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# *EARTH SHELTERED HOUSING: DEFINED, EXPLAINED, EXAMINED*

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## *ABSTRACT*

*Interest in earth sheltered housing (ESH) and increased ESH construction have made it important for housing educators to have basic knowledge about the topic. This paper is a synthesis of information from related literature, seminars, proceedings, tours, and interviews. Basic concepts related to the function of the earth in this form of housing are explained. Various aspects of planning such as siting, orientation, building materials, waterproofing, insulation, and heating/cooling are discussed. The viability of this housing form is examined. Reports of test studies related to energy savings are summarized. A list of major ESH research centers is included.*

## *INTRODUCTION*

This paper is a synthesis of information from related literature, seminars, discussions with architects and builders, and inspections of various types of earth sheltered houses. The growing interest and building activity in this housing form makes it important for housing educators to be knowledgeable on the subject. They can fill a vital role in informing students and directing potential ESH consumers to credible sources of information.

## *WHAT IS EARTH SHELTERED HOUSING?*

The many terms used to designate this form of housing are not necessarily accurate indicators of the type of earth sheltering used. Such terms as underground, earth sheltered, earth coupled, earth integrated, earth contact, or geo-built are examples. The terms do not necessarily have any communication value as to a specific design of earth sheltered house. Since a wide range of earth sheltering techniques are being used, the name "earth sheltered" can apply in all cases. Earth sheltered housing (ESH) can be any structure that makes the earth an integral part of the design to achieve energy savings and other benefits.

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Earth sheltering can be achieved in various ways. The popular, but mistaken, idea is that an earth sheltered house must be built into the side of south facing hill (Lane, 1979). Some common methods of earth sheltering include chambering (the structure is buried) with an atrium in the center, recessed (into the side of a hill), bermed (earth pushed up against the walls), or earth covered. The house can be on grade, below, or partially above and below grade.

The form, or shape, of ESH will partially depend on the construction methods and materials used. Thin wall ferrocement houses will almost exclusively be dome or shell shaped to gain strength from the curvilinear design. Poured in place or tilt up slabs will result in more traditional straight wall structures. The barrel vault may have a curved top and straight walls. Some structures have been built from very large steel culverts (Anderson, 1981).

## *FUNCTIONS OF THE EARTH*

Earth is still sometimes erroneously referred to as an insulator. Other materials are more effective insulators. Many feet of earth on a roof would be required to equal the R factor of a few inches of rigid insulation. The resulting earth load would be impractical (Lane, 1979). Concepts important in the earth related energy savings are thermal moderation, thermal lag, disturbed versus undisturbed earth, cooling effects of the earth, and the earth envelope.

### *Thermal moderation*

The earth maintans a fairly constant temperature at deep levels because solar heat passes through it slowly and is dissipated gradually. The phenomenon is referred to as thermal moderation. A claim is often made that the earth maintains a constant 55 or so degrees at depths around 12 feet. That constancy is dependent upon numerous variables.

### *Thermal lag*

The thermal moderation characteristic of the earth results in a thermal lag. The short term effect of the 24 hour thermal lag cycle and the long term effects of the seasonal heat-transfer lag contribute to relatively stable (but not constant) temperatures of the earth at deeper levels. The reduction of the rapid heat transfer and the wide temperature fluctuations that occur in above grade construction can greatly reduce energy consumption in ESH (Bligh, 1975).

A seasonal cycle occurs as heat that is slowly absorbed by the surrounding earth during summer months reaches the walls during winter months. This heat is radiated into the structure during winter months. During the cooling season the process is reversed. Active manipulation can increase earth cooling in the winter to ensure greatest absorbtion of interior heat by the earth envelope in the summer. Vertical air drains filled with pebbles installed about two to three meters away from the structure will allow cold air to flow downward in the winter and chill the earth more rapidly (Labs, 1981). This procedure can be especially useful in climates where there is a long summer and short winter.

*Cooling effects*

Earth sheltering can greatly reduce cooling loads. The heating load can be virtually eliminated. In one study, as soil depth around the building was increased to 3.6 meters the cooling load dropped 50 percent lower than for the control structure built at grade. The on grade house had R-38 insulation in the ceiling and R-19 in the walls (Bircher, 1981). In an area north of Denton, Texas when temperatures reached or exceeded 100 degrees for 42 consecutive days, a thin shell, curvilinear earth-sheltered structure maintained temperatures at or below 80 degrees with no air conditioning system. That house was half below and half above grade and earth covered.

The cooling effects of the earth are derived from contact at the floor, the walls, and on the roof. One study comparing the effects of earth contact through berming (earth covered sides--at or near grade) and chambering (buried in the earth) found little difference in performance. The cooling effects of the earth through berming resulted in a 40 percent reduction in cooling costs (Bircher, 1981). In another study of two occupied ES houses, temperatures were appreciably lower near earth-backed wall surfaces. The cooling effects derived from earth contact can provide both radiant and convective cooling (Grondzik, 1981). Boyer and Johnston (1981) recommended maximum amount of direct contact with cool earth-backed walls to induce summer heat loss. Labs (1981) agreed, but pointed out that at some point the benefits of deeper contact become less desirable as problems of lighting and ventilation increase.

*The earth envelope*

The earth can do the best job of cooling if it is protected from moisture and solar heat. The earth envelope, or the earth close to and surrounding the structure, should be kept dry and shaded during the cooling season, and perhaps insulated. Labs (1981) listed four ways to modify ground temperatures: 1) lower the mean temperature of the earth envelope surrounding the building, 2) reduce the amplitude of the surface temperature fluctuations that are propagated into the subsoil, 3) manipulate the thermal properties of the soil to reduce heat penetration from the surface and to favor heat dissipation from the sturcture, and 4) displace the phase of the natural ground temperature wave to increase the separation between the annual air or soil-air maximum temperature and that of the ground coupled building.

Another function of the earth is to prevent heat transfer through infiltration of air. A conventional home loses from 35,000 to 70,000 BTU per hour through cracks, doors, and windows. Heat loss through the earth covered north, east, and west walls of a test house was reduced to from two to four BTU per hour from higher loss usually experienced in above grade houses (Bannon, 1980).

## *BUILDING MATERIALS*

Advances in chemistry and technology have greatly eased construction problems for underground housing. The variety of materials available, however, have made the need for technical information and advice imperative. Any building material used for above grade construction can be used below grade if properly treated and the surrounding area properly prepared and maintained. Certain materials, obviously, lend themselves best to this type of construction. Concrete is desirable due to its low water permeability, superior strength, durability, and--when used in thick wall construction--its thermal mass characteristics. Low cost homes are possible with ferrocement construction which involves the use of reinforcement mesh to create a curvilinear form which is then covered in cement to a thickness of about one and one-half inch. Special knowledge is required to properly use concrete for underground construction.

Anderson (1981) listed ten different types of building materials. Cast in place concrete was cited as the primary choice of building material in the South Central Plains. Post tensioned concrete was found primarily in Kansas, Missouri, and Nebraska. Reinforced concrete block is often used in conjunction with precast concrete. Precast prestressed plank, often called hollow core plank, is sometimes used for roof material. Precast reinforced plank, or waffle crete, contains standard reinforcing steel and spans up to 16 feet have been achieved. Dry-stacked concrete blocks may have fiberglass mortar troweled or sprayed over the surface. Treated wood and fiberglass coated wood can be used, although life could not be expected to equal concrete. Steel culverts have also been used (Lane, 1979). Shotcrete domes offer perhaps the most economical construction material and approach. There is lack of consensus regarding the strict meaning of this term. Some confusion exists in distinguishing shotcrete from gunnite. Shotcrete is usually a mixture of larger aggregate--as large as pea gravel--to facilitate the flow of the mix through the nozzle. Shotcrete can be pumped at a much lower cfpm (150) whereas gunnite is usually pumped at 600 cfpm. Gunnite is a finer mixture and .often is associated with swimming pool construction.)

### *INSULATION*

Insulation may be used to retain interior-generated and solar-collected heat during winter months. It can save heating fuel without decreasing the summer cooling benefits of the earth. Whether the climate is primarily winter or summer oriented will partly determine insulation decisions. Boyer and Johnston (1981) warned that winter design principles should not be applied in summer oriented climate and vice versa. Once the earth loses contact with the structure (thermal decoupling), cooling effects of the earth are greatly reduced. Interior insulation is not generally recommended (Concrete Construction, 1980). Lane (1979) recommended use of exterior wall insulation on heavy mass concrete structures to keep solar gain and manmade BTU's inside the structure without sacrificing the thermal mass attributes of the concrete walls. This concept is particularly important in colder climates where the heating season is longer than the cooling season. He stated,

> Proper insulation will reduce the steady state conductive heat transfer, and soil berming will effectively moderate the soil temperatures of the structure, resulting in a much narrower range of temperature extremes in the soil in comparison to the ambient air temperatures (p 147).

Some designers of thin shell cement structures also recommend that insulation be placed in the earth envelope around these curved structures some distance away from the walls. Rigid waterproof insulation board can act as a heat barier especially in cooling seasons without eliminating the cooling effects of earth coupling. Atkinson (1981) recommended Styrofoam for insulation. It must be closed-cell styrofoam for moisture repellence. Lane (1979) recommended rigid board insulation of the closed cell type. He emphasized it must have good compressive strength to withstand the earth's pressure. Another source recommended extruded polystyrene for its high R value per dollar (Concrete Construction, 1980).

## *ECONOMIC ADVANTAGES OF ESH*

The total expense load of homeownership is seldom calculated in the cost of housing. In addition to initial construction costs, maintenance and repair, heating, cooling, and insurance can make a difference in total cost of one house compared to another. Until recently, initial costs rather than potential ongoing expenses have tended to have a greater impact on home purchases. This perspective generally saw ESH as more costly than other housing forms. Energy costs are changing this perspective and the savings offered by ESH appear more significant. The cost gaps are narrowing as design and construction experience and efficiency increase. Some types of construction such as ferrocement curvilinear structures and shotcrete domes are less expensive to build due to the speed with which they can be constructed and the reduced amount of concrete needed (Impson, 1981). Cost comparisons are difficult due to the experimental aspects of ESH, the lack of competition between contractors, lack of streamlined production techniques, and the incidence of custom designs. The following estimates were given in an editorial for *Underground Space*:

> It appears possible to construct earth-sheltered housing for approximately the same cost as good quality conventional housing, i.e., $40 to $45 per square foot. It is unlikely, however, that earth sheltered housing can compete at this time with lower cost mass produced housing. . . .Site work, concrete walls, and roof, and waterproofing represent about 40 percent of the total cost of the house. In a conventional house, the site work and concrete would be about 10 percent of the total cost. This increase, however, is offset by a substantial reduction in carpentry costs from 50 percent on a conventional home to 30 percent of the total cost for an earth sheltered home (Sterling, 1979, p 125).

Use of the life-cycle cost concept gives a more accurate estimate of the actual cost of a house. The reduced costs of maintenance and energy (Harrison, 1973) and the increased total life of the structure prorated over the projected length of ownership would significantly reduce the actual cost of shelter. Reduced heating and cooling costs are the most touted advantages of ESH: 30-40 percent (Boyer, 1981); 50-70 percent (Barker, 1980); 80-85 percent (Moreland, 1979). An underground house in Buffalo, New York was monitored for two years with no solar energy adaptations. A 68 percent savings in energy costs were recorded compared to a similar above-ground house that was fully insulated. The construction costs were 18 percent greater for the ESH (Barnard, 1981).

Siting to maximize solar gain in the heating season and minimize it in the cooling season can increase energy savings. Uncovered concrete floors near the glazed area can act as an effective heat storage material. Covering these areas with carpet, obviously, would somewhat negate this potential (Boyer and Johnston, 1981). Most surveys have shown that few ESH have central heating and cooling systems. Lane (1979) said a well designed ESH can be heated with a wood stove. Heating is often provided mostly with wood stoves, fireplaces, and passive solar systems. The earth itself provides the primary cooling source. Heat pumps are often used (Boyer, 1981). Maintenance costs on traditional structures range from 5 to 20 percent a year depending on age, materials, climate, and other factors. Exposure, the main cause of deterioration, is greatly reduced in ESH (Sterling, et al., 1980). The more stable deep earth temperatures also reduce thermal expansion, another source of deterioration (Lane, 1979).

Insurance companies have not collected enough information to develop actuarial data for ESH (Underground Space, 1979). Cheaper rates are possible by shopping for knowledgeable companies. According to Kiesling (1980) some ESH owners choose to insure only the contents of the dwelling, not the structure.

### *OTHER ADVANTAGES OF ESH*

Protection from manmade and natural disasters is an accepted benefit of ESH (Kiesling, 1980; Swayze, 1980; Harrison, 1973). Danger from fire, wind, hail, and vandalism are virtually eliminated. Kiesling (1980) stressed resistance to structural damage and protection to occupants from high winds. Swayze (1980) cited protection from air pollution as a benefit.

The added privacy offered by ESH is evident. Reduction in noise is one feature often noted by visitors and residents. Some owners have commented that their environment seemed too quiet (Boyer, 1981). A certain amount of noise in an environment is desirable and serves as an accoustical background (Boyer, 1981).

Although not a major concern of the average housing consumer at the present time, land space saved by putting structures underground can be significant. Barker (1980) noted that underground structures have the potential for solving urban sprawl problems. He pointed out the feasibility of building townhouses and condominiums underground in otherwise unacceptable locations such as near freeways or industrial areas.

For the conservationists, reduction in pollution through lowered heating and cooling demands, less land defacement, saving of space through higher density and saving of scarce material in initial construction are all pluses for ESH (Boyer and Grondzik, 1981; Moreland, 1979).

### *PLANNING AN ESH*

Probably the main cause of dissatisfaction with ESH is lack of accurate information. Many attempts have been do-it-yourself projects. The results were not always good examples of what ESH can be. Problems with condensation, leakage, odor, and lighting sometimes resulted. As ESH has become newsworthy, more material is appearing in newspapers, magazines, and paperback books. Many of these sources are less than credible and their lack of complete, accurate information can be misleading.

*Resources*

The services of an experienced architect should be sought (Atkinson, 1981). Relying on an inexperienced contractor may be risky because of lack of standardization of construction methods and lack of prototypic designs (Lane, 1979). Knowledge of how to control for the added weigh and pressure of the earth is critical. An earth cover 10 feet deep with major vegetation can present loads that approach 1440 pounds per square foot (Moreland 1977). The following centers can provide publications, information, and names of reputable architects and builders.

Underground Space Association Department of Civil and Mineral Engineering University of Minnesota Minneapolis, Minnesota 55455

The Underground Space Center University of Minnesota 11 Mines and Metallurgy Minneapolis, Minnesota 55455

Oklahome State University Architectural Extension School of Architecture Oklahoma State University Stillwater, Oklahoma 74078

Center for Energy Research Civil Engineering Departmen Texas Tech University Lubbock, Texas 79409

*Soil, siting, and orientation*

In addition to the usual concerns related to siting for above grade structures, special emphasis must be placed on climate, topography, soil type, ground water conditions, water table, location of adjacent structures, egress requirements, and site access. Sun, wind, and view are especially important when siting an underground house.

According to Lane (1979) the soil is a functioning part of the house and not just incidental in the design. All aspects of the soil should be studied, such as: composition, percolation rate, water table, settlement, and bearing capacity (Lane, 1979; Lytton, 1975). Because of the weight of the structure and the depth of the construction, soil tests should be made and steps taken to minimize the disadvantages of the soil's characteristics. Some types of clays expand when wet and can exert pressures great enough to damage vertical walls (Lytton, 1975). Lytton (1975) listed ideal conditions for soils where below grade or earth covered construction is desired: 1) diggable, 2) flat slopes, 3) bedrock below soils, 4) seismically quiet, 5) low water table, and 6) arable land (for thermal efficiency).

Lighting, ventilation, humidity, the cooling effects of the earth, and solar gain can all be manipulated through proper orientation. Opinions differ as to the best exposure for underground houses. Solar gain can be increased considerably in the winter months without undesirable accumulation in the summer by correct orientation and glazing (Boyer and Johnston, 1981). Most authorities recommend south facing orientation for maximum winter and minimum summer solar gain (Boyer and Johnston, 1981; Sterling, 1980; Barker, 1980). Sterling (1980) found that south facing double glazed windows produced a net energy gain even without night protection.

*Landscaping*

Landscaping can increase the effectiveness of earth sheltering. Contouring can help control drainage. Rocks and pebbles can be used to increase percolation rate and to allow cold air to penetrate the earth in winter so that during summer months the maximum earth cooling benefits can be achieved.

*Moisture control*

With appropriate initial precautions unwanted moisture need not be a problem. Several interrelated factors affect successful moisture control. Siting and orientation, as already mentioned, are critical. Use of drain tile and gravel beds may also be needed.

Many effective waterproofing substances are on the market. Choice will depend on the construction material and methods used. Type of soil, water conditions, and preferred method of application should also be considered. Generic names for the available materials are: bentonite, composite sheet membranes, synthetic rubber sheet membranes, liquid applied membranes, and cementitious coatings. White (1980) described the following waterproofing materials: bentonite, is a natural clay that will expand up to 16 times its original volume upon water contact. This product comes in panels or a mastic that can be troweled or sprayed on. Composite sheet membranes are rubberized asphalt with a polyethylene top laminate. Synthetic rubber sheets should be applied professionally for the best results. Liquid applied membranes such as rubberized asphalts, pure urethanes, modified urethanes, and extended urethanes were listed. Cementitious coatings are Portland cement based, and their disadvantage is that they will not bridge cracks.

A considerable amount of moisture is produced within a home from normal living activities. Such moisture is easily dissipated in above grade structures but in earth sheltered houses where little air infiltration occurs, it must be controlled, circulated, and exhausted to prevent condensation on windows and cool earth-coupled walls (Boyer and Grondzik, 1981). Failure to control humidity level and air movement are two causes of odor unfortunately associated with ESH. Techniques to assure adequate ventilation include orientation to achieve good cross ventilation and minimal use of interior walls (Boyer and Johnston, 1981).

*Lighting*

Another concern of potential ESH dwellers is lighting. When visitors to an ESH research dwelling in South Carolina were questioned, they were unwilling to substitute artificial lighting for natural light sources. Most of them wanted skylights in the back rooms which had no outside exposure, and they preferred having one elevation exposed. Nevertheless, 75 percent of the visitors did rate the natural light in the dwelling satisfactory (McKown and Stewart, 1980).

Correct orientation can increase natural lighting without unwanted solar gain. Use of atriums and skylights can provide the natural light normally gained through windows. Decorating techniques using mirrors and reflective surfaces and light colors can also make the best use of existing light. Fewer interior walls, glazed areas above interior doors, and such ideas as use of rice paper screens rather than partitions or walls can allow greater penetration and diffusion of available light.

*Financing and regulations*

In spite of the many advantages of ESH, it has not made a marked effect on the housing market. Two deterrents have been financing dificulty and code problems. Many of the homes have been primarily owner financed. Lenders are concerned about the possible resale value of an unconventional structure. Appraisers, unfamiliar with this type of structure, cannot easily apply their standard appraisal techniques to ESH. Many of these deterrents to financing will be eliminated as more successful examples become available.

Existing codes and standards were not written for application to earth sheltered construction. Innovative structures, often cannot be accurately evaluated using standards and codes designed for more traditional construction techniques. Performance, rather than prescriptive standards are more suitable for ESH. Such standards as "habitable rooms for residential occupancies shall not have less that 50 percent of their story height above grade," from the National Building Code or, "every sleeping room shall have at least one operable window from the inside to a full clear opening without the use of separate tools," from the One and Two Family Dwelling Code, are but two examples of prescriptive standards that cause difficulties when applied to ESH.

## *CONCLUSION*

As energy costs continue to rise and construction costs for conventional housing increase, more people are seeking less expensive methods of building and maintaining houses. The cost of earth sheltered housing, like any other housing form, is not determined solely by the materials or construction methods but by the myriad of consumer choices that complete the total housing environment. ESH has the potential, both in initial costs and in reduced heating and cooling requirements and virtual elimination of maintenance costs, to provide more housing for less dollar expenditure.

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