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Earth-Sheltered Housing, An Evaluation of Energy-Conservation Potential

R. L. Wendt

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ERRATA

Please note the following corrections to ORNL/CON-86:

P-24 Change the second reference 11 (last line of page) to reference 12

P-27 Change reference 12 to reference 13
Change reference 13 to reference 14
Change reference 14 to reference 15

P-28 Change reference 15 to reference 16
Delete the second reference 16 (last line of sixth paragraph)

R. L. Wendt

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EARTH-SHELTERED HOUSING, AN EVALUATION OF ENERGY-CONSERVATION POTENTIAL

R. L. Wendt

DEPARTMENT OF ENERGY
Office of Buildings Energy Research and Development
Buildings Division

Date Published: April 1982

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ABSTRACT

The U.S. Department of Energy's Innovative Structures Program (ISP) began an evaluation of the energy conservation potential of earth-sheltered houses in late 1979. Since that time, several projects have been undertaken by the ISP as part of this evaluation. The findings of these projects, plus a discussion of the work of others in the field, form the body of this report. Although a comprehensive evaluation of earth-sheltered housing has not been completed, this report presents a compendium of knowledge on the subject. The conclusions of this report are more qualitative than quantitative in nature because of the limited information on which to base projections. However, these conclusions will, in all likelihood, remain reasonably valid even with in-depth investigation.

The major conclusions to date are as follows:

- Earth-sheltered houses are capable of very good energy performance. Thermal integrity factors ranging from about 1 to 4 Btu/ft^2 per heating degree day are common. This rate is comparable with other energy-efficient approaches such as super-insulated and passive solar constructions and much better than "traditional" above-grade construction with a thermal integrity factor in the range of 10 to 12 Btu/ft^2 per heating degree day.
- Earth-sheltered houses, as a passive means to conserve energy, perform significantly better in some climatic regions than in others.
- Earth-sheltered houses are not the optimum passive concept in several major housing growth regions of the country.
- Earth-sheltered houses, including their land and site improvements, will cost an estimated 10 to 35% more than comparable aboveground houses, and this additional cost may not be justified on a life cycle cost basis, given 1981 market conditions.
- The use of earth sheltering will probably grow in some parts of the country; however, broad-scale national or regional utilization is not likely to occur in the next 20 to 30 years.

EARTH-SHELTERED HOUSING, AN EVALUATION OF ENERGY-CONSERVATION POTENTIAL

INTRODUCTION

Interest in the use of earth-sheltered housing has increased markedly over the past few years. Since the mid-1970s, a major reason for considering earth sheltering has been its potential to conserve energy, which has been claimed to be as high as 80% or more when compared to traditional, non-energy-conscious, aboveground houses. This conservation potential and increased public interest, juxtaposed with numerous uncertainties, such as the concept's actual energy performance and cost to build, led to the necessity of this report. The report investigates the energy conservation potential as well as the potential for broad-scale utilization throughout the United States. It is based upon activities undertaken by the U.S. Department of Energy's (DOE) Innovative Structures Program (ISP), both at the Oak Ridge National Laboratory (ORNL) and through subcontractors, as well as the published work of a number of experts in the area. It uses the methodology developed by the ISP in its overall approach to the evaluation of earth-sheltered housing, discusses the activities of the ISP in earth sheltering, and shows the relation of these activities to the overall analysis. Finally, it draws some conclusions regarding the future potential of this concept.

EARTH-SHELTERED HOUSING

Scope

The focus of this report is on earth-sheltered housing rather than on earth-sheltered buildings in general. Commercial, institutional, and industrial structures have been excluded because nonresidential structures are built below-grade primarily in response to issues other than energy conservation. Examples of these issues are the preservation of open space, the high value of a particularly desirable location, or storm protection (as in Oklahoma schools). In addition, a wide disparity between the physical requirements of commercial, industrial, and residential space inhibits transfer of research between these building uses. It was decided to focus attention on the housing sector where energy conservation is a major issue and, for the purpose of this evaluation, to exclude the others. This decision was not meant to imply that significant energy conservation, through earth sheltering, cannot be obtained in commercial, industrial, and institutional facilities. Clearly it can, and this may be a fruitful area for future evaluation.

High-density or multifamily residential housing was also not investigated in depth because the successful application of the earth-sheltered concept to these areas depends heavily on neighborhood design and community planning issues which were beyond the scope of the ISP. This area, however, appears particularly promising as energy conservation can accrue from both improved building performance and a significant reduction in transportation, utility distribution, and embodied energy consumption resulting from the higher density.

Description of Earth-Sheltered Housing*

Numerous publications exist which amply describe both the concept of earth-sheltered housing and the state of the art. Some of the more instructive documents are available from sources listed in the section of this report entitled ADDITIONAL SOURCES OF INFORMATION. However, since this report may be read by persons unfamiliar with the concept, a very basic description follows.

Earth sheltering uses the earth as both a moderator and a barrier. The earth provides a more stable and moderate environment in which to place structures than does the atmosphere. It also provides a barrier to wind and storm effects and a large thermal storage capacity that allows intermittant energy sources, such as the sun, to be used effectively.

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* Information in this and the following section has been borrowed liberally from *Earth Sheltered Housing: Code, Zoning, and Financing Issues*, prepared for the U.S. Department of Housing and Urban Development by the Underground Space Center, University of Minnesota. Used with permission.

Earth-sheltered housing varies widely in design and layout. Typical relationships to the ground surface are shown in Fig. 1. Some residences have only earth-covered walls; for others, earth also covers the roof. Most types can be constructed at the natural grade.

One of the most common types of earth-sheltered housing is the elevational design (Fig. 2) in which windows and openings are grouped on one side of the structure. The three remaining walls are earth-covered. When the windows face south, a maximum amount of passive solar heating can be obtained. Those rooms used most frequently during daylight hours are usually placed along the window wall.

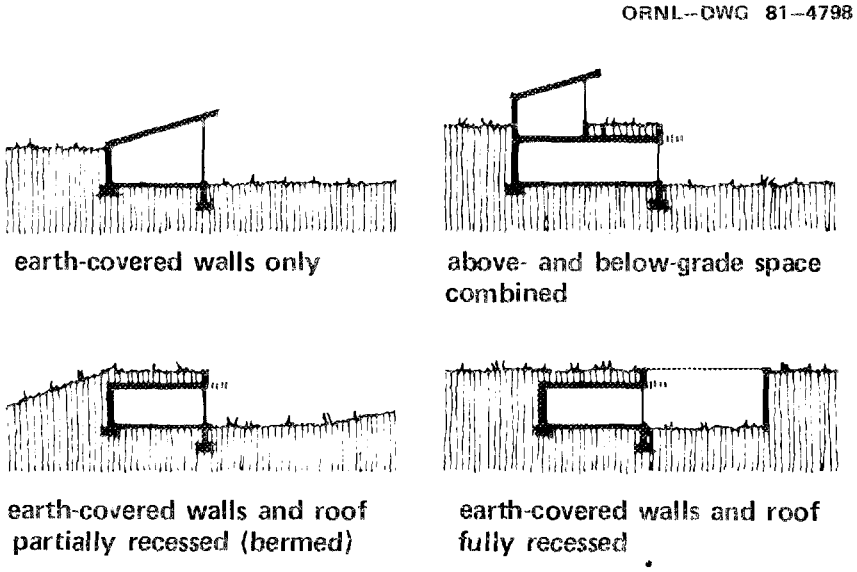

Fig. 1. Typical relationships to the ground surface.

Another common type is the atrium design (Fig. 3). In this design, the habitable rooms cluster around the atrium or courtyard to provide exterior exposure. Atrium designs are most commonly used on flat sites or on those surrounded by intense development.

Other earth-sheltered dwellings have windows on more than one wall and begin to more closely resemble a traditional house plan than either the elevational or atrium designs (Fig. 4). These designs are best in milder climates where the impact of cold winter winds and hot summer afternoon sun will not significantly reduce overall energy performance.

Many earth-sheltered residences perform well from an energy conservation point of view. The level to which they perform varies with the specifics of their design. The range of their actual energy performance will be discussed in the section entitled EVALUATION OF THE CONCEPT.

Factors Influencing Energy Performance

One significant advantage of earth-sheltered housing and the reason for ISP evaluation is its potential energy savings when compared to traditional aboveground housing. This potential is based on several unique physical characteristics.

The first is the reduction of heat loss due to conduction through the building envelope. The amount of heat lost in this manner is a function of the thermal transmission coefficient

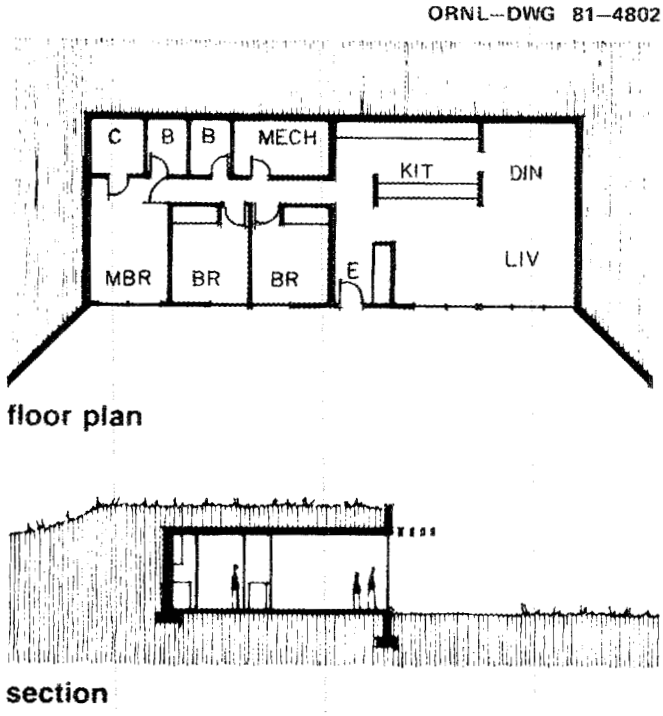

Fig. 2. Elevational design.

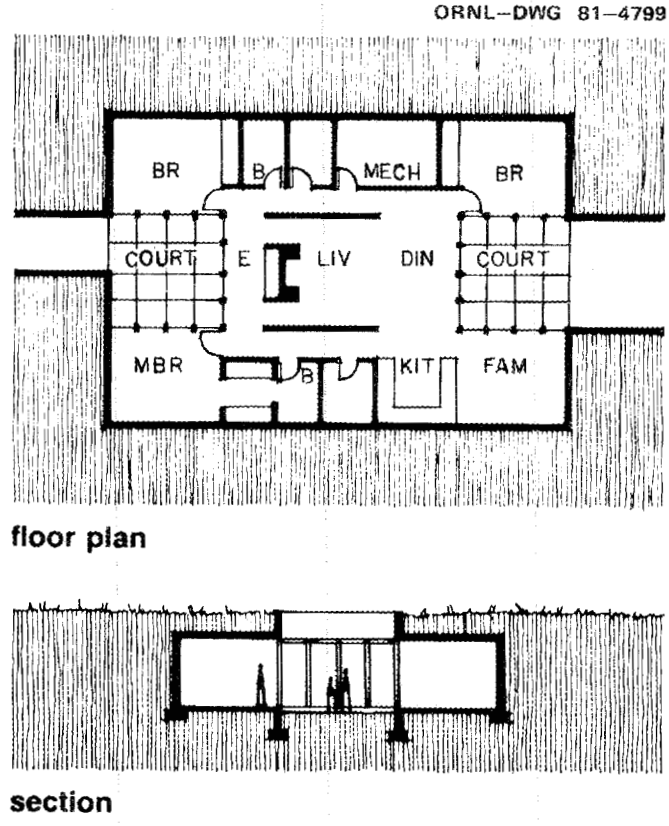

Fig. 3. Atrium design.

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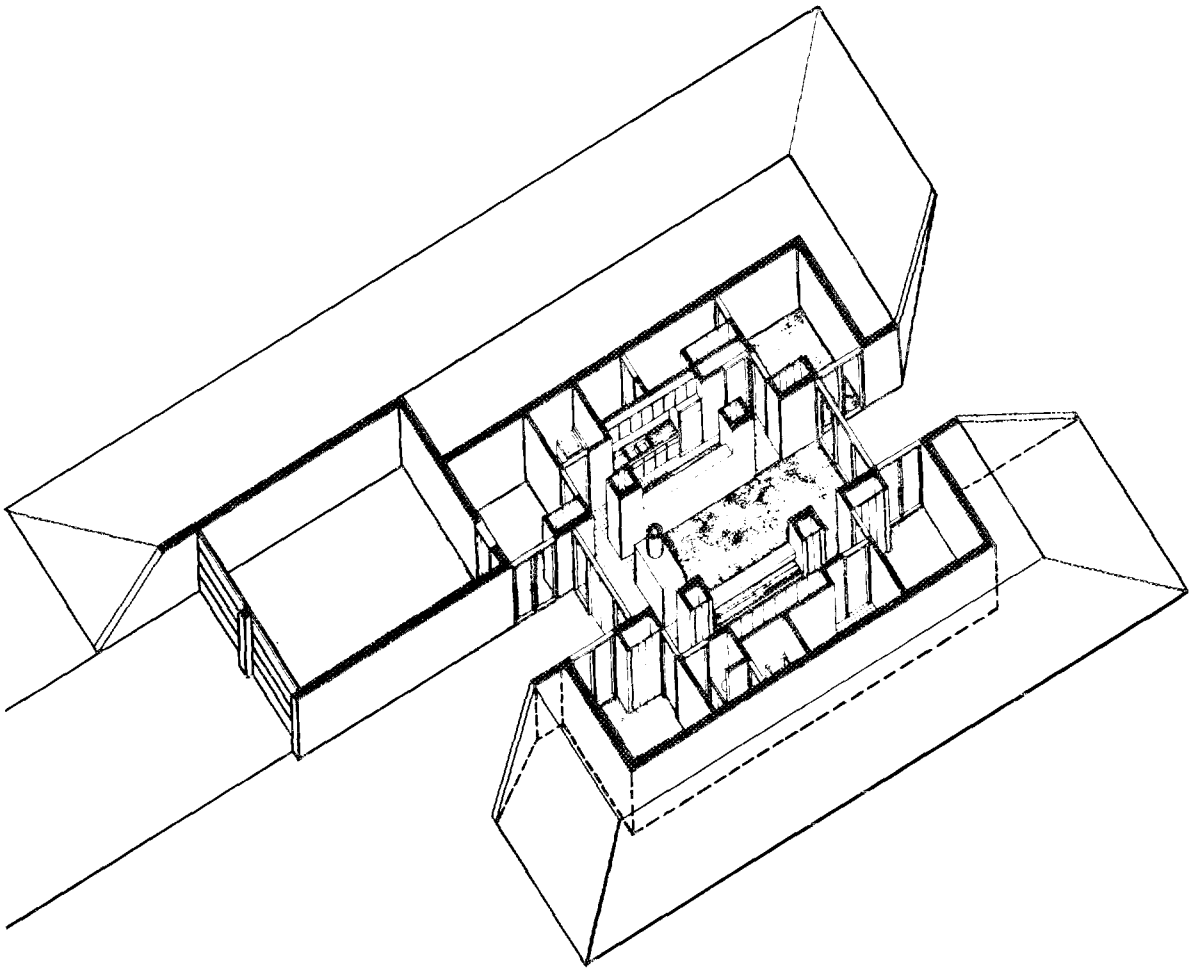

Fig. 4. Earth-sheltered house with a more traditional plan.

(R-factor) of the envelope and the temperature difference between the inside of the envelope and the outside. While the R-factor for earth is substantially lower than that of other insulating materials, the large amount of earth inherent in earth sheltering can provide an overall R-factor comparable with more highly insulated structures.

The temperature differential for aboveground structures is the difference between the outside air temperature and the interior temperature maintained for the comfort of its inhabitant. Under extreme conditions, this differential can be as much as 32°C (90°F) or more in some parts of the country. The daily and seasonal fluctuations of temperature below the surface of the ground never equal those of the air above. The deeper the temperature is taken, the less severe will be the variation. This concept, illustrated in Figs. 5 and 6, shows the daily and yearly soil temperature fluctuations at various depths. This reduced temperature differential results from the thermal storage capabilities of the soil which moderate extremes of temperature and create seasonal lags, wherein energy from one season is transferred to the next season.

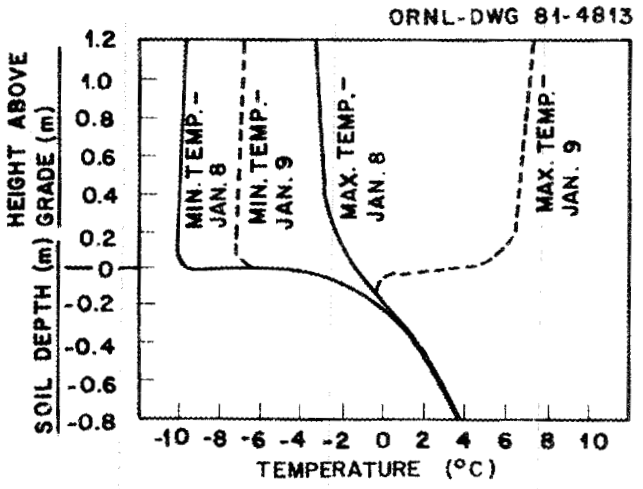

Fig. 5. Daily temperature fluctuation.

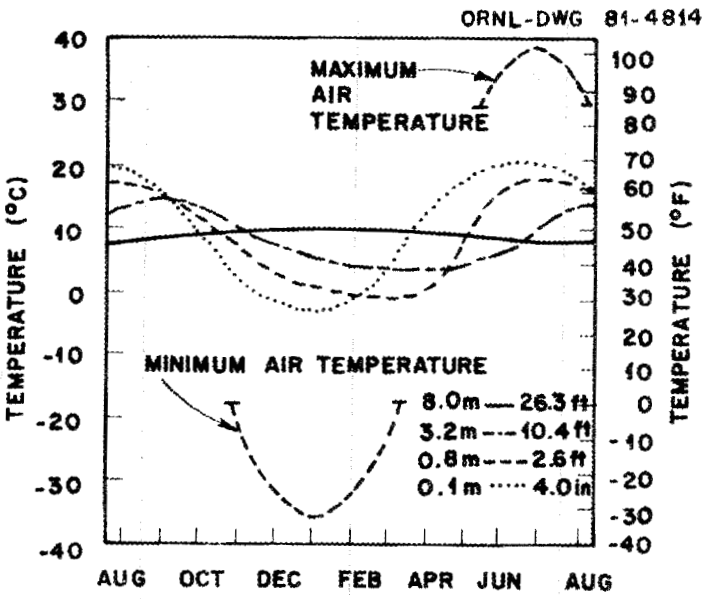

Fig. 6. Annual temperature fluctuation (Minneapolis).

Figure 5 shows that daily fluctuations are virtually eliminated at depths as shallow as 0.2 m (0.7 ft) of soil. At greater depths, soil temperatures respond only to seasonal changes, and the change occurs after considerable delay. Figure 6 shows the seasonal temperature fluctuation at various depths in the Minneapolis-St. Paul area. At a depth of 5 to 8 m (16 to 27 ft), the ground temperature is virtually constant. In addition to the damping effect, there is also a significant thermal lag effect which occurs at depths below 3 m (11 ft). At this depth, the soil temperature lags behind the surface temperature. This effect can carry some of the stored coolness of winter into summer and some of the stored heat of summer into winter. Few residential buildings are built to a depth to take full advantage of this phenomenon.

The thick earthen blanket around much of an earth-sheltered dwelling effectively eliminates infiltration through those portions covered. This reduces energy loss due to infiltration to only the exposed portions of the structure. While this loss of infiltration may require the installation of a ventilating system to maintain indoor air quality, these systems can be readily designed to recover a large portion of the energy normally lost when ventilation by infiltration is utilized.

Many earth-sheltered dwellings are constructed of concrete or concrete block, which has a large thermal storage capacity. In addition, under certain circumstances, the earth around portions of the structure can be thermally coupled to the building wall so that the storage capacity is significantly increased. This thermal storage capacity can absorb excess energy from the air or from direct solar insolation. This heat is released back into the dwelling whenever the inside air temperature is below that of the thermal mass. This process can be slow enough to "carry" a house for several days should the energy source be interrupted. An example of this effect is shown in Fig. 7. The thermal storage capacity can also be integrated with energy systems (fireplaces, wood stoves, passive solar, etc.) which provide heat on a fluctuating basis. This integration can effectively dampen the fluctuations and thereby provide a greater degree of overall comfort.

With proper design, the effects of these physical characteristics can result in a significant reduction in both heating and cooling energy requirements.

In addition to the potential energy savings described above, there are several other factors that indirectly reduce energy consumption and thereby enhance the viability of the earth-sheltered dwellings concept.

With the development of clusters or neighborhoods of earth-sheltered houses, earth berms and earth-covered roofs can create a far less built-up appearance than traditional development. This factor, plus the potential use of flat earth-covered roofs as open space, would allow earth-sheltered housing to be built to higher densities, that is, more dwelling

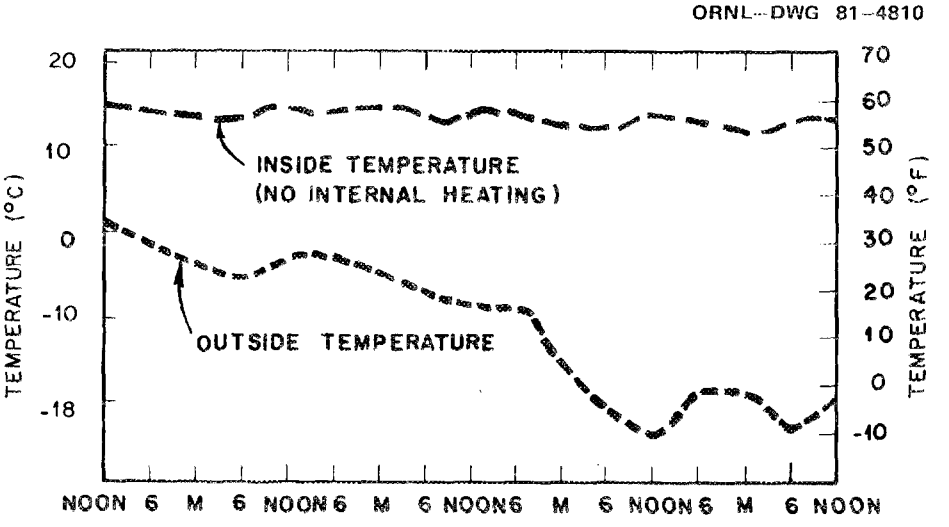

Fig. 7. Temperature stability of an earth-sheltered house (Rolla, Missouri).

units per land area, than traditional single-family, aboveground housing, without loss of amenities. The potential increase in density and the utilization of "marginal" lands within an urban or suburban area could reduce the total energy consumption of the community by shortening transportation and utility distribution distances. Marginal lands are those which, because of proximity to various other community functions such as heavy industry, transit corridors, and airports, are normally considered inappropriate for traditional residential development. The sound and visual isolation potential of earth-sheltered housing could allow some of these marginal lands to be considered for residential development, while some reduction in the embodied energy of a community's physical structure could occur through the development of more efficient road and utility systems. Whether this would be offset by the higher embodied energy of materials normally associated with earth-sheltered construction is uncertain.

Finally, properly designed structures that are substantially surrounded and covered by earth can be inherently protected from many "weathering" influences that cause deterioration. This slowing of deterioration reduces the energy consumed in the maintenance of the structure.

EVALUATION OF THE CONCEPT

Energy Performance

Background

The initial effort in the evaluation of energy conservation in earth-sheltered housing was an attempt to determine the energy performance of these dwellings. Current information about this performance and a comparison of it with other types of housing has been compiled from "claimed," calculated, and monitored energy performances. Claimed performance is typified by such phrases as "My earth-sheltered house uses 60% less energy than that used by a traditional above-grade dwelling." Calculating the energy performance utilizes the various modeling tools available to the building designer. The final approach is to field measure an inhabited dwelling's actual energy performance.

Claimed performance

This approach is the least scientific and the most prevalent method of describing the actual energy performance. The popular press and descriptive brochures on earth-sheltered houses have most frequently carried claims of "heating and cooling energy savings of up to 75% over conventional aboveground houses." Claims also take other forms — for example, "We burned only 1-3/4 cords of wood during the last heating season," or "My heating bills for December and January were only $45 to 50 — not bad!" The more radical claims suggest that energy savings as high as 90% can be expected, while the more conservative claims expect savings of around 50 to 60%.

Although all of these claims are interesting and certainly get people's attention, they have a fundamental problem. They offer no basis for true comparison. They represent a wide variety of earth-sheltered housing types, climatic regions, sizes of structure, comfort ranges, and lifestyles. In most cases, the "traditional above-grade house" comparison is made with a poorly insulated frame house which has received no weatherization improvements, in short, with a type of house that is no longer built.

The potential inaccuracies of this approach, coupled with the lack of accurate knowledge of the actual energy performance of various types of housing and the many significant improvements, such as increased insulation, improved weather stripping, and multipane glass, that are being applied to currently constructed housing severely challenge the creditability of these claims. What is needed is a more objective, analytical approach, which can respond to the shifting base of comparison, and a multitude of differing design and construction features. A calculated performance (if accurate) and a monitored performance (if representative) can fulfill this need.

Calculated performance

This approach uses various analytic models available to the building designer for calculating the energy consumed by a building based on a theoretical design year for various climates. This approach eliminates many of the subjective factors and provides a more objective comparison of various designs and concepts. Earth-sheltered and aboveground houses are now compared on the same set of assumptions. Only the structure and the temperature around the structure are variables.

The calculated performance for five different locations in the United States is shown in Table 1. For comparison, the performance of the same size of house, built above-grade to "good energy conservation standards for 1980," was also calculated. The specific designs of the two houses (one earth-sheltered and one above-grade) are illustrated in Figs. 8–11 (see ref. 1).

Table 1. Comparison of the calculated annual energy performance (in millions of Btu) for earth-sheltered and above-grade residences in five cities

Type of residence	Heating		Cooling		Total		Total energy savings	Percentage of energy savings
	BLAST	SOLEST	BLAST	SOLEST	BLAST	SOLEST		
			Boston					
Earth-sheltered	26.7	16.3	3.6	1.0	30.3	17.3	15.7	48
Above-grade	30.0		3.0		33.0			
Conventional (new)		83.8		9.6		93.4		
			Houston					
Earth-sheltered	3.7	0.0	5.7	9.9	9.4	9.9	4.9	33
Above-grade	5.2		9.6		14.8			
Conventional (new)		25.7		55.8		81.5		
			Knoxville					
Earth-sheltered	13.4	5.7	2.2	6.6	15.6	12.3	10.0	52
Above-grade	12.5		12.8		25.3			
Conventional (new)		60.8		30.0		90.8		
			Minneapolis					
Earth-sheltered	49.4	35.3	5.3	1.7	54.7	37.0	34.7	49
Above-grade	67.1		4.6		71.7			
Conventional (new)		92.4		9.4		101.8		
Conventional (older)		172.0		12.0		184.0		
			Salt Lake City					
Earth-sheltered	27.9	14.6	3.8	0.0	31.7	14.6	20.0	58
Above-grade	24.3		10.3		34.6			
Conventional (new)		85.0		18.5		103.5		

Heating and cooling loads were calculated for both the aboveground and the earth-sheltered structures, using BLAST with the new PLATO front end. Loads for the earth-sheltered structures were also calculated with SOLEST by Davis Alternative Technology Associates (DATA). DATA also provided an estimate of energy loads for conventional and old structures of the same size in the studied regions.

The BLAST program has been widely accepted and thoroughly debugged for conventional structures. Because the data input was "standard," the results are acceptable. The BLAST program, however, has limitations in the codes for simulation of massive structures. The program does not recognize many passive heating features and earth-sheltering characteristics, so an extrapolation was employed to overcome these shortcomings. For this reason, an energy analysis from DATA was obtained which simulates earth-sheltered and passive structures in a more acceptable manner. The SOLEST program has its shortcomings in that the analysis is not an hourly time-step scheduling analysis for infiltration, occupancy, lighting, and equipment; instead, it uses constant average values for these parameters. It can, however, estimate the thermal mass and the ground temperatures surrounding the structures as was called for in the designs.

Table 1 shows that the heating and cooling loads for the earth-sheltered structures were generally lower in the SOLEST calculations. Because of this fact and the higher confidence in the accuracy of the calculations in SOLEST, the SOLEST data was used to represent the earth-sheltered houses. The BLAST data was used to represent the above-grade houses in the life cycles cost study (described in the subsection entitled "Life Cycle Cost").

The calculated energy reductions for space conditioning of an earth-sheltered house, in comparison with an energy-conserving above-grade structure, range from 34.7×10^6 Btu in Minneapolis to 4.9×10^6 Btu in Houston. The percentage reduction ranges from 58% in Salt Lake City to 33% in Houston. These comparisons utilize the BLAST calculation for above-grade structures and the SOLEST calculation for earth-sheltered structures.

Other calculations of energy reductions for space conditioning have been made for earth-sheltered houses. These reductions, which tend to be somewhat greater than those indicated above, are frequently based on a standard average heat loss/gain rate rather than a specific comparable design.

Calculated performance, while providing a better comparison between concepts, does have limits. While aboveground temperature data is available for many locations, relatively little data exists for ground temperatures at various depths within the earth. This lack of data can impact the accuracy of the various modeling programs. The programs currently available are limited, as described earlier, in their ability to accurately portray the effect of the large amount of thermal mass inherent in most earth-sheltered buildings. In addition, soil moisture can significantly increase the heat loss of the earth-sheltered structure. This variable is not considered in the models. More validation of the models, plus development of the ability to address thermal mass and soil moisture, will be needed before the calculated performance will be a highly accurate indication of the actual energy performance.

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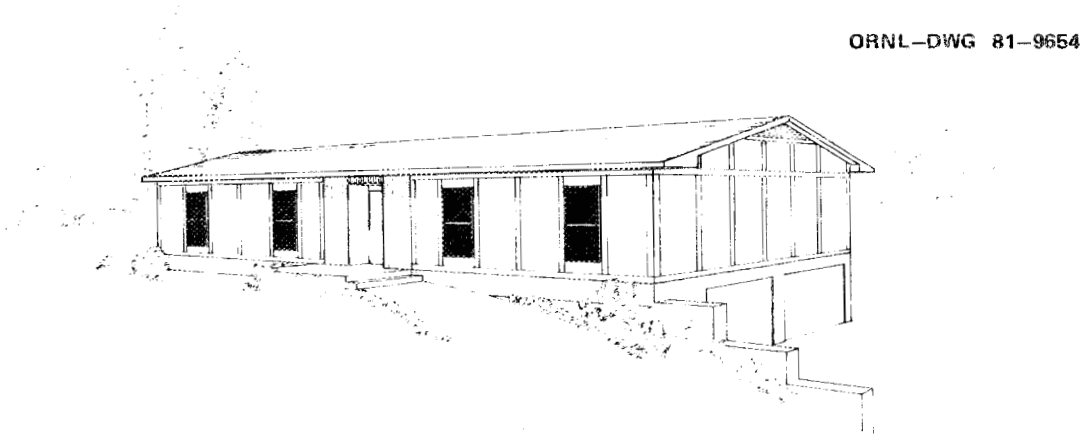

Fig. 8. Rendering of above-grade house in Minneapolis, Minnesota.

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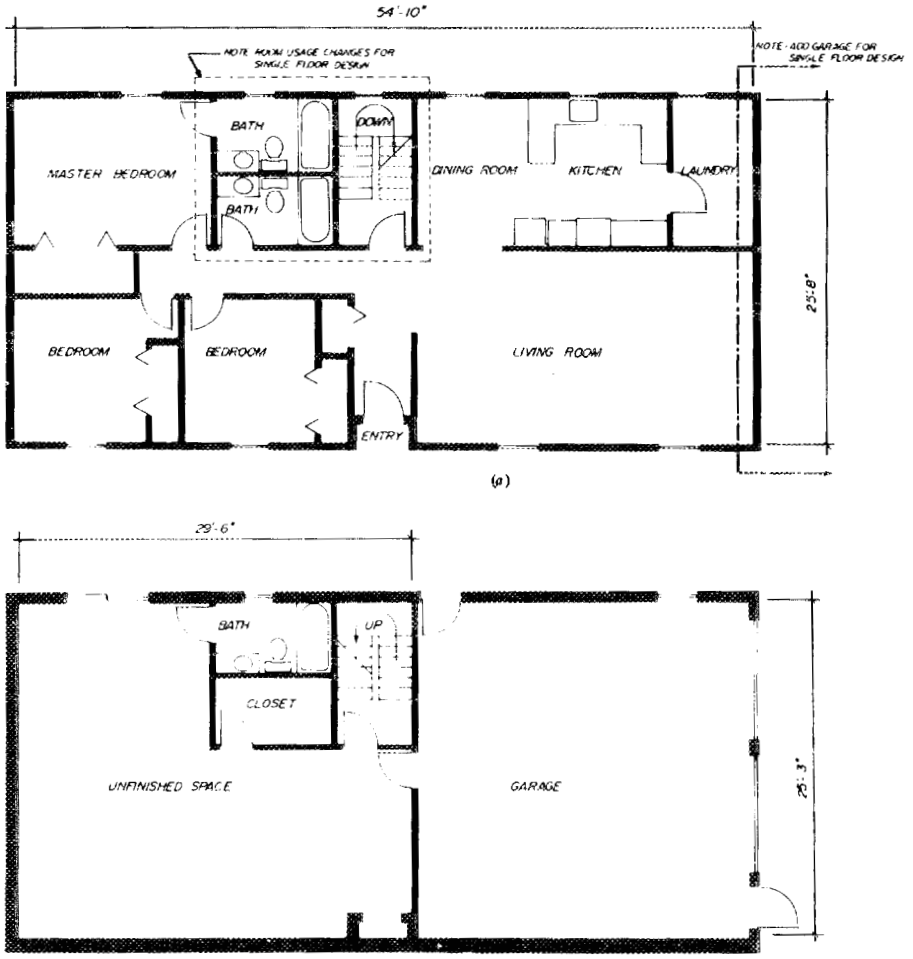

Fig. 9. Floor plans for above-grade house: *(a)* top floor; *(b)* basement level.

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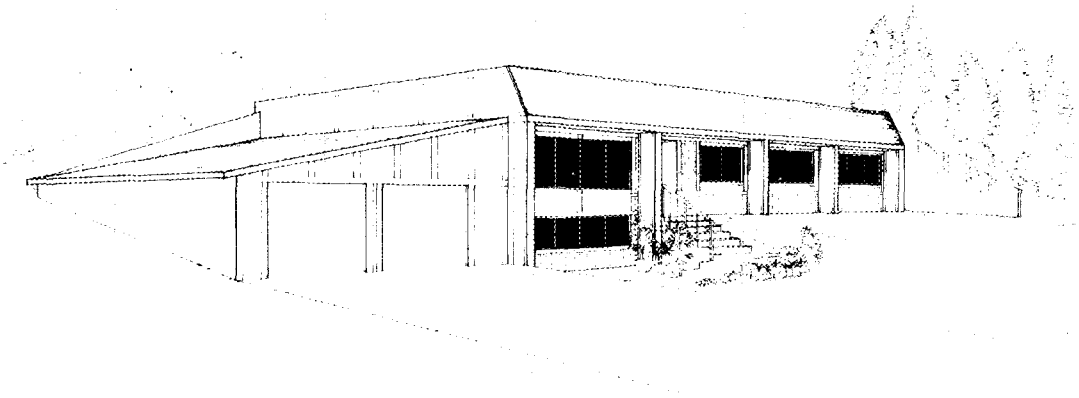

Fig. 10. Rendering of earth-sheltered house in Minneapolis, Minnesota.

Measured performance

For the information obtained by measuring the energy performance to be most useful, it should be expressed in units which allow a direct comparison among various housing types, sizes, and heating, ventilating, and air-conditioning systems as well as various climatic conditions. One such method of comparison currently in use is known as the Thermal Integrity Factor (TIF). It reflects the Btu/ft^2 per degree day to provide space conditioning.

Figure 12, prepared by the Lawrence Berkeley Laboratory, shows the range of TIFs for various classes of aboveground houses. The Mastin house at 2.3 and the Brownell house at 3.0 are two innovative aboveground structures that were monitored by the Brookhaven National Laboratory.

Only a handful of earth-sheltered houses have been monitored in such a manner that the TIF can be accurately identified. One house located near Rapid City, South Dakota, was monitored during 1978 and 1979.[2] It consumed about 28,000 Btu/ft^2 for 8144 heating degree days, which yields a TIF of 3.5 Btu/ft^2 per heating degree day. The report on this house went on to note that typical aboveground frame construction homes in the same location generally require 10 to 12 Btu/ft^2 per heating degree day.

The energy performance of five earth-sheltered houses is currently being monitored as part of the Minnesota Housing Finance Agency Demonstration Program.[3] Several of the houses have been monitored since June 1980; others were not begun until November 1980. Based on the limited data acquired thus far, the TIF appears to range from about 0.8 to slightly over 3.0 Btu/ft^2 per heating degree day. Table 2 reflects various TIFs for the period between September 1980 and February 1981.

Another earth-sheltered house in suburban Minneapolis is being monitored.[4] Based on the data from June 1979 through January 1980, the TIF was found to be 1.02. However, a TIF of 1.6 or 1.7 is expected when the house completes a full annual cycle. Typical TIFs for conventional houses in this location were between 4 and 15.[4]

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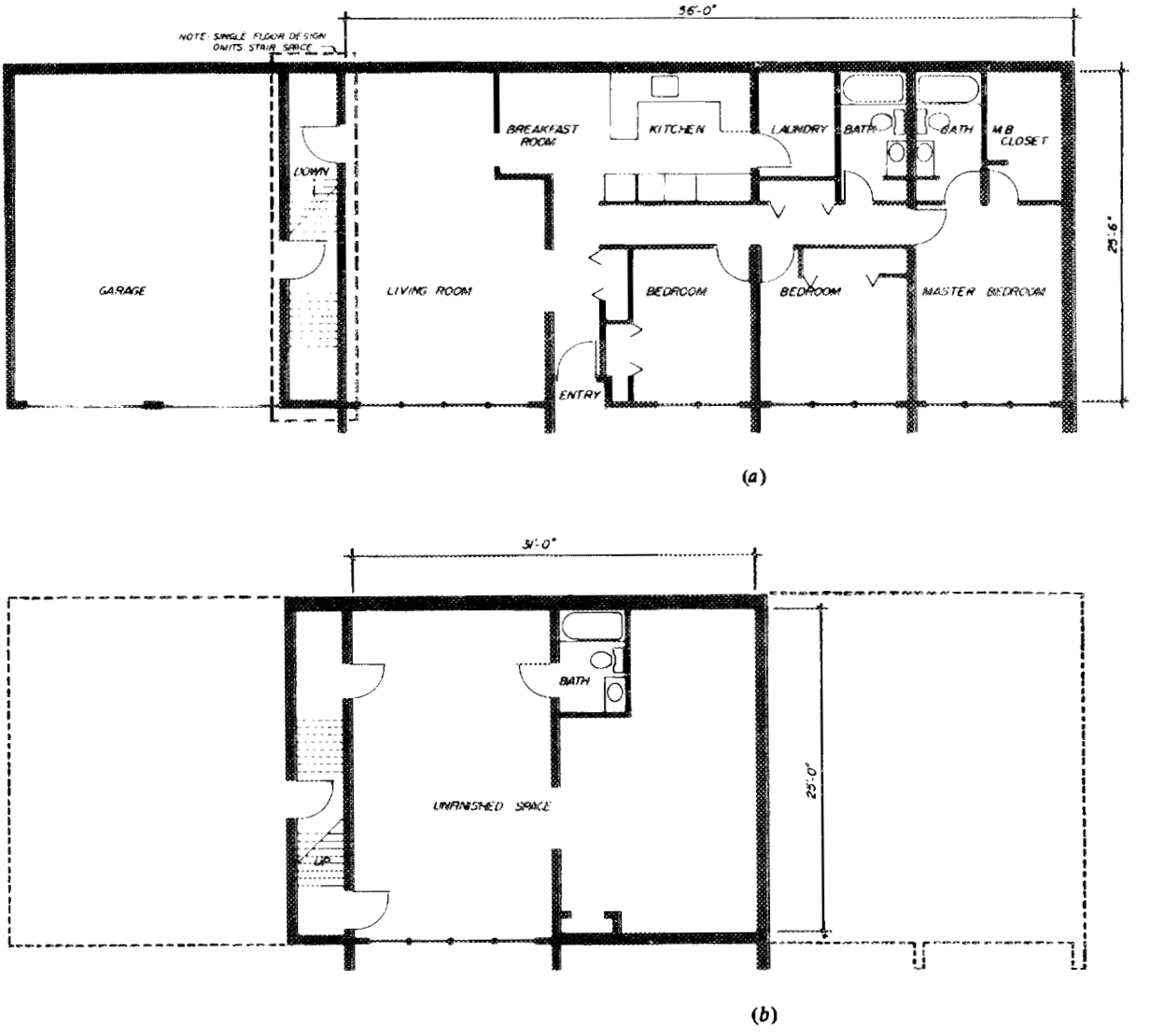

Fig. 11. Floor plans for earth-sheltered house: *(a)* top floor; *(b)* basement level.

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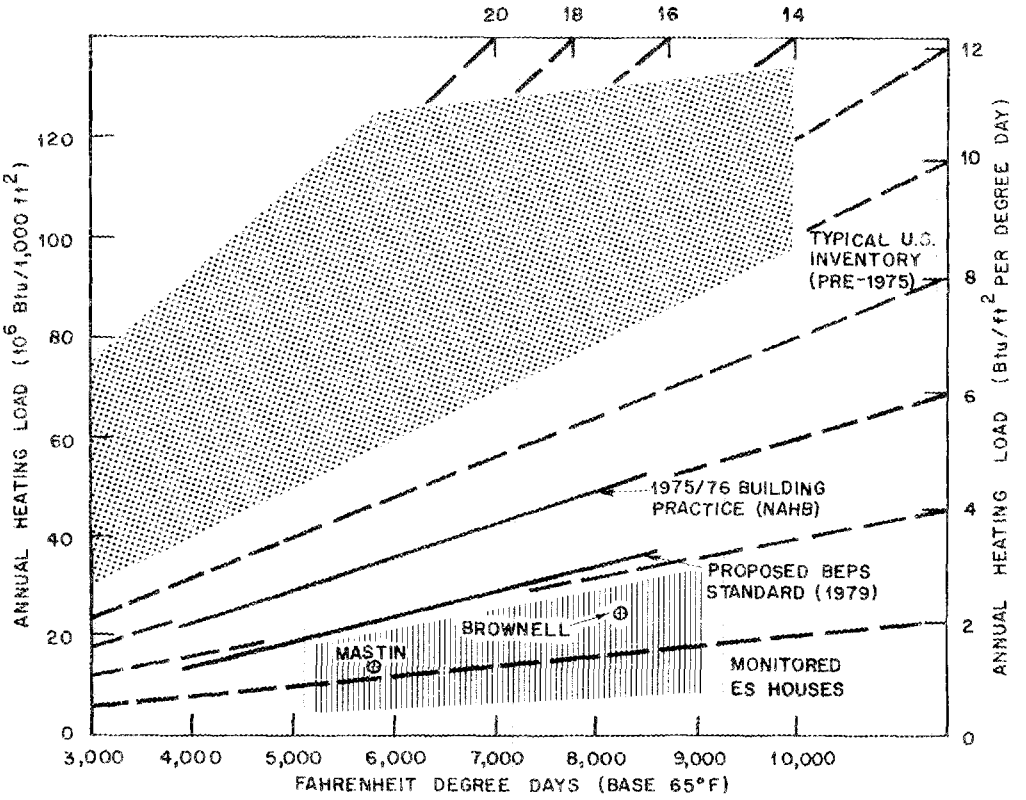


Fig. 12. Thermal integrity factors for various houses.

Some monitoring through the reading of electric meters has also been accomplished in various parts of the country. In one study, five earth-sheltered Oklahoma houses were monitored between 1977 and 1978.[5] Unfortunately, the energy consumption recorded included appliance usage and domestic hot water heating as well as the energy expended for space heating and cooling. This fact makes it extremely difficult to factor out lifestyle differences; therefore, the results are difficult to compare quantitatively. Figure 13 illustrates the energy performance of the five earth-sheltered houses. Figure 14 compares the monthly total energy usage in conventional aboveground and earth-sheltered houses. The aboveground consumption is based on the mean usage of 20 randomly selected, all-electric

Table 2. Monthly thermal integrity factor for five Minnesota earth-sheltered residences

House	June 1980	July 1980	Aug. 1980	Sept. 1980	Oct. 1980	Nov. 1980	Dec. 1980	Jan. 1981	Feb. 1981
Burnsville	*a*	*a*	*a*	0.65	0.84	*a*	*a*	*a*	2.03
Camden	0	0	0	0	0.89	1.20	2.65	1.92	*a*
Seward	0	0	0	0	0	2.14	3.60	2.53	3.19
Wild River	0	0	0	0	0.19	2.05	1.08	0.91	1.27
Willmar	*a*	*a*	*a*	2.28	2.34	1.23	2.72	2.01	*a*

[a]No data taken.

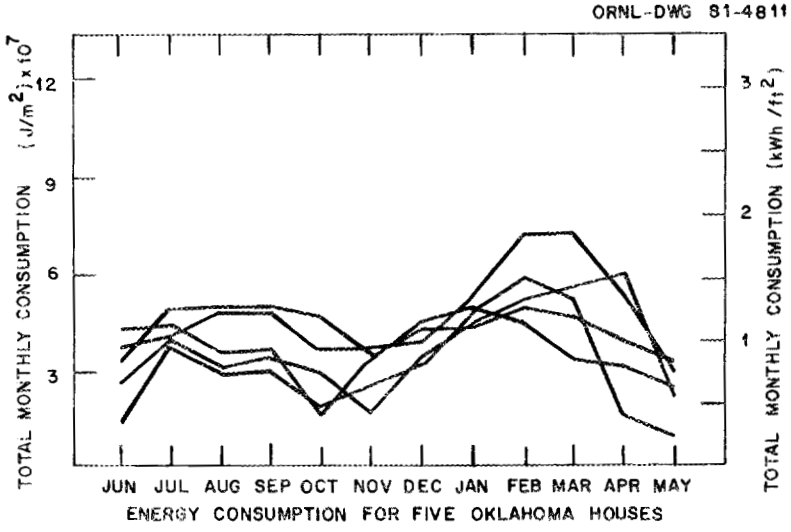


Fig. 13. Monthly energy usage in five earth-sheltered projects in Oklahoma.

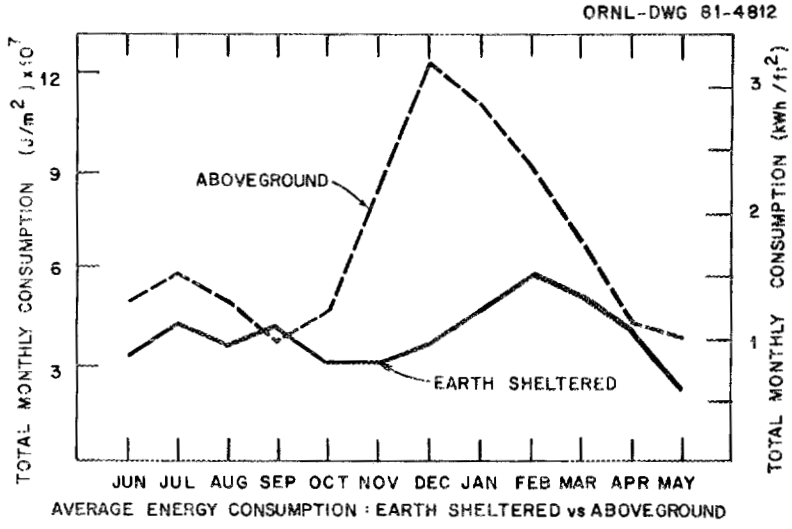


Fig. 14. Comparison of monthly total energy usage in conventional aboveground and earth-sheltered homes.

dwellings in the central Oklahoma area. This approach compared the earth-sheltered houses to aboveground houses, which may or may not have been built with conservation in mind. A comparison with recently built, energy-efficient, above-grade houses would probably have reduced the differential in energy consumption. However, in both cases, earth-sheltered houses would have consumed less energy. Other isolated examples of measured performance are undoubtedly occurring in other regions, although, to date, no results from these activities have come to the attention of the author.

Evaluation to date

Based on the limited information gathered to date, it can be said that earth-sheltered houses can perform significantly better than traditional above-grade dwellings. The claim that heating energy consumption can be reduced 75% appears to be substantiated when one compares a well-designed, earth-sheltered house having a calculated or monitored TIF of 2.5 with a traditional house having a TIF of 10. Because the intuitive claimed performance, the calculated performance, and the monitored performance are in the same range, the probable degree of conservation that can be obtained through earth sheltering is believable. However, earth-sheltered housing is not competing with the traditional dwelling, but rather with current home-building practice and with other forms of innovative, energy-conserving housing. The TIF of these structures differs markedly from that of the traditional house. A TIF of 7.5 is considered as representative of a "baseline, moderately insulated house."[6] Figure 12 shows the National Association of Home Builder's 1975/1976 Building Practice ranging from 5.8 to 6.2. Values in the 0.6 to 1.1 range are predicted for superinsulated houses.[7] From this information, it appears that earth-sheltered housing does have strong competition from superinsulated houses in the area of energy conservation. Whether or not home buyers will choose an earth-sheltered house or some other type of housing as a means to conserve energy will undoubtedly depend on many factors (which are discussed in the following sections).

Further work

It appears that the measured energy usage of a handful of earth-sheltered residences may not be sufficient to accurately portray the energy performance of this concept. In addition, most of the monitored houses have been professionally designed with the intent to minimize energy consumption. For these reasons, a broader monitoring effort, covering a variety of climatic regions and both professionally and nonprofessionally designed houses, could produce significantly more useful information and enhance the ability to further evaluate the concept. Work to improve the calculated performance through the use of computer models could also benefit from this data as a means of verifying or improving existing codes. The results of this extended monitoring should be publicized in conjunction with the results from a variety of other energy-efficient housing concepts so that the public will be able to immediately grasp the relative advantages or disadvantages of each concept.

Another poorly documented variable is the impact of the inhabitant's lifestyle on the energy performance of the house. Dwellings that house two working adults who keep the

temperature of the unoccupied structure at 12°C (55°F) in the winter will undoubtedly consume significantly less energy than the same dwelling that houses a family of six where the temperature is maintained at 18°C (65°F) and where frequent opening and closing of the exterior door by the children is expected. It has also been suggested that some people who move into houses which are classed as "energy conserving" actually change their lifestyles to enhance the effect of the structure. This is particularly true of passive solar dwellings. Whether or not this additional energy savings, achieved through a change in lifestyle, would be universally applicable has not been determined. It is, therefore, with a sense of some uncertainty that one must view the actual energy performance of earth-sheltered houses.

Applicability of the Concept

Background

To assess the overall energy impact resulting from the optimum utilization of earth-sheltered housing, it is necessary to determine to what extent this concept can be prudently applied throughout the United States, that is, to understand the factors that influence the applicability of earth-sheltered houses. Earth-sheltered houses achieve their energy-conserving performance through the use of inherent architectural features such as being below-grade, having massive construction, etc. These "passive" measures are sensitive to climatic conditions. In fact, the climatic condition is the dominant factor in determining to what extent an earth-sheltered house is the appropriate response to the homeowner's desire to minimize energy consumption.

These houses also have certain unique physical characteristics which are impacted by topography, subgrade conditions, and other factors that can limit the cost-effective application of the concept in certain locations. The added costs, accrued from responding to these various factors, tend to inhibit, but not eliminate, the application of the concept. In general, these factors have little or no impact on the dwelling's energy performance.

Demographic factors such as the type, size, and location of housing units being built, along with current population and growth trends, assist in determining the applicability of the earth-sheltered approach.

Climate

Earth-sheltered houses are able to significantly reduce the energy consumed in heating and cooling through the use of various inherent elements of their design. These include an earthen blanket over and around the structure to reduce infiltration, close coupling to deep ground temperatures to minimize the temperature differential between indoors and the surroundings, limited opening in the envelope, solar-oriented windows to permit passive solar heating, heavy masonry construction to permit the storage of solar energy, etc. This "passive" performance is heavily dependent upon the above- and below-grade climatic conditions.

A study by K. Labs in 1981, sponsored by the Innovative Structures Program, accomplished an in-depth analysis of earth-sheltered houses in the various climatic regions throughout the United States.[8] This study looked at both summer and winter impacts of

earth sheltering and compared the concept with other passive concepts to determine which were the most appropriate under the differing climatic conditions. Twenty-nine cities, listed in Table 3, were analyzed in this study. These cities were chosen because weather data for them was readily available, and more generalized climatic regions could be developed. The potential usefulness of earth sheltering, as well as other passive approaches such as enhanced ventilation or evaporative cooling, were identified for each city. The overall conclusions of the study were that earth-tempering techniques are more suited to some regions of the country than to others. The regions in which the earth sheltering is most useful include the northern tier, the Rocky Mountains, the Pacific Northwest, and the desert southwest.

While earth tempering offers energy-saving benefits in most areas of the United States, when it is compared to other passive concepts, these benefits are sometimes outweighed by potential disadvantages such as problems with condensation. Regions with this characteristic include the Deep South and southeastern parts of the United States. A summary of the findings of this study are shown in Fig. 15. This data is only an indicator of the potential

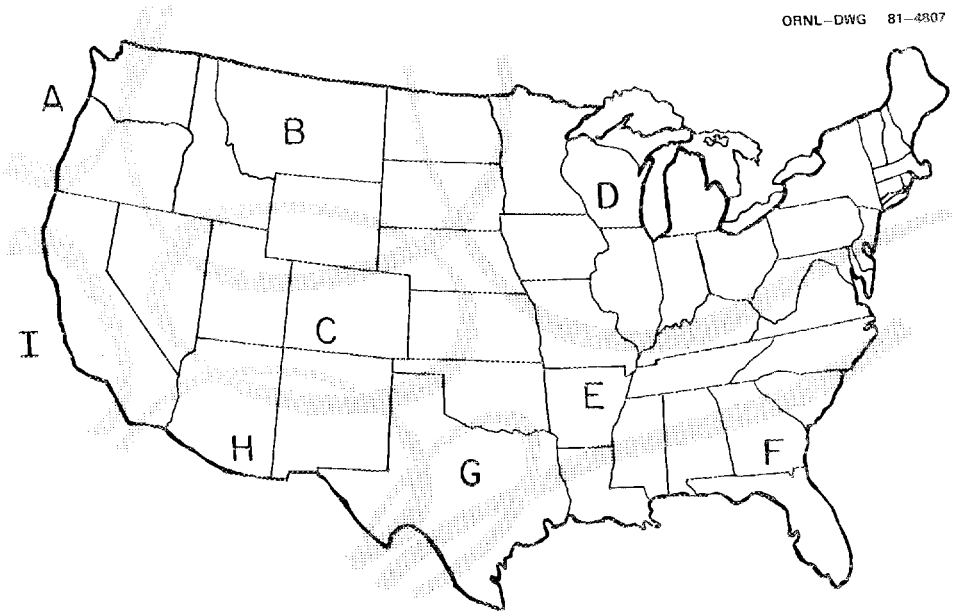
Table 3. Twenty-nine cities investigated in a regional analysis of ground and aboveground climates

Albuquerque, New Mexico	Minneapolis, Minnesota
Atlanta, Georgia	Nashville, Tennessee
Boston, Massachusetts	New Orleans, Louisiana
Chicago, Illinois	New York City, New York
Dallas, Texas	Oklahoma City, Oklahoma
Denver, Colorado	Phoenix, Arizona
Houston, Texas	Raleigh, North Carolina
Indianapolis, Indiana	Salt Lake City, Utah
Jackson, Mississippi	San Antonio, Texas
Kansas City, Missouri	San Francisco, California
Little Rock, Arkansas	Seattle, Washington
Los Angeles, California	Tucson, Arizona
Medford, Oregon	Washington, D.C.
Miami, Florida	Windsor Locks, Connecticut
Midland, Texas	

Source: K. Labs, *Regional Analysis of Ground and Aboveground Climate*, Underground Design Research, New Haven, Conn., 1981.

value of earth sheltering and is not necessarily a total measure of the success or failure of this climate-control concept. The success or failure of any structure to conserve energy depends less upon whether it is above- or below-grade than upon how it was designed to respond to the climate in which it is placed.

Another climatic factor (not investigated in ref. 8) that influences the energy performance of earth-sheltered houses is rainfall. Rainfall directly impacts the amount of moisture in and moving through the top few meters of the ground. It is in this depth range that most houses are built. The presence of water in the soil markedly increases the potential



LEGEND

A Cold, cloudy winters maximize value of earth-tempering as a heat conservation measure. Cool soil and dry summers favor subgrade placement and earth cover with little likelihood of condensation.

B Severely cold winters demand major heat conservation measures, even though more sunshine is available here than on the coast. Dry summers and cool soil favor earth-covered roofs and ground coupling.

C Good winter insolation offsets need for extraordinary winter heat conservation, but summer benefit is more important here than in zone B. Earth cover is advantageous, the ground offers some cooling; condensation is unlikely, and ventilation is not a major necessity.

D Cold and often cloudy winters place a premium on heat conservation. Low summer ground temperatures offer a cooling source, but with possibility of condensation. High summer humidity makes ventilation the leading conventional summer climate control strategy. An aboveground, superinsulated house, designed to maximize ventilation, is an important competing design approach.

E Generally good winter sun and minor heating demand reduce the need for extreme heat conservation measures. The ground offers protection from overheated air, but not major cooling potential as a heat sink. The primacy of ventilation and the possibility of condensation compromise summer benefits. Quality of design will determine actual benefit realized here.

F High ground temperatures. Persistent high humidity levels largely negate value of roof mass and establish ventilation as the only important summer cooling strategy. Any design that compromises ventilation effectiveness without contributing to cooling may be considered counterproductive.

G This is a transition area between zones F and H, comments concerning which apply here in degree. The value of earth-tempering increases moving westward through this zone, and diminishes moving southward.

H Summer ground temperatures are high, but relatively much cooler than air. Aridity favors roof mass, reduces need for ventilation, and eliminates concern about condensation. Potential for integrating earth-tempering with other passive design alternatives is high.

I Extraordinary means of climate control are not required due to relative moderateness of this zone. Earth-tempering is compatible with other strategies, with no strong argument for or against it.

Fig. 15. Earth-tempering regional suitability summary map.

for heat loss in winter by significantly reducing the soil's insulating characteristics. Flowing water next to a structure can also carry away heat. These losses can be offset, however, by increasing the building's insulation.

The magnitude of heat loss due to moisture in the soil has not, to date, been well documented. Many of the variables remain uninvestigated. Despite this general lack of knowledge in the area, it is felt that the impact of moisture in the soil on the energy performance of an earth-sheltered house is small by comparison to the impact of placing the dwelling below-grade. Therefore, while arid regions may be best to reduce wintertime heat loss and wet regions best in the summer to promote loss and reduce air conditioning loads, this factor does not appear to play a key role in the decision as to whether or not to build below-grade.

Topography

Topography is another factor which can influence the applicability of earth-sheltered houses. Unlike climate, topography tends to impact on a micro or site-specific scale. Slopes can change dramatically in short distances, and this fact precludes drawing any regional conclusions. However, if a region has many steeply sloped ridges running in a northeast/southwest direction, it may offer the opportunity for some ideal earth-sheltered building sites.

While the impact of topography is difficult to generalize, certain topographic features can enhance the viability of the earth-sheltered concept. Sites that are too steeply sloped for most forms of traditional construction can frequently be easily adapted to earth-sheltered houses. On such sites, traditional construction requires either massive grading, a basement, or tall piers to provide a horizontal plane on which to build the structure. Earth-sheltered houses, on the other hand, are built into the hillside or slope, and frequently this topographic feature reduces the grading requirement normally associated with this mode of construction (Fig. 16).

South-facing slopes can be utilized effectively to make the earth-sheltered house a passive solar structure. North-facing slopes may be beneficial in areas where the need to cool the structure is dominant. East- and west-facing slopes, in general, should be avoided since they offer little winter passive solar heating benefit and can be significant summertime liabilities.[9]

The cost of excavating, grading, and building foundations for traditional construction on slopes is an inherent cost in earth-sheltered houses. This fact makes the earth-sheltered approach somewhat more competitive where housing in hilly regions is desired.

Because many earth-sheltered houses are below-grade in some portions of the structure, careful consideration has to be given to the direction and amount of site runoff. Local flooding problems can easily occur if site runoff is not an integral part of the design consideration.[10]

Low spots, where flooding can occur periodically, are also unacceptable to earth-sheltered buildings. Such spots might be considered suitable for aboveground structures if they can be raised above the maximum expected flood level.

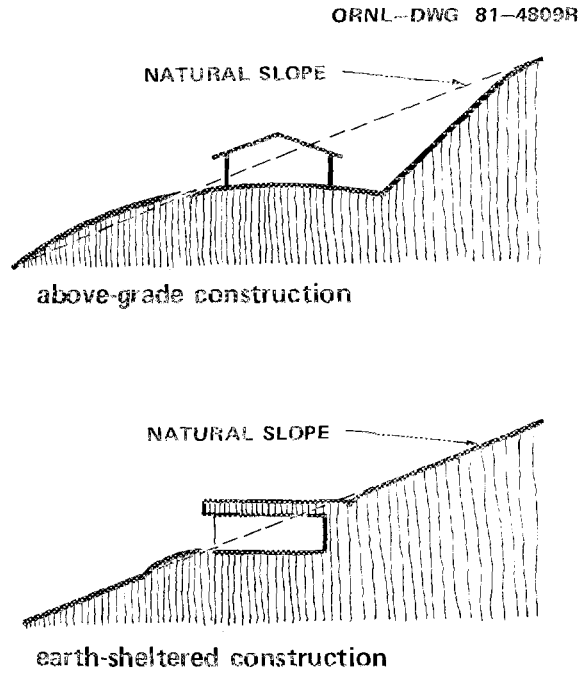


Fig. 16. Typical constructions on sloping terrain.

Topography can be an asset or a liability to earth-sheltered houses. A careful understanding of topographic impacts and a responsive design are required if the earth-sheltered dwelling is to be a success.

Subgrade conditions

Since earth sheltering implies building within the earth, subgrade conditions can become a major consideration. These conditions include soil type, presence of rock, level of the water table, and location of underground water courses. While not precluding the construction of an earth-sheltered dwelling, many of these conditions can have a significant impact on the cost of such construction.

The increased cost of mitigating these usually unseen conditions frequently cannot be offset by any potential energy savings. It is, therefore, important that the prospective builder understand these factors before purchasing a site or deciding to build below-grade.[11]

Sandy soil could pose a problem to earth sheltering in that it may require special shoring during excavation. In addition, this soil can provide for easy movement of groundwater during seasons of the year when the flow of water adjacent to the structure could significantly reduce the energy performance by taking heat away from the structure. However, as has been mentioned before, the magnitude of the heat loss is small when compared to the benefit of building below-grade.

Clay soil, which expands and contracts in response to wet and dry seasons, requires special design considerations to ensure that the structure is not damaged during these cycles.[12]

Figure 17 illustrates the types of forces being applied to a structure built in expansive clays. Several design options can be utilized to overcome these forces. They include developing a heavily reinforced structure that resists the forces, maintaining a stable moisture level in the clay around the structure (Fig. 18), placing the structure above-grade and berming it (Fig. 19), or picking another more suitable site for the dwelling. The added costs of building in an expansive clay subgrade or the relocation to another site can tend to inhibit the applicability of the concept in some areas where it makes a great deal of sense from the viewpoint of climate.

Subgrades containing boulders or ledges of rock are found in various parts of the country. While excavation and removal of the rock may be viable from a design viewpoint, the cost of doing so may dictate building the earth-sheltered structure above-grade and importing soil to bury the structure. In either case, a significant increase in costs for an earth-sheltered house, above that of an aboveground house, could be expected. This fact also tends to inhibit the use of otherwise viable earth-sheltered housing sites.

A fluctuating water table can, if it is near the surface, adversely affect some potential earth-sheltered building sites. While below-ground structures have been successfully built within the water table, these structures have cost significantly more than they would have if the water table were well below the structure. Frequently these additional costs for sophisticated waterproofing systems and construction techniques cannot be justified for small structures such as dwellings.

Underground streams, either seasonal or year-round, can further reduce the potential number of buildable sites for below-grade, earth-sheltered dwellings in some parts of the country. The location of these streams tends to be highly localized and, therefore, has much less impact on where an earth-sheltered house can be built than does the water table.

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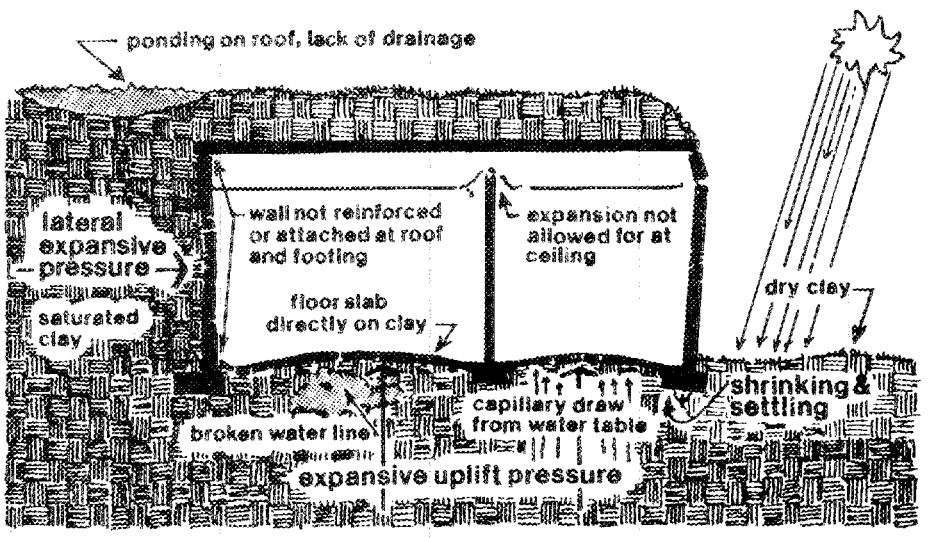

Fig. 17. Structural problems resulting from improper design in expansive clays.

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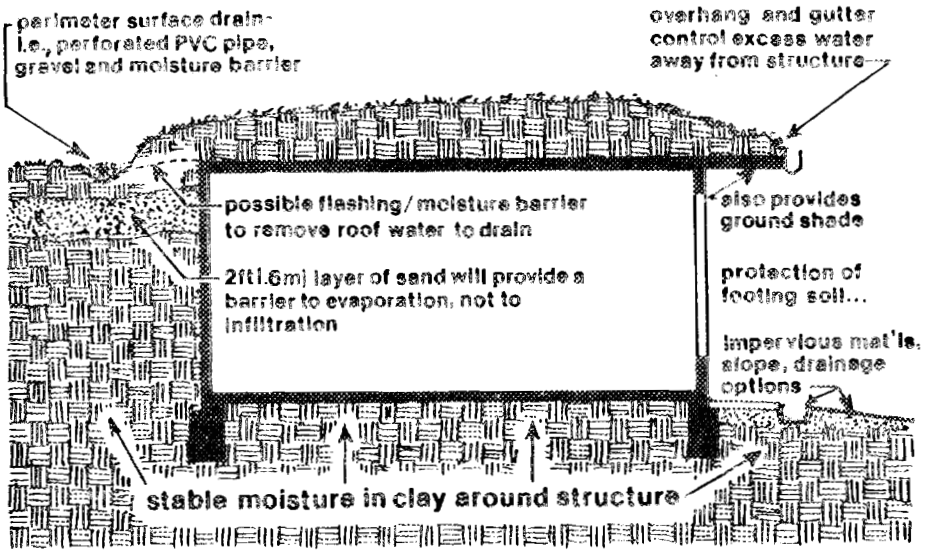

Fig. 18. Control of moisture balance by surface removal.

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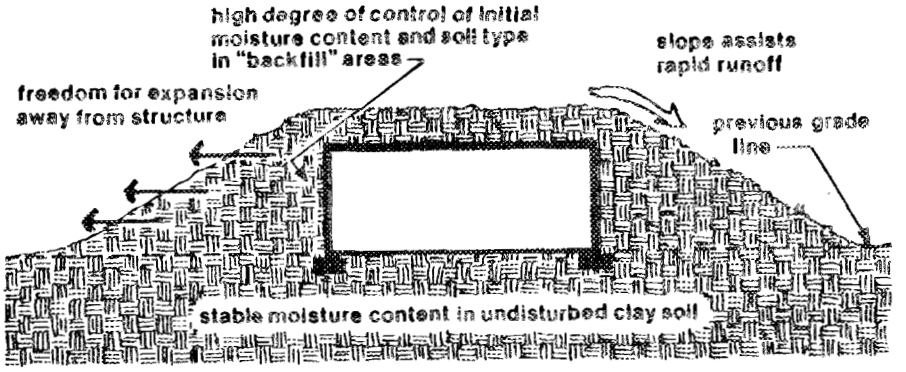


Fig. 19. Reduction of expansive loads from berming structure on grade.

Development trends

The potential location, either urban, suburban, or rural, affects the applicability of earth-sheltered residences. A vast majority of the earth-sheltered houses built to date have been single-family, detached structures. In most urban areas of the country, this type of dwelling is being supplanted by higher density, multifamily structures, which constituted 42% of all housing built in 1980 and 1981.[13] In the "top 20 markets," Minneapolis posted 33% multifamily, Chicago posted 59% multifamily, and Seattle posted 64% multifamily. All three cities are indicated as appropriate climates for earth sheltering.[8] The overall U.S. average, including rural areas, shows multifamily housing between 34 and 41% for the years 1980–84.[14] While earth sheltering has the potential of exploiting its earthen roof as usable open space in a dense urban development, very few examples of this type have been developed. If earth-sheltered houses are to have an impact on urban area development, where most of the people live, then multifamily as well as moderate-density, single-family units will have to be developed and accepted. While the concept appears very promising, it has not yet adequately demonstrated its applicability to urban areas.

Another trend in some urban areas is to build to densities (dwellings per unit area) above what earth sheltering can support. Earth-sheltered dwellings are limited to two or perhaps three stories in height because daylight and view are important habitability factors. This causes earth sheltering to be more horizontal than vertical in nature. High-rise apartments and condominiums, on the other hand, are vertical in nature and can easily add units in response to escalating land and construction costs. This trend would have to be reversed if earth-sheltered housing were to be a viable alternative in these urban areas.

Suburban development, in contrast to urban development, has taken the form primarily of single-family detached housing. While most existing earth-sheltered homes are single-family, in many parts of the country suburban lots are just a few feet bigger on two sides than a traditional aboveground house. This situation, coupled with zoning ordinances requiring minimum setbacks from the property line, has caused some problems in siting earth-sheltered houses on suburban lots.[15] The higher density developments in which the earth-sheltered houses could share common party walls, like row houses, have generally not been acceptable to suburban communities.

This lack of compatibility with the current density requirements, in both urban and suburban locations, tends to make the approach less competitive economically. In some urban areas, the lower density potential of earth-sheltered houses, when compared with high-rise construction, increases the per unit land and site development costs. This means that the home buyer gets less house for the same money. In suburban locations where densities and lot sizes inhibit the development of optimal earth-sheltered dwellings, these dwellings are forced to low density locations. The larger lot sizes of low density areas permit earth-sheltered houses to be built within the setback criteria. However, the added land and site development costs, again, mean that the homeowner will get less house for the same money.

The density of development in communities is continually evolving. As such, it is possible that some urban areas could impose a density limit compatible with earth sheltering in

order to preserve a "sense of open space." Suburban areas, pressured by increases in land values, could allow the increased densities which permit optimum earth-sheltered construction. The evolution takes time, and it may be many years before earth-sheltered houses "fit" within the urban and suburban development trends.

Most earth-sheltered houses in the United States, to date, have been built in rural or small town areas. These areas have neither high-density demands nor space limitations. While earth sheltering does provide energy-efficient rural housing, it is clear (see "Marketability of the Concept") that this segment of the housing market is not where significant improvements to the overall energy efficiency of the country will be made.

If earth-sheltered buildings are to play a major role in the future of cities and suburban areas, the communities will need to evolve either to lower or to higher densities. Although it appears feasible to increase the densities of suburban communities over time, it appears less likely that the market forces, which have dictated the current trends in urban areas, will change to permit reduced densities.

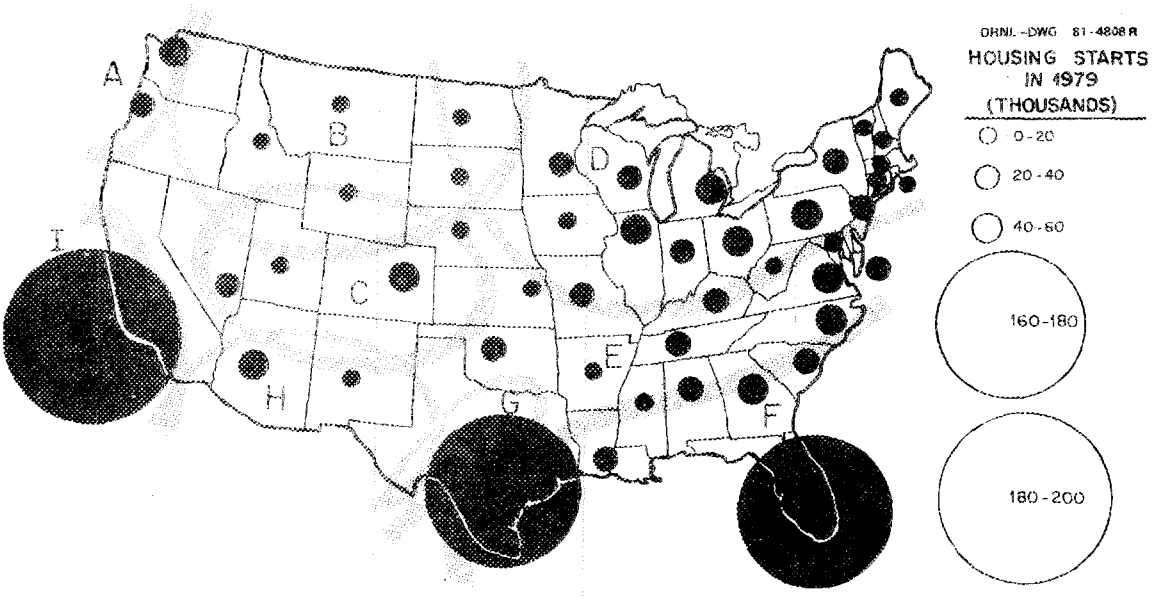
This is not meant to imply that no earth-sheltered buildings will be built in urban areas. Unique conditions such as steeply sloping sites or "marginal lands," like those next to freeways, will encourage some development; however, these situations appear to be the exception rather than the rule.

Current population and growth trends

A major indicator in determining the overall applicability of earth-sheltered housing is the comparison of climatically and physically desirable locations with current population and growth trends. Figure 20 combines the regional suitability based on climate developed by Labs[8] with the total housing starts in 1979. Data from 1979 was used because 1980 data reflected a severely depressed housing market.

This information indicates that in a number of cases major growth areas do not correspond with climatic areas where earth-sheltered houses are a particularly valid passive approach to energy conservation. The southeastern sunbelt states and California constituted 39% of the total housing starts in 1979.[16] In Texas, most of the growth is occurring in regions where earth sheltering is marginal in benefits. In California, most growth is occurring along the coast where the climate is mild and houses gain no significant benefit from earth sheltering.

The current population of the northcentral and northeastern states, where earth-sheltered housing is a viable passive approach, is a large percentage of the total U.S. population. However, as was indicated in the 1980 census, most of these areas are remaining relatively stable in population, while a few are actually declining. This fact suggests that many of the new housing starts in these regions are for the purpose of replacing older homes. As a result, the number of new housing starts is likely to remain well below the growth areas of the country. The rapid escalation of construction costs, coupled with high mortgage rates, is likely to significantly inhibit the development of the replacement market. People in older homes are increasingly more likely to upgrade them rather than to move to a new house



LEGEND

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I Extraordinary means of climate control are not required due to relative moderateness of this zone. Earth-tempering is compatible with other strategies, with no strong argument for or against it.

Fig. 20. Comparison of regional suitability of earth-sheltered housing with housing starts in 1979.

with much higher monthly payments. Even the dramatic energy cost savings of an earth-sheltered house will not offset the costs of relocating in many cases.

What do these trends mean to the earth-sheltered concept? The population growth in the Southwest is a stimulus to possible earth-sheltered structures, especially those utilizing passive solar heating. However, the tremendous growth in the Deep South and Southeast is less likely to stimulate earth sheltering in this region since the high humidity prevents earth sheltering alone from mitigating the discomfort associated with high temperatures. Either dehumidification or enhanced air flow is important in overcoming discomfort. Other energy-efficient, passive approaches may be more cost-effective in overcoming discomfort, except where hilly topography dictates that at least a portion of the structure be underground.

The severe winter parts of the United States, the Pacific Northwest and the Rocky Mountain states, where earth sheltering performs well, are, in general, growing slowly. A long time will be required before the existing housing stock is replaced and the impact of any change as a result of earth sheltering is significantly felt.

The growth in the suburbs will probably permit the more cost-effective, higher density, earth-sheltered housing. However, these strongholds of the single-family, detached house may well resist the trend toward a higher density urban environment. The lack of growth in rural areas will not stimulate a rapid increase in earth-sheltered houses even though most are currently built in rural areas.

The shift towards less-expensive forms of housing, reflected in the fact that mobile homes constitute about 10% of the market and multifamily homes another 40%, will inhibit earth sheltering in the forms that exist today. The inherent higher cost of construction (see "Marketability of the Concept") may eventually make earth sheltering a luxury beyond the means of most prospective home buyers.

Evaluation to date

It is clear that the unique benefits achieved from the use of earth sheltering, as a passive means to conserve energy in housing, are primarily regional and not universal in nature.[8] Other passive techniques also share this regionalism. In addition, the applicability of earth-sheltered housing is more dependent on such site-specific issues as topography and subsurface conditions than are many other approaches to housing. Current development trends will need to change markedly for earth-sheltered housing to reach its potential. Finally, population and growth trends in the United States generally do not coincide with the area of optimum utilization of earth sheltering.

These factors suggest a somewhat limited area of applicability. However, before one could clearly define the exact boundaries of that area, a substantial amount of additional work would be required — for example, further study of the relation of climate to energy performance, an in-depth analysis of the site-related factors (surface and below-surface conditions) as they affect the potential for earth-sheltered construction, and a much more thorough analysis of the impact of future building trends as they relate to where earth-sheltered buildings are likely to be built.

Marketability of the Concept

Background

The total amount of energy saved through the utilization of earth-sheltered houses is dependent on both the number of dwellings actually built and the energy performance of individual structures. The number of earth-sheltered houses built will be determined by their acceptance in the marketplace. There are several key factors in determining market acceptance. These include emotional factors, factors affecting the ease of acquisition, and economic factors. Emotional factors include such diverse items as aesthetics, "curb appeal," status image, durability, habitability, and the environment created by the dwelling. The factors affecting the ease of acquisition include financing, compatibility with building codes, and finding qualified contractors and designers. The economic factors influencing acceptance of the concept are initial costs, operating and maintenance costs, life cycle costs, and the prospective homeowner's financial capabilities.

Emotional factors

Real estate agents and others versed in the buying and selling of houses have long realized the important role that emotional factors play in the decision to purchase a particular dwelling. Once a house fulfills the basic physical needs (i.e., three bedrooms, two baths, and within the general price range which the buyer can afford), the decision to buy is, in most cases, predominantly an emotional one.

The specific emotional factors fall into three main categories, which include how the potential buyer relates to himself, that is, ego, how he relates to a dwelling, and how he relates to the larger environment. The ego factors include the need for a status image. A house can physically represent where a person is or where a person aspires to be. A large, impressive house sitting atop a hill overlooking the region will be the only way to satisfy some people's emotional needs. An earth-sheltered house dug into the same hillside would make a much different statement and could relate to other people's needs.

Another ego factor is the need to conform versus the need to be different. In most urban and suburban areas, the decision to live in an earth-sheltered house is clearly nonconformist. In rural areas where physical separation and individualism is a norm, earth sheltering may not be considered so "different." Judging from the millions of colonial, tudor, ranch, California Spanish, and French Provincial homes being built throughout the country, it appears that "fitting in" is important to many Americans.

Curb appeal is another ego factor but primarily relates to how others view the house. This is particularly important when marketing the house since some decisions to buy or not to buy are made before entering the door. Traditional houses develop their curb appeal from factors which in some cases are difficult to obtain in an earth-sheltered dwelling. For example, a particularly attractive formal entry into a traditional house might have to be compared with a shaded, less visible, sunken entry into an earth shelter. With only a few hundred earth-sheltered houses having been bought and sold to date, it is too early to be able to generalize on the items that are important for best curb appeal.

The buyer's emotional relation to the dwelling is embodied in his desire for a habitable surrounding. Habitability includes such factors as the need for light, comfort, warmth, and a sense of security. If the buyer envisions a house dank, dark, and damp, the popularized, erroneous description of earth-sheltered houses, he is not likely to have a positive emotional response to that dwelling. The durability of a structure can also be an emotional need, especially for those who want to leave their mark in life or those who want to set roots and grow in a particular location. Durability can be one of the factors that enhances the earth-sheltered concept in the mind of some buyers.

How the buyer desires to relate his home to the larger environment can also affect what type of house to buy. One extreme of this relationship can be seen in a pristine white metal and glass geometric form, that is, a house set on a plane of carefully manicured lawn. At the other extreme could be the earth shelter dug into a rolling meadow where wild flowers and tall grass dominate the view and only a narrow slit of glass and recessed entryway give any evidence that this is the location of a home. The first extreme embodies a desire to dominate and control the environment, the second a desire to submit to and blend with the environment.

Most houses built today fall between these extremes. While some traditional above-grade houses have been effective in harmonizing with the environment, most tend toward the domination and control of the environment. Earth shelters, on the other hand, because of earthen-covered walls and roof, tend to blend more strongly with the surrounding environment. Based on the number of aboveground houses, which are designed to blend with their environment, and the almost universal use of some landscape material to soften and tie most houses into the environment, it would be fair to say that most Americans desire their houses to harmonize with the environment. To the extent that this factor is significant in the mind of the home buyer, it can enhance the earth-sheltered concept.

The composite impact of all the emotional factors on the decision as to whether or not to buy an earth-sheltered house has not been scientifically studied. Several small-scale studies of the buyer's views of habitability of an earth-sheltered house have been reported.[17,18] Because refs. 17 and 18 appear to be based on the same survey information, which has an extremely limited number of responses (200) and has not been duplicated, per se, at other places and other times, they should be regarded only as indicators of people's responses and not as containing definitive information which could be applied broadly.

In ref. 17, an experimental earth-sheltered home was presented to a group of people, 95% of whom had never seen an earth-sheltered home before. Two hundred people responded to the questionnaires used in the study. Over 40% of the respondents reported that they were "somewhat" to "very" likely to build an underground home in the next five years. These respondents were not faced with such real-world issues as obtaining financing and the various cost factors. Therefore, it could be inferred that to a large extent, they were responding emotionally to the dwelling.

In ref. 18, various construction features and alternatives of an earth-sheltered house were presented to a group of consumers. "The respondents preferred having one elevation of the house exposed rather than having the entire structure built underground. There was strong support for the addition of skylights over rooms in the back of the house where

natural light was limited. Respondents were skeptical of the use of treated wood instead of masonry for the foundation." These items of interest show a need for the structure to be visable from the surface (probably an ego need as well as a habitability need), a need for more natural light (a habitability need), and a preference for masonry rather than wood construction (a durability need).

This study indicated that 60% of the respondents said they would have to realize savings of $3000 or more in initial costs before they would consider purchasing an earth-sheltered house, and 68% felt that $300 or more a year in utility savings would be required for them to consider purchasing such a house. One might infer from this fact that, when the real world factors of economics enter the picture, emotional factors related to earth sheltering are not positive enough to convince people to buy even at the same construction cost as above-grade. Some financial inducement resulting from reduced utility costs is also required.

In another study, which focused on the habitability aspects, it was found that energy savings that were realized in earth-sheltered homes were achieved with little decrease, and often an increase, in comfort and habitability.[19] Most respondents were highly satisfied with the safety of the structure and the layout of rooms, which in most cases were custom designed for the occupants. However, they were less satisfied with daylighting and privacy aspects.

These studies indicate that people respond to earth-sheltered dwellings in an emotional manner, not unlike how they respond to a traditional above-grade home. The studies do not, however, contain enough information to identify how people respond to them in comparison to an above-grade dwelling. It is this comparison that will ultimately determine the market acceptance of the concept. With only an estimated 3000 to 5000 earth-sheltered homes in existence throughout the country, it is far too early to infer that they have been emotionally accepted on a broad-scale basis by potential home buyers.

Ease of acquisition

The ability to acquire a particular type of house with a minimum of difficulty or hassle will positively impact its marketability. All homes have some "barriers" to be overcome before they can be acquired, including finding a competent builder, obtaining a building permit, arranging a mortgage, etc. Earth-sheltered homes, however, have experienced all the traditional barriers plus some new ones. Some of these barriers are permanent while others are transient and will change with time.

Barriers that earth-sheltered home buyers must overcome include the lack of experienced architects and contractors.[15] Few architects are experienced with earth-sheltered housing design. Those that are may not be available when their support is desired.

Many residential contractors are not qualified to deal with some of the materials and construction techniques used in underground construction. This lack of qualification can raise prices as the contractor includes "learning time" on the first such projects. During construction, more time is spent studying and supervising various critical areas of detail such as waterproofing. In addition, the total construction time has been longer due to scheduling and coordinating various facets of the work.

Finding a suitable site on which to construct an earth-sheltered dwelling can also be a problem. Not only must the natural constraints such as topography and subsurface conditions be dealt with, but also code and zoning limitations, as well as aesthetic integration with the surroundings. These constraints have helped limit the number of earth-sheltered houses built in urban areas.

Many people consider financing to be the biggest obstacle to the construction of earth-sheltered houses. In a study done for the Department of Energy in 1979,[20] 36% (19 persons) eventually obtained financing on their earth-sheltered housing, but only after experiencing difficulties at one or more lending institutions; 27% (14 persons) were unable to finance their project; 25% (13 persons) had no difficulty obtaining construction loans and mortgages (of this group, 8 had ties to the lender); 8% (4 persons) financed their project with private capital; 4% (2 persons) had not received a decision at the time. While some improvement has occurred since this study was made, many of the problems associated with financing still exist.

These problems primarily stem from the relative uniqueness of earth-sheltered homes and the prospective home buyer's inability to effectively communicate the benefits of this type of innovative, energy-conserving home to potential lenders. As a result, the financial community's perception of risk is increased.[21] With relatively few earth-sheltered homes and even fewer resales of these homes, it is virtually impossible to determine an earth-sheltered house's market value based on experience. Although various alternative methods have been suggested,[22] these methods have not been broadly tested.

A strong market demand is the most effective means of overcoming the transient barriers which stand in the way of acquiring earth-sheltered houses. Such a demand would increase the design and construction expertise, focus attention on zoning laws which inhibited the concept, and demonstrate a market for the houses, thus easing the problem of obtaining loans. Thus far, the earth-sheltered home concept has received only "good press coverage" and moderate interest in certain parts of the country. With fewer than an estimated 1000 new units per year, compared to a total of 1.5 to 2.0 million total new units per year, a strong market demand has not been demonstrated. This fact has caused the barriers to earth sheltering to be removed at a much slower pace.

Economic factors

Once emotional and acquisition barriers have been overcome, then costs or economic factors become a key element of the decision-making process. Those factors, in conjunction with the prospective home buyer's financial capabilities, will determine whether or not a particular concept will be utilized.

Most home buyers view initial construction costs, as reflected in their monthly mortgage payment, as the dominant economic factor. In recent years, operating costs, which are made up primarily of utility bills, have become recognized as another economic factor to consider. Maintenance costs are hard to predict beyond a relative level and are therefore not one of the major decision-influencing factors. Life cycle costs, which factor all of the above with interest rates, taxes, cost escalations, etc., are complex and hard to apply to the home buying situation. The satisfaction of the emotional needs embodied in the purchase of a home

far outweighs the economic considerations reflected in a life cycle cost analysis. This is not meant to imply that this analysis has no role in the evaluation of buildings. It can play a significant role in those buildings where cost or return on investment is the crucial economic factor. Commercial and industrial structures are examples of such buildings.

Initial costs. There is not yet a sufficient body of data from which to draw definitive conclusions on the initial construction costs of earth-sheltered houses.[23] Based on the existing examples, construction costs have most often been higher for earth-sheltered dwellings than aboveground wood frame structures. How much higher has been difficult to assess, because few earth-sheltered houses have been directly compared in size, location, finishes, and amenities to an aboveground house. The numbers most frequently used by those familiar with earth-sheltered housing costs are "about 10% more." Unfortunately, the extremely limited sample of earth-sheltered houses to draw numbers from and the lack of an objective comparison with comparable aboveground structures makes this number little more than an unsubstantiated claim.

To gain a clearer picture of the relative cost differential, the Oak Ridge National Laboratory undertook a study to develop the various costs associated with two comparable residences, one above-grade and one earth-sheltered, in five different locations in the country.[1] The goal of this study was to address regions distinctly different, not only in climatic characteristics but in construction practices as well. Based on maps and graphs available through the National Weather Bureau and the U.S. Census Bureau, all areas in the United States were plotted for the following characteristics:

- heating degree days,
- cooling degree days,
- precipitation,
- humidity,
- sunshine availability,
- termite and infestation probability, and
- material decay probability.

Five metropolitan areas were selected. This selection was based primarily on the maps mentioned above; however, population size was also considered. The cities are Boston, Houston, Knoxville, Minneapolis, and Salt Lake City.

Once the five cities were selected, the following points were addressed:

1. What does the market look like in the specific regions?
2. What house sells best in the region and could be classified as typical? [This description would include information on exterior style, building material, floor plan style (split level vs ranch, for example), car parking facilities (carport, garage, or none), type of foundation, etc.]

This information was obtained primarily from:

- U.S. Department of Commerce, Bureau of Census, "Characteristics of New Housing"; and
- "Housing Special Report," courtesy of the National Association of Home Builders, which addresses the issue of what home buyers seek in six major markets.

Pertinent data from the local chambers of commerce, including real estate magazines, were also used. Census Bureau statistics indicated that 52.6% of the houses built are ranch style and that 1480 ft^2 of main living space is probably "equally" popular in all the regions selected in the study. In this study, we refer to the 1480 ft^2 of main living space, which includes basements and garages as the base. The following information describes the house design we adopted for the five regions:

- Boston: base on the main floor, basement level with unfinished space and a two-car garage;
- Houston: base slab on grade, two-car garage attached;
- Knoxville: base on main level, lower level crawl space and two-car garage;
- Minneapolis: same as Boston; and
- Salt Lake City: base on main level, over crawl space with a two-car carport attached.

The design of the earth-sheltered and above-grade structures had identical room sizes, storage areas, and unfinished space for each of the regions. Naturally, the floor plans differ in that the earth-sheltered home has windows facing south only and in that the unfinished space is not necessarily a basement area. But, for the home buyer, the exterior of the house, the general arrangement, and the finishing materials are identical for each region in both the above- and below-grade structures. The differences are only the ones inherent in the energy and earth-sheltered aspects of the houses.

Both houses were designed for a high degree of energy conservation, but neither could be classed "high performance/experimental" in conservation features. The aboveground house is comparable to the better energy-conserving houses built in 1980 and, as such, costs somewhat more initially than conventional houses with lower performance.

Ten sets of working drawings were prepared. In addition, a limited specification document for each of these sets was prepared to outline the elements that are different in the ten designs. As stated before, all aspects except the ones inherent in the earth-sheltering and energy factors were identical for each set of two houses in the five locations.

These sets of blueprints, along with specifications, were forwarded to a consulting architectural engineering firm which provided a detailed cost analysis. The firm worked closely with builders in the localities and reflects not only the different structural design but also materials and labor costs particular to each of these areas.

The initial construction costs developed by that study are shown in Table 4. The initial construction costs are greater than the "about 10% more" figure usually used for earth-sheltered houses. The numbers in Table 4 represent the estimate from only one source and

may, therefore, be challenged as to their broad-scale applicability. However, because they were developed through the use of labor and material takeoffs and because these two factors utilized broadly accepted unit cost figures, the differential between the two concepts is likely to remain even with a broader base of estimating. In addition, costs in excess of the "about 10% more" have been confirmed in other preliminary investigations (Ralph Johnson, President, National Association of Home Builder's Research Foundation, Washington, D.C., personal communication).

It is the opinion of the author that the difference between the "about 10% more" and the 31 to 49%, indicated in Table 4, is a result of the direct comparability this study achieved between earth-sheltered and above-grade dwellings. Figures 8–11 illustrate the comparability of overall appearance and finishes of both structures in Minneapolis, Minnesota. Similar designs were developed for the four other cities studied.

Table 4. Estimated construction costs for 1480-ft^2 earth-sheltered and above-grade dwellings in five cities

Location	Earth-sheltered structure		Above-grade structure		Additional cost for earth sheltering (%)
	Structure[a]	Total[b]	Structure[a]	Total[b]	
Boston, Mass.	$111,394	$135,882	$75,556	$100,044	47
Houston, Tex.	84,849	99,087	59,109	73,347	43.5
Knoxville, Tenn.	76,026	89,514	57,825	71,313	31.5
Minneapolis, Minn.	105,656	132,144	70,611	97,099	49.6
Salt Lake City, Utah	80,042	103,030	61,115	84,103	31

[a]Structure cost includes the building and its internal support equipment (heating, cooling, plumbing, electrical system, etc.).

[b]Total cost includes the basic structure plus site improvements, utilities, and land costs.

Whether or not the initial cost figures have had an impact on the number of earth-sheltered houses being built today is doubtful. Most earth-sheltered houses today are built in direct response to a prospective home buyer's desire for an earth-sheltered house. Relatively few are built on the speculative market. Because of this desire on the part of the buyer for an earth-sheltered home, he may be willing to modify his criteria in terms of size and amenities to permit the price to fall within his range.

If earth-sheltered houses are to penetrate the mass market, they would have to be built on a speculative basis and, therefore, compete on a comparable basis with aboveground construction. While some reduction in costs could be expected from increased builder familiarity with the concept and efficiencies gained from improved designs and materials, it is doubtful that these reductions would close the gap between above-grade and earth-sheltered construction. The heavier structure and more sophisticated waterproofing of an earth-sheltered home will, in all likelihood, continue to keep its cost higher than above-grade structures.

Operating costs. The operating costs include heating and cooling energy costs, insurance, and other smaller items. As indicated in a previous section on energy performance, earth-sheltered buildings use less energy in space conditioning than traditional

above-grade houses. The relative energy savings in dollars, from the ORNL study,[1] is shown in Table 5.

Savings from reduced costs in insurance for earth-sheltered dwellings has occurred in some circumstances, but has not been universal in its applicability. Because the bulk of insurance premiums covers the costs of small losses, theft, and administrative costs, it is unlikely that reduction in catastrophic loss potential (fire, wind, etc.) due to earth sheltering will significantly impact insurance rates in the long term.

Table 5. Annual fuel costs for heating and cooling of an earth-sheltered and above-grade dwelling using an electric heat pump with a coefficient of performance of 2.0 and the prevailing local electric rates in 1980

Location	Earth-sheltered structure	Above-grade structure
Boston, Mass.	$292.00	$522.00
Houston, Tex.	73.64	91.09
Knoxville, Tenn.	116.69	199.05
Minneapolis, Minn.	282.00	511.00
Salt Lake City, Utah	226.73	426.42

Maintenance costs. It has been said that earth-sheltered houses will have much lower maintenance costs than aboveground dwellings. This statement is true if you compare a well-built, properly waterproofed, reinforced-concrete earth-sheltered house with an above-grade house with wood siding, asphalt shingles, and galvanized gutters and downspouts. However, readily available, but expensive, materials can also give the aboveground house comparable low maintenance costs. These include brick, slate roofing, and copper or aluminum gutters and downspouts.

In the case of the aboveground house, the buyer can choose between higher initial or higher maintenance costs. Earth-sheltered houses, in general, do not permit this choice. More durable walls are required for structural reasons. Waterproofing is far more crucial and, therefore, given more care and better materials. The buyer really has no choice. To compromise could result in structural failure or a leaky roof that is extremely difficult and expensive to repair.

Interior maintenance costs are highly subject to life style and the personal desires of the occupants. As such, no important difference is believed to exist between above- and below-grade construction.

Life cycle cost. A number of life cycle cost analyses have been done to compare earth-sheltered and above-grade residences.[1,23-26] Most were done on different sets of assumptions.

> As an example of how the assumptions can change the results, an earth-sheltered house, assumed to cost $10,000 more than a conventional house, was analyzed for several different conditions. Assuming a 9% interest rate, 80% energy savings, and an energy cost escalation of 12% per year, the payback period (considering mortgage and energy cost only) was 11.2 years.

> Increasing the energy cost escalation rate to 20% per year changed the payback period to 7.2 years. Including an insurance savings of 30% per year improved this to 5.3 years, and even increasing the interest rate to 11.5% did not prevent the payback period from coming in the first year of ownership when the proposed Federal Solar Bank Bill incentives for earth-sheltered housing were included.[23]

The above example shows clearly how changing assumptions can change the results. Few of the assumptions, however, reflect the actual market conditions in 1981. Typical housing costs were significantly more than the $10,000 suggested, interest rates ranged from 14 to 16%, energy savings were typically 60% or less, and insurance costs were not universally 30% less. The Federal Solar Bank Bill was not being implemented.

Because of the deviation from current market conditions, the paybacks of from one to eleven years are not valid for 1981. In another analysis, the life cycle costs were compared using another set of assumptions and included maintenance and replacement costs (Table 6).[24]

Table 6. A comparison of life cycle costs for typical conventional and underground structures

Conditions	Conventional structure	Underground structure
Price	$86,500	$110,650
Down payment	$17,500	$17,500
Mortgage	$69,000	$93,000
Interest, %	9	9
Owner's tax bracket, %	35	35
Money inflation rate, %	6	6
Energy cost inflation rate, %	12	12
Housing inflation rate, %	7.5	7.5
Total maintenance cost for 30 years	$11,805	$3,105

Based on this analysis,[26] the underground house costs less to own than the aboveground house after 16 years on a straight dollar cost basis, and after 20 years on a discounted basis. Changing the assumptions used in this study to more closely reflect 1981 market conditions would significantly extend the payback period.

Another life cycle cost analysis,[1] including maintenance costs, was based on the actual market conditions existing in 1980. The results for each of the five cities studied (Table 7) indicate that the total present-value life cycle costs for the earth-sheltered dwellings were consistently higher than for aboveground dwellings. This means the payback is beyond the 30-year assumed life of the structure.

Life cycle cost analyses were run independently for each of the designs. Identical economic factors were used for each of the two designs for the same city; however, these factors were city-specific.

Table 7. Total present-value life cycle costs based on actual estimated construction cost and 1981 market condition in five cities

Location	Earth-sheltered structure	Above-grade structure
Boston, Mass.	$105,381	$85,425
Houston, Tex.	76,257	61,113
Knoxville, Tenn.	72,117	62,367
Minneapolis, Minn.	101,677	82,409
Salt Lake City, Utah	79,669	72,527

For each one of the cities, the following information was obtained:

- state income tax,
- property tax rate (state, city, and county),
- sales tax,
- median household income per capita,
- cost of living index,
- type of mortgage and rates available,
- energy costs (fuel),
- expected fuel escalation rate, and
- maintenance cost for the two different designs for both heating, ventilating, and air conditioning and the structure itself, which included exterior and interior painting cost and frequency, roofing, carpeting and other flooring, plumbing repairs, electric repairs, appliance service and/or replacement, appliances, hardware, pest control, and miscellaneous items.

The study also tested the sensitivity of the basic construction costs to determine whether or not initial costs of 10% more could be economically justified by savings in energy and maintenance costs. The results (Table 8) indicate that added base construction costs of as much as 10% more might be justified in Minneapolis and Salt Lake City, but that costs below 10% more would have to be obtained for Boston, Houston, and Knoxville.

Table 8. Total present-value life cycle costs for an assumed base construction cost for earth-sheltered dwellings of 10% more than above-grade and 1980 market conditions in five cities

Location	Earth-sheltered structure	Above-grade structure
Boston, Mass.	$85,832	$85,425
Houston, Tex.	62,987	61,113
Knoxville, Tenn.	63,590	62,367
Minneapolis, Minn.	82,419	82,409
Salt Lake City, Utah	71,035	72,527

Another study compared construction and operating costs of earth-sheltered and above-grade homes in Seattle, Washington; Dallas, Texas; and Madison, Wisconsin.[26] The results of this study showed that the ten-year cost of ownership for an aboveground house was less than for a below-grade house in all cities studied.

A newsletter published by a builder of earth-sheltered houses included the following:

> In an earth-sheltered building, there is a point which is rather difficult to compute, at which the building will pay for itself in utility savings, maintenance, insurance, etc. Based on an 8% inflation, a 10% escalation in energy prices, and countless other factors, this payback seems to be somewhere between 20 and 25 years. This will not be easily perceived by those whose vision extends only between their wallet and property line, but for the discerning homeowner, these buildings represent one of the best investments that you can make.[25]

A five- to ten-year payback period is probably the maximum length that is likely to have any effect on the choice of housing type. The average length of residence in any given home in the United States is about five years. Therefore, for a buyer to consider potential long-term savings of benefit to him, it should occur during his period of occupancy. A five- to ten-year period, while not meeting the average, does cover a large portion of the population. It is also likely that the "durability" factor, which appeals to many prospective earth-sheltered home buyers, would indicate a longer-than-average residency.

As can be seen from the various results listed above, a wide disparity exists between the various life cycle cost analyses with payback ranging from 1 to 30 years or more. Since there has been little agreement on what constitutes valid assumptions to date, this disparity is likely to continue. However, it is fairly evident that earth-sheltered houses are not economically attractive (payback in the five- to ten-year range) when the life cycle cost is based on current (1981) market conditions.

Impact of economic factors. Earth-sheltered residences cost more than comparable above-grade dwellings. This cost is somewhat offset by reduced operating costs and potentially lower maintenance costs. However, the higher initial costs, which have been escalating at a rate faster than inflation, coupled with the high mortgage rates prevalent in 1980/1981, have pushed the monthly costs of such houses well beyond the means of most Americans. Although traditional housing also shows the plight of escalating costs and high mortgage rates, the premium cost of houses that are earth-sheltered suffers more because of the compounding effect of high interest rates on high construction costs. Unless marked changes occur in these economic factors, it is likely that the energy conservation potential of earth sheltering will never be fully realized because it is simply too expensive to obtain.

CONCLUSIONS

One goal of the Innovative Structures Program in assessing earth-sheltered housing was to attempt to identify the overall energy impact resulting from the fullest possible utilization of this concept. After reviewing the information available on which to make an evaluation, it is apparent that there are many gaps and weak points. To achieve a defensible quantitative estimate would require a tremendous amount of additional data. However, certain qualitative trends have appeared in the information collected to date. It is these trends that will form the conclusions of this report.

Based on both monitored and calculated performance, it is clear that earth-sheltered houses are capable of very good energy performance. TIFs ranging from about 1 to 4 Btu/ft^2 per heating degree day are typical of the earth-sheltered structures monitored. Although few structures have been monitored, the calculated performance of earth-sheltered houses also falls in this range. Additional monitoring and improvements in analytic techniques would be expected to improve confidence in the performance, and a significant change in the numbers would not be expected.

When compared with "traditional" above-grade construction built before 1975 with TIFs in the 10 to 12 Btu/ft^2 per heating degree day range, earth-sheltered houses have an impressive ~75% reduction in energy for space conditioning. However, when compared to current housing standards with TIFs about 6.0, the percent reduction for earth sheltering is less impressive. When compared with other premium-price, high-performance, energy-conserving houses, there is no detectable difference in performance. Earth sheltering is but one of the range of options that should be considered from an energy-conservation viewpoint.

Earth-sheltered houses, as a passive means to conserve energy, were analyzed to determine the impact of various climates on the performance of the concept. As would be expected of any passive and, therefore, climate-sensitive approach, earth sheltering performed significantly better in some climatic regions than in others. In general, those areas with significant temperature extremes (either summer or winter or both) and low humidity were best suited for earth sheltering. While all areas potentially gained some benefit from the concept, in certain areas other passive strategies appear to be more appropriate.

Those regions in which earth sheltering is a particularly valid passive approach do not coincide with the major growth regions of the country. The sunbelt states, and in particular Florida, Texas, and California, dominate the housing market. The energy benefits for earth sheltering in these areas would not offset the extra construction costs.

Other demographic trends also run contrary to the concept of earth sheltering as it has developed to date. The high-density urban development, evident in the rapid increase in

high-rise dwellings, is above the density which earth sheltering can appropriately develop. Moderate- to low-density suburbs also do not quite fit the density expected from earth-sheltered dwellings. The least housing activity is in the rural areas, where most earth-sheltered houses have been built to date.

Significant changes in demographic trends will have to occur before earth sheltering will penetrate the market in a significant way.

All evidence indicates that earth-sheltered houses will cost more to build than aboveground structures, except where topographic features create abnormal costs for traditional construction. How much more is subject to what point of comparison is used. It is likely that the added cost, inherent in earth sheltering, will be in the 10 to 35% range. The lower operating costs, resulting from reduced energy consumption and potential lower maintenance costs, tend to offset the added construction costs. However, given the market conditions existing in 1980/1981, it is extremely unlikely that these cost reductions will offset the high initial costs within a period of time that would influence buyers to consider the concept. Life cycle cost studies, based on current market conditions, indicate the "payback" to be 30 years and longer, depending on the particular set of assumptions.

Based on the foregoing conclusions, earth-sheltered housing will probably continue to grow in some regions of the country, but broad-scale national or regional utilization is not likely to occur without major changes in the current trends of housing. Such major changes, when they occur, usually evolve slowly and can take as long as 20 to 30 years.

Those areas most likely to see continued growth in earth sheltering are rural areas that have severe extremes of weather (which can damage aboveground structures) and uncertain fuel supplies. Those climatic areas where integrating earth sheltering with passive solar heating can eliminate space-conditioning equipment altogether may also see an increase. Growth in urban areas will likely be restricted to responding to non-energy-related situations such as the use of "marginal" lands next to incompatible neighbors, for example, airports, freeways, and heavy industry.

The limited potential applications of earth sheltering, envisioned above, is not likely, in itself, to have a major impact on the energy consumption of our houses. This reduction in energy consumption, however, when added with all the others, will give the United States what it needs — fuel-efficient homes.

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ADDITIONAL SOURCES OF INFORMATION

In addition to the references cited in this report, there are a number of publications available on a broad range of topics related to earth-sheltered housing. The list is too large to include here, and additional excellent material is in various stages of preparation. Therefore, the reader is urged to contact the following sources or to obtain the periodicals listed for an up-to-date listing of available material.

Organizations:

American Underground Space Association
% TLH Associates
Suite 900, Minnesota Bldg.
St. Paul, Minnesota 55101

Center for Natural Energy Design
Architectural Extension
Oklahoma State University
Stillwater, Oklahoma 74078

Underground Space Center
University of Minnesota
Minneapolis, Minnesota 55455

Periodicals:

Earth Shelter Living

Published bi-monthly by
WEBCO Publishing, Inc.
1701 E. Cope
St. Paul, Minnesota 55109

Underground Space

the official journal of the
American Underground Space Association
Published bi-monthly by
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111-210. L. L. Boyer, Center for Natural Energy Design, Architectural Extension, Oklahoma State University, Stillwater, OK 74078

211-310. R. Sterling, Underground Space Center, University of Minnesota, Minneapolis, MN 55455

311-410. American Underground-Space Association, c/o TLH Associates, Inc., Suite 900, Minnesota Building, Fourth at Cedar, St. Paul, MN 55101

411-412. Office of the Assistant Manager for Energy Research and Development, U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, TN 37830

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