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Sustainable housing in island conditions using Alker-gypsum-stabilized earth: A case study from northern Cyprus

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Abstract

The materials and energy sources needed for construction are limited by island conditions. Until recent decades, earth was widely used as a construction material in northern Cyprus due to its abundance and many technical advantages, however, as a construction material, earth is vulnerable to moisture. Ongoing research into gypsum-stabilized earth (known as Alker) at Istanbul Technical University since 1978 demonstrates the superior physical properties, increased durability, and human health benefits of this improved earthen material.

This study examines the use of Alker as a wall material to contribute to sustainable development in Northern Cyprus. The historical building materials and environmental resources of Cyprus are investigated and documented to gain an idea of what is involved in the socio-cultural, economical, and ecological sustainability.

Keywords: Sustainable housing; Island conditions; Northern Cyprus; Adobe; Gypsum; Alker

1. Sustainability and island conditions

Sustainability requires resources to be conserved, the environment to be protected, and a healthy environment to be maintained [1]. The World Commission on the Environment and Development suggested the following definition for sustainable development:

> Sustainable development is the development that responds to the needs of the present, without abandoning the ability of future generations to supply their own needs.

The influence of sustainable development on culture, economy, and ecology is of global significance, but there are specific measures for particular regions, such as islands [2]:

> Due to their fragile ecosystems and their geographic isolation from other countries, islands have a role of improving the living standards while conserving the environment [2].

2. Facilities for social-cultural, economical, and ecological sustainability in northern Cyprus

According to data collected in northern Cyprus, cultural, economic, and ecological sustainability are closely related to the climate, geography, and heritage of Mediterranean region.

2.1. Geography and climate of northern Cyprus

Cyprus, as the third largest island in the Mediterranean, is located at the crossroads of three continents. It has its own share of rich archaeological sites and medieval castles. The area of the entire island is 9851 km^2, with the Northern Republic of Cyprus comprising 3335 km^2 (Fig. 1). The majority of the land is mountainous or highlands. The Kyrenia Mountains and the Torsos Mountains on Cyprus are extensions of the Taurus Mountains of Turkey; the highest peak of the Kyrenia Mountains is 1023 m above sea level. Summers are dry and hot, and winters are warm and

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Fig. 1. Map of Cyprus.

rainy, as in many other Mediterranean countries. During the summer months (July–August) the temperature ranges between 37 and 40 °C and there are 12 h of sunlight per day. During the winter months (January–February), temperatures range from 9 to 12 °C. The average precipitation is 397.6 mm/y, and average sunlight hours are 5 h/day.

2.2. Factors Influencing Economical Sustainability in Cyprus

Agricultural lands make up 56.7% of northern Cyprus, with 19.5% (60,955 ha) of the island forested. Villages, towns, and lakes, etc. make up 10.7% of the land, while 8.2% of the island is made up of unexploited areas.

The agricultural sector contributes 9.8% of the gross domestic product (GDP) and employs 24.3% of the working population. The total power production capacity of the island, based on the measure of electric use, is 195 MW. There is a 35% shortfall in total water resources. To supply drinking water to the island, water is transported from Turkey by balloon. Cyprus has very rich copper mines, however, there are currently no corporations to operate these mines fully, so they only produce raw material for the construction sector. In fact, the old mines of Cyprus constitute a significant part of its natural resources, including limestone, marble, plaster-stone, bentonite, clay, sandstone, and iron oxide.

2.3. Architectural Heritage, Building Materials, and Cultural Elements of Cyprus

Neolithic remains reveal that Cyprus has been inhabited since the New Stone Age. As a result of its strategic position, combined with its attraction as a place to live, Cyprus has had many different rulers over the centuries. The Egyptians followed the Hittites, and were in turn followed by the Assyrians. Persians, Romans, Byzantines, Lusignas, Venetians, and Turks in turn have occupied the island. Gothic churches rub shoulders with crusader castles and ruined temples with British colonial-style buildings in a fascinating blend of styles [3]. The Ottoman Turks ruled Cyprus for 307 years, which is why the effects of Turkish culture and architecture are apparent on the island. The current population of the Turkish Republic of Northern Cyprus is approximately 220,000, 99% of whom are Muslim.

During ancient times, different building materials were used in Cyprus. In both the Luzinian (1192–1489) and Venetian periods (1489–1571) stone was the major construction material, however, during the Ottoman period (1571–1878) stone was only used for the ground floor, as adobe construction was employed on the upper floors of residential buildings. During the British period (1878–1930), stone was used as a structural material (Fig. 2). After 1940, reinforced concrete was introduced to Cyprus. Today 90% of contemporary buildings are made of reinforced concrete.

3. The built environment and sustainability

The built environment has a huge impact on the natural environment. Table 1 shows the environmental impact of the built environment on cultural, economical, and ecological sustainability.

3.1. Building Design and the Housing Sector

In the case of building design, priorities for sustainability are [5]

> Save energy, recycle buildings, create community of awareness, reduce material use, protect the site, select low impact materials, maximize longevity and durabil-

Fig. 2. Traditional Stone and Earthen Buildings in Northern Cyprus.

Table 1
The percentage of total environmental impact caused by the built environment [4]

Energy consumption	50%
Use of resources	40%
Ozone-hazardous gases	50%
Land use	80%
Water consumption	50%

ity, save water, make the building healthy, green your business.

The housing sector therefore also has an impact on the environment in the following ways: land use for housing, use of natural resources for construction materials, energy consumption for producing the construction material, energy use during the construction period, energy needed for heating and cooling in the lifecycle of the building.

3.2. Global prospects for sustainable housing

Construction materials in the housing sector have a significant effect on the environment and the ecosystem. In the early 1990s, the demand to protect the earth's natural resources increased in order to provide healthy living conditions for human beings. As discussed in the RIO I 1992 [6] earth environmental conference, modern dwellings must provide healthy living conditions in terms of heat, humidity, and clean air. They must also operate with technologies that minimize harm to the earth's natural resources. UNDP's activities focus on saving the environment and policies required supporting new energy trends for the Service Lines of UNDP [7]; these focus on four priority areas: strengthening national policy frameworks, promoting rural energy services, promoting clean energy technology, and increasing access to finance energy. The Thematic Trust Fund on Energy for Sustainable Development [8] supports the needs of local sustainable development. In addition, according to the SIDS (Small Island Development States) Barbados 94 Declaration [9], the fragile nature of island ecology demands measures for sustainability.

4. Material selection and sustainability

Material selection for housing is one of the most significant strategies of sustainability. It is therefore wise to rely on the surrounding facilities and environmental resources when choosing building materials and construction technology.

Earth is a well-known wall material that was commonly used until recent decades. Locally available earthen material used in buildings contributes to the maintenance of a balanced ecology, because earthen material has low embodied energy when compared with other building materials. Furthermore, its low heat transfer value provides healthy indoor environments and contributes to economic sustainability.

4.1. Traditional adobe

Clay is the major binder in traditional adobe. Earth used in traditional adobe production must contain approximately 30% clay. The production stage requires a large area to be set aside for curing the clay in the wet soil, block production, and covered storage, and this area should be protected from the sun and rain. Adobe production is time-consuming and requires intensive labor.

Straw in the mixture catalyzes homogenous drying. Water absorption is rapid and the blocks disintegrate when permeated by rainwater. The large amount of clay required in the binding process causes an increase in shrinkage. Straw in the mixture minimizes the shrinkage and prevents cracks in the earthen blocks; however, even walls built out of partly dried blocks crack over time due to shrinkage. While drying, the traditional adobe or earthen blocks must be turned upside-down after they have been formed in the field. To obtain the final dried material, the blocks must be cured for 15–21 days prior to utilization in a site sheltered from rain.

4.2. Traditional adobe and alker composite

Earthen wall material is vulnerable to moisture and requires intensive labor for its production. Consequently, there is a need to improve the durability, production, and

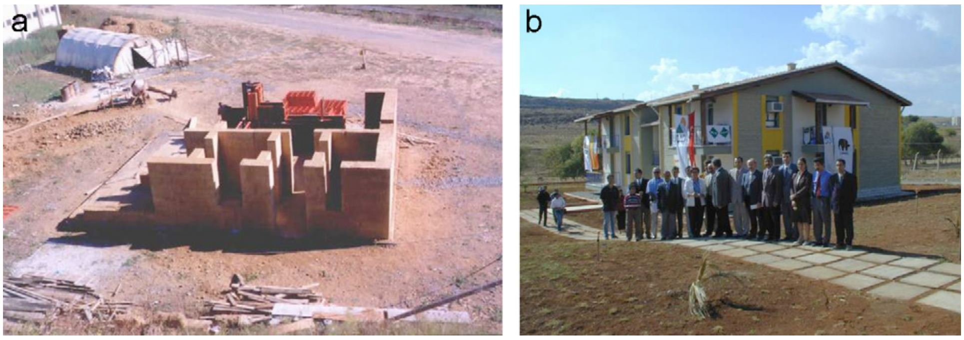

Fig. 3. (a) Construction Period of Alker Building (b) Urfa Pilot Building.

workability of earthen construction technology. Throughout its history as a building material, earth has been stabilized with different additives. Istanbul Technical University recovered gypsum used as a stabilizer from historical buildings in Eastern Turkey. Ongoing research since 1978 [10] proves that this combination of earth and gypsum called Alker (an abbreviated form of the Turkish words for gypsum and adobe, meaning gypsum-stabilized adobe) has improved physical properties. There are Alker buildings constructed and inhabited since 1983. Construction period of Alker Building, 1995, can be seen in Fig. 3a and Urfa Pilot Building 1999 on Fig. 3b.

5. Alker technology

Alker technology utilizes earth containing only about 8% clay, which is widely available. To improve the water resistance, workability, and mechanical properties of this earth, it can be stabilized with gypsum. Earth material that is stabilized by gypsum ($CaSO_4$ 1/2 H_2O) hardens in 3–5 min and becomes load-bearing under normal conditions. The rapid hardening of gypsum does not leave enough time to work with the material on the construction site. To gain about extra 20 min of working time, lime ($CaCO_3$) is added to the processing water before the gypsum is added [10,11]. First, these components are mixed for 3 min in a concrete mixer [11]. Then the mixture is shaped into blocks or molded immediately as in situ walls. The quality of the material processing affects the strength and durability of the building and the appearance of the surface. The recommended proportions for Alker processing are as follows: lime 2%, gypsum 10%, and water 20–22% (according to the soil's dry weight before mixing). However, the percentage of processing water must be decided according to the desired production technique of the material, as shown in Table 2.

Gypsum-stabilized adobe production is faster than traditional adobe production, and as a building technology it requires fewer man-hours and a smaller preparation area. Table 3 shows the physical properties that result from earth stabilization with gypsum.

The mechanical properties of this material are listed in Table 4. Compressive strength and shrinkage can be compared with the values stated in the SIA standards (Swiss Architect and Engineer Chamber Standards).

Table 2
Water used for Alker production [11]

Water component (%)	Production
18–20	Rammed earth
20–22	Unburned clay brick
>30	Segregation

Table 3
Physical properties of Alker

Alker properties	Alker, numerical information from [13]	Earthen wall material, numerical information from SIA [12]
Lower heat transmission, λ(W/m K)	0.4	1.13
Reduced shrinkage (%)	1	2
Specific, c (kJ/kgK)	1.0	1.0

Table 4
Mechanical properties of Alker [10,12]

By unit weight	1600–1700 kg/m^3
Compressive strength	2.0–4.0 N/mm^2
Shear strength	0.9–1.3 N/mm^2

6. Human health and Alker technology

In addition to its many large-scale environmental benefits, Alker technology offers improved living conditions for the occupants of Alker-constructed buildings.

6.1. *Risks posed to health by unsuitable indoor environments*

Human beings are biologically weaker than other living organisms. The built environment has a great impact on the protection of human biological life from natural influences. The indoor environment must provide a balance between heat and humidity to create the healthy conditions necessary for human biology. The importance of this balance cannot be overstated. Unless the required conditions exist, diseases such as blood balance disturbance, rheumatism, skin mycosis, allergies, cancer, tuberculosis, asthma, and fatigue can develop in the human body [14].

6.2. Indoor Heat-Humidity Balance

The perception of heat in the living space varies according to relative humidity. It would be inaccurate to state a single value for heat and humidity with regard to comfortable living conditions. Fig. 4 shows day period temperature changes during summer and winter, with an indication of the comfort zones of the indoor temperature (18–22 °C). According to the curve seasons of the year (winter or summer), have some comfortable temperature in a day period. Building envelope is significant to conserve the required comfort.

The conditions for comfortable living are affected not only by the indoor temperature of the building, as determined by the wall, ceiling and floor, but also by air movement in the living environment created by the temperature difference between indoor air and the enveloping surfaces. In this case, the graphics in Fig. 5a help us to observe how the wall surface temperature T_i (°C) can vary to sustain comfortable living conditions when the indoor air temperature is between 18 and 22 °C. The corresponding relative humidity φ (%) is shown in Fig. 5b, and air current velocity v (cm/s) is shown in Fig. 5c, each on the y-axis.

Unless the comfort zones indicated in Fig. 5 are achieved, a feeling of discomfort is perceived. Mostly a discomfort indicates a disease risk. The material and

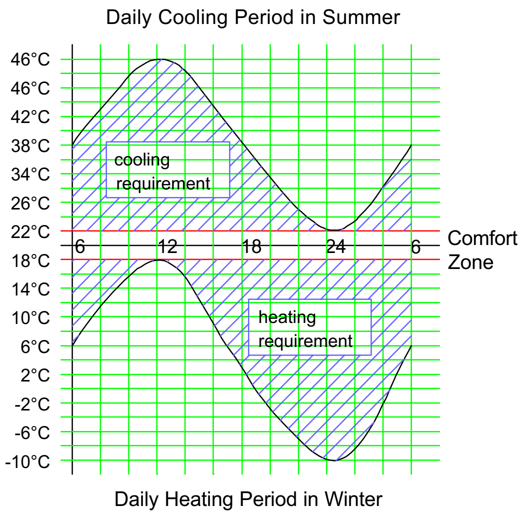

Fig. 4. Daily maximum and minimum temperature changes during summer and winter in the hot dry climate.

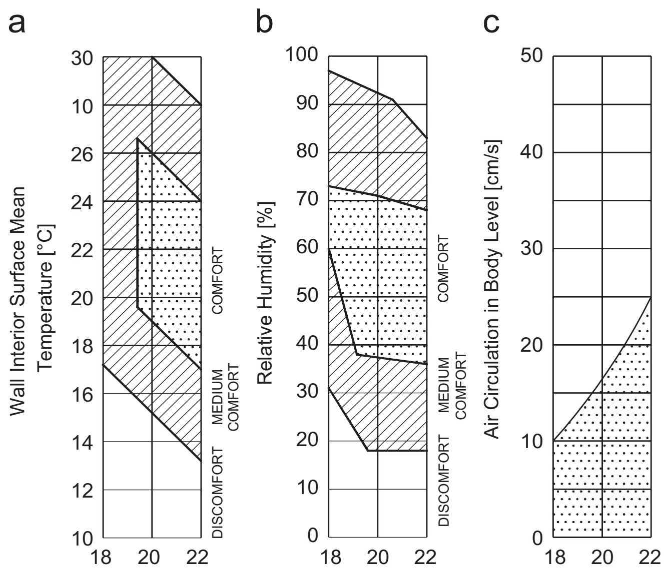

Fig. 5. Comfort zones considering indoor air temperature 18–22 °C; (Goromossov M.S., 1969) [15] (a) Wall Surface Temperature: T_i (°C) (b) Relative Humidity: φ (%) (c) Air Current Velocity Close to Indoor Wall Surface: v (cm/s).

design of the building envelope have a significant effect on the healthy indoor environment and thus sustainable housing [16].

7. Economic contribution of Alker technology to sustainable housing

Although earthen material supplies healthy living conditions for human beings, it became outdated in the 20th century. This regression was a result of the increase in market shares of industrial building materials. The building materials industry supports research for developing technology and provides the financial resources demanded by the marketing sector to increase their market shares.

It cannot be denied though that the embodied energy of industrial building materials such as cement, brick, and steel aluminum is high. Furthermore, most of this structural material has a high heat transfer value, so that buildings made of these materials consume more energy for heating and cooling during their life cycles. Extensive energy consumption in buildings decreases their ecological sustainability.

7.1. Environmental economy with Alker

Comfort conditions, in which outcome is related to heat and humidity, depend upon the heat transmission value U (W/m^2 K) of the material that forms the building envelope. The fact that the heat transmission U of Alker walls (thickness of 45 cm creates 0.70 W/m^2 K) is low implies that the heat loss of the building is also small. When the heat transmission is low, the heating and cooling budget spent both by the homeowner and the nation is decreased; the

Table 5
Cost and emission comparison of exterior walls with equivalent heat transfer coefficient [17]

	Concrete wall	Burned rick	Lightweight concrete	Alker block	Compactedalker
1. Wall properties	20 cm	19 cm	20 cm	45 cm	45 cm
2. U Value (W/m^2 K)	3.23	1.25	0.95	0.7	0.7
3. Physical properties	$\lambda = 2.090$ W/m K; $\gamma = 2.4\,kg/m^3$	$\lambda = 0.580$ W/m K; $\gamma = 1400\,kg/m^3$	$\lambda = 0.240$ W/m K; $\gamma = 600\,kg/m^3$	$\lambda = 0.40$ W/m K; $\gamma = 1600\,kg/m^3$	$\lambda = 0.40$ W/m K; $\gamma = 1600\,kg/m^3$
4. Pollution (kg/yr)		$CO_2 = 7090$; $SO_2 = 40.5$; $CO = 35$	$CO_2 = 5675$; $SO_2 = 32$; $CO = 27.5$	$CO_2 = 5151$; $SO_2 = 29$; $CO = 25.5$	$CO_2 = 5751$; $SO_2 = 29$; $CO = 25.5$
5. Cost without heat insulation	3.3	9	9	4.4	4.4
6. Insulation required for equal U value ($U = 0.7\,W/m^2\,K$)	20 / 5 / 9 cm	9 / 5 / 19 cm	20 / 5 cm	45 cm	45 cm
7. Total wall cost ($/$m^2$, 1995)	11	14	12.9	4.4	4.4

earth's non-renewable energy sources can be protected and emissions reduced. The embodied energy of Alker is less because the production energy of gypsum is less than that of cement; consequently, less energy is required for the 10% gypsum in the admixture.

7.2. Housing economy with Alker

Considering building economy, factors such as project planning, site facilities, construction period, materials, and technology choices are relevant. The effect of gypsum-stabilized adobe on the construction cost or its share in the overall construction economy can be stated in a comparison with other wall construction materials. Table 5 [17] provides a cost and emission comparison of different exterior wall materials with the same coefficient of heat transfer. Comparisons are made between the thermal properties of, for example, solid concrete (blocks or curtains), burned brick used in rural areas, lightweight concrete (one of the most commonly used building materials in wall construction), Alker block, and rammed Alker. The listed values for wall properties, U values, physical properties, pollution values per year, costs without insulation, insulation required for equal U value, and total wall costs, clearly show the relative qualities of these materials. The thickness values in use and the heat transfer values U (W/m^2 K) of walls made from these materials are also listed. Table 5 also shows the levels of CO_2, SO_2, and CO emissions based on the type of wall material, which depend in turn on their heat transfer and energy loss values. The heat insulation that is added to decrease both energy consumption and environmental pollution can be seen in row 6 of Table 5; row 7 shows the cost for one wall-unit with insulation. The cost of Alker walls without insulation is 1/3 that of the cost of insulation-added walls made from other materials.

8. Conclusions

We are faced with the question of how to protect our global environment. The fragile ecological balance of islands has a marked effect on their economic and socio-political life. The construction industry in particular has a dramatic and extremely significant impact on the environment. Innovative policy programs can achieve energy reduction for sustainable living in island conditions.

With the new physical properties, the role of Alker in the sustainable housing of northern Cyprus should not be underestimated. In fact, it is of the utmost importance for policy-makers to grasp the vast contribution that this construction material can make to the economic, cultural, and ecological sustainability of the island. To preserve and improve the natural and man-made environment, we collected data from documentation of historical buildings and environment facilities in northern Cyprus. We conclude that Alker wall material, with its low embodied energy, low heat transfer value, and significant health advantages, could make a major contribution toward sustainable housing in this region. To convince the public and the building industry of this potential, this study on the use of Alker for housing in northern Cyprus aims to provide a step forward in the area of cultural, economical, and ecological sustainability.

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