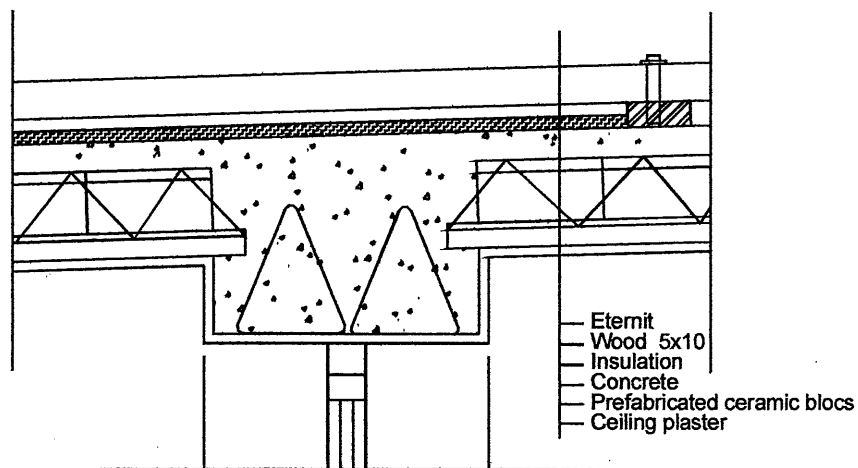**Fig. 5.** Mould used for in-situ pouring

Fig. 6. Mould used for continuos pouring

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Eternit
Wood 5x10
Insulation
Concrete
Prefabricated ceramic blocs
Ceiling plaster

Cross section

Prefabricated beam

Eternit
Wood 5 x 10 cm
Insulation 2.5 cm
Concrete 3 cm
Prefabricated ceramic blocs 12 cm
Ceiling plaster
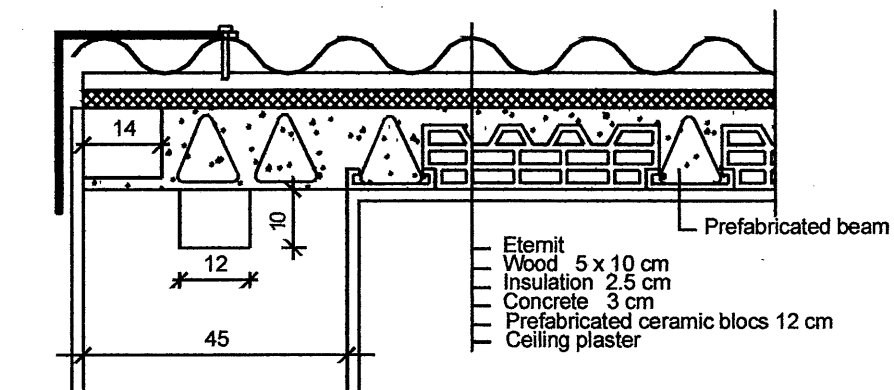
Transverse section

Fig. 7. Details from the roof of the test building

The rubble filling for the floor was covered with concrete. A 2.5 cm layer of alum (to keep moisture permeation) , 2 cm of styropor, underground heating system and ceramic floor covering were used.

Gypsum plaster was used in the interior. The outside plaster was made of earth with four different percentages of additives. Faience was in the bathroom

provides heat for the underground heating used for the walls in the kitchen and bathroom, and wooden frames were used for the windows. An electric heater system. The heater has two resistances of 2.000 W which can be used either independently or together according to weather conditions.

(b) Measurements on the building

The test building was subjected to constant observation and measuring for three years. The measurements were carried out with rather simple methods, aimed at determining the thermal properties of the building.

<u>Energy spent for heating</u>

The amount of energy spent on heating buildings in Turkey is quite large and, therefore, one of the main objectives of this research was to study the possibilities of saving energy. Despite its higher cost, the electric heater was chosen because the energy expenditure can be determined much more accurately trough it. This type of heater is normally used for heating water in bathrooms but in the case of the test building it was used for heating the whole house through water pipes located under the floor. The electricity consumed by the heater was measured every day and it was found that on the oldest days of winter a temperature of $22\text{-}23^{o}$ C could be maintained with an energy expenditure of around 45 kW (see annex II for heating project and measurements). Energy expenditure was recorded from February 1986 through to June 1987 with measurements being taken day and night. As shown in annex III, energy expenditure, which was 40-45 kW/day and 1.7-1.8 kW/hour in the cold days, could drop to 0.5 kW/ hour in warmer days. This amount is one fourth of the average expenditure on heating in Turkey.

Heat values in the interior and exterior, and measurement of relative humidity values.

Measurements recorded during the period when the test building was being used as nursery show important results in terms of the thermal behavior of the building. However, as was indicated above, rather simple methods were used.

The interior and exterior temperatures and relative humidity values were noted in weekly diagrams from the winter of 1986 to the summer 0f 1987. The superimposed diagrams of seven sample days are given in annex IV. Comparison of these diagrams with the table in annex II gives the following results:

- The interior heat balance and humidity considered appropriate for daily comfort were not affected by exterior condition.

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- The building housed 15 to 20 children aged two to six years from 9 a.m. to 5 p.m. In winter the children spent all of their time inside the building, while in summer most of their time was spent in the garden. In winter, the increase of 2^0 C in temperature and the humidity of 50 to 60 per cent coincided with the hours the children were in the building. No other climate regulating system was used, as the building is able to set its own heating and humidity balance. In annex IV, it can be seen that during the vacation period of 27 and 28 February, when nobody was in the building, the heat and humidity values did not change.

- At the beginning of winter, on days when the weather was not too cold, it was observed that although the interior climatic condition did not change, the amount of energy spent on heating decreased considerably.

- The climatic comfort conditions of the building remained stable also during the summer. During August the ideal humidity value of 60 per cent was kept in spite of daily changes of 10^0 C temperature and of 40 per cent in humidity.

- During the summer season, the children were constantly going in and out of the building and, therefore, doors were left open with the consequent increase in temperature in the interior. If it had been possible to control the opening and closing of doors the interior would have been cooler. In countries with hot climates, this kind of building could provide comfortable conditions without artificial climatic regulator.

- The difference in temperature between the surface interior wall and the interior was 2-2.5^0 C which was considered suitable for the people using the building and for the building itself. This also means that comfortable conditions
- can be maintained even lower heating temperatures and, thus, more energy can be saved.

(c) The importance of saving energy on heating in Turkey and in countries with similar climatic condition

It has been shown that, in the ALKER building, the most suitable bioclimatic conditions could be achieved with the least amount of energy. In developing countries, the proportion of energy needed for development to the total energy consumption of the country is an important indicator. In countries where a certain amount of energy is needed for heating during the winter, the amount of energy consumed has to be subtracted from the energy need of the industrial sector. If the country is importing energy, the problem will have major

consequences. A developing country with a high rate of population growth and housing problems must seek solutions other than those of developed countries. The importance of this approach has been clearly set by recent official studies in Turkey. It is now know that between 1970 and 1985, the energy spent on heating could have been decreased by 40 to 50 per cent. According to the same sources, this number should be 35 per cent in 1986 and 18 per cent in 2010. In the coming 25 years, Turkey`s population is expected to double, thus increasing the need for appropriate housing /2/. The saving measures for the production and usage of housing are implemented.

5. Thermal properties of the ALKER test building

In this section we will try to determine the thermal properties of the test building constructed with ALKER by using the evaluations of the measurements and observation recorded. The main point is to work not only theoretically using the figures from previously published material, but also to reach conclusion based on the measurements taken from a building that is being used.

(a) Heat transfer, heat accumulation capacity and difference 'n phase in an ALKER wall

The test building was constructed according to the project in annex I. Some of the values used for the calculations of the building are shown in table 1.

Table 1. Values used in the design of the test building

External wall surface	94.75 m2
Door and window surface	10.02 m2
Opaque wall surface	84.73 m2
Ceiling surface	82.24 m2
Total heat loss surface	166.97 m2
Transparency ratio	0.12
External wall width	0.50 m
Weight/surface ratio of external wall	750 kg/m2

The same temperature was found on the internal surface of the north and south walls and on the ceiling. In the calculations made at this stage to determine the behavior of the building, it was assumed that there was no heat loss from the floor and that heat loss from other surface was equal. It was found that the heat transfer coefficient was very close to the real value. For thermal consideration, external walls were built with of 45 - although it was possible to build them with a width of 30 cm like the internal walls. For the calculation the wall was

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considered as a homogeneous single layer element with a width of 50 cm and an equal amount of plaster on both sides.

The heat transfer coefficient of the internal surface was accepted as $\alpha_i = 6$ W/m^2 K and $\alpha_a = 23$ W / m^2 K after comparing the calculation on the building and the values in the literature. Heat conservation values of the ALKER wall were calculated according to the energy spent and according to the internal and external atmosphere and surface temperatures. The overall heat transfer coefficients found were very close to each other.

In order to minimize error, the calculations shown below were based on electricity consumed on 12 February - the day when maximum energy was spent - at a time when the buildings was - between empty - between 5 p.m. and 9 a.m.

The electricity consumed in a period of 16 hours was 31.4 kWh.
The heat loss value of the building was taken as Q = 31.4 W
Internal heat at 9 a.m. was $t_i = +21^0$ C
Internal wall surface heat at 9 a.m. was $t_1 = + 19^0$ C

External heat was $t_a = + 4^0$ C $\Delta_t = 17^0$ C
Overall consumption in one hour was 31.4/16 = 1.962 KW/h
Total heat - losing surface of the buildings was 167 m^2
Heat loss from areas unit was q = 1,962/167 = 11.75 W/m^2h

Using the formula q =k_m. t, k_m q/Δt=11.75/17= 0.69 W / m^2K
The internal wall surface temperature according to this k_m value is

$$t_1 = t_i - \delta t_1$$
$$t_1 =$$

$$t_1 = 1.6/1.44 \times 17+1,96$$
$$t_1 = 21.00 -1.96 = 19.40^0c$$

As the internal wall surface is 19^0 C and the difference with the internal heat is 2^0 C, km can be calculated using the t formula

$$1/K_m = (\Delta t/ \delta t_1) \times (1/ \alpha_1) = (17/2) \times (1/6) = 1.417 \ m^2K/W \text{ and } k_m =0.70 \ W/m^2$$

The values of 1.449 and 1.417 found by two different methods justify the evaluations made above. The thermal conductivity coefficient can, then, be calculated according to these as

$$\frac{d}{(1/k - (1/ \alpha+1/ \alpha_a)}$$

$$\frac{0.50}{1.449 - 0.210} = 0.40 \ W/mK$$

In the laboratory this value has been found to be 0/46 W /m K using a small sample. We are of the opinion that in precise measures made on the building the real values of ^ will be less than 0,40 W/mK. The fact that a material with a density of 1,500 kg/m3 has such a low l is very relevant for the saving of energy spent on heating and achieving bioclimatically comfortable condition. The relationship between density and heat transfer coefficient values is well illustrated by the available literature./3/. These studies show that the increase in density has positive effects for almost all climatic regions.

The increase in the external wall mass results in a considerable decrease in the k value of the wall which helps to keep the interior of the building cool end delays the heating process in hot-dry climates where the temperature changes noticeably between day in the night. It has also been observed that continuous heating in building whit denser walls helps in saving energy. The values of k and λ found on the building were lower that those found in the laboratory.

The thermal properties of the building can be determined using the heat and humidity diagrams in annex IV and the surface temperatures of the walls.

- The internal climatic conditions remained constant without being affected by external conditions throughout the year. The internal temperature diagram shows little variation in spite of temperature differences with the exterior of $10\text{-}14^0$ C.

- The difference in the wall surface temperatures on 2 February and 7 July 1987 (coldest and hottest days respectively) present the same characteristics.

- In periods of seasonal change (when heating is initiated or stopped), the decrease in external temperature can be overcome by an energy expenditure of 11 to 13 kW per day. In winter the daily average is 35 - 40 kW.

- Despite the great difference in external wall temperature during winter and summer, the temperature of the internal wall surface changed only 1^0 C.

- In winter and summer, the internal wall surface temperature differs from the interior atmosphere temperature by $\pm 2^0$ C. In all spaces within the building and on all wall surface, same values were found; the heating system also helps to maintain a constant temperature.

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- No condensation occurs because of the balance between heat conservation and humidity diffusion of the wall and, therefore, it is constantly dry (see figure 8).

- In winter, the presence of about 20 children and 4 adults in an area of 57 m^2 - a volume of 142.5 m^3 - increases the temperature and humidity although these increases are limited to 2^{0}C and 5 to 6 per cent, respectively.

$t_e = 32\ C^0$

t_s

28 C^0

$t_e = 29\ C^0$

$t_{is} = 27$ date: 03.07.1987   time: 16:00

19 C^0

$t_{iw} = 27$ date: 12.02.1987   time: 06:00

$\varphi = 0.80$

t_w

Psi = 2484.8   Pa

$t_{ew} = 29\ C^0$

P_s

Pi = 1367.8   Pa

$P_{se} = 812.9$ Pa

P

(*) As the external surface temperature t could not be measured, it has been calculated according to the k$_n$ value
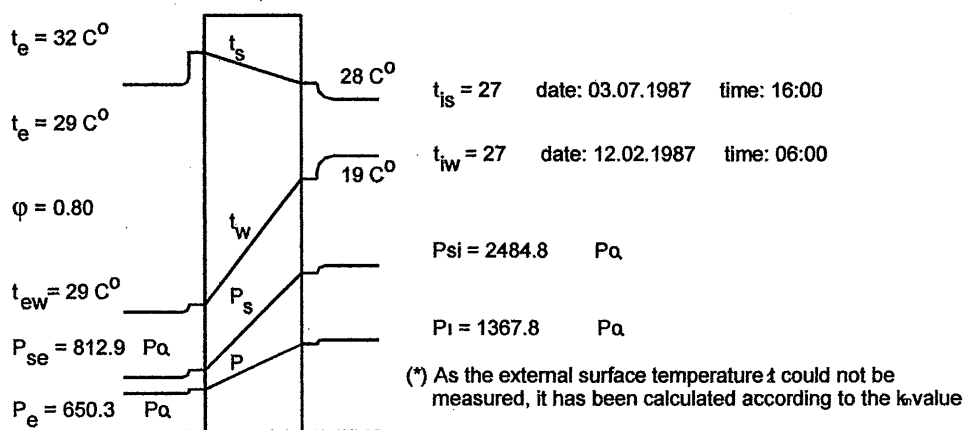
$P_e = 650.3$ Pa

Fig. 8. Temperature and humidity values on the wall in the hottest and coldest days

In view of the previous points, it is possible to conclude the following:

1. The heat conservation value of the building itself is sufficient for saving energy and for attaining bioclimatically comfortable conditions.

2. The building works as a regulator by keeping the internal climate et the desired level when changes in external temperature and humidity occur.

3. Despite the relatively low heat transfer coefficient of 0.69 - 0.70 of the walls, a density of 750 kg /m^3 provides a high level of heat accumulation while decreasing the amplitude and time required for the transfer of the external wall temperature to the interior.

4. After taking precise measurements to determine the specific heat 'c' and the heat transfer coefficient λ, the values of S_{24}, k_m, Φ and h can be determined according to the climatic data and habitation condition of the building and the appropriate wall thickness for that location and building can be calculated.

5. Compared to other wall building materials. There is no scale limitation in buildings made with earth. Due to the high resistance to pressure of ALKER, the width of external walls can be decreased as much as 30 cm. The increase in width required for thermal reasons can be made in-situ by changing the molds, with a negligible increase in costs.

(b) Evaluation of the thermal properties of ALKER test building

<u>The relationship between the structure of the building and its inhabitants.</u>

In the test building constructed with earth, the internal temperature and relative humidity were kept constantly at a level appropriate for human health. No additional system was required for providing these conditions. This type of building can provide the desired conditions particularly in hot and dry regions where sharp daily and seasonal changes of temperature occur. People can live in invariable atmosphere where climatic changes are limited and very slow because the temperature and humidity changes seen in the diagram in annex IV are not reflected in the interior of the building.

The temperature of the internal wall surface hardly follows the external conditions. The overall temperature change during one day on the north wall was recorded as 1^0 C, similar values were found on the other walls. The difference between the internal wall surface and the internal atmosphere temperatures is limited to 2^0 C. These conditions decrease the radial heat loss of people to the minimum, and they are able to live in lower internal temperatures.

As the wall surface temperature decreases, the temperature of the internal atmosphere should be increased, further increasing this difference and thus affecting negatively the comfort condition of the building. Obviously, the opposite situation occurs during hot periods. Both conditions result from the fact that the heat conservation value of the wall building material is low. This problem can be solved by using earth constructions, which will also avoid the negative affects of air currents caused by the difference in temperature between internal atmosphere and wall surface.

<u>Structural health of the building</u>

In buildings constructed with earth, comfortable living conditions are attained naturally, whereas today, materials constituted by multiple layers of different materials are produced in order to achieve the same conditions. As some of these materials are new and not well-known, builders art likely to face faults and problems, causing early deterioration of the buildings. Walls formed by a single

homogenous layer of the earth have a healthy structure in themselves and, thus, the problems often seen in other kinds of construction are avoided.

Saving of energy

The building industry consumes a large amount of energy. Energy saved in the construction and usage of buildings can be utilized for development in developing countries.

The first step in the identification of the opportunities for energy saving in the building industry is to determine the energy consuming areas of a building. Walls account for the largest proportion of energy consumed due to their weight and mass. They also have an important role in the relationship between nature and the building. Thus, energy saved by improving the properties of walls can be very effective.

(i) Energy spent on the production of wall building materials

Table 2 gives an idea of the amount of energy consumed in the production of different wall building materials.

Assuming that there are 30 m^3 of wall material in a house with an area of 80 m^2, the number of bricks needed for the walls can be estimated to be around 15,000. In a country where 50,000 houses are built every year, the amount of energy which could be saved by building with earth would be considerable. Saving would be even greater if the energy expenditure of factories producing bricks and the capital and time necessary for the construction and organization of those factories was included in the calculation.

Table 2. Energy expenditure in the production of wall building materials

	Nature of fuel	Calorific value per tonne a/	Weight of fuel equivalent to burn 1000 bricks b/	Heat needed to burn 1000 bricks c/	Capital cost of firing installation c/
Modern oil-fire tunnel kiln factory	oil	44 000	0.11	4 800	2 000
Traditional wood fired clamp brickworks (East Africa)	firewood	16 000	1.00	16 000	3
Traditional coal fired Bull's Trench continuos kiln (India, Pakistan)	Coal	27 000	0/20	5 400	20
Coal fired clamp (India, Turkey, United Kingdom)	Coal	27 000	0/32	8 600	1

Source: J.P.M. Parry, Brick-making in Developing Countries, BRE department of the Environment, p.4
A/ Mega joules
B/ Tonnes
C/ Thousand British pounds at 1987 cost prices

(ii) Energy spent for the transportation of wall building materials

The use of bricks, concrete blocks or similar materials implies transportation from the factory to the construction site. Assuming an average transportation distance of 50 km and that the amount of material needed for one house is 45 to 50 tones, Then, approximately 2,500 tone-km of transportation work is required. Construction with earth, where possible, will result in a considerable amount saving in transportation.

Assuming that there are 30 m3 of wall material in a house with an area of 80 m2, the number of bricks needed for the walls can be estimated to be around 15,000. In country where 50,0000 houses are built every year, the amount of energy which could be saved by building whit earth would be considerable.

Saving would be even greater if the energy expenditure of factories producing bricks, and the capital and time necessary for the construction and organization of those factories was included in the calculations.

(iii) Energy spent for heating and cooling the building

Expenditure on production and transportation of materials occurs only once, when the building is constructed, whereas expenditure on heating and cooling as necessary as long as the building as used/ Therefore, using a wall building material which cab minimize this expenditure is highly relevant. Producing this type of material may result in an increase of the initial cost but long-term saving will compensate this. Heating and cooling values of walls built with different materials are compared in figure 9. Parallel to the increase of the overall heat transfer coefficient of the wall, the amount of energy needed for heating and cooling also increases. As was mentioned before, excellent bioclimatic condition and energy savings can be achieved if walls are constructed with the appropriate material. When the temperature difference between the internal atmosphere and the wall surface is decreased by 2 to 30C, the energy needed to attain a comfortable condition is significantly reduced. A decrease from 22 to 200C in the interior in a region where the external temperature is between -3 and 00C will save 8 to 10 per cent in heating energy.
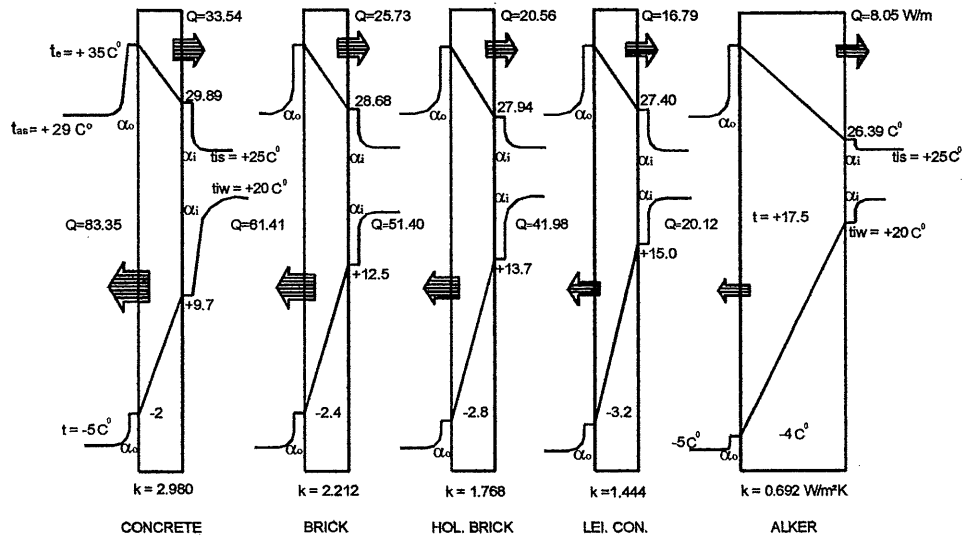

Figure 9. Comparison of the internal and external wall surface temperatures, heating and cooling values of different building materials

6. Conclusion

The history of earth construction in Turkey goes back to prehistoric times and is still being used. Nevertheless, earthen materials in their natural state have disadvantages as building materials, however, the transfer of technology and materials from developed countries to developing ones and people's belief that the new materials and technologies are better then their old ones, have made earth an "out of date" building material. Developing countries should make use of technologies and materials suited to their specific conditions. Unfortunately, they have often made the mistake of blindly importing technologies as solutions for their rapidly growing housing problems, disregarding the fact that, in most cases, the best solution lies in the country's own resources.

This paper has shown that the use of ALKER, which is a developed version of an earthen material, offers the opportunity to construct buildings with physical and mechanical properties adapted to the needs of contemporary civilization. These buildings would also help to solve the energy problem, an important point for most developing countries. Except for densely populated urban areas, this building method can be used in rural areas, houses, workshops and agricultural buildings. Earth is the most appropriate material for the social and economic condition of our day.

Table 3. Electricity consumption (averages)

Date of heating	Days	Energy spent /a/	Daily average /a/	Hourly average /a/	Graph in annex IV
18/02-28/02 1986	10	461.5	41.650	1.735	2
01/03-31/03 1986	31	1119.1	38.722	1.61	
01/04-30/04 1986	30	1234.5	41.150	1.715	3
01/05-26/05 1986	26	329.7	12.680	0.528	4
End of heating period					
06/10-31/10 1986	26	308.0	11.788	0.491	
01/11-30/11 1986	30	629.9	20.199	0.841	6
01/12-31/12 1986	31	1055.1	34.035	1.418	
01/01-28/02 1987	59	2722.9	46.151	1.923	6
01/03-31/03 1987	31	1407.1	45.390	1.891	
01/04-28/04 1987	28	1157.6	41.343	1.723	7
29/04-05/05 1987	7	281.3	40.185	1.647	
End of heating period					

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