DOE / GO-10097-373
FS 120
February 1997

ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

Earth-Sheltered Houses

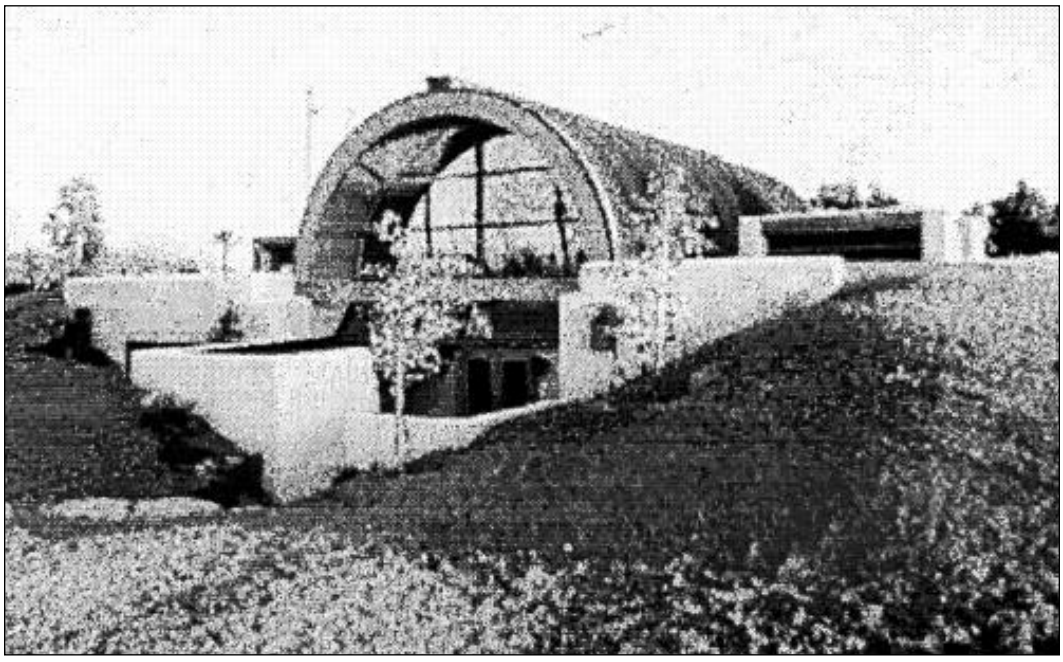
Let's assume you're in the market for a new home. Let's further assume that, like many other people, you're concerned about the limited supplies of domestic oil and gas, the unpredictable cost, and the environmental price tag attached to the continued use of these fuels.

Is there any way to reconcile your concerns and still build your dream home? The solution might lie in earth-sheltered housing. These structures offer many energy-efficient features and are often designed to use solar energy for heating and cooling. Some designs make use of recycled materials in their construction.

If you do your homework, earth-sheltered construction can be an attractive and rewarding choice in housing. The following sections—*Advantages, Disadvantages, Beginning Your Project,* and *Cost*—will answer some questions you may have. Once you've decided on an earth-sheltered house, the sections on *Design, Construction Considerations,* including location, climate, site, and soils, and *Construction Materials* can help you make the house a reality.

Advantages

There are many advantages to earth-sheltered construction. An earth-sheltered home is less susceptible to the impact of extreme outdoor air temperatures, so you won't feel the effects of adverse weather as much as in a conventional house. Temperatures inside the house are more stable than in conventional homes, and with less temperature variability, interior rooms seem more comfortable.



NREL / PIX02909

This house in Tempe, Arizona, uses earth-sheltered construction methods to help decrease cooling costs.

This document was produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a DOE national laboratory. The document was produced by the Information Services Program, under the DOE Office of Energy Efficiency and Renewable Energy. The Energy Efficiency and Renewable Energy Clearinghouse (EREC) is operated by NCI Information Systems, Inc., for NREL / DOE. The statements contained herein are based on information known to EREC and NREL at the time of printing. No recommendation or endorsement of any product or service is implied if mentioned by EREC.

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste

Earth-sheltered houses moderate the impact of extreme outdoor temperatures so that the interior remains at a relatively constant temperature.

Because earth covers part or all of their exterior, earth-sheltered houses require less outside maintenance, such as painting and cleaning gutters. Constructing a house that is dug into the earth or surrounded by earth builds in some natural soundproofing. Plans for most earth-sheltered houses "blend" the building into the landscape more harmoniously than a conventional home. Finally, earth-sheltered houses can cost less to insure because their design offers extra protection against high winds, hailstorms, and natural disasters such as tornados and hurricanes.

Disadvantages

As with any type of unusual construction, there are some disadvantages associated with earth-sheltered housing. Principal downsides are the initial cost of construction, which may be up to 20% higher, and the level of care required to avoid moisture problems, during both the construction and the life of the house. It can take more diligence to resell an earth-sheltered home, and buyers may have a few more hurdles to clear in the mortgage application process.

Beginning Your Project

You may want to start your project by contacting the organizations that can help you locate architects, builders, and contractors with earth-sheltered building experience (a few are listed in the *Source List*). The experienced builders in your location can also ensure that construction plans meet area building code requirements, which can depend on a local official's interpretation. Earth-sheltered designs can present some potential difficulty, such as conformance to minimum window sizes in each room prescribed by fire codes or building codes. Other problematic areas are roofing specifications and insulation requirements specified by codes; earth may or may not be considered an acceptable substitute for materials specified. Builders can inform you of the local guidelines, and may also provide cost comparisons between earth-sheltered housing and conventional housing in your area.

Using experienced professionals will reduce your personal time investment in researching details of earth-sheltered construction. Securing financing may also be easier if you work with those who have firsthand knowledge of earth-sheltered construction and its benefits.

Cost

Comparing cost factors for building an earth-sheltered house to those for building a conventional house can be like comparing apples and oranges. Costs vary by region, depending on the area's construction activity and cost of materials. Many earth-sheltered houses are built by their owners and are customized in different ways, adding amenities that can dramatically increase final costs.

However, when you factor costs, remember to consider important expenses that occur over the life of a house, such as exterior maintenance and utility costs. Greater initial investment can actually mean your ongoing costs, such as heating, cooling, and maintenance, will be reduced. Making the best use possible of natural resources may be one of an earth-sheltered house's greatest advantages. Therefore, in comparison to standard houses, while earth shelters tend to be slightly more expensive to build, these higher initial costs may be offset by the lower energy costs after completion. And while energy savings have been documented by families living in earth shelters, attributing that savings solely to the earth-sheltered design would be difficult, because most earth-shelters incorporate a wide variety of energy-efficient features.

Design

There are two basic types of earth-sheltered housing—underground and "bermed" (or banked with earth). Certain characteristics such as the location and soils of your site, the regional climate, and design preferences are central to which type will work best for you.

Since at least part of the earth-sheltered house is covered with earth, it usually requires less exterior maintenance such as painting and gutter cleaning than does a conventional home.

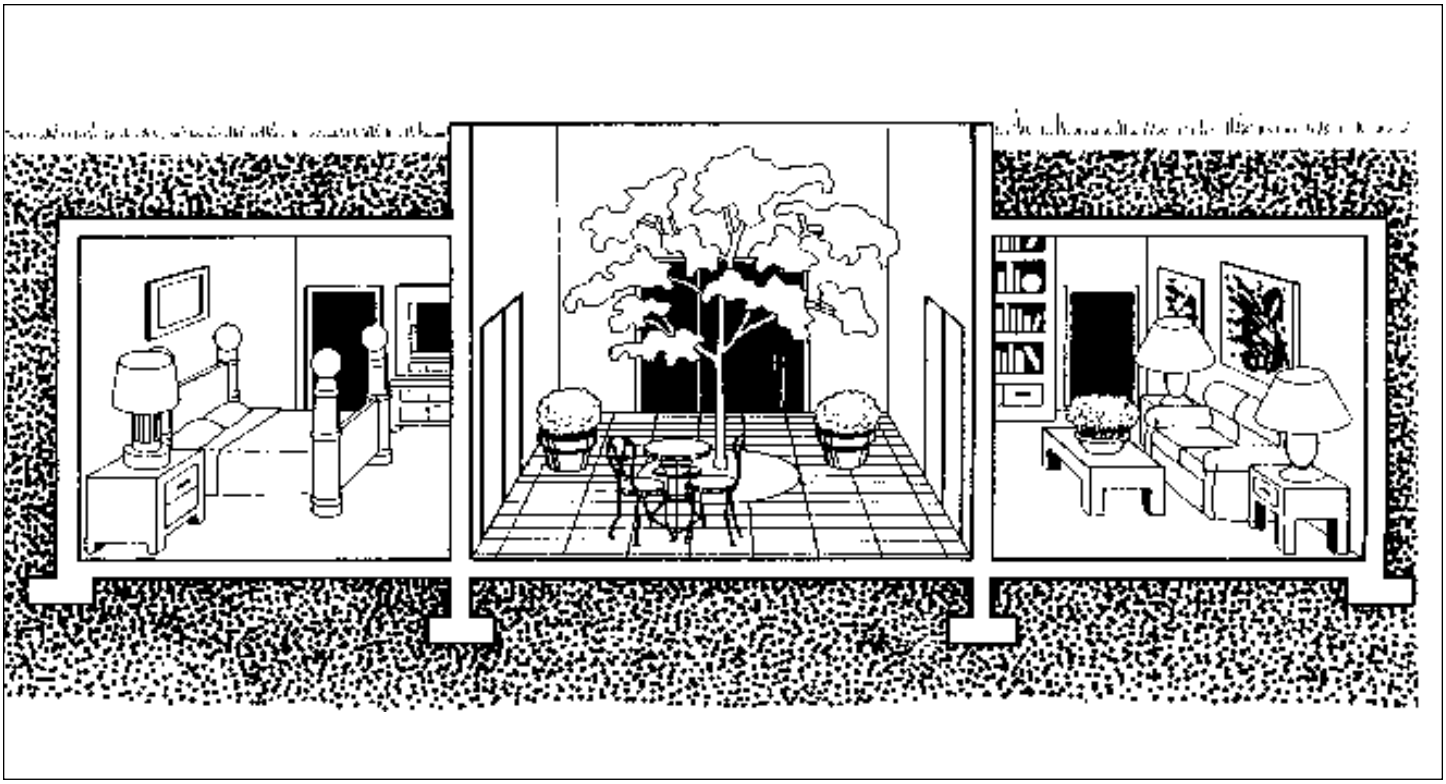
Underground housing means an entire structure built below grade or completely underground. A bermed structure may be above grade or partially below grade, with outside earth surrounding one or more walls. Both types usually have earth-covered roofs, and some of the roofs may have a vegetation cover to reduce erosion.

From these two basic types, three general designs have been developed. They are the:

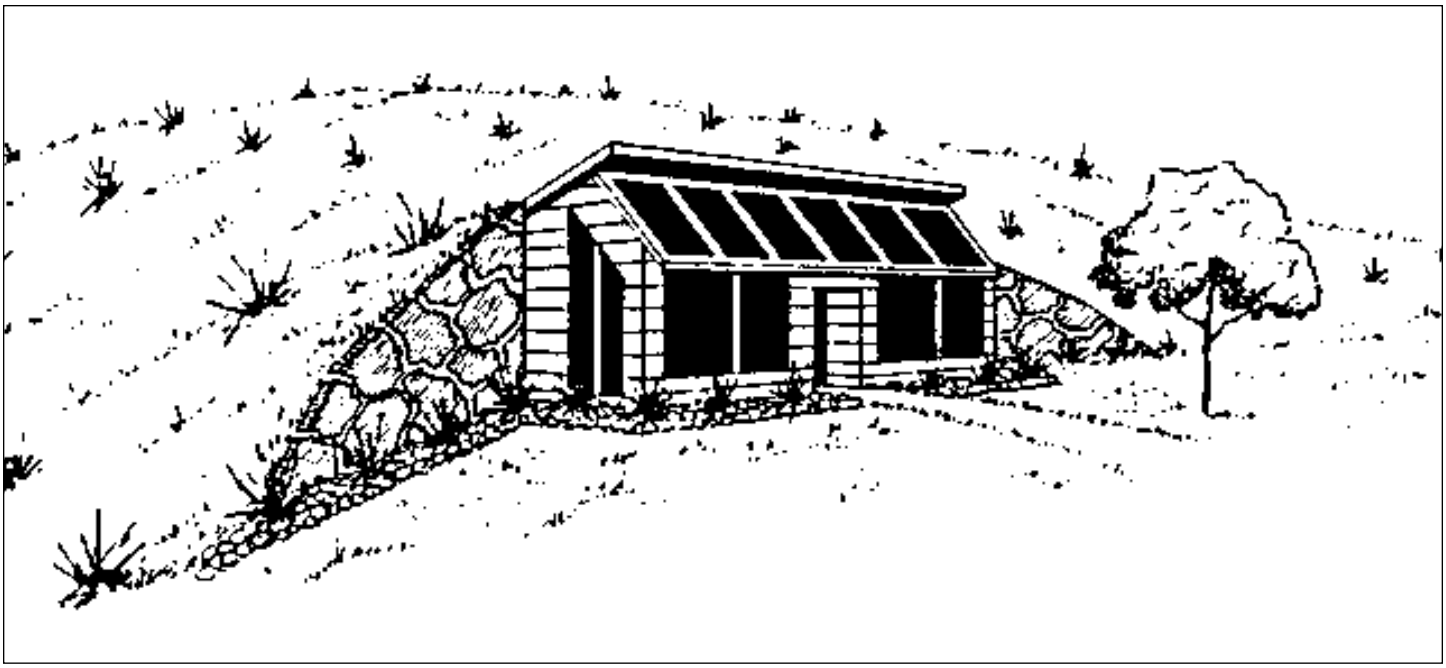
- *atrium (or courtyard)* plan—an underground structure where an atrium serves as the focus of the house and the entry into the dwelling;
- *elevational* plan, a bermed structure that may have a glass south-facing entry; and the
- *penetrational* plan, which is built above or partially above grade and is bermed to shelter the exterior walls that are not facing south.

An earth-covered dwelling may have as little as 6 to 8 inches (0.2 meters) of sod or as much as 9 feet (2.7 meters) of earth covering the structure. An atrium design offers an open feeling because it has four walls that give exposure to daylight. This design uses a subgrade open area as the entry and focal point of the house. It is built completely below ground on a flat site, and the major living spaces surround a central outdoor courtyard. The windows and glass doors that are on the exposed walls facing the atrium provide light, solar heat, outside views, and access via a stairway from the ground level. Atrium/courtyard homes are usually covered with less than 3 feet (0.9 meters) of earth primarily because there is no benefit in energy efficiency from greater depths. This style also offers the potential for natural ventilation.

The atrium design is hardly visible from ground level and barely interrupts the landscape. It also provides good protection from winter winds and offers a private outdoor space. This design is ideal for an area without scenic exterior views, in dense developments, and on sites in noisy areas. Passive solar gain—heat obtained through windows—might be more limited, due to the window position in an atrium plan. Courtyard drainage and snow removal are important items to consider in design.



Barely visible above ground, the atrium design provides good protection from weather extremes.



Usually set into the side of a hill, the elevational design exposes one face of the house and covers the other sides—and perhaps the roof—with earth.

Using designers and builders experienced with earth-sheltered houses can reduce the challenges associated with constructing a non-conventional house.

The elevational and penetrational plans are more conventional earth-sheltered housing designs. Elevational plans expose one whole face of the house and cover the other sides—and perhaps the roof—with earth. The covered sides protect and insulate the house. The exposed front of the house, usually facing south, allows the sun to light and heat the interior. The floor plan is arranged so common areas and bedrooms share light and heat from the southern exposure. This type of house may be placed at varying depths below ground level and is usually set into the side of a hill. The view provided will be one of landscape, rather than open sky, as in the atrium design. A structure designed in this way can be the least expensive and simplest to build of all earth-sheltered structures.

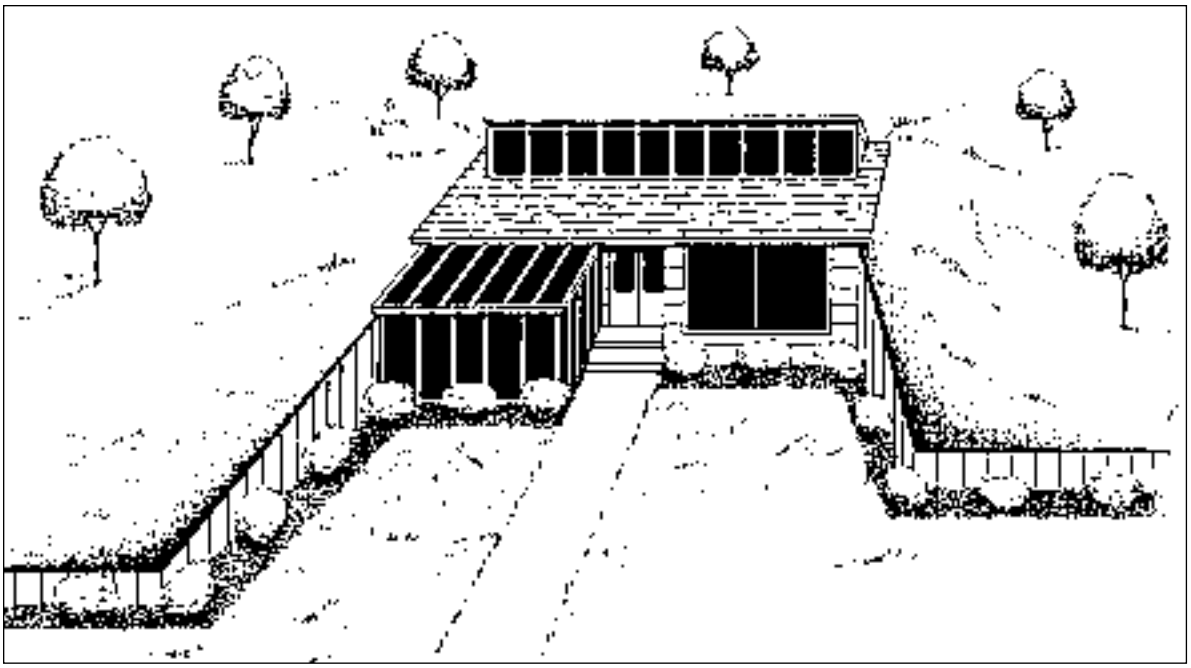
However, the elevational design may have limited internal air circulation and reduced daylight in the northern portions of the house, although there are ways to alleviate these problems by using skylights. The wide design of the house can be offset by close attention to architectural details, landscaping, and exterior materials.

In the penetrational plan, earth covers the entire house, except where it is retained for windows and doors. The house is usually built at ground level, and earth is built up (or bermed) around and on top of it. This design allows cross-ventilation opportunities and access to natural light from more than one side of the house.

Construction Considerations

The climate in your geographical area will determine whether an earth-sheltered house can be a practical housing solution. Studies show that earth-sheltered houses are more cost-effective in climates that have significant temperature extremes and low humidity, such as the Rocky Mountains and northern Great Plains. Earth temperatures vary much less than air temperatures in these areas, which means the earth can absorb extra heat from the house in hot weather or insulate the house to maintain warmth in cold weather.

The site's topography and microclimate determine how easily the building can be surrounded with earth. A modest slope requires more excavation than a steep one, and a flat site is the most demanding, needing extensive excavation. A south-facing slope in a region with moderate to long winters is ideal for an earth-sheltered



A house built in the penetrational design is usually built at ground level and earth is then built up around and on top of it.

It makes economic sense to think beyond the initial purchase price and consider lifetime energy costs.

building. South-facing windows can let in sunlight for direct heating, while the rest of the house is set back into the slope. In regions with mild winters and predominantly hot summers, a north-facing slope might be ideal. Every site differs, but generally southern exposures offer more sun and daylight throughout the year than north-facing slopes. Most designs can be built to take advantage of each site.

The type of soil at your site is another critical consideration. Some types of soil are more suitable than others for earth-sheltered construction. For example, the best soils are granular, such as sand and gravel. These soils compact well for bearing the weight of the construction materials and are very permeable, which means they allow water to drain quickly. The poorest soils are cohesive, like clay, which may expand when wet and has poor permeability. Soil tests, offered through professional testing services, can determine load-bearing capability of soils and possible settlements that may occur.

Radon is an invisible and odorless radioactive gas produced naturally when uranium in rock decomposes. It is found in the soil and in outdoor air in harmless amounts, but can reach dangerous levels when trapped. Radon levels are another factor to consider in locating your home. Areas with high concentrations of radon can be hazardous, although there are methods that can reduce radon buildup in both conventional and earth-sheltered dwellings.

The groundwater level at your building site is another important consideration. Building above the water table is almost essential. Choosing a site where the water will naturally drain away from the building is the best way to avoid water pressure against underground walls. The site should be surveyed for low spots and areas where water will collect. Seasonal or regular surface water flows should be channeled away from the structure. Drainage systems must be designed to draw water away from the structure to reduce the frequency and length of time the water remains in contact with the building's exterior. Underground footing drains similar to or greater than those required by a house with a basement are necessary in many cases.

Construction Materials

The construction materials for each type of structure will vary, depending on characteristics of the site, climate, soils, and design. However, general guidelines show that houses more deeply buried require stronger, more durable construction materials. Materials must provide a good surface for waterproofing and insulation to withstand the pressure and moisture of the surrounding ground. When soil is wet or frozen, the pressure on the walls and floors increases. Pressure also increases

with depth, so materials such as concrete and reinforced masonry, wood, and steel are all suitable. To reduce your transportation costs, it helps if appropriate materials are locally available.

Concrete

Concrete is the most common choice for constructing earth-sheltered buildings. Not only is it strong, it is also durable and fire resistant. Several forms of concrete are used. Lightly reinforced concrete, which is poured and reinforced at the site, is used for noncritical structural elements such as concrete foundations, floor slabs, and exterior walls with less than 6 feet (1.83 meters) of earth cover. Precast reinforced concrete can resist loads at any reasonable depth and can be used for floors, walls, and roofs. Concrete absorbs and stores heat, helping to prevent temperature swings that can damage some building material.

Precast concrete components are cured at a plant or on-site location before they are used, thereby decreasing construction time and cost in comparison to cast-in-place forms. The uses and advantages of precast and cast-in-place concrete are similar, except that precast concrete works best in simple or repeatable shapes. Special care must be taken to make the joints between sections watertight.

Concrete can also provide supplemental strength in other types of earthen construction. For example, a concrete topping can be added to wooden roof planks, and cement "parging" (or coating) can be added to walls with masonry construction before waterproofing.

Masonry

Masonry (i.e., brick or stone) can be used for walls that will receive vertical or lateral pressure from earth cover. It is reinforced with steel bars that are put in the core of the masonry in places of high stress, such as weight-bearing walls or walls with earth against them. Masonry generally costs less than cast-in-place concrete.

Wood

Wood can be used extensively in earth-sheltered construction for both interior and structural work including floors, roofs, and exterior walls. Wood is attractive for its color and warmth, and complements tile and masonry, as well as concrete walls, floors, and ceilings. However, using wood as a structural material requires wooden frame walls, which must withstand lateral pressure, be restricted to a burial depth of one story. Beyond this depth, the rapidly increasing cost of wood construction restricts most builders from using it as a structural material. Although wood can cost less than other materials, it does not offer the strength that a material such as steel does, so it may not be the best choice for structural material in some houses. Wood must also be treated with preservatives to prevent damage from moisture. If your structure can make practical use of wood as a framing material, employing carpenters who can rapidly construct a timber frame for an earth-sheltered house can decrease labor costs.

Steel

Steel is used for beams, bar joists, columns, and concrete reinforcement. It is particularly useful because of its high tensional and compressional strength. The primary disadvantage of steel is that it must be protected against corrosion if it is exposed to the elements or to groundwater. It is also expensive, so it must be used efficiently to be economical as a structural material.

Building With Soil

There has been a recent surge in homes that use soil as a primary building material. This type of construction is literally "old as the hills." Some ancient architecture, such as the Great Wall of China, shows the durability of earthen construction. So building with earth and sand, always plentiful and inexpensive, is not a new idea.

Although these houses do not typify the earth-sheltered construction designs discussed in this publication, earth is a major component in their construction material and many of the same energy efficient ideas are used. Many buildings in the southwestern United States use adobe—bricks constructed of tightly compacted earth, clay, and straw—as their main construction material.

Another building material is "rammed earth." This process entails mixing earth and cement, and packing it into the wall forms with a pneumatic tamper. The result is a rough approximation of sedimentary rock. In fact, this "stabilized earth" achieves compressive strengths estimated to be about half that of concrete. Walls can be made even thicker with little added cost, since the labor and the formwork are the more costly items of a wall. Although a steel-reinforced, eight-inch (20.32 centimeters) thick earthen wall is strong enough for load-bearing walls, extra mass, coupled with good solar design, can offer better insulation and increased heating and cooling capacity. Compared to earth-sheltered houses, additional insulation may not be necessary in rammed-earth houses, depending on the area's climate.

Climate, soil composition, groundwater levels, and topography affect which type of earth-sheltered house is best for your site.

Alternative Construction Materials

A form of earth-sheltered house that has been receiving much attention is referred to as an "Earthship." These houses are built to be self-contained and independent; their design allows occupants to grow food inside and to maintain their own water and solar electrical systems. Some builders believe they have proven the design's ability to tap into the constant temperature of the earth and store additional energy from the sun in winter, although a back-up system, usually electric, may be recommended.

These Earthships carry out their environmentally conscious theme by employing unusual building materials in the form of recycled automobile tires filled with compacted earth for thermal mass and structure. Aluminum or tin cans are also used for filling minor walls that are not load-bearing. Foam insulation can be applied to exposed exterior or interior walls and covered with stucco. Interior walls can also be drywalled for a more conventional look.

Other Considerations

Waterproofing

Waterproofing can be a challenge in earth-sheltered construction. Keep in mind these three ways to reduce the risk of water damage in your house: choose the site carefully, plan the drainage both at and below the surface of the house, and waterproof your house.

There are several waterproofing systems currently in use, including rubberized asphalt, plastic and vulcanized sheets, liquid polyurethanes, and bentonite. Each has its advantages and the one you choose will depend on your site and house plan.

- *Rubberized asphalt* combines a small amount of synthetic rubber with asphalt and is coated with a polyethylene layer to form sheets. It can be applied directly to walls and roofs and has a long life expectancy.
- *Plastic and vulcanized sheets* are among the most common types of underground waterproofing. Plastic sheets include high-density polyethylene, chlorinated polyethylene, polyvinyl chloride, and chlorosulfonated polyethylene. Suitable vulcanized membranes or synthetic rubbers include isobutylene isoprene, ethylene propylene diene monomer, polychloroprene (neoprene), and polyisobutylene. For all these materials, the seams must be sealed properly, or the membranes will leak.
- *Liquid polyurethanes* are often used in places where it is awkward to apply a membrane. Polyurethanes are sometimes used as a coating over insulation on underground structures; however, weather conditions must be dry and relatively warm during their application.
- *Bentonite* is a natural clay formed into panels or applied as a liquid spray. The panels are simply nailed to walls; the spray is mixed with a binding agent and applied to underground walls. When the bentonite comes in contact with moisture, it expands and seals out the moisture.

Humidity

Humidity levels may increase in earth-sheltered houses during the summer, which can cause condensation on the interior walls. Installing insulation on the outside of the walls will prevent the walls from cooling down to earth temperature; however, it also reduces the summer cooling effect of the walls, which may be viewed as an advantage in hot temperatures. Mechanical air conditioning or a dehumidifier is often necessary to solve the humidity issue. Proper ventilation of closets and other closed spaces should keep the humidity from becoming a problem in those areas.

Insulation

Although insulation in an underground building does not need to be as thick as that in a conventional house, it is necessary to make an earthen house comfortable. Insulation is usually placed on the exterior of the house after applying the waterproofing material, so the heat generated, collected, and absorbed within the earth-sheltered envelope is retained inside

the building's interior. If insulating outside the wall, a protective layer of board should be added to keep the insulation from contacting the earth. Depending on the type of structure—wood, masonry, concrete, or steel—insulation may instead be placed inside the walls before the waterproofing material is applied.

Air Exchange/Air Quality

Adequate air exchange must be carefully planned when building an earth-sheltered dwelling. Generally, well-planned, natural ventilation or ventilation by exhaust fans can dissipate ordinary odors. Any combustion appliances that are installed should be "sealed combustion units," which have their own, direct source of outside air for combustion, and the combustion gases are directly vented to the outside. In addition, indoor pollutants emitted by formaldehyde foam insulation, plywood, and some fabrics can accumulate and become an irritant if ventilation is not properly planned.

A Home for the Future

If you are looking for a home with many energy efficient features that will provide a comfortable, tranquil, weather-resistant atmosphere, an earth-sheltered home could be right for you. With the general information in this publication and more details available from the sources listed below, you are on your way to owning a home that can protect you from the elements and the rising costs of energy and building resources.

Source List

The following organizations can provide you with more information on earth-sheltered construction.

American Underground-Construction Association
511 11th Avenue South, Suite 248
Minneapolis, MN 55415
(612) 339-5403

Rocky Mountain Research Center
P.O. Box 4694
Missoula, MT 59806
(406) 728-5951

Solar Survival Architecture
P.O. Box 2009
El Prado, NM 87529
(505) 751-0462
Fax: (505) 751-1005
E-mail: earthshp@taos.newmex.com

Texas Energy Extension Service
Center for Energy and Mineral Resources
Texas A&M University
College Station, TX 77843-1243

For information about many kinds of energy-efficient building ideas and renewable energy topics, contact:

The Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
(800) DOE-EREC (363-3732)
Fax: (703) 893-0400
E-mail: doe.erec@nciinc.com

EREC provides free general and technical information to the public on the many topics and technologies pertaining to energy efficiency and renewable energy.

Reading List

The following publications provide further information about earth-sheltered houses. The list is not exhaustive, nor does the mention of any publication constitute a recommendation or endorsement.

Complete Book of Underground Houses, R. L. Roy, Sterling Publishing Co., 1994.

Earth Sheltered Housing, G. Klodt, Reston Publishing Company, 1985.

Earth Sheltered Housing Design, J. Carmody, Van Nostrand Reinhold, 1985.

Earth Sheltered Residential Design Manual, R. Sterling, Van Nostrand Reinhold, 1982.

Earth Shelter Technology, L. Boyer and W. Grondzik, Texas A&M University Press, College Station, TX, 1987.

Earthship Systems and Components, M. Reynolds, Solar Survival Press, 1991.

Passive Annual Heat Storage: Improving the Design of Earth Shelters, J. Hait, Rocky Mountain Research Center, 1983.