Earth Sheltered Housing: An Old Concept Being Refined

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Abstract

Earth sheltered housing has always been used by man throughout the ages. The need to conserve energy has forced man to seek alternative methods of housing that will meet this need. Earth sheltered housing has been in the shadow of above ground structures for many years. Recently the value of earth sheltered housing has been reexamined and a great deal of work has taken place towards the refinement of this old housing concept.

In the process of refining an old concept many new ideas, materials, and problems have surfaced. There have been many trial and error approaches to refinement as well as many scientific and technological approaches in coming up with solutions to problems of earth sheltered design and implementation. In recent years much has been learned, tested, and written about, in the area of earth sheltered housing. It is the intent of this research to study the most effective designs and methods of building earth sheltered housing. In some issues a "best" method or design may not be determinable. Thanks to the work of a mall but growing number of individuals and groups interested in earth sheltered housing a lot has been learned in recent years. It is necessary to research the work of many different people and to synthesize the best presently known methods of earth sheltered housing implementation.

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Background of the Problem

Living in earth sheltered houses is in no way new to man. Caves served as man's first dwellings in prehistoric time (Martindale, 1979). Caves provided protection for man from the dangers of weather, wild animals' and other men. It seems that early man was very content with his early earth sheltered houses. He decorated his walls with the first graphic evidence of his life. To accommodate his growing population caves were often expanded into complex earth sheltered communities. After thousands of years of living in the earth man developed the tools and technology that allowed him to construct shelters above ground (Consumers' Research Magazine, 1980). Man's ability to live in structures above ground is clearly evident. Why man chose to give up the security of living in earth sheltered habitats for surface dwellings still remains partially unanswered. History clearly shows that mankind has not always made the wisest decisions. Maybe early man's choice to forsake the use of earth sheltered housing was a very unwise decision. For the most part man did abondon life in the earth. However, life in the earth started with the caveman and to some degree has always remained (Demperwolff, 1977).

Man first used earth sheltered houses for protection and continued doing so for thousands of years. Only recently has an emphasis been placed on reasons other than protection. In the recent past earth sheltered housing has been used in order to preserve open space and natural beauty. This desire to preserve nature became very secondary in the aftermath of the 1973 energy crisis. The oil embargo brought about a great need for energy conservation. Resorting to earth sheltered houses as a means to reduce energy consumption is providing strong impetus for a very old and reemerging type of house construction (Martindale, 1979).

Significance of the Problem

In the aftermath of the 1973 oil embargo and the resulting energy crisis it became very evident that a long overdue attempt to conserve energy must be made. At present, according to a 1978 report made by David Haviland and Walter Kroner to The National Solar Heating and Cooling Information Center, in the United States 100 million households are consuming three billion barrels of crude oil each year. This expenditure accounts for 20% of the United States total energy budget! Recent studies have indicated that fundamental construction improvements such as upgrading insulation, weatherstripping, and double glazing could reduce crude oil consumption by 25-35% (Haviland & Kroner, 1978). The utilization of passive designs by architects in house designs could increase the percent of savings well over the 35% level.

A form of passive design that has proven to decrease energy consumption is earth sheltered housing. Very reliable studies have verified that savings up to 80% for heating and cooling can be achieved (Consumer's Research Magazine, 1980). With the cost of energy rising, and no stopping point in sight, it is imperative that measures be taken to decrease the amount of energy consumed. It is exciting to imagine what would happen if the United States could cuts its household consumption of crude oil in half. Earth sheltered housing cannot account for a savings of 50% of all United States household consumptions by itself. It is, however, a very feasible, effective, and long lasting solution that can readily be used by many home builders to conserve energy.

Statement of the Problem

Earth sheltered housing has always been used by man throughout the ages. The need to conserve energy has forced man to seek alternative methods of housing that will meet this need. Earth sheltered housing has been in the shadow of above ground structures for many years. Recently the value of earth sheltered housing has been reexamined and a great deal of work has taken place towards the refinement of this old housing concept.

In the process of refining an old concept many new ideas, materials, and problems have surfaced. There have been many trial and error approaches to refinement as well as many scientific and technological approaches in coming up with solutions to problems of earth sheltered design and implementation. In recent years much has been learned, tested, and written about, in the area of earth sheltered housing. It is the intent of this research to study the most effective designs and methods of building earth sheltered housing. In some issues a "best" method or design may not be determinable. Thanks to the work of a small but growing number of individuals and groups interested in earth sheltered housing a lot has been learned in recent years. It is necessary to research the work of many different people and to synthesize the best presently known methods of earth sheltered housing implementation.

Limitations of the Study

Although earth sheltered housing has a very early beginning, it has not been until recently that strong consideration has been given to this type of living environment. Most of the literature pertaining to earth sheltered housing has been of recent origin. Many of the ideas and attempts in construction have shown that more research and better ideas are needed. The field is rapidly changing and even though the most recent information to date has been used, it is very likely that tomorrow will bring better design and construction methods that will be very important to future earth sheltered inhabitants.

Many types of structures have been built that use earth sheltered design. Factories, libraries, storage facilities, shopping centers, and many other structures have gone underground. This report will deal primarily with earth sheltered housing for single family occupany. In many aspects construction methods are the same for earth sheltered sewage treatment plants or housing. Ideas and results will be drawn from all types of earth sheltered structures and used in relationship to single family dwellings.

The United States is not the only area in the world where earth sheltered designs have been developed and implemented. Many other countries such as Japan, Sweden, France, and Russia

(Campbell, 1980) are building underground structures. This report however, is based on information pertaining to earth sheltered designs in the United States.

Definition of Terms

British Thermal Unit (BTU). The amount of heat required to raise one pounds of water one degree Fahrenheit

Earth sheltered housing. A term that includes a structure that has earth against it on one or more sides and/or has an earth covering on the roof. This term is used to encompass terms such as underground housing, underground architecture, terratecture, geotecture, terrasolatrium architecture, earth covered, earth integrated, and topotectonic platforms.

R-value. Represents the resistivity or resistance which is the reciprocal of conductivitiy or conductance. A good insulation material will have a high R-value.

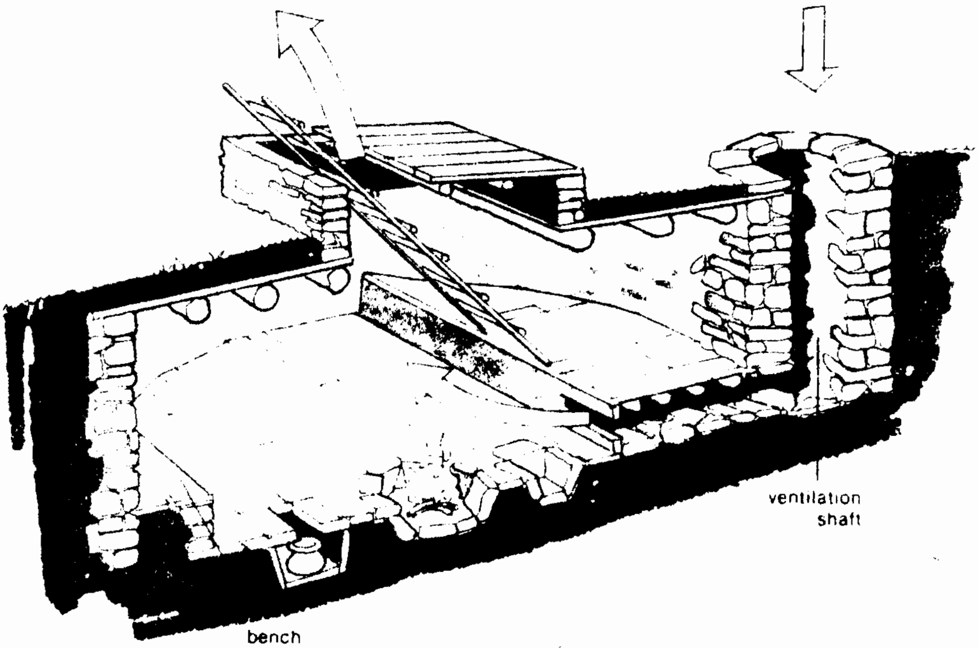
Review of Related Literature

Historical Developments

Mankinds use of underground space for living area is older than recorded history. Demperwolff (1975) writes, "Recently, archaeologists unearthed 5000-year-old subterranean villages in the Negev, where troglodytes protected themselves and their families from desert heat and smarting, windblown sand" (page 44). In more recent history when the Romans conquered Tunisia in Northern Africa they built their houses underground to escape the intense heat. In central Turkey 41 subterranean cities have been uncovered. One of these cities encompassed an area greater than two square miles. The city had eight to 10 different levels and houses animals as well as people (Consumers' Research Magzine, 1980). In his masters thesis, Kenneth Lads (1979) describes churches and towns that were cut from rock in Cappadocia, Turkey. Over 70 churches have been uncovered and the towns were uncovered in 1965. One town has a single entrance and covers an area of over six square kilometers. These structures are presently being inhabited even though they were carved-out over 1000 years ago (Demperwolff, 1977).

In the United States the only history we have of underground housing are the "kivas" built by early American Indian tribes in the Southwest (Campbell, 1980). Campbell (1980) points out that sod houses were constructed by early pioneers but were usually built of sod above ground. He adds that because of the very poor insulating qualities of earth that the sod house walls would have an R-factor of about one by todays standards.

In northern and western China it is estimated that over 10 million people are living underground in order to receive protection from the bitter cold winters (Demperwolff, 1977). Living underground serves an additional purpose in China. By living below the earth's surface more land is left to be farmed. From aerial photos smoke may be seen rising from small smokestacks in the middle of a cultivated field (Moreland, 1976).



Underground "kivas" are still preserved in Mesa Verde National Park. They're the only archeological evidence of underliving on the North American continent. At first, they were used for religious purposes. Later, the ingenious ventilation system made them suitable for habitation.

Figure 1. Cross-section of underground "kivas" (Campbell, 1980, p. 11).

Modern Developments

It is estimated that less than 3000 earth-sheltered homes were built prior to the end of 1979 (Wall Street Journal, 1979). Campbell (1980) suggests that anyone building a subterranean house before 1980 be considered a pioneer in the development of earth sheltered housing.

Even though the architect, Frank Lloyd Wright, is not normally associated with earth sheltered housing, he is considered to be a pioneering architect in the field (Campbell, 1980). Wright designed a boathouse at the turn of the century using many concepts of todays underground architecture. He put these concepts to work for Herbert and Katherine Jacobs, of Madison, Wisconsin in 1943. Wright named this house the Solar Hemicycle and said that it's design was suitable for use anywhere in the country (Campbell, 1980).

In the past few years there has been a great surge in the use of underground space. For example, Japan has more than two dozen shopping centers located underground. Radio City, New York has a large underground shopping mall. Sweden has been building factories, power plants and sewage treatment plants underground for a number of years. Place Ville Marie and Place Boneventure in Montreal, Canada are underground as are Les Halles in Paris, France and the Vienna Opera House plaza. In Artesia, New Mexico children have been attending school underground for the last sixteen years. There is also a school in Reston, Virginia that can accommodate 1000 students underground. Many institutions of higher education are building underground for a number of reasons. At the University of Northern Iowa in Cedar Falls, Iowa, the university union received a progressive architecture award in 1967 (Moreland, 1976).

At the University of Minnesota in Minneapolis, Minnesota, the university book store and admissions office are located in an 83,000 square foot structure that is 95% underground. Williamson Hall was built underground in order to conserve energy, preserve the view of two historical campus sites, and make pedestrian traffic continue to flow unimpeded. Due to the Underground Space Center at the University of Minnesota, Williamson Hall has been a testing ground for earth sheltered design (Martindale, 1979).

At present the largest use of underground space in the United States is in Kansas City, Missouri. There, a subterranean industrial complex is located 50-200 feet below the surface. The complex is a result of caverns left after limestone is created (Martindale, 1979). In 1980 over 100 companies employed over 2000 people in this industrial park. One company, Inland Storage Distribution Center, has more than 38 million cubic feet of food storage. This company estimates that it saves energy equal to the amount of energy consumed by 7,600 homes aboveground.

The amount of underground construction taking place at present is not easily determined. Consumers' Research Magazine (1980) estimates that there are 200 underground or earth sheltered homes in the United States with an additional 400-500 homes on the drawing board or under construction. This is in contrast to the

3000 houses built by the end of 1979 as reported earlier by the Wall Street Journal. Further uncertainty is added by Lorenz (1980) who reports that 50,000 underground homes have been built across the United States in the last few years. The exact number is not important. What is important is the fact that earth sheltered construction is growing. Frank Moreland is presently designing a 600-acre underground housing facility for Dallas, Texas (Consumers' Research Magazine, 1980). Campbell (1980) states:

> By 1985, 39 percent of our residential space and 40 percent of all commercial buildings will have been constructed after 1974. That's what the Energy Research and Development Administration (ERDA) tells us, anyway. How much of this space will be underground is hard to predict.
>
> Proponents of underliving would have us believe that in-earth structures will constitute as much as 30 percent of the housing market by the mid-1980's - an optimistic projection, it seems (pages 10 & 11).

Advantages of Earth Sheltered Housing

Energy conservation. There are many advantages to living in an earth sheltered home. Today, the most important advantage is the opportunity offered by earth sheltered design in the area of energy conservation. This opportunity is present because of a variety of reasons.

The main reason that earth sheltered homes conserve energy is because the soil or earth is a very good temperature moderator.

Earth has the ability to absorb heat in large quantities over a long period of time and then release the stored heat over an equally long period of time. Many people confuse temperature moderation with insulation properties. These two attributes are in fact very dissimilar. Earth does have some insulative properties, but they are very poor. According to Demperwolff (1977), three feet of earth has the same thermal resistivity as .75 inch of polyurethane or 1.50 inches of fiberglass batts. He continues to point out that although the thermal resistivity is poor a three foot layer of soil around a 1600-square-foot house would weigh over 800 tons and could store 300,000 B.T.u's. Since the earth is a good moderator at a depth of approximately 10 feet the soil temperature stays fairly consistent all year round. Ground temperature is often referred to as well water temperature. From 10 feet down to 100 feet the earths temperature is very similar and water coming from a well would indicate the temperature of the earth (Labs, 1979). Due to constant earth temperature at depths greater than 10-12 feet, the top 10-12 feet of earth changes temperature much slower than the air temperature. This slow changing characteristic is known as thermal lag (Metz, 1979) and is very important in temperature moderation. Thermal lag creates what is called a thermal flywheel affect in temperature moderation. The results of the thermal flywheel affect is that soil temperatures,down to 10 feet,lag average air temperatures by about three months. This results in the August hot weather arriving in November to heat the house and the cold weather of February starting to cool in the month of May (Wells, 1977).

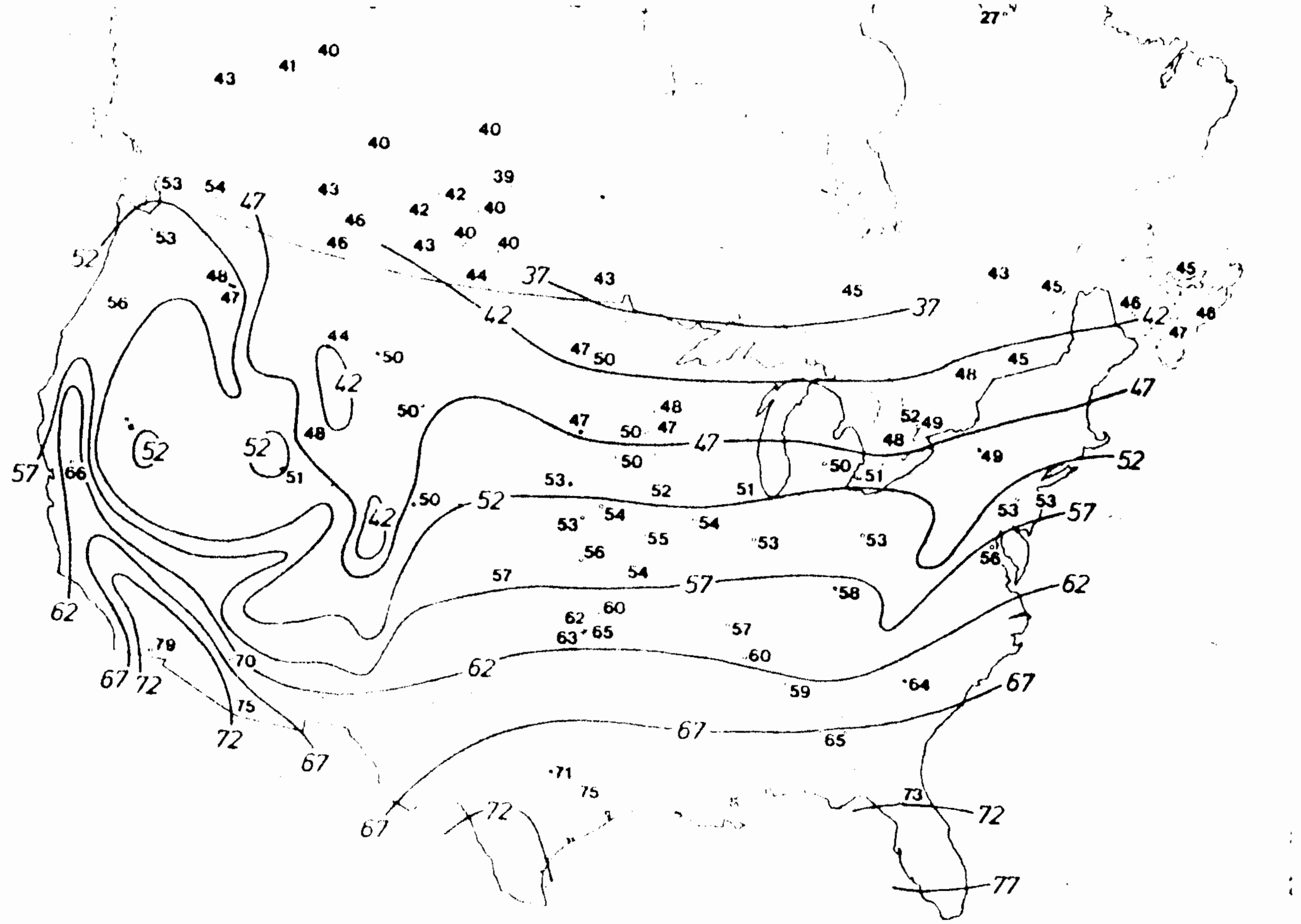


Figure 1. Collins' estimated well water isotherms are superimposed on reported T_g values from individual earth temperature stations in the U.S. and Canada. Note that observed ground temperatures are higher in northern regions than predicted by Collins. This is attributable to the insulating effect of winter snow cover.

Figure 2. Estimated well water isotherms (Labs, 1979, p. 44).

Labs (1979) has a formula to determine actual lag time. A fairly accurate conclusion is that for average soil conditions, the soil temperature will lag the air temperature by one week for every foot of depth.

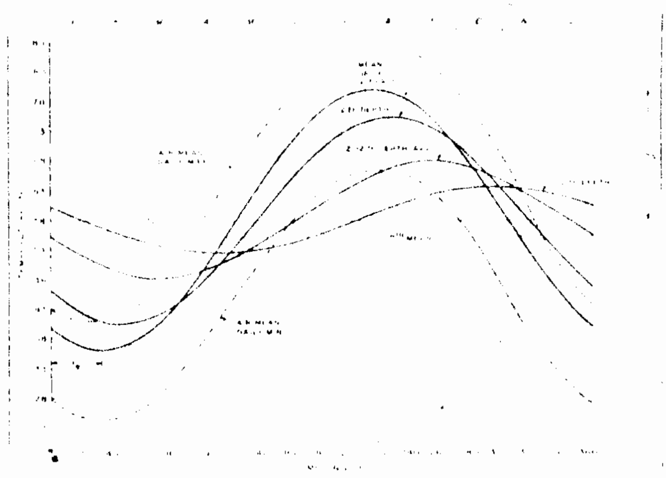


Figure 2. Temperatures at different depths are compared here to daily and annual ranges of air temperature. Note typical excess in T_m over mean annual air temperature, and attenuation of amplitude and accompanying phase shift with depth. Values correspond to generalized conditions at Lexington, Kentucky.

Figure 3. Daily and annual temperature ranges (Labs, 1979, p. 45).

An earth cover acts as a good blanket and prevents a cold wind from stealing heat from the outside of a building (Dean, 1979). In other words, an earth sheltered building does not lose heat due to wind chill. The presence of earth also reduces heat loss due to air infiltration (Zubarth, 1980). Air infiltration is one of two methods by which heat loss occurs. According to The Underground Space Center University of Minnesota (1979), air infiltration can be greatly reduced or eliminated by earth covered construction.

Another means by which energy can be conserved with earth sheltered housing is through the use of passive solar energy. Depending on the method of construction many underground houses are beautifully designed for passive solar energy. Most earth sheltered houses to date are made of concrete or concrete blocks. These construction materials have the ability to act as heat sinks if the structures are designed correctly in accordance with sunlight. Due to the fact that earth sheltered houses are very energy efficient they require a much lower energy input. Consumers' Research Magazine (1980) reports that solar collectors for common construction houses require one square foot of solar collector for every two square feet of living space. Underground houses require only one square foot of collectors for every 10 square feet of living space.

Energy savings are very important for home owners and of course along with energy savings comes financial savings. Just about every article on earth sheltered housing expounds the percent of savings for heating and cooling. Most owners or authorities claim energy savings of 50-80%. Lorenz (1980) states that claims of 85-90% should not be believed. Whatever the energy savings are and assuming they are at least 50% another savings is seen. Heating and cooling units do not need to be near as big in order to supply the lower requirement of heating or cooling. This creates a savings in money and space.

An earth sheltered home owner in Provo, Utah reports that he loses 12,000 BTUH when the outside temperature is zero degrees Fahrenheit. A conventional home under similar conditions give up 55,000-60,000 BTUH. His house is heated with a 41,000 BTU mobile home furnace that operates about two hours each morning (Mother Earth News, 1978).

Another home owner reports that he left his underground house for six days when the temperature dropped to zero degrees Fahrenheit. Without any source of heat other than passive solar and the earth the house temperature dipped to only 57°F. During a summer heat wave in 1980 the internal air temperature rose to a high of 86°F. when the outside temperature was well over 100°F. (The Mother Earth News, 1980).

In an interview with The Mother Earth News, (1977), Andy Davis tells how he heated his earth sheltered house (Davis Cave in Armington, Illinois) over an entire winter for $1.29. Davis got his wood free by cutting down old trees that the city wanted removed. He figured he spent $1.29 on gas and oil for his chain saw. But, since he didn't need all the wood he cut out for $1.29 that winter, he was looking forward to a substantial cut in his heating bill during the next year. His house is even unique as earth sheltered houses go. It faces west instead of the normal south or east so it doesn't receive the heating effect of the sun in winter. When asked if he would change this fact if he could so that his house would be even easier to heat he replied "...I don't know...$1.29 is hard to beat for fuel the way it is.... We just took the hill we had to work with as we found it, and that hill faced west a long time before we decided to build a house in it." (page 28)

Preservation of earths natural surface. One very important purpose of underground housing is to preserve the environment both physically and visually (Demperwolff, 1977). The United States is starting to feel pressure that many other countries have felt for hundreds of years. We are running out of available land for farming, constructing buildings and living in general (Campbell, 1980). Frank Moreland is designing an underground housing development that will have 86% clear surface area instead of the normal 56% (Consumers' Research Magazine, 1980). An increase in surface area will allow for more trees, grass, and flowers that not only look better than black shingle roofs but serve the purposes of increasing oxygen production, providing more living space, and creating a cool insulating cover for the homes below.

Minimal maintenance. Depending on the design and materials used in the construction of an earth sheltered house maintenance may be completely eliminated or greatly reduced at worst (Calvert, 1979). If all that is exposed is concrete owners can catch up on their golf, tennis, or other recreation while their neighbors are busy residing, painting, or staining. Some underground houses may require a little touch up work on redwood trim for instance but usually only one side is left exposed so they only have one-quarter of the work. The expense of replacing shingles or roofing materials are also eliminated. Care for the roof of an earth sheltered house may consist of mowing the fireproof, naturally green cover every now and then.

Soundproof. "Natural soundproofing is a major fringe benefit of living in the ground." (Campbell, 1980, page 30) Proof of this fact can be shown by asking the Andy Davis family. When a neighbor's fence was broken a herd of cattle traveled across their roof and no one inside heard a thing (The Mother Earth News, 1977). The fact that the earth is a good soundproofing media makes some land sites more attractive. Malcolm Wells purchased a lot just 20 feet from a busy interstate. After building an office underground he reports that once inside the earth covered structure no sound of the interstate can be heard (Wells, 1977). In Oklahoma there are 27 school systems that are at least in part underground. Teachers report that the lack of noise and distractions make it much easier to keep students attentions (Bannon-Harwood, 1980). To some people the lack of noise is the only annoying factor. Gilbert Kopp, the owner of an earth sheltered house in Maquoketa, Iowa, commented at an Energy for Iowans conference that it took his family a while to ..."get used to the quiet."

Air pollution. It has been explained how an earth sheltered structure greatly reduces air infiltration. Air inside an underground structure can be more closely regulated and filtered if necessary. Rinker (1978) reported that doctors in New Mexico have sent children with respiratory problems to a local earth sheltered elementary school to help clear up the ailments.

Humidity. Just as the earth moderates temperature change it also has a strong tendency to moderate a change in humidity. Many home owners report that the humidity level usually stays around 50% the year round (The Mother Earth News, 1977). If the structure is composed of concrete it will be necessary to dehumidify the air for a period of time while the concrete is curing. The period of time may be a year or so because all the moisture must be released into the structure since the external waterproofing will prevent moisture from going out (The Underground Space Center University of Minnesota). Because the humidity remains constant under most conditions there is a more consistant living environment. A humidity level of approximately 50% will help reduce static electricity, drying-out of wooden furniture, will keep a lower humidity in summer when outside humidity may be much greater, also humidity in the winter time will cause a lower temperature to feel warmer to inhabitants. If the humidity level is too high it can easily be reduced by a small dehumidifier at a very low cost. Excessive humidity if not controlled may cause pipes or fixtures to rust and condensation to occur on windows.

Superior durability. At present most earth sheltered houses are formed from reinforced concrete. If proper procedures and materials are used the structures should last indefinitely (Metz, 1979). Concrete does not rot and is not attractive to termites, rodants or other destructive plants or organisms.

There are some houses being built out of treated wood. This material will be more thoroughly examined later but for now it is enough to state that it is resistant to destructive forces as is concrete. Because it is a fairly new product its life cycle is yet to be determined (Metz, 1979). Another new method uses wood and fiberglass to make panels. Calvert (1979) reports that the panels will last at least

40 to 50 years and can see no valid reason why they will not last much longer.

Increased security. The final advantage of earth sheltered housing that will be discussed is security. An increase in security is due to many different reasons. Campbell (1980) points out that since earth sheltered houses blend into the environment they are less conspicuous and therefore less attractive to thieves. They are also easier and cheaper to make secure because there are normally fewer windows and many times windows and doors are present on only one side of the structure.

Fire hazards are much less because the main building media; concrete, will not burn. Because of this factor some insurance companies are offering owners of earth sheltered houses lower rates.

Many natural catastrophes that could completely destroy a structure above ground will have very little if any affect on underground structures. Because of the protection that the earth provides against wind storms and tornadoes there are many earth sheltered houses being constructed in areas that have had high occurances of tornadoes (Campbell, 1980). Storm related hazards such as hail, lightning, and falling trees will have very little effect on underground houses or people within them.

Flooding could damage earth sheltered houses just as easily as houses above ground are damaged. However, areas that have high water tables or low lying areas that may be damp are not good sites for building underground. For this reason, most underground structures are built on higher ground and are not in a location that would be susceptible to flood waters.

Even earthquakes should not effect underground houses if they are designed and built properly. Houses built underground should move with the ground and not in opposition to it as do structures above ground. Of course a fault going directly through an earth sheltered house could ruin the owners and inhabitants entire day. This is not too likely and even if it did occur a house built above ground would not be any safer (The Mother Earth News, 1977).

Disadvantages of Earth Sheltered Housing

Attitudes. At the present the most prevalent disadvantage of earth sheltered housing is centered around the myth that living underground is like living in a cave. Most people think they would be living in dark, damp, depressing atmosphere, surrounded by walls ready to collapse at any moment (Demperwolff, 1977). In fact the only truth in the above statement is that if the structure is made of concrete it could be damp in the initial years until the concrete sures. However, the dampness would cause no problem and would not even be noticeable if proper ventilation and a dehumidifier were used (Better Homes and Gardens, 1980). With houses that have been properly designed and constructed most people, if blindfolded and placed into an earth sheltered house then allowed to see, could not tell if they were above or below ground. There are some people who, for whatever reason, are just psychologically opposed to living underground (Martindale, 1979). As more information is being disseminated to the general public attitudes toward living in earth sheltered structures are changing.

Financing. There is some concern by banks and other lending institutions that earth sheltered houses are a fad (The Mother Earth News, 1978). There is also a reluctance to invest money into an as yet unproven market (Campbell, 1980). Banks are weary of a borrower defaulting on a loan and leaving them with a structure that they will be unable to sell. Campbell (1980) describes a vicious cycle that is present in earth sheltered financing. He points out that bankers want more facts and figures pertaining to earth sheltered designs. In order to create data houses must be built and the market tested. If contractors cannot get the financing needed to build houses of this nature the banks will not get their desired facts and figures. At the present the federal and state governments are leading the way with loans from their various agencies such as the Federal Housing Administration. It is expected that that private lending agencies will follow the example set by state and federal governments. Experts in the area of earth sheltered housing all agree that potential borrowers must be able to sell their plans and ideas to lenders. A good working knowledge of underground housing is important. It is also strongly suggested that all plans be drawn or varified by a competant architect and that a reliable contractor be contacted if lending institutions are going to be expected to invest their money. One plus that earth sheltered advocates have going for them is the fact that energy prices will continue to rise. If there is one fact that no one can argue about concerning underground houses it is that they are energy efficient. Most lenders can see that lower energy bills will allow borrowers to be able to make payments much easier (Campbell, 1980).

Zoning and building codes. Most zoning and building codes on the books today were written with conventional housing in mind. There are so many as 1700 different building codes in the United States. Some of the codes contain ordinances that very a great deal from laws of nearby cities or towns. In many cases laws are present that rule out the possibility of earth sheltered homes. It is possible to gain a variance in some instances but that may be a lond and frustrating experience. It is much easier to build a house in compliance with local standards than it is to try to get around the local coes (Campbell, 1980).

There are many examples where codes designed for conventional housing do not allow or advocate earth sheltered structures. Many codes state that each habitable room be designed to allow a fire-escape route and natural lighting. Natural ventilation may be required in each room as well as a minimum amount of glazing requirements. A real problem to design around occurs when there are certain roofing materials that are specified. Obviously roofing materials that are safe and sound above ground cannot be expected to perform adequately on underground structures

(Campbell, 1980). At present there is a great need for states to follow the example set by Wisconsin. On January first, 1980 a new state wide policy went into effect in the state of Wisconsin. The new codes were the first in the country to consider and allow for the unique characteristics of underground buildings (Campbell, 1980). In the future there may be dual sets of codes. One for above and one for below ground structures. Another aspect of building energy efficient buildings that is certain to end up in court concerns laws relating to sun rights. If the interest in earth sheltered designs continues as it has , Campbell (1980) predicts that the decade of the eighties will be very active and important in areas of laws, codes, and policies dealing with underground housing.

Design and construction experience. Martindale (1979) describes a disadvantage of earth sheltered design that has been mentioned by many other advocates in this area. The disadvantage at present is that there is a major shortage of architects and contractors with experience in the area of underground housing. Most architects have little or no working experience. One leader in the field, Malcolm Wells (Wells, 1977) writes that he can only supply service for a few selected projects each year. He suggests getting in touch with local architects and looking around until an architect with experience is found. It would appear, however, that architects are in a similar position of builders trying to borrow money. Banks want data before the loan and builders want experienced architects and contractors before they will hire them. It would appear that it is very necessary for all facets of home building to work together towards a common goal. A good amount of trust between parties may be necessary to achieve the end result of living underground. Also, based on a review of the literature it would appear that a person with an interest in architectural design or construction could get involved in a very promising future by working toward competency in earth sheltered construction and design.

Expansion problems. This disadvantage may not be encountered by most builders but it is important to take into consideration. Because of the nature of earth sheltered construction, adding another bedroom or enlarging the garage may be a very expensive venture if undertaken after completion of the structure. Original designs and living requirements must be carefully considered in order to avoid later construction costs (Martindale, 1979).

Radon effects. A final disadvantage of living in an earth sheltered house may have to do with radiation dangers. This question is still being investigated but it may be an important disadvantage to houses built out of rocks and surrounded by soil. Structures made of large amounts of brick, stone, or concrete give off a natural pollutant called radon that is a radioactive gas. The reason that radon is a problem in earth sheltered houses and is not a problem in surface structures made of smilar materials is a result of an earth sheltered advantage. The lack of air infiltration into underground structures allows the radon level to increase. In conventional houses or public buildings, air infiltration and forced ventilation keep the radon level very low. In an earth sheltered house designed with proper ventilation radon gas should not create a hazard (Earth Shelter Digest & Energy Report, 1980). Radon is a result of the decay of radium that is found everywhere in the soil and in many building materials. Dr. Harold May has been studying radon effects for the last two years. His conclusion is that conventional houses are just as or more likely to have higher levels of radon than earth sheltered housing and that more research is needed. May explains how proper waterproofing and drainage will keep the level of radon low by preventing radon from entering the structure out of the soil. May stated,"I believe there is no reasonable expectation of detectable radiation effects upon individuals living in earth-sheltered houses, at least if they continue to be built without infiltration of radon-rich soil gas and are ventilated as well as those reported so far. If there is cause for apprehension it applies equally to many conventional houses " (Earth Shelter Digest & Energy Report, 1980, page 20).

Costs of Earth Sheltered Houses

This aspect of earth sheltered housing receives special attention because it is not easy and may not be possible to determine whether or not cost of a structure is an advantage or disadvantage. Even among the leading experts in the field there is a discrepancy over a range of approximately 30%. This range is attributed to differences in soil conditions, site locations, methods of construction, materials used, and how much of the work is hired out. John Barnard's Ecology House cost $27.00 per square foot in an area where conventional houses cost from $30-$40 per square foot. On the other side of the coin Malcolm Wells states that underground structures cost 10% more than a similar aboveground house (Demperwolff, 1977). Additional structural requirements and waterproofing costs may raise the overall costs but Zubarth (1980) explains that these additional costs are offset by the elimination of exterior finish costs.

Dean (1979) breaks the cost of construction into different categories. He estimates that construction costs will range from $40-$60 a square foot. Builders, he says, anticipate a profit of from 10-15%. Twenty percent of the inital cost is for lumber, nails, gypsum board and other basic materials for a conventional house. For an earth sheltered structure made of concrete the basic concrete structure would run 20%. A major portion of the expense goes to plumbing, heating and cooling, wiring, kitchen equipment, insulation and finishing materials for floors, walls, and ceilings. Dean states, "Constructing a house underground does not reduce its cost. There is additional expense because of additional structural and waterproofing needs. The value of an underground house lies in its' long-term effectiveness through lowered energy consumption " (page 106).

Consumers' Research Magazine (1980) has determined that earth sheltered homes are generally competitive in cost with conventional homes. No special technology or materials are needed. They state that any competent contractor should be able to do a good job.

Ralph Bullock advertises that people can save up to 20% installation charge by doing the work themselves. He further expounds that a Solartron house (will be discussed more later) is equal to or less than conventional structures.

Lorenz (1980) feels that earth sheltered houses can be built for less than convention homes, "...but beware of a contractor saying significantly less " (page 44). There are however builders that make the claim of substantially less. Hedden (1979) built a house that contained 2,000 square feet of living space. This included an 11 foot x 29 foot garage. He estimates his cost at $15 per square foot. Another home owner built a post-and-beam earth sheltered house that contained 3,400 square foot. This included a 950 square foot garage. The cost of the structure was $80,000 or a low $23.52 per square foot price tag.

The initial cost of an earth sheltered house will vary a good deal from house to house. For estimating cost it would be safe to say that the cost would be equal to the cost of a conventional house. The price would vary plus or minus approximately 10 percent. If the owner could do some of the work himself the cost would be less. If the design was a little more elaborate or if the building site, materials, or methods of construction were unique the cost could be higher. There is one cost aspect that is certain. After the initial cost the price of owning and operating an earth sheltered house is lower than a conventional house. There is general agreement between people in the field that prices for earth sheltered homes will drop slightly as more architects and contractors become familiar with this type of building.

Design of an Earth Sheltered Structure

Site selection. Finding the perfect site for an earth sheltered house is not an easy task (Campbell, 1980). Many times the builder must compromise on some aspects of his design in order to build on an available site. There are some criteria for a site that cannot be compromised. Soil type is of great importance. Soil is composed of four basic elements - sand, gravel, silt, and clay. Most soils are a combination of two or more of these elements (Labs, 1979).

SOIL CLASSIFICATION SYSTEM USED BY THE UNITED STATES DEPARTMENT OF AGRICULTURE (SEE LYNCH)

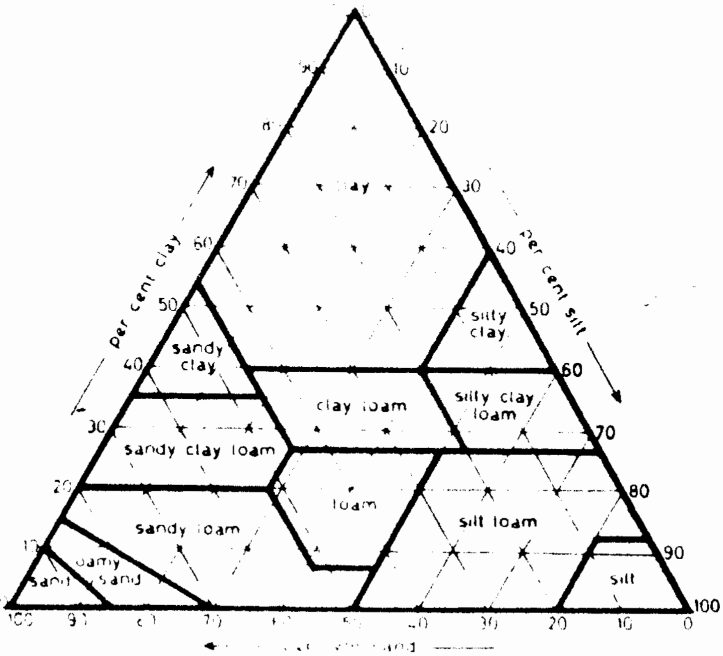


Figure 4. Soil classification system (Labs, 1979, p. 1113).

It is necessary to have a soil that has proper strength to support a structure, drainage, and percolation in order to allow moisture to be moved away from the structure. Different types of soil also vary in weight. This fact is very important for design of proper structural strength (Well, 1977).

Orientation of a site in reference to the sun, wind and even neighbors is very critical. For most beneficial solar application the front of the house should face south. Campbell states, "The perfect exposure for a window meant to collect solar radiation is 15 degrees west of true south, but 20 degrees to either side of this point is still excellent " (page 21). He also states that a southern exposure should be the number one consideration after proper soil is located. There are others who have designed and built buildings that are not oriented towards the south. Andy Davis (The Mother Earth News, 1977) is a prime example of orienting a building to a lot rather than the sun. Malcolm Wells has elected to design a building facing east in order to prove that it will work and to show that lots oriented to the east can be used for earth sheltered structures (Wells, 1977).

In the United States the prevailing winter winds are from the northwest. Protecting the building from cold winds can greatly reduce heating costs by stopping or limiting heat loss due to wind chill effect and infiltration (Sterling, 1980). In the summer the prevailing winds are from the southeast leaving the house open to these winds will help to cool the house and aid in proper ventilation of the structure.

The location and orientation of a house will of course determine its' view. In underground housing there are more factors involved. Because an earth sheltered house many set low into the ground the view may be hindered. It is also important to note that neighbors may be in a position to look down into a house. Houses should be designed so that desired privacy can be achieved as well as a desired view.

Type of design. The site selected may very well determine the type of earth sheltered design or the design may determine the site selected. What comes first is not always easy to determine. There are many types of design for earth sheltered houses. Most generally they fall into one of two basic types. A bermed structure is built on grade then covered with earth. A chamber structure is built below grade (Dempewolff , 1977). Each of the two basic types can be further subdivided into four styles. A vault sytle is just a box or area completely covered on all sides by earth. There is of course an entrance, and skylights could be present. A vault would be the most efficeint in relationship to using the warmth or temperature moderation properties of the earth. It would not loan itself to passive solar collection because of its covering. Proper ventilation could be a design problem in a vault structure.

An atrium is a courtyard surrounded by a house. This style allows light to enter all rooms that face the atrim. This style also meets the demands of many codes that require direct fire exits or a certain amount of glazed surface. The atrium may or may not be covered. Some houses are designed so that a cover may be removed if desired (Mother Earth News, 1978). An atrium will require special design consideration in order to reduce or eliminate air turbulance in the atrium. Proper drainage must also be designed into the structure since an open atrium could catch a lot of rain or snow (Dean, 1979). John Barnards' "Ecology House" uses an atrium style and it allows them a sunken patio complete with flowers, pool, and trees (Demperwolff, 1977).

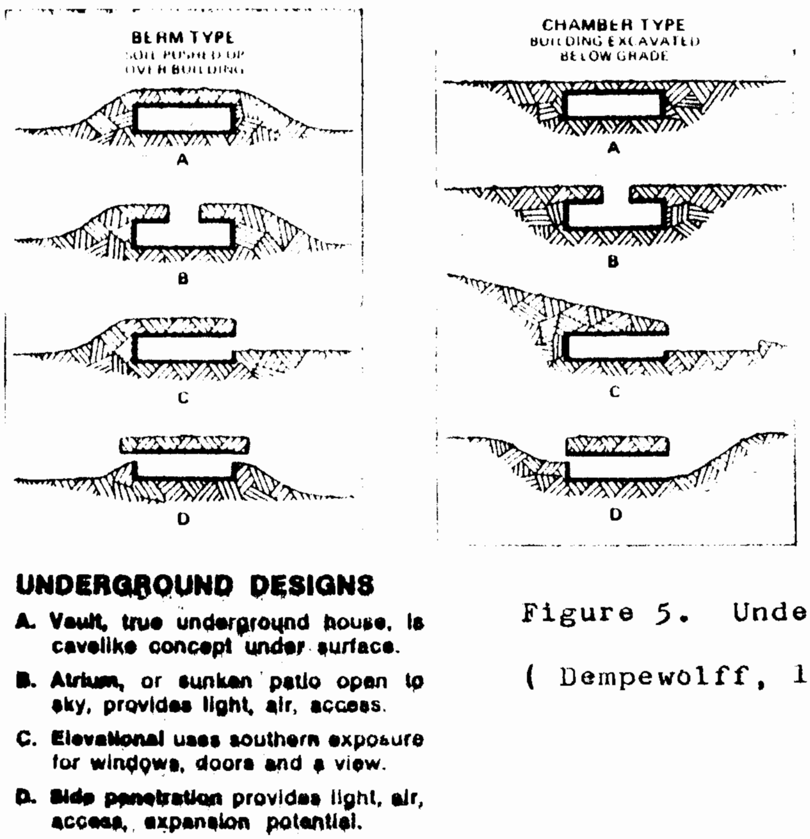


Figure 5. Underground designs (Dempewolff, 1977, p. 80).

An elevational style generally has the south side of the structure open to allow for windows, entrance and a view. In a style of this type special consideration must be given to ventilation since the only openings may be on the south.

A side penetration style would have at least two sides left open. Probably the east and south sides. This style allows light and air to enter readily if desired. This particular style could also allow for later expansion at a reduced cost in comparison to expanding other styles (Demperwolff, 1977).

The eight types and styles shown in figure five are the most basic ideas. There are many hybrids that may combine different types and styles. These styles are all for a single story structure. Multi-story structures may be built but they require special design due to greater strength requirements (Lorenz, 1980).

Footings. Because earth sheltered houses carry a much greater weight directly overhead larger footings are required. Footings are made of concrete and these should be reinforced with steel reinforcement rods so that the footings will have an even bearing on the soil. When greater strength is needed, the footings should be reinforced rather than deepened. Spread footings are most generally used because they provide a lot of surface area, strength, and stability (The Underground Space Center University of Minnesota, 1979).

Drainage. Labs (1979) suggests that the best method of dealing with soil water is to drain it away from the building as quickly as possible. If the surface is contoured correctly a lot of surface water will drain away from the building by gravity. Any water that soaks into the soil should be removed by a system of drain tiles and backfill that allows for fast drainage. "Regular four-inch perforated drainage pipe should be placed in a bed of 1-1½-inch crushed stone at the base of the concrete footings. The holes in the pipe face towards the five or seven o'clock position, not directly down " (Campbell, 1980, page 67). According to The Underground Space Center University of Minnesota (1979) the use of drains will remove ground water and also decrease the need to design strength into the walls and floor to compensate for positive water pressures. The tiles should be placed as low as possible in respect to the foundations. Drainage tile must completely encircle the footings and may be placed beneath the floor as well. The tile should be placed at a slight angle to allow for gravity flow. The tile must be able to dump the water into a well or leach field Care must be taken if the tiles are dumped at the surface in order to prevent clogging due to ice formation in the winter (Campbell, 1980). Campbell (1980) states, "Engineers often advise that wherever possible, ground water should be drained by gravity rather than mechanical pumps. 'It's less expensive and more reliable. Gravity never breaks down" (page 67).

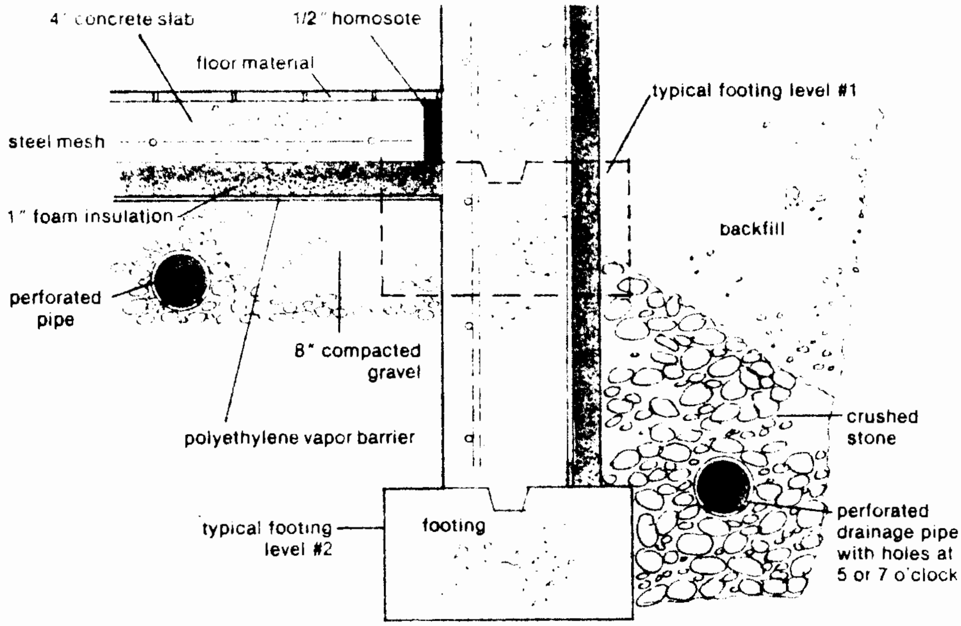


Figure 6. Typical wall base and footing cross-section (Campbell, 1980, p. 66).

Shell design. The shell of an earth sheltered house consists of the walls and roof of the structure. The shell rests on the footings and must be strong enough to withstand the weight and pressures exerted on it. There are many types of shell materials that are in use today. By far the most widely used material is concrete (Campbell, 1980). Concrete gets stronger as it gets older and is very versatile to work with. Concrete may be cast in place around reinforcement bars inside of forms. It may be precast into panels for walls or planks that are used to span overhead distances. Concrete has a very high compression strength which makes it ideal for dome type structures. Concrete can be ordered in a variety of strengths. The strength depends on the amount of water, amount of cement, and the size of aggragate added. Norton (1980) suggests that a medium strength concrete mix be used. This mix would contain 520 pounds of cement per cubic yard. He also states than an often used admixture called fly ash not be used in earth sheltered buildings. "Because many concrete suppliers use fly ash as a matter of course unless specifically asked not to, special attention regarding this matter is required" (Norton, 1980, page 659). Andy Davis elected to go with a stronger mix of concrete. He chose 4000 pounds per square inch (psi) concrete for his walls and roof. Don Metz suggests 2500 psi concrete for footings and floor slabs. He uses 3000 psi mix for walls (Campbell, 1980).

Concrete block walls can be used instead of cast-in-place or precast concrete. However, block walls need more reinforcement and must be filled with concrete in order to withstand horizontal and vertical pressures. Block walls would probably cost more than poured concrete walls (Demperwolff, 1977).

The use of concrete offers a builder many directions to go. A house could have block walls with a plank roof, plank walls and roof or cast in place walls and roof. In fact one firm, Terra Dome Corporation has special aluminum and fiberglass forms that allow the walls and domed roof of a 24 foot square and 12 foot high module to be poured all at once (Scafe, 1979).

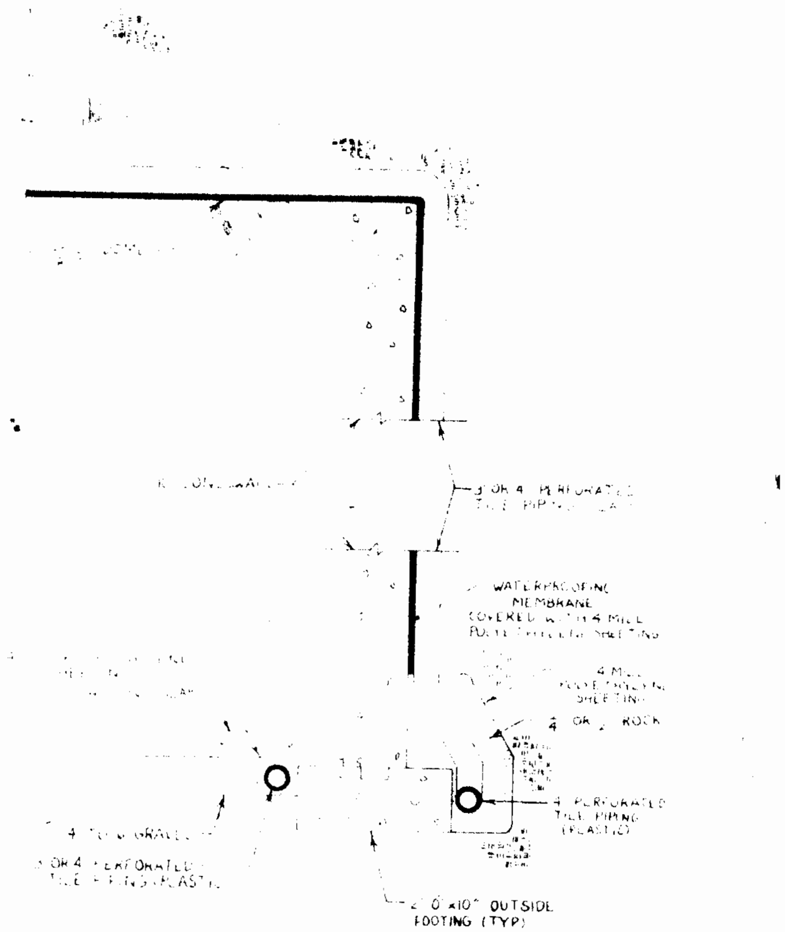


Figure 7. Drainage diagram (Scafe, 1979, p. 26).

Calvert (1979) reports about a firm that started to make planks or precast sections of concrete that could be shipped to a building site and constructed. In an effort to reduce shipping charges the firm developed wood and fiberglass panels that weigh only 300 pounds for wall planks and 500 pounds for reef panels. They can be easily assembled by hand. The panels are made by nailing two 5/8 inch pieces of construction grade plywood to a 2 x 6 framework that has studs 16 inches on center. The panel measures eight feet by nine feet four inches. Both sides of the plywood are laminated with a fire retardent resin and layers of fiberglass. When a panel that is seven-1/8 inch is built up a fine mesh glass veil is laminated to the exterior portion of the panel to waterproof the panels. The panels are put together by tongue-and-groove or shiplap joints. Roof portions are convex in order to prevent build up of water. The roof sections are glued to the edges of the wall with a bead of pliable silicone sealant. The panels are designed and tested to withstand a load of 550 pounds per square foot. Because the panels are light and can be put in place by two men, a standard 1,231 square foot building can be constructed in about eight hours.

Shells may also be made of corrugated steel road calverts or specifically designed steel arches. The inside of the arches are covered with insulation and can be ordered in about any practical size. Corrosion of the steel remains a problem with this type of construction. Presently these types of structures are used as forms onto which a material such as gunnite is sprayed. After the gunnite sets up the forms are removed. The shape of an arch gives it a lot of strength so thin walls of gunnite can support a great deal of weight (Campbell, 1980).

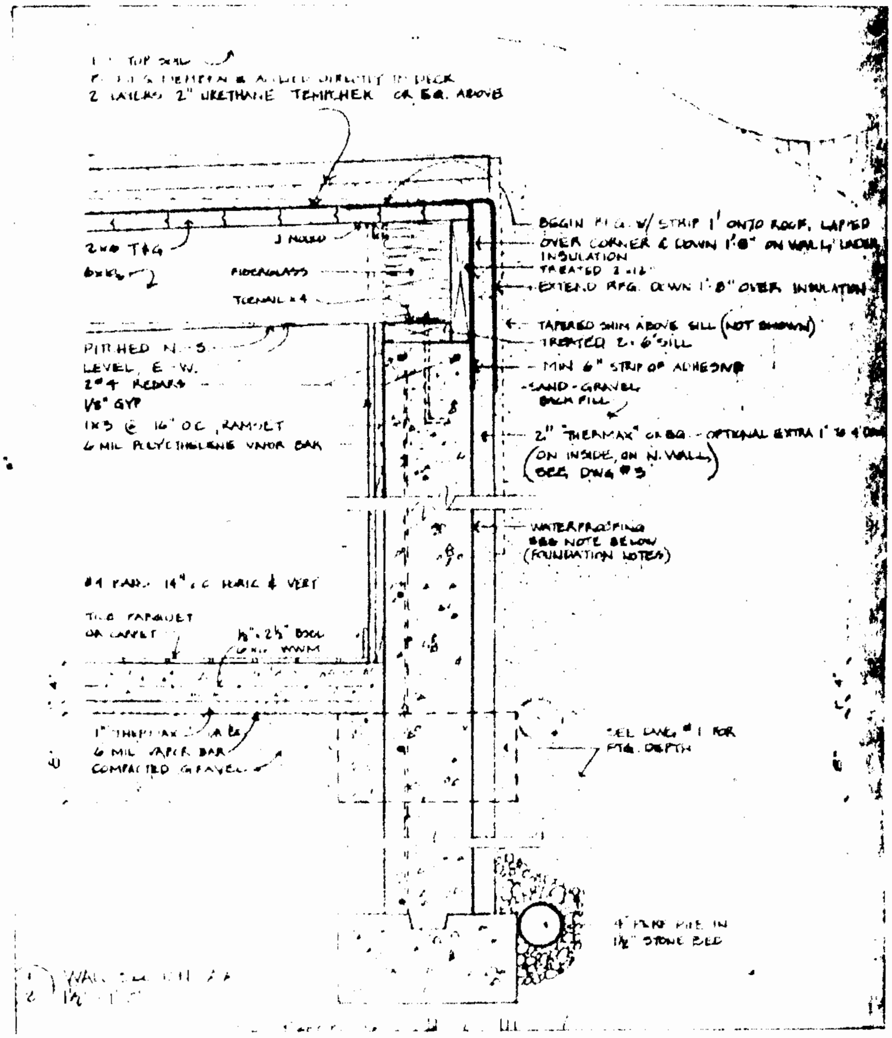
There have been houses built underground that have incorporated the use of steel and concrete in a post and beam method. This style of construction is normally reserved for large commercial buildings. Steel beams were used to span between concrete posts.

Steel corrugated panels were placed between the beams and were used as forms and reinforcement for a poured concrete floor. Gifford Knapp, built his 2,450 square foot home by the post and beam method and state that this method is one of the simplest construction methods going. This method according to Knapp is the reason that he was able to construct his house for under $33 a square foot (The Mother Earth News, 1980).

Wood that has been pressure-treated with chemicals has also been used to forms shells. Southern pine is treated at 50-60 pounds per square inch of pressure with chemicals to prevent the wood from rotting or being destroyed by insects. The house is constructed as normal using zinc-dipped fasteners to place treated plywood sheets on 2 x 6 studs placed 12 inches on center. All earth covered walls are braced with diagonal sheets of 3/8 inch plywood. The roof is made of treated plywood nailed to 2 x 12 ceiling joints placed 12 inches on center. The roof and walls are then insulated and waterproofed (Rinker, 1978).

There are other materials that may be used to construct the shells for earth sheltered houses. Alfredo De Vido used a brick wall that allowed light to enter the structure through the brick "snorkel" (Smay, 1978).

An earth sheltered house was built of interlocking silo blocks and no mortar. The curved walls acted like arches in order to resist horizontal pressure exerted by the earth.



The wall section from Earth Tech 5 illustrates the methods Don Metz used to insulate the house.

Figure 8. Wall section with cast-in-place wall (Metz, 1979, p. 38).

Figures eight, nine and 10 show three methods of constructing an earth shelterd shell. Figure eight shows the cross-section of a cast-in-place wall with a treated wood roof. Figure nine shows an eight inch concrete block wall topped with eight inch concrete plank. A wall section for treated wood construction is shown in figure 10. Refer back to figure seven for a cross-section of a cast-in-place concrete wall and roof structure.

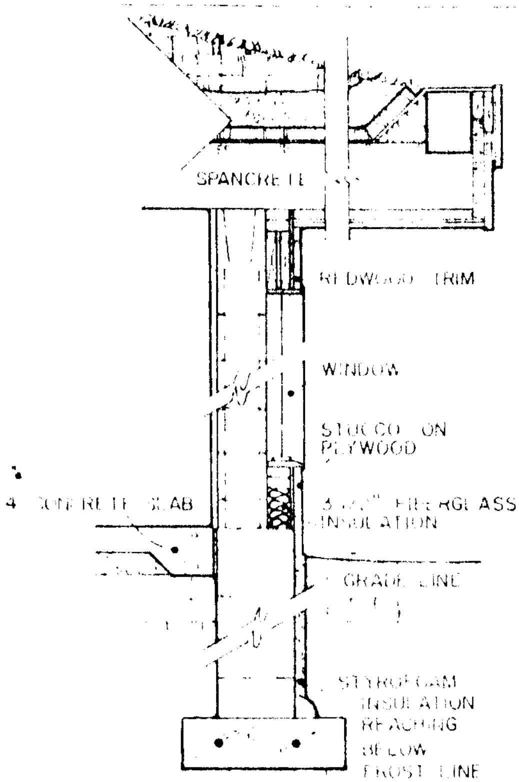


Figure 9. Wall section with concrete block wall (Lorenz, 1980, p. 46).

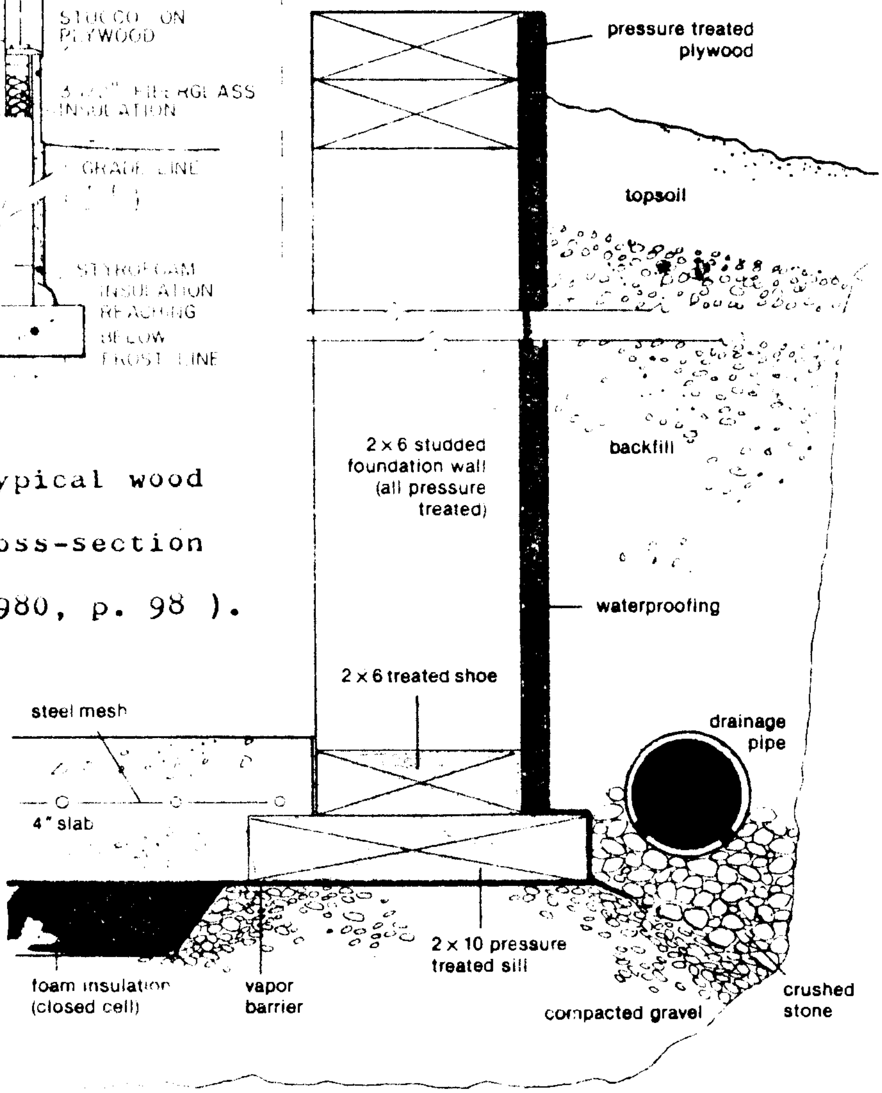


Figure 10. Typical wood foundation cross-section (Campbell, 1980, p. 98).

Windows make up some parts of the wall sections and sky lights may be installed in the roofs. Windows are not weight bearing items and so the frames must be designed to hold the windows in place and prevent any strong forces from being applied to the windows. Windows or glazed surfaces allow light, air, and radiation to enter the house while holding the wind and cold or hot undesireable air outside. Windows are areas that lose a great deal of heat during cold weather. However they do allow a larger amount of passive energy to enter in the form of radiation. Most windows used today are double or triple glazed with dead air or an inert gas sandwiched between the glazings. It is very important to make certain that opening for skylights and windows are sealed correctly. Extra waterproofing precautions must be taken to prevent leaks around skylights. Windows should be air-tight in order to increase energy conservation and prevent condensation from building up between or on the glazings.

Flooring materials. There are very few different flooring styles that are used in earth sheltered housing. Most floors are made of four inch wire reinforced concrete. A vapor barrier is placed under the floor and sometimes rigid insulation is also installed beneath the concrete. Different materials may be used on the concrete floor. -Carpet provides a warm, comforable top but does not absorb radiation as well as a dark colored concrete or dark tile floor (The Mother Earth News, 1978).

The floor of an earth sheltered house must be designed so that it is free floating in relationship to the walls and footings. Floors, due to their broad area and relative light weight will not have a tendency to settle as do the walls. If there is a solid joint, cracks may be created and the floor may buckle. With proper construction and drainage the floor should not change location in relationship to the walls or footings but a small shift will do no damage unless there is a solid connection between the floor and walls.

Waterproofing. This area is one of the most critical design and construction areas in underground structures. Once an underground house is backfilled and covered over it is a very difficult and expensive process to locate and repair leaks. There are many waterproofing techniques and materials on the market today. No matter what methods of waterproofing are employed they must be able to prevent moisture infiltration due to hydrostatic pressure and capillary draw.

Hydrostatic pressure can best be prevented by proper and adequate drainage. There are times of increased moisture build up when the drainage system alone will not keep all water away from the structure. As the water table raises or as the soil around the structure becomes saturated water pressure will increase and pressure will be applied against the structure. Below the saturation line for every foot of depth hydrostatic pressure will increase by 62.4 pounds of pressure per square foot. Structures require strong construction and reliable waterproofing to withstand this potentially great pressure (Campbell, 1980).

Capillary draw must also be stopped by waterproofing materials. According to The Underground Space Center University of Minnesota (1979) capillary draw is responsible for most dampness problems in an earth sheltered house. Capillary action occurs when the walls absorb moisture from the damp soil and pull it inwards. When the moisture reaches the inside of the wall it can either evaporate into the air or condense on the walls and cause them to be damp. If evaporation occurs, the walls will stay dry but the humidity level will be increased within the structure. Capillary draw may be prevented by proper waterproofing or by designing an air gap of very porous material into the wall. This gap or material will not allow moisture to be drawn through it. This technique will stop capillary action but is not a substitute for waterproofing (The Underground Space Center University of Minneosta, 1979).

The selection of a waterproofing material must be able to protect against hydrostatic pressures and capillary draw. The material must be able to seal any minor leaks that could occur in the waterproofing material. The material must also be able to withstand the underground environment and not deteriorate over a period of time.

There is no single waterproofing material that is the best for all conditions and structures (White, 1980). Knowledge of the limitations of the different materials must be known in order to select the best waterproofing material or materials.

Cementitious materials or pargetings are a dense cement plaster or similar material. They are applied to the outside of the wall very easily and are inexpensive. However they do not have the ability to bridge gaps or small cracks should any appear. In fact, since cement is a major ingredient in these waterproofing materials it is very likely that as the waterproofing material itself cures, cracks will be created.

Liquid-applied membranes or liquid seals take in a large variety of materials (White, 1980). Rubberized asphalts, pure urethanes, modified urethanes, and extended urethanes all fall into this category. These materials are either trowelled or sprayed on. For best results trowelling is recommended (The Underground Space Center The University of Minnesota, 1979). If applied correctly good adhesion to the substrate is achieved. This is an important feature if a leak should appear. The leak will be contained in a very localized area that will make repairing the leak much easier. Asphalts are materials that have been used for many years as waterproofing. It is inexpensive and easy to apply. Asphalt will, over a period of time, deteriorate. Recently the quality of asphalt has also come under question (Campbell, 1980). Most liquid-applied membranes do not have the ability to seal any gaps that may occur. Because of cool temperatures that occur underground many liquid seals become brittle and will crack if cracks occur in the structure.

Built up membranes consist of layers of asphalt and pitch between felt or fabric reinforcing. Usually there are at least four layers of reinforcing. This type of membrane can be used on walls or roofs. Glass fiber fabric is recommended over organic materials because organic felts will rot if subjected to water for long periods of time. Because asphalt is used deterioration may occur. Bridging characteristics are normally not very good. This type of waterproofing has been used for many years on both large and small structures. Many leading authorities in earth sheltered construction have used this type of waterproofing and recommend its use. The cost of this membrane varies with the number of layers applied (The Underground Space Center University of Minnesota, 1979).

Another built up membrane consists of alternating layers of polyethylene and mastic. This type of membrane will withstand only temporary immersion in water. It must be used with a good drainage system. It is recommended for use on the walls of earth sheltered houses but not on the roof. Polyethylene embedded in mastic does not have good bridging characteristics (The Underground Space Center University of Minnesota, 1979).

Synthetic rubber sheet membranes include butyl rubber, ethylene propylene diene moromer (EPDM), neoprene membranes, and elastomeric membranes. Application of all these materials are critical to their effectiveness. Care must be taken to prevent any water that may leak from traveling under the membranes and appearing as a leak somewhere else. If this occurs repairing the leak may be very expensive. This type of membrane is expensive but if applied properly will result in a very waterproof structure. Campbell (1980) states, "Butyl rubber sheeting seems to be the best synthetic waterproofing membrane available " (page 71).

A very inexpensive damp-proofing material is polyethaylene sheeting. If placed with care and with large overlaps it will supply a good barrier against capillary draw. It has some bridging capabilities but degrades when exposed to sunlight. It should not be used by itself as a waterproof barrier (The Underground Space Center University of Minnesota, 1979).

The Underground Space Center University of Minnesota (1979) describes pitch as another material that is applicable for underground structures. It is better than asphalt because it is not decomposed by soil. Most pitch used today is for aboveground roofing applications but may be used underground. Pitch has a softening point around 150°F. and therefore is brittle at temperatures present underground.

Metz (1980) lists bituthene as one of the top three waterproofing agents. Bituthene is a polyethylene-coated, rubberized asphalt. It is relatively inexpensive and studies show that it will elongate or bridge up to 300 percent at temperatures down to -15°F. Because it is made partially of polyethylene it will decompose if subjected to sunlight. Bituthene is available in liquid form or in rolls 36 inches wide and 60 feet long. For best adhesion to surfaces it should be applied to surfaces that are dry and above 45°F. (Campbell, 1980 & The Underground Space Center University of Minnesota, 1979).

The last waterproofing material to be mentioned is another of Metz's top three agents. It is available in panel form or can be sprayed or trowelled onto walls. Bentonite is a clay found in the western United States. It will never decompose and when subjected to moisture can expand 15 times its dry size. Because of this natural feature bentonite can reseal holes and bridge gaps and cracks. It is applied in a ¼ inch to 3/8 inch layer by spraying or trowelling. If sprayed it must first be mixed with a small amount of mastic binder to assure adhesion. Bentonite also comes in four foot-by-four foot corrugated cardboard panels 3/16 inch thick. The panels can be easily placed on walls or roofs with nails or other means. Bentonite must be protected from heavy rains until the backfill is placed. This waterproofing agent should not be used where running water can erode it away. Bentonite is also rendered ineffective if there is a high concentration of salts in the ground water. Because bentonite reacts to water it should not be used directly on wood decks (Metz, 1980, Campbell, 1980, & The Underground Space Center University of Minnesota, 1979).

method	approximate cost/sq. ft.
dampproofing	
ironite pargeting	$0.75 - 1.10
asphalt or pitch coatings	
brushed on	.20 - .35
sprayed on	.22 - .25
trowelled on	.30 - .45
addition coat-add	.20
polyethylene sheet - .010 in. thick	.13
.004 in. thick	.08
waterproofing	
built up roofing w/fabric	
1 ply	$0.35 - .55
3 ply	.65 - .90
5 ply	.85 - 1.35
bituthene	.75 - .95
butyl, EPDM, neoprene membranes (without full adhesion)	1.15 - 1.50
liquid membranes	.70 - .85
bentonite	
panels	.60 - 1.00
spray on	.50 - .90

Figure 11. Waterproofing materials and costs (The Underground Space Center University of Minnesota, 1979, p.144).

Insulation. Insulating an earth sheltered house is necessary because the concrete shell will act as a heat sink and continually draw heat from the interior and pass it to the surrounding soil. This process will take place until the interior and soil temperatures are the same. Most soil will be around a temperature of 58°F. and this is just a little too cold for comfortable human habitation. Insulation placed on the outside of a structure will alter the concrete shell from a heat sink to a heat storage unit. As heat is produced or enters a underground house the entire structure is heated. The insulation prevents a loss of heat from the structure. Insulation may be placed on the outside. Figure number 12 shows characteristics that are required for insulation placed inside and outside the structure.

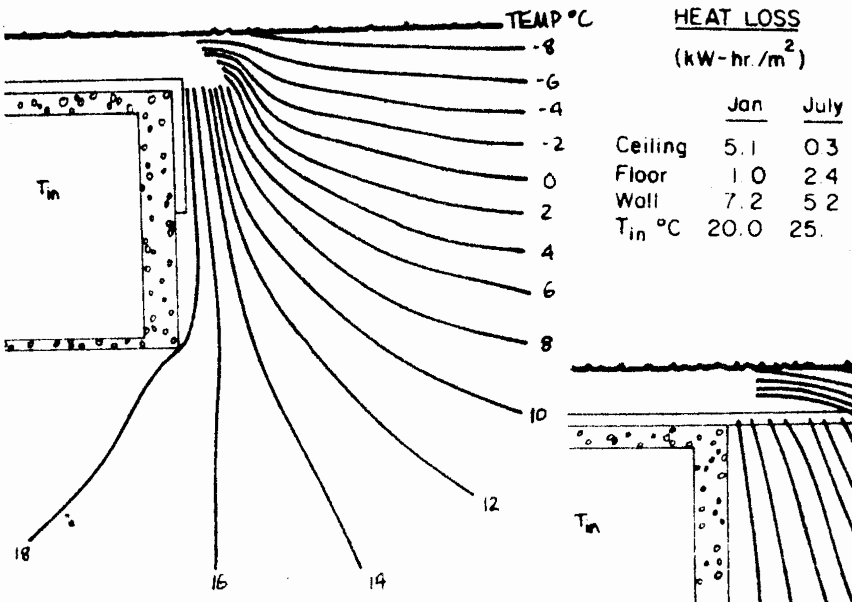
Characteristics	Installed on exterior	Installed on interior
Compressive strength sufficient to resist lateral earth loads	20 to 30 psi*	No
High resistance to fire	No	Yes
High resistance to producing toxic fumes during fire	No	Yes
High resistance to water absorption to maintain high R value	Yes	No
High resistance to chemical attack by soil constituents	Yes	No
Dimensional stability	20 years or more	20 years or more
R value stability	20 years or more	20 years or more
Tongue and groove interlock between sheets to prevent heat flow or water movement	Yes	No
High R value per dollar	Yes	Yes

* 140,000 to 210,000 pascals

Figure 12. Characteristics of insulation for earth-sheltered buildings (Concrete Construction, 1980, p. 667).

Insulation is also best placed on the exterior side of waterproofing materials. The insulation helps to protect the fragile waterproofing. It also helps to keep the waterproofing material from freezing which increases the life and effectiveness of the waterproofing material. Insulation should be placed as completely around the structure as possible, the roof, walls and floor should all have adequate insulation. The insulation does not need to be the same thickness all over because there will be less heat loss through the floor and lower walls than from the upper walls and roof. The roof requires the most insulation. The amount of insulation will vary depending on the R-value of the insulation, depth of structure, and outside climate. Recently studies have shown that insulation extending horizontally away from the roof will increase insulation efficiency by 20 percent over verticle wall installation. Horizontal insulation will have to be supported during settling of soil by the use of plywood or flashing. However, an added advantage of this placement of insulation will be to help channel water away from the structure thereby reducing the load on the waterproofing.

There are three types of insulation that are used for exterior insulation on earth sheltered structures. Extruded polystyrene, polystyrene bead board, and polyurethane are the only practical insulations in use today. For interior insulation fiberglass may also be used.



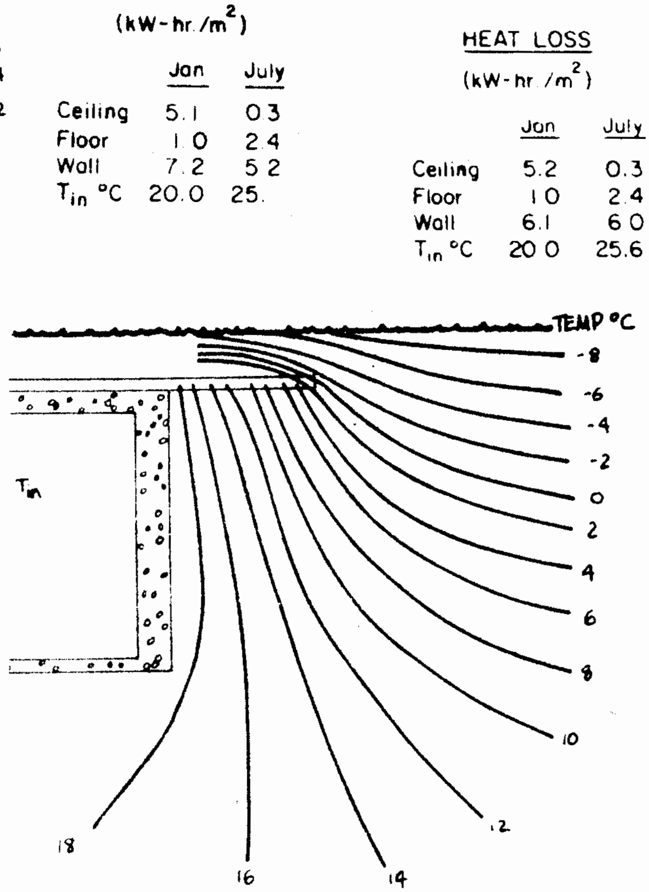


Figure 13. Horizontal wall insulation comparison (Campbell, 1980, p. 182).

Extruded polystyrene is the best insulation even though its' R-value is not as high as polyurethane. Polyurethane has a loss of R-value after long exposure to the ground because it absorbs water. Polystyrene bead board also absorbs moisture which lowers it's R-value. Polyurethane will lose up to 20 percent of its efficiency as it ages. It is also considered very delicious by some insects. Polyurethane is still used a lot because even with a loss of 20 percent efficiency its' R-value would still be higher than extruded polystyrene (Concrete Construction, 1980 & The Underground Space Center University of Minnesota, 1979).

	initial[1] R-value per inch	final[2] R-value per inch	cost[3] per board ft.	R-value[4] per $
extruded polystyrene	5.0	4.54	.16	28.38*
bead board	4.0	2.85	.11	25.91
polyurethane	6.89	2.98[5]	.19	15.68
fiberglass	3.5 (for comparison)			

1. Initial value for insulation given in study
2. Final R-value for 10 years exposure to the ground, from study
3. Installed cost per board foot based on 1977 Dodge & Means Cost Handbooks
4. Cost efficiency using the 10 year R-value (for illustration since prices vary)
5. This data for polyurethane has been questioned as being unusually low

Figure 14. Insulation materials and costs (The Underground Space Center University of Minnesota, 1979, p. 146).

Covering. The covering and backfilling are the last items that make the structure truely an earth sheltered structure. Just about any thickness of earth cover may be placed so long as the structure has been designed to withstand the load. Wells (1977) estimates the weight of one squre foot of soil to range from 75-96 pounds. With the weights considered he gives a range of 150-400 pounds per square foot for a structural design. The Underground Space Center University of Minnesota (1979) gives the weight of earth between 100 and 120 pounds per squre foot. Applied dead loads are stated to be around 200 pounds per square foot and an additional 100 pounds per square foot for the structure itself. Live loads may range from 30-50 pounds per square foot. But when figuring the live and dead loads remember that water in soil may add an additional 62.4 pounds per square foot for each foot of depth. Also it may be easier to get a heavy snow that stays on an earth sheltered house much better and thicker than on a conventional roof.

Around the entire structure, outside of the insulation a layer of porous sand and gravel should be used as back-fill to improve drainage. Most experts agree that between one foot and two feet of cover on the top of the building is plenty. If a good insulation is used the waterproofing will not freeze. A thicker layer of earth may be used and an increased R-value would be obtained. However the additional structural cost to support the increased weight would not justify the very slight R-value gained. Wells (1977) suggests a thick layer of mulch to top off the structure. Mulch will weigh between 5 and 50 pounds per squre foot. It is very good for starting plants and grasses growing. After a short period of time it may be necessary to get out the mower and trim the roof.

Conclusion

Earth sheltered housing has been with man for thousands of years but only recently, due to energy shortages, has mankind started to take a more serious look at returning to life underground. For the first pioneers in this field trial-and-error has been the rule rather than the exception. Much has been learned by different individuals and fortunately this information has been shared.

In the future new ideas, new materials, and more trial-and-error will result in better and less expensive earth sheltered homes.

This field is very exciting and offers a great opportunity for growth. Of course earth sheltered housing will not solve all the problems of energy conservation, housing needs, and space utilization. It is quite clear that a very old concept can be utilized to solve, in part, some of today's problems. If man can continue to learn from the past mistakes and achievements while refining the knowledge and techniques he presently has, the future for earth sheltered housing appears to be on very stable ground.

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