PB82-189564

EARTH-COVERED BUILDINGS:

AN EXPLORATORY ANALYSIS FOR HAZARD AND ENERGY PERFORMANCE

MORELAND ASSOCIATES
FORT WORTH, TEXAS

Prepared for
THE FEDERAL EMERGENCY MANAGEMENT AGENCY
DIVISION OF MITIGATION AND RESEARCH
WASHINGTON, D.C. 20472

November, 1981 Approved for Public Release Distribution Unlimited
Final Report FEMA Work Unit Number 4411E Contract 81-600091

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER MA1-81	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER PB82 189564
4. TITLE (and Subtitle) Earth-Covered Buildings: An Exploratory Analysis For Hazard And Energy Performance		5. TYPE OF REPORT & PERIOD COVERED Final Report 9-79 / 11-81 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Frank L. Moreland, et al.		8. CONTRACT OR GRANT NUMBER(s) 81-600091
9. PERFORMING ORGANIZATION NAME AND ADDRESS Moreland Associates 908 Boland, Fort Worth, Texas 76107		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4411E
11. CONTROLLING OFFICE NAME AND ADDRESS FEMA - Washington 20472		12. REPORT DATE November 1981 13. NUMBER OF PAGES 312
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

earth-covered buildings, earth-covered settlements, performance, long-term benefits, fire, storms, nuclear radiation shielding, energy consumption, economic analysis, hazard analysis, public policy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The performance of earth-covered buildings is examined regarding storms, nuclear detonations, earthquakes, fire, nuclear radiation energy consumption, compatibility with solar energy systems, peak-load effects, soil and groundwater effects, air and climate effects, occupant evaluation, and resource management. Potential longterm benefits are assessed, including the areas of economic benefits, community benefits, and security benefits.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

EARTH-COVERED BUILDINGS:

AN EXPLORATORY ANALYSIS FOR HAZARD AND ENERGY PERFORMANCE

MORELAND ASSOCIATES
FORT WORTH, TEXAS

Prepared for
THE FEDERAL EMERGENCY MANAGEMENT AGENCY
DIVISION OF MITIGATION AND RESEARCH
WASHINGTON, D.C. 20472

November, 1981 Approved for Public Release Distribution Unlimited
Final Report FEMA Work Unit Number 4411E Contract 81-600091

1-a

This material is based on research supported
by the Federal Emergency Management Agency
under contract number DCPA01-78-0308.

Library of Congress Number 81-600091

This report has been reviewed in the Federal Emergency
Management Agency and approved for publication. Approval
does not signify that the contents necessarily reflect the views
and policies of the Federal Emergency Management Agency.

Printed in the United States of America

CONTENTS

i-d

FOREWORD AND ACKNOWLEDGMENT

This study was undertaken to explore the overall utility of earth-covered buildings from a variety of performance perspectives. The study examines the proposition that earth-covered buildings can have high levels of performance across a broad range of categories, including short and long-term energy efficiency, relative safety under physical stress, economic performance, and environmental effects. Our conclusion from this exploratory analysis is that the potential for public and private benefit from earth-covered buildings is significant and worthy of further development.

The list of acknowledgments for a study of this sort can never be complete. Certainly Ralph Garrett of FEMA was a prime mover of the study. With the civil defense agencies from the beginning 26 years ago, Mr. Garrett provided agency oversight, and his wisdom, support, and perserverance were crucial to the successful completion of the study. Mr. Garrett retired near the end of the study and his successor, Ralph Swisher, has continued the history of support. Other members of FEMA who gave counsel to the study were George Sisson, Charles Thiel, and Mike Puchata. Anna Saunders helped my firm negotiate the straits of government contracts, which I deeply appreciate. Dr. Conrad Chester of Oak Ridge National Laboratory was helpful in many ways. Forrest Higgs and Mark Magnussen proofread with a vengence, thank goodness.

During the course of the study far more people were consulted than were reimbursed for their contribution,

they include Royce LaNier, Craig Hollowell, Thomas Bligh, Lloyd Jones, Raymond Sterling, Dick Vasaka, Garvin Warnock. The paid consultants made contributions beyond the tasks asked of them; they were:

Storms: Dr. Joe R. Ealgeman, University of Kansas

Blast: Thomas Carroll, Carroll Associates, Bethesda Maryland and H. L. Murphy, H. L. Murphy Associates, San Mateo, California

Earthquake: Dr. Ronald Scott, California Institute of Technology (principal author)

Fire: Dr. Robert Fitzgerald, University of Massachusetts (principal author)

Nuclear Radiation: Thomas Carroll, Carroll Associates, Bethesda, Maryland; H. L. Murphy, H. L. Murphy Associates, San Mateo, California

Energy Requirements: Dr. Ashley Emery and Dr. Charles Kippenhan, University of Washington

Compatibility with Solar Systems: Dr. Jan Kreider, University of Colorado

Soil and Ground Water Effects/Air and Climate Effects: Dr. Douglas Cargo, Cargo and Company, Dallas, Texas (author)

Psychological Response: Dr. Robert Bechtel, University of Arizona (author)

Economic Analysis: The Ehrenkrantz Group, New York City (a special thanks to Ezra for suggestions early on)

Public Policy: Richard Hamburger, Washington, D.C. (a special thanks for early suggestions)

The Earth-Covered Building Movement: Kenneth Labs, Undercurrents, New Haven, Connecticut

Earth Forming and Plant Selection: Dr. Geoffrey Stanford, Greenhill, Dallas, Texas

In a different vein, Charles Fairhurst and Tom Atchison of the American Underground Space Association have shown a patience throughout the research period that I appreciate.

The staff at Moreland Associates deserves recognition, they are: Jon Hand, research associate; Don Strickland, graphics; JoAnn Carson, secretarial assistance. Adaire Fisher and Shannon Halwes made editorial and production contributions that went beyond the call of duty, as did Karen Hardwick, typist of the manuscript. I am indebted to these people. Tenacious Adaire should write a story about this report and its five rewritings. As for me, this study was a major event, but I look forward to a vacation from words.

Jon Hand has noted that his blood is on many of these pages and that is true. Jon had major responsibilities for the development and presentation of data throughout the study, and he contributed most importantly to the Energy and Hazard parts of the study. Many of the drawings were made by Jon as well. I admire his perseverance and I am grateful for his contribution. Indeed, Jon's own contributions to research and development in habitat design are already significant, and his work here was indispensable.

This research was conducted over a two-year period that saw for me a transition from academia to the so-called real world. That transition and this report have benefited greatly from the support of my parents, and I am deeply grateful to them in more ways than can be expressed.

Three people funded earlier studies that led to this one, they are Seth Tuttle and William Hakala, both of the National Science Foundation, and John Cable of the Department of Energy. I am indebted to these people and many others, we all hope this document assists decision makers as they determine the form of new construction.

Richard Hamburger has made the point that forces of nature aren't in themselves hazards, so our use of the word needs clarification. People underprotected in the presence of the forces considered in this study probably see them as hazards, and it is in this sense the word hazard is used here.

Frank L. Moreland
September 5, 1981

PART I OVERVIEW

MAIN INTRODUCTION

The decade of the 1970s saw concern developing in the United States about energy use in buildings. It also saw a reawakening of concern for the safety and durability of buildings. These dual concerns resulted in the decision by the Federal Emergency Management Agency (FEMA) to undertake this study. FEMA and building specialists in general have known for a long time that buildings that perform well under conditions of stress from earthquakes, blast, radiation, fires, and storms, are usually long-lasting and durable. More recently, it has become apparent that one class of high-performance buildings, earth-covered buildings, usually requires significantly less energy for heating and cooling than conventional buildings. It is natural then for FEMA, as an agency of the United States Government, to examine the use of earth-covered buildings for the dual national goals of reducing energy demands and increasing safety from the hazards defined under FEMA's mandate.

Earth-covered buildings are explored across a broad spectrum of performance interests in this study. The performance categories examined include energy consumption and safety under earthquake, fire, blast, radiation, and storm conditions. Also discussed are performance levels relative to environmental impact, life-cycle cost, and psychological impact. The study concludes with a chapter on public policy and several appendices, including 1) the earth-covered building movement and

2) proposed exurban earth-covered villages. This study also explores the domain of public policy interest in earth-covered buildings and explores their likely utility to the United States.

A Brief Introduction to Earth-Covered Buildings

An introduction to earth-covered buildings is in order before the main body of this report. An ideal building to begin with is the Oakland Museum, completed in 1967. The museum is one of the first major buildings in the United States to make extensive use of roof plantings and gardens; however, it makes little use of earth berming against the walls, and only a modest percentage of the roof area is earth-covered.

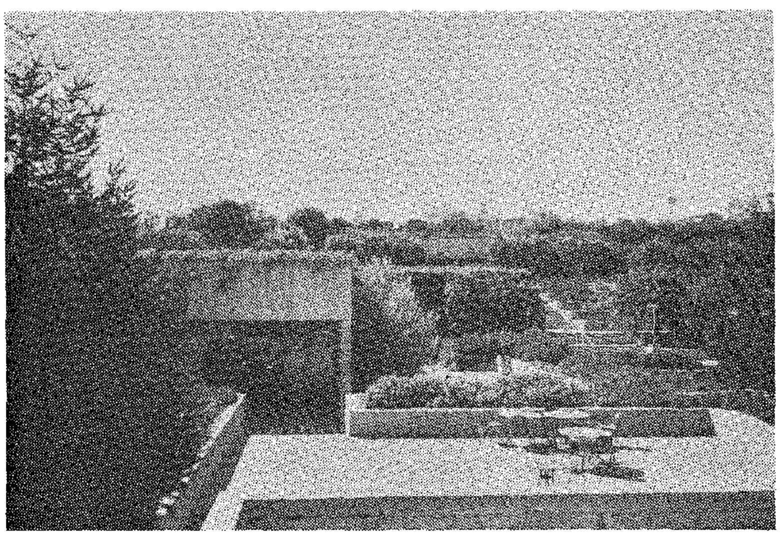


FIGURE 1 Oakland Museum, Exterior Patio
Oakland, California
Kevin Roche, Architect, 1967

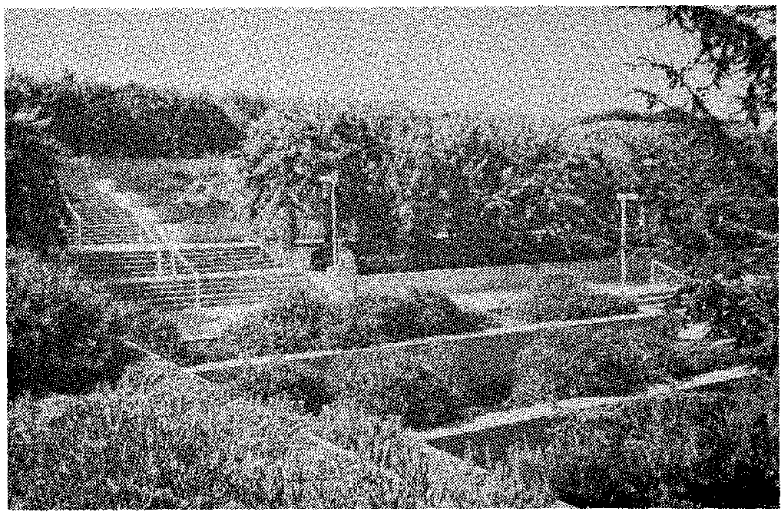


FIGURE 2 Garden Area over the Third Floor of the Oakland Museum

The Oakland Museum (architect Kevin Roche), a partially earth-covered building, is not only a public museum, it is also a very well-received public garden and park. The museum director, Bill Mumma, says:

> People really feel comfortable with it and they like the views, and the park. It is a popular gathering place (for civic activities, especially outdoors).
>
> People come from all over the region--say 50 miles plus.
>
> Public response is excellent to the building, the park, the location, and the atmosphere; there is no vandalism to speak of.
>
> Indeed, the people at City Hall are proud of the Museum (think it's the best building in town).[1]

A prime example of an earth-covered school is the Terraset Elementary School completed in 1976 in Reston,

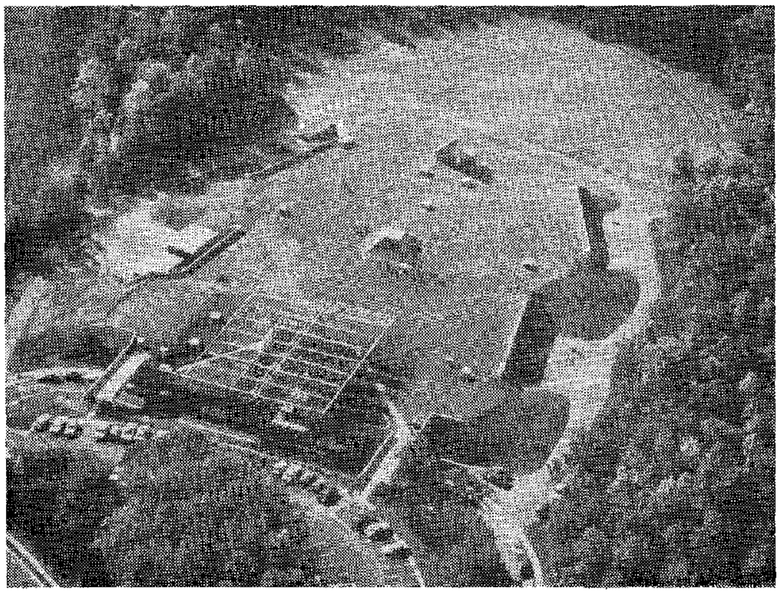


FIGURE 3 Terraset Elementary School
Reston, Virginia
Davis, Smith and Carter,
Architects, 1976

Virginia. Figure 3 is an aerial view of the school. Davis, Smith and Carter (Doug Carter partner-in-charge) were the architects of this and subsequent earth-covered schools for Fairfax County. Figure 4 shows a vehicular approach to the school which has 3-to-6 feet of earth cover. Construction costs, save for the solar system, were nearly identical to those of an energy-conscious school built by the same school district at about the same time. The other school, Hunters Woods Elementary, was completed one month before Terraset, and is a two-story school designed to be energy efficient with nearly

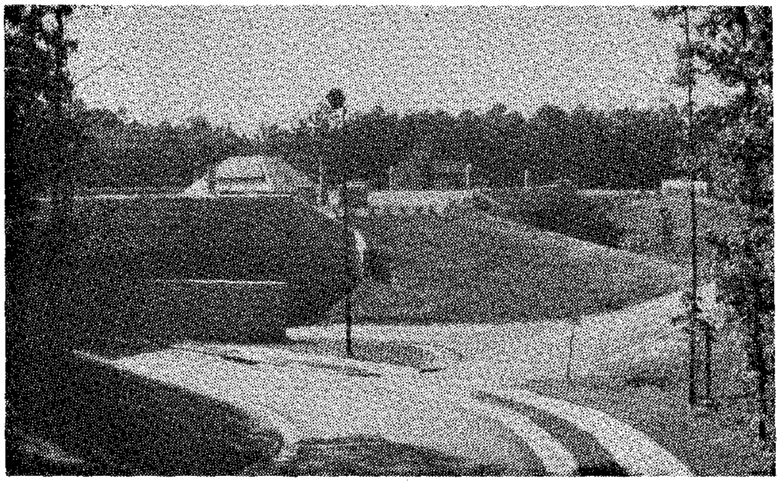


FIGURE 4 Terraset Elementary School

the same program and floor area as Terraset. According to Doug Carter, architect of the school:

> One fortunate aspect of the Terraset design is the availability of average operating costs for the other Fairfax County Schools. Fairfax County has one of the largest school systems on the east coast, thus providing ready access to average operations costs based on a per square foot system, but also for schools designed from the same educational specifications as Terraset, in terms of both size and function. It is against these average costs that the projected savings of the school are compared.
>
> One comment often made is that earth-covered construction costs more than conventional construction. This has not proved to be true at Terraset since the budget for the project was established before contracting the architects. Initial cost studies showed a possible cost penalty of approximately 35% to the earth-covered concept, but the project came in on target as far as conventional construction was concerned. (The one obvious exception was the addition of the solar heating and cooling system through the grant of

$655,000.) This may be attributed primarily to the elimination of exterior architectural decorative treatment; and the considerable reduction of HVAC equipment due to reduced loads. Both offset (the increased costs of structure because of) the higher superimposed loads.

But perhaps one of the most important aspects which has been demonstrated during the buildings' short life is the tremendous reception by the community of the earth-covered concept. There was in the initial presentations to local population some hesitancy of acceptance but since school opening some 2 months ago between 10,000 and 12,000 people have visited the building, with no negative reaction whatsoever.[2]

The finished school is called Terraset and sits inside the upper part of an original hill. It has been in operation since February, 1977, has received a number of awards for innovative energy conserving design, and has proven its performance ability with annual purchased energy savings exceeding $30,000.[3]

The University of Minnesota Bookstore/Admissions and Records Building, Williamson Hall, is an example of an earth-covered public building. Completed in 1977, the building has a central sunken courtyard for light and view. Williamson Hall, shown in Figures 5 through 7 on the following pages, was designed by BRW, Inc. Architects, Minneapolis, with David Bennett the partner-in-charge.[4] The building is 95% below grade and has 83,000 sq. ft. (gross). The total construction costs were $3,500,000.

According to Dr. Thomas Bligh, the research mechanical engineer for the building:

> The large thermal mass of underground structures allows the heating and cooling system to operate at a more constant load with a concommitant increase in efficiency During the non-work days the heating and

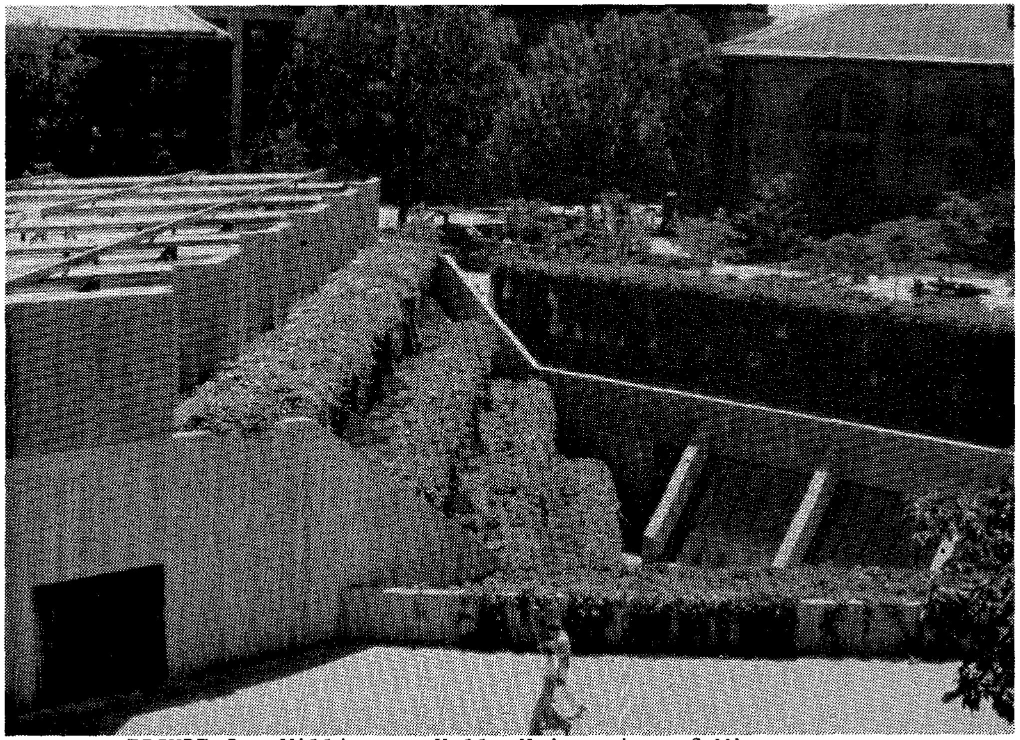


FIGURE 5 Williamson Hall, University of Minnesota
View of Courtyard, Minneapolis, Minnesota
BRW, Inc., Architects, 1977

FIGURE 6 Williamson Hall
View of Courtyard from Inside

cooling systems can be shut down completely and the building temperature allowed to drift slowly as heat is exchanged from the building mass and surrounding soil.[5]

Figures 8 through 9 on the following pages are of the University of Minnesota--St. Paul Student Center (Bennett/Meyers, Architects), and the Walker Library, Minneapolis (Bennett, Meyers, Arthitects). The St. Paul Student Center is 71% underground and this segment of the building demands only 20% as much energy per square foot as the existing aboveground portions. Completed in 1980, the total area is 50,500 sq. ft. and construction costs were $3,227,800.

The Walker Library, completed in 1980, had construction costs of $1,400,000. According to the architects:

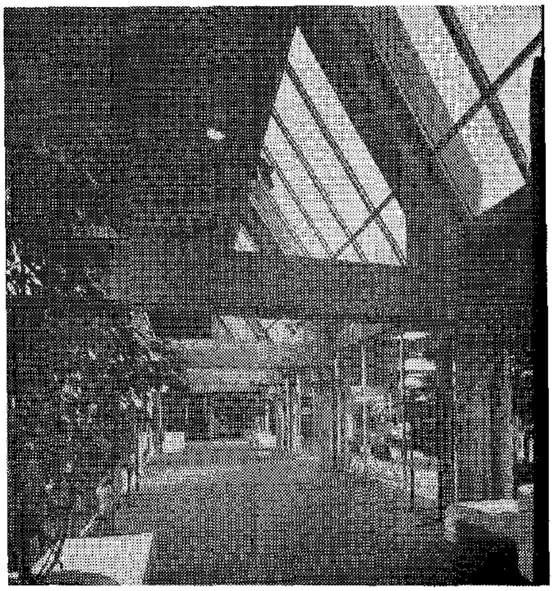


FIGURE 7 View of Pathway, Williamson Hall

In order to maximize utilization of an expensive urban site, the building has been depressed to provide space for parking on the remainder of its roof. The 18,000 sq. ft. library was built on a 20,000 sq. ft. site. This alternative cost less than acquiring additional land and building a conventional above grade building with adjacent on grade parking. Elevating the building and parking below it was investigated and discarded as less accessible and less cost effective for a small building, as well as undesirable for library patrons.

Constructing the building underground not only provided a satisfactory physical solution, but also provided the Library Board with an immediate economic benefit. By reducing the required land area by 15,000 sq. ft., land acquisition costs were reduced by $195,000. Set against this savings were the additional building construction costs, not of building

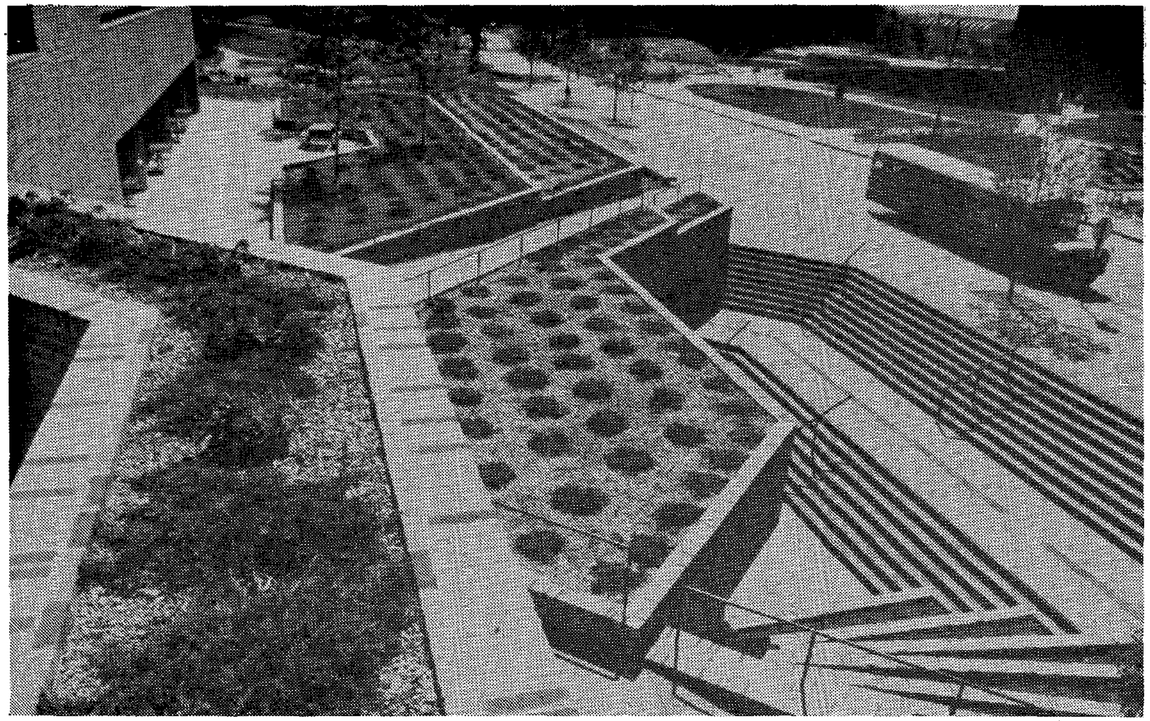


FIGURE 8 Student Center, University of Minnesota--St. Paul
BRW, Inc. Architects, Minneapolis, 1980

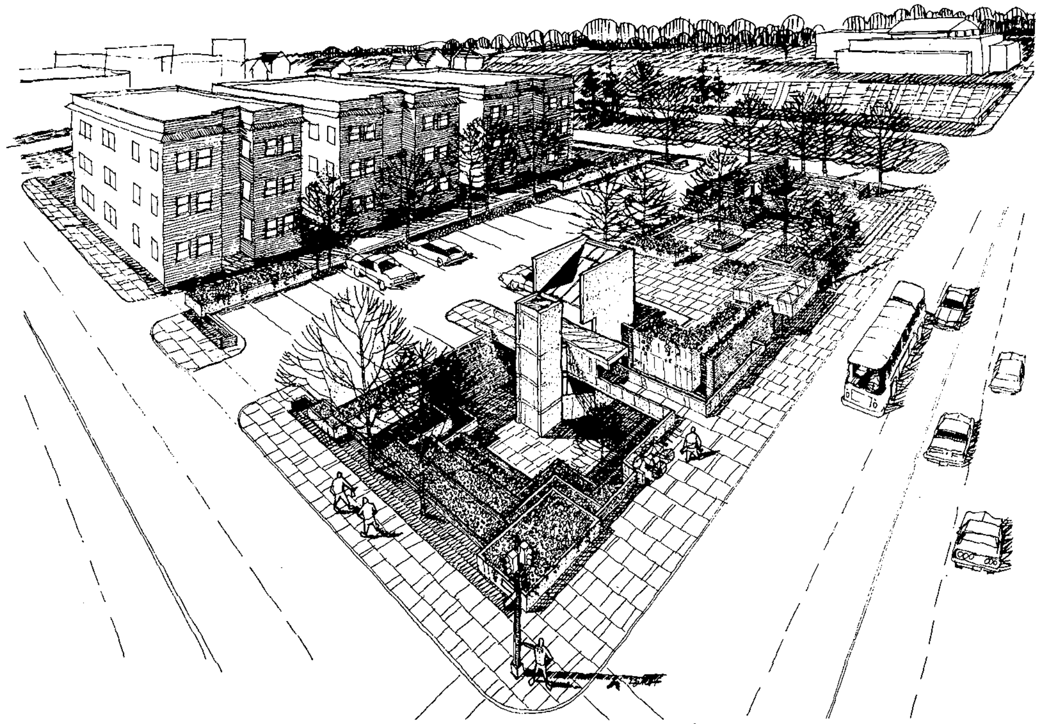


FIGURE 9 Walker Library, Minneapolis
BRW, Inc., Architects, 1980

underground itself, but of preparing the roof surface to accommodate automobile parking and landscaping. These costs totalled approximately \$70,000. Therefore, the Library Board enjoyed an immediate net saving of about \$125,000--roughly 9% of the construction cost of the project.[6]

Figure 10 shows the Pusey Library in Harvard's Yard. This three-story rare books library is covered by 3-to-5 feet of earth. Designed by Hugh Stubbins Architects, the building was completed in 1976.

One of the first earth-covered housing complexes was completed in 1975 in Baja California, Mexico, by architect Ricardo Legorreta of Mexico City (Figure 11). The condominium project is on a beach and is primarily sand covered.

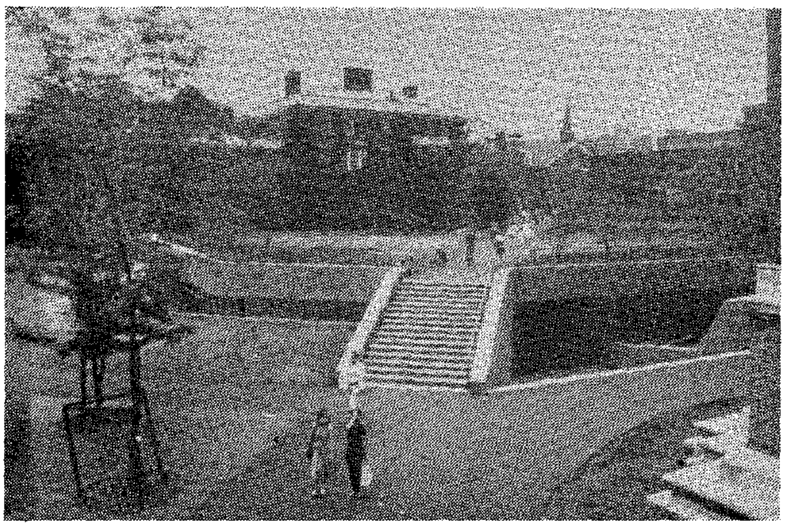


FIGURE 10 Pusey Library, Harvard University
Cambridge, Massachusetts
Hugh Stubbins, Architect, 1976

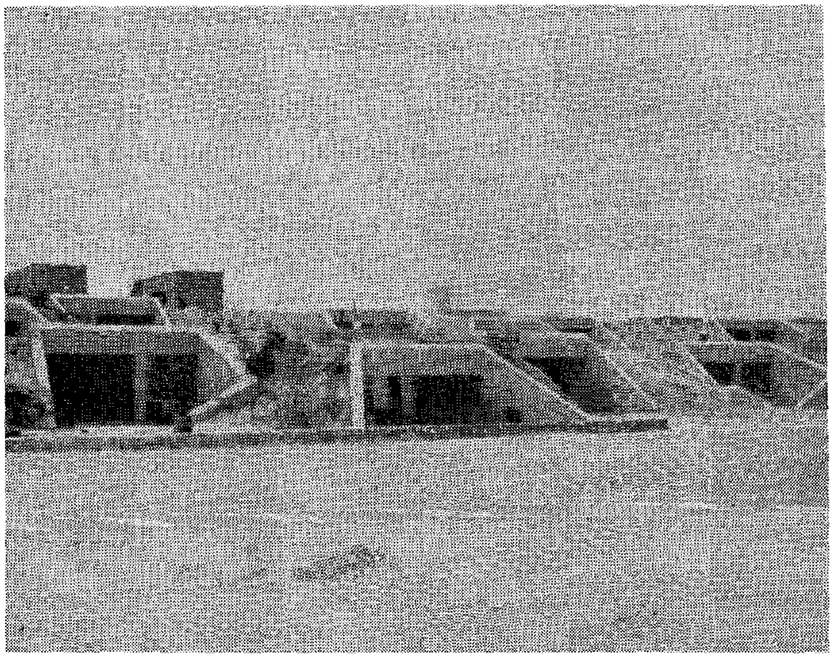


FIGURE 11 Beach Side Condominiums, Baja, Mexico
Ricardo Legorreta, Architect, Mexico City, 1975

Another example of earth-covered housing condominiums as shown in Figure 12, is a project in Minneapolis by Michael Dunn of Close Associates, Inc., architects, which was completed in 1979.

Examples of single-family earth-covered dwellings abound across the country. Examples from two very different climatic zones are shown in Figures 13 and 14.

Figure 15 gives an estimate of where earth-covered and earth-sheltered buildings, including residences, are in the United States. The Underground Space Center at the University of Minnesota estimates more than 3,000 earth-sheltered dwellings exist in the country, with the number increasing rapidly.

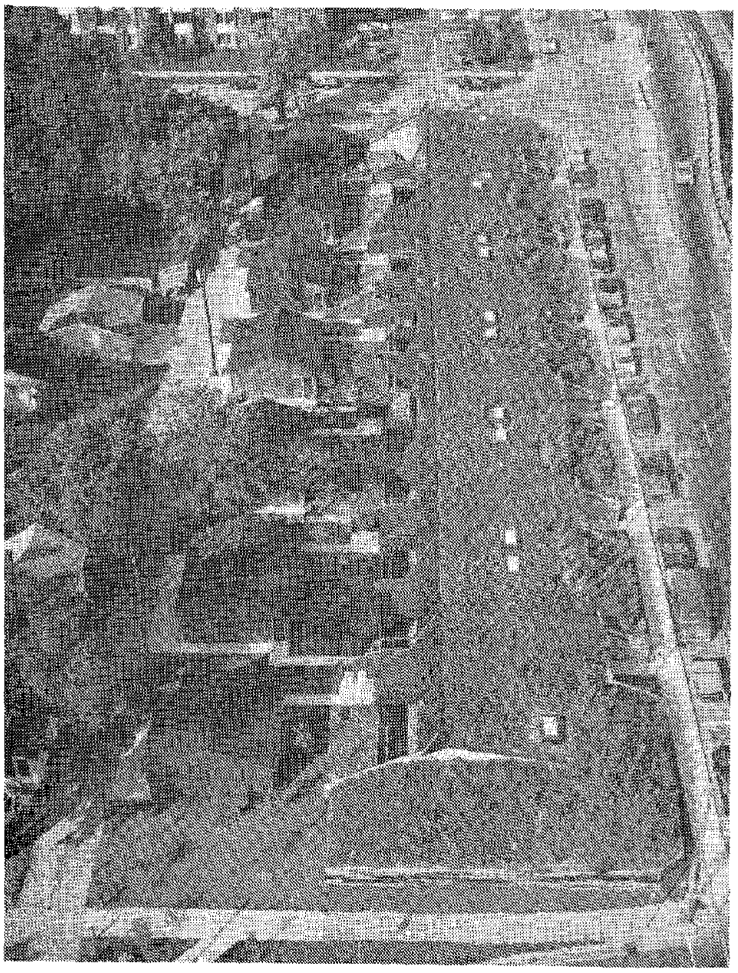


FIGURE 12 Seward Townhouses
Minneapolis, Minnesota
Close Associates, Inc., Architects, 1979
Photo by Jerry Mathiason

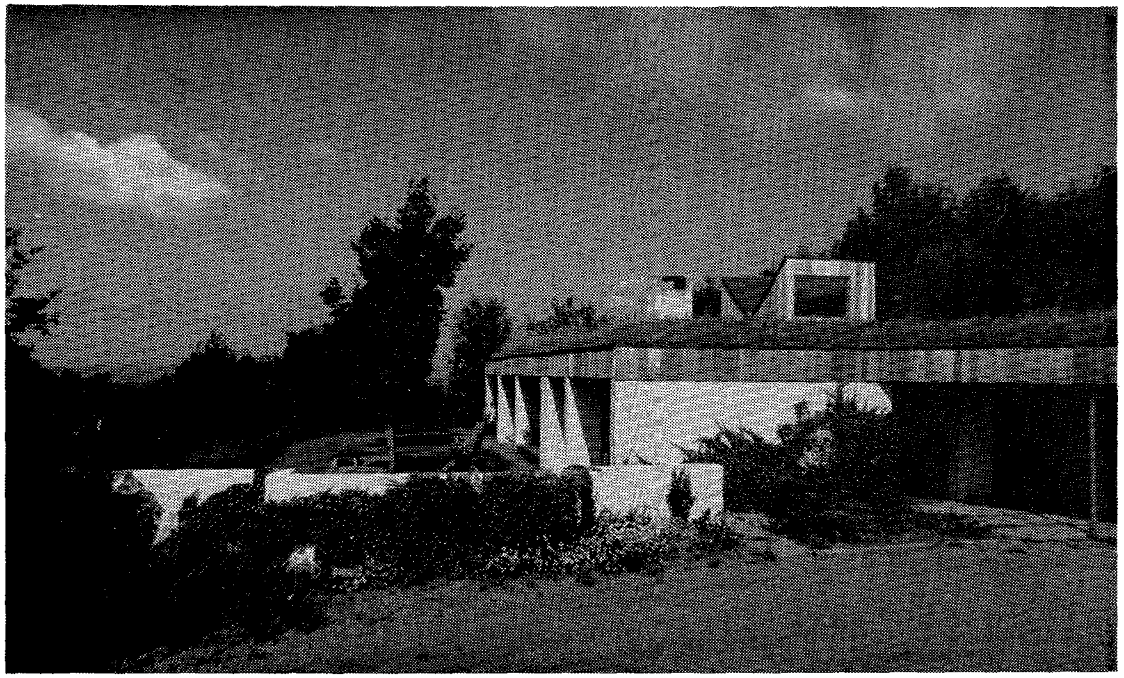


FIGURE 13 New Hampshire Residence
Don Metz, Architect, Lyme, New Hampshire
Photo Courtsey of Ken Labs and Don Metz

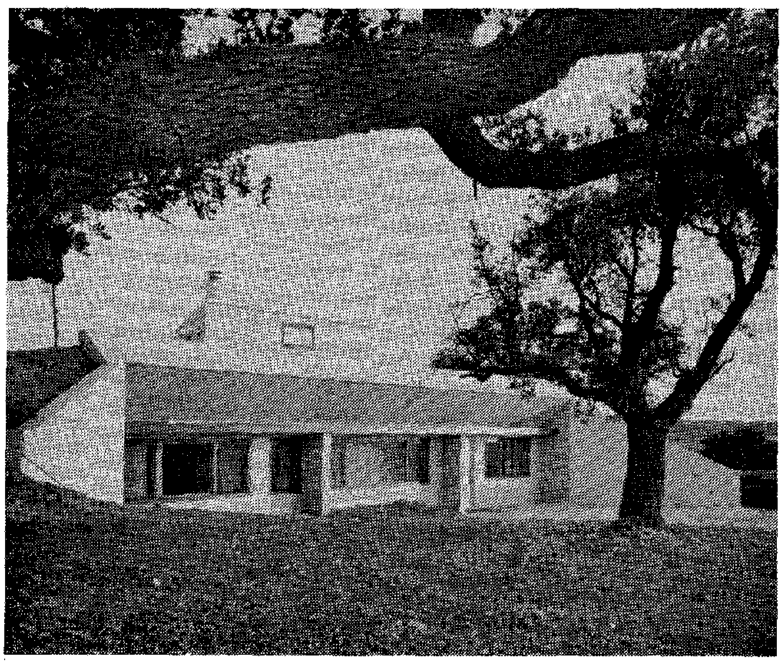


FIGURE 14 North Texas Residence
Moreland Associates, Architects,
Fort Worth, Texas, 1980
Loan Insurance by the Veterans
Administration
(FHA also insures loans for earth-
covered housing)

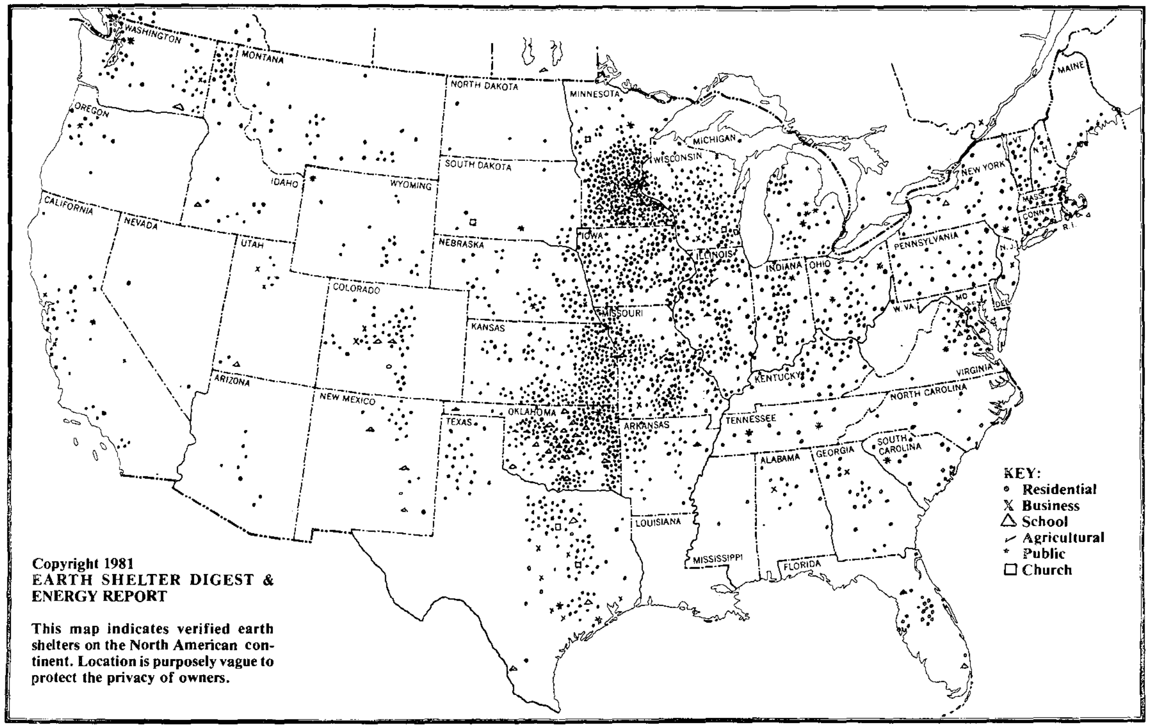


FIGURE 15 Incidence of Earth-Sheltered and Earth-Covered Buildings in the United States, used by permission of Earth Shelter Digest and Energy Report, St. Paul Minnesota

Earth-covered buildings and dwellings are a rapidly growing innovation in the United States. Orville Lee with FHA says that this is one of the fastest, if not the fastest, growing innovations FHA has seen. For additional introductions to earth-covered buildings and dwellings see:

Alternatives in Energy Conservation: The Use of Earth Covered Buildings, edited by Frank L. Moreland. Funded by the National Science Foundation. Superintendent of Documents, Government Printing Office, Washington, D.C., 20402, 1976.

Architecture Underground, Ken Labs, McGraw Hill, New York, to appear, 1982.

Earth Covered Buildings and Settlements, Frank L. Moreland, editor, Department of Energy, 1979.

Earth Covered Buildings: Technical Notes, Frank L. Moreland, Forrest Higgs, Jason Shih, editors, Department of Energy, 1979.

Earth Shelter Homes--Plans and Designs, Donna Ahrens, Tom Ellison, and Ray Sterling, Van Nostrand Reinhold Company, New York, 1981.

Earth Sheltered Housing Design: Guidelines, Examples, and References, A report by the Underground Space Center, University of Minnesota, 1978.

Earth Shelters, David Martindale, E. P. Dutton, New York, 1981.

Earth Shelter Digest and Energy Report, available from Webco Publishing, Inc., 479 Fort Road, St. Paul, MN.

David Haupert, "Underground Housing is Coming on Strong," Better Homes and Gardens, September 1979, p. 97-105.

David Martindale, "New Homes Revive the Ancient Art of Living Underground," Smithsonian, February 1979, pp. 96-105.

Allan Temko, "Evaluation: A Still-Remarkable Gift of Architecture to Oakland," AIA Journal, June 1977, pp. 30-37.

Prototypical Designs for this Study

The following approaches to earth-covered building design were used to orient the consultants to this project. While there are many approaches being explored in the United States today, these prototypes are adequate for an exploratory study. The dwellings are in the 1600 to 2000 sq. ft. range and the mid-sized buildings are in the 40,000 to 120,000 sq. ft. range.

HOUSING

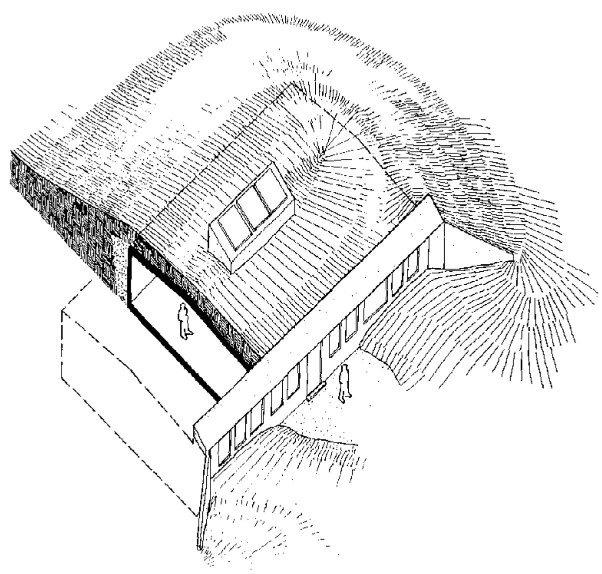


FIGURE 16 Type D-1 Single Window-Wall Dwelling

All drawings by Jon Hand
after sketches
by Frank L. Moreland

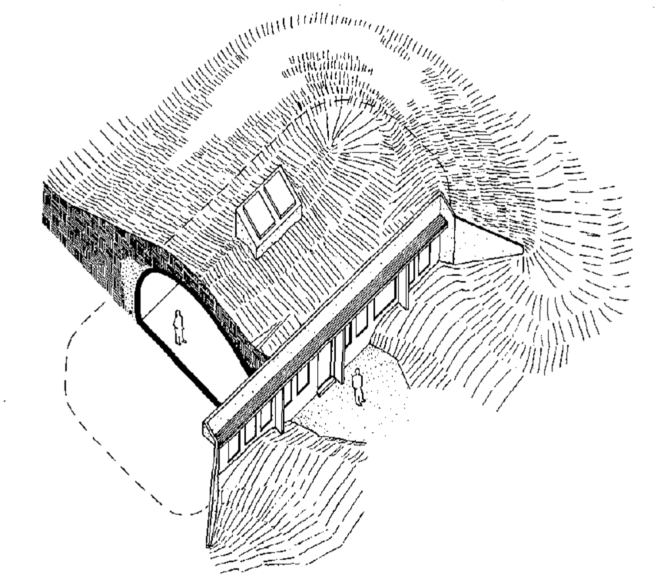


FIGURE 17 Type D-2 Single Window Wall Dwelling

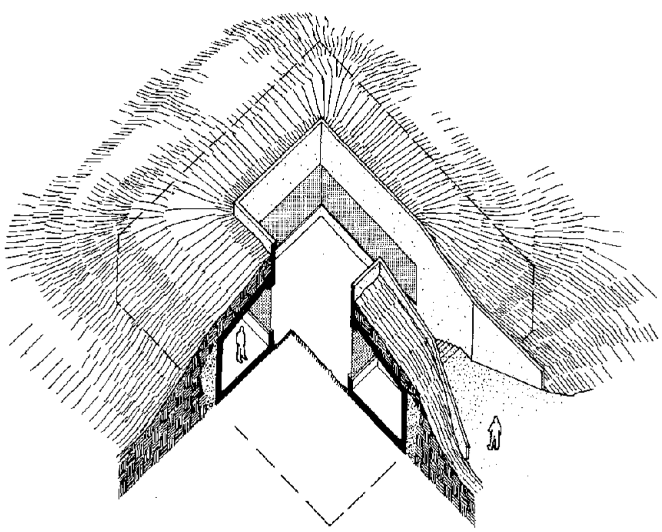


FIGURE 18 Type D-3 Atrium Dwelling

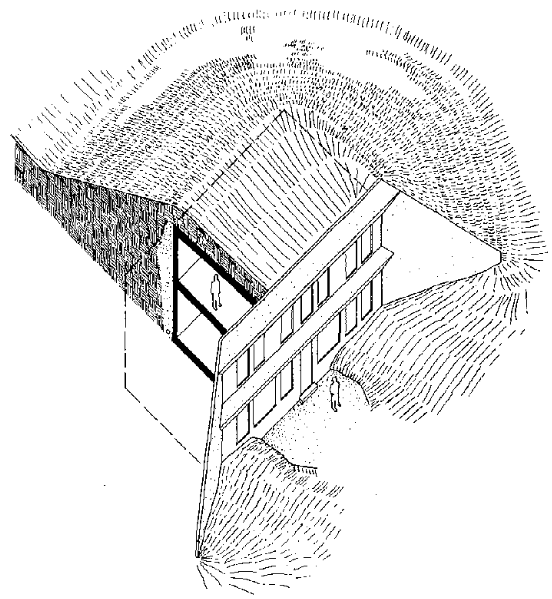


FIGURE 19 Type D-4 Two-Story Single Window-Wall Dwelling

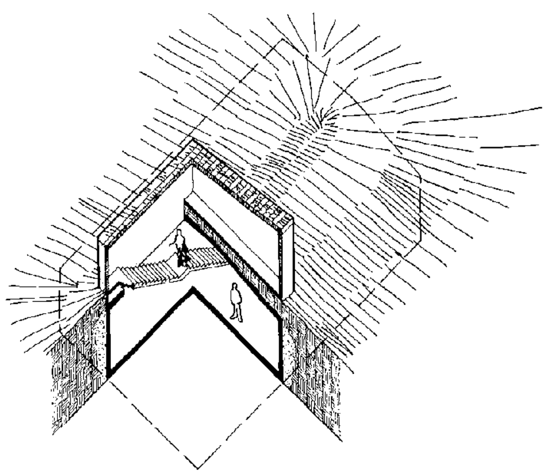


FIGURE 20 Type D-5 Underground (Below Grade) Dwelling

Mid-Sized Buildings

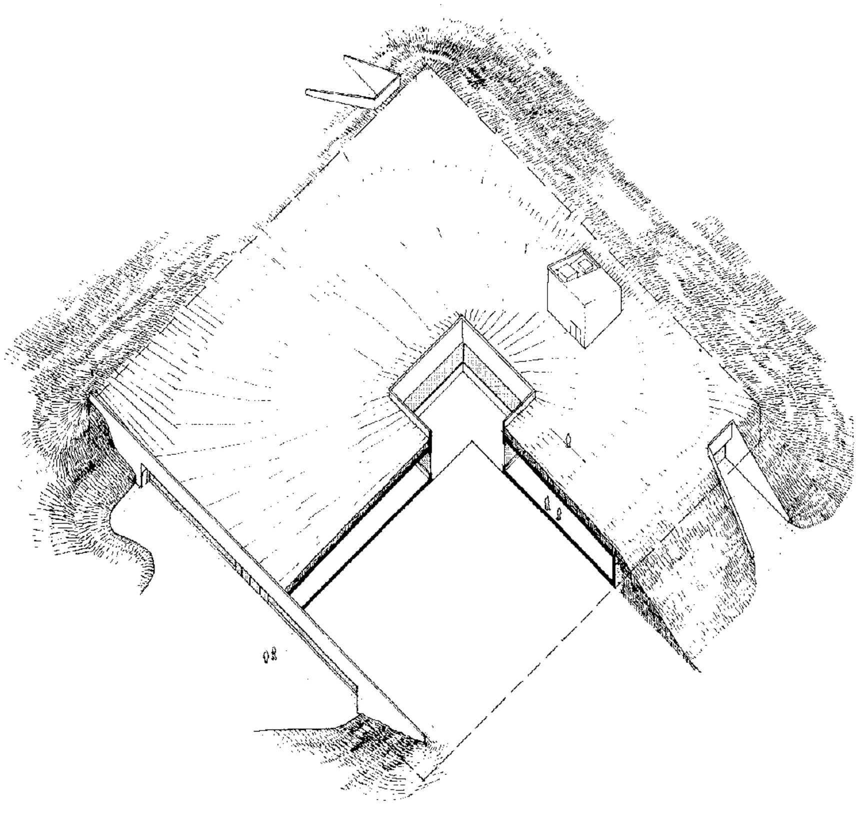


FIGURE 21 Type B-1 Single-Level
50,000 sq. ft. (gross)
Mid-Sized Building

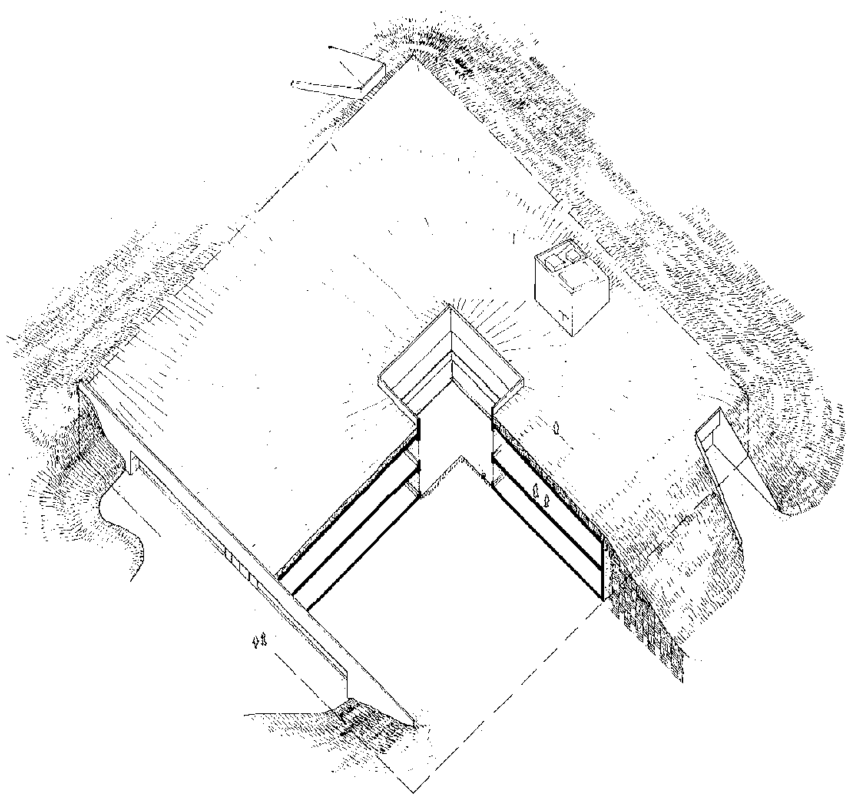


FIGURE 22 Type B-2 Two-Level 100,000 sq. ft. (gross) Mid-Sized Building

FOOTNOTES:

1. Interview with Bill Mumma, Director, Oakland Museum, Oakland, California, September 1980.

2. Interview with Doug Carter, Architect, Davis, Smith, Carter and Rider, Reston, Virginia, December 1980.

3. A quote regarding the active and passive solar contribution to the performance of the earth-sheltered Terraset Elementary School reprinted from Proceedings of the Fourth National Passive Solar Conference, Published by American Section of the International Solar Energy Society, University of Delaware, Newark, Delaware.

4. The following statement by David Bennett appeared in the paper "Earth Sheltered Buildings Coupled With the Sun: Opportunities and Constraints in Design," in The Potential of Earth Sheltered and Underground Space, Edited by Holthusen, Pergamon Press, 1981:

   > As well as meeting urban design and energy conservation objectives, the design of Williamson Hall demonstrates that earth sheltered buildings can provide a humane and pleasant living/working environment. Completed and occupied, Williamson Hall is described as the "sunniest building on the campus." Numerous articles published about the building have quoted occupants as expressing their pleasure with the interior spaces.
   >
   > A unique planter system was designed for Williamson Hall using Engleman Ivy as a solar control device to screen out summer sun and permit winter solar collection. This may be among the first contemporary deliberate applications of landscaping for passive solar control in a building.
   >
   > The construction cost of the building was .6% below its pre-established budget, which was originally determined for a conventional on-grade building.

5. Interview with Dr. Thomas Bligh, Massachusetts Institute of Technology, Cambridge, Massachusetts, February 1981.

6. Interview with David Bennett, BRW, Inc., Architects, March 1981.

MAIN SUMMARY

This study explores how earth-covered buildings relate to a number of building performance categories. Based on a sampling of expert opinion, sparse data, and exploratory studies, we conclude that well-designed earth-covered buildings offer exceptional benefits. The potential for social benefit appears large enough to warrant a public policy that would encourage the development of technologies for such buildings and their use.

A few additional caveats and comments are required on summary statements. First, the study explored the likely performance of designs for reinforced concrete shell earth-covered buildings with roughly 3 feet of earth cover. Proper design[1] and construction was assumed. Even so, we must add the caveats that 1) this is an exploratory study, 2) some disasters can defeat the best of buildings, and 3) the performance of buildings is crucially a function of their crafting and construction.

Some properly designed buildings with less cover may perform less well in some categories, notably nuclear radiation attenuation and perhaps vegetation development. Buildings with more than three feet of cover would likely perform better in some conditions. Appropriate technologies for the proper construction of earth-covered buildings exist widely and are found commonly in cities these days; therefore the requirement that the buildings all be properly constructed is not excessive. Mid-sized public buildings, as well as residences, in many parts of the U.S. have exhibited many of the performance levels assumed.

Second, on energy, our view is that any building whose occupancies result in high-internal heat loads present special problems and opportunities for all building designers throughout the country. Our view is also that high-mass buildings can make especially good economic sense, particularly in hostile climates, perhaps most especially in hot or cold arid areas. We believe as well that some designs of earth-covered buildings will prove to be exceptionally acceptable to a broad range of building purchasers, partially because of the overall performance of earth-covered buildings.

Throughout most of the country, conventional low-mass buildings can pose serious consequences in periods of power outages. Such consequences can go well beyond initial concerns for the occupants and contents of buildings, even to the buildings themselves during periods of extended shortage or outage. Consequences extend as far as the functions of the occupants and contents of the buildings extend. Such costs are difficult to quantify, but are nonetheless real. In this sense, buildings are an inherent part of our social fabric; serious disturbance with their performance in one location can cause serious disturbances throughout major subsection of society.

Throughout the country, conventional buildings are gradually, too gradually in the view of many, being replaced with much more energy-efficient buildings, or are being retrofitted for higher than conventional performance. Higher levels of performance in buildings is becoming more and more widespread. That is to be applauded regardless of which of the many building technologies is used, given the usual disclaimers that anti-social technologies be excluded. The shopping basket of alternative building technologies is getting fuller, with each alternative favorable to some limited set of concerns.

Several years ago the "inherent" high, or at least higher than conventional, energy performance of earth-covered buildings was hailed as a marvel of the modern world. And, indeed, many of those early examples continue to perform at high levels. The point remains, however, that six or seven years ago conventional buildings were generally at a low level of performance, because not much was expected. That low level has, in many cases, improved greatly. There are examples of energy-efficient non-earth-covered buildings, say new-wave, conventional buildings throughout the country. It is also true that earth-covered buildings often cost more to construct than many of the new-wave conventional buildings. Whether the possible additional costs are warranted depends on the overall performance characteristics of the building alternatives, the views of the purchaser, and the views of possible lenders, not on any single design or cost criteria. In that context, earth-covered buildings will likely remain appropriate choices for many building purchasers.

We conclude the following:

HAZARDS:

STORMS: Tornadoes, the only type of storm considered in this study, are among the most violent of storms and cause damage primarily because of the air pressure (wind load and suction) they impose on structures and because of objects blown into structures by the high winds (up to 300 MPH). Vehicles or trees blown at high speeds can cause enormous damage on impact. The earth mass and structure of the earth-covered buildings considered here can usually absorb such impact loads. Moreover, the generally low profile of earth-covered buildings is more likely to deflect than confront wind-generated forces. In addition, the structural toughness of these buildings and the stability of their masses combine to resist the buffeting of abrupt air-pressure changes.

The general characteristics of tornadoes suggest that damage from wind and flying debris is reduced if major window areas are oriented away from the south and southwest. Moreover, the provision for a shelter space within earth-covered buildings offers an exceptionally high degree of protection from storm effects such as blown glass fragments. Indeed, earth-covered buildings are being used in increasing numbers in areas of high storm-damage probability because of their expected performance.

Hurricanes, which are less turbulent although longer lasting than tornadoes, would likely cause far less damage to earth-covered buildings than to conventional buildings. The flooding which often accompanies such storms is also likely to be less destructive, although rendering many earth-covered buildings inappropriate as shelter space. Hail damage, which can result in significant damage to conventional buildings, will have little or no effect on earth-covered buildings of the type considered here.

The mass of earth-covered buildings (good for absorbing large impact loads), the generally low profile of earth-covered buildings (good for not confronting high winds), and the structural integrity combined with the mass of earth (good for sustaining abrupt air-pressure differences), all make earth-covered buildings dramatically less prone to tornado or hurricane damage than conventional buildings are.

EARTHQUAKE AND NUCLEAR DETONATIONS: There are two mechanical consequences of a nuclear explosion: one is air pressure waves radiation outward from the blast, the other is rapid transient vibrations of the ground. The latter characteristic is shared with earthquakes, although the nature of the two ground motions are different in the source region. A structure outside the region of total destruction is subjected to a range of air-blast overpressures and strong ground shaking. Structures in a seismic zone may also encounter intense ground motions. Earth-covered buildings are less susceptible to damage from both these effects than are surface structures, since they are designed with relatively strong walls and roofs to resist the static earth pressures. If attention is paid to wall/roof connections, the earth-covered building can be designed to be substantially earthquake resistant. Its resistance to nuclear explosion depends on the distance from ground zero. The roof load from the explosion overpressure will likely be worse for most structures than the wall shocks from earth vibrations. Structural designs common in earth-covered buildings reduce the likelihood of catastrophic structural failure. In fact, the threshold of structural failure from blast overpressure and ground motion will be much higher in an appropriately designed and constructed earth-covered building than in most conventional buildings, including may which are also constructed of reinforced concrete. In both respects the earth-covered structure is significantly superior in resistance to normal above-ground structures designed conventionally.

FIRE: The performance of earth-covered buildings in fire conditions has several aspects. The first relates to threats to life by fire inside a building. This threat is two-fold, one to the inhabitants seeking to leave the building, and the other to firefighters seeking to enter. Convenient and safe paths must be provided in each case, and this can be particularly difficult in any limited access multistory building. Indeed, it may be that some designs of multistory, below-grade buildings may be worse than highrise buildings in the level of life protection provided. However, examples abound of nearly windowless, belowgrade buildings which are models of attention to lifesafety engineering, for instance, the Central Library of Fort Worth, two schools in Fort Worth and perhaps fifty others nationwide. What is clear is that many belowgrade or earth-covered buildings exceed or match the level of lifesafety engineering provided in non-highrise conventional buildings. Certainly the levels of risk in highrise and most lowrise buildings can be reduced in the earth-covered buildings likely to be built in the next 20 years.

What we wish to emphasize is that lifesafety must be designed in by qualified firesafety specialists, simple adherance to most codes will not necessarily lead to an adequate building from a lifesafety point of view. It is true that earth-covered buildings can be exceptionally good from a lifesafety perspective: it is also true that such performance happens only by proper planning. Three areas for emphasis are 1) smoke evacuation (and detection), particularly for residences (because of contents), 2) windowless well-below-grade spaces, 3) quick access to egress means. This last point is true for all buildings because fires tend to spread very quickly through many new construction and furnishing materials.

Good examples of lifesafety engineering in housing can be seen in houses insured by FHA and VA which have only one door to the outside. Because windows in each "lived-in room" have easy access to the ground, the houses were judged to be at least as safe as conventional houses.

The second threat to life in fire conditions is the threat to life for people inside a building from a fire outside the building. The threat is two-fold: first, that the fire outside might set afire the exposed edges of an earth-covered building and spread to the inside of the building, or second, in the case of a fire storm, the oxygen in the building might be depleted and the air in the building become super heated. In the first case (internal fires started by fire spreading from nearby buildings or vegetation), earth-covered buildings are particularly resistant to the hazards for a number of reasons. First, earth-covered buildings in general, and particularly the types considered here, present little exterior exposure of the building for ignition and second, the little that is exposed can be made of highly non-combustible materials. In addition, the mass of the earth cover provides significant protection, potentially even under some fire storm conditions. Insurance underwriters say that the two main reasons earth-covered buildings have lower rates are their inherent protection from <u>ex</u>ternal fires (if lawn sprinklers were to be counted as fire sprinklers, the rates could perhaps drop even more) and their usual reinforced concrete shells.

In the firestorms effects case, it appears that there could be firestorms adequate to superheat, or at least cause oxygen concerns even for earth-covered buildings. Perhaps if earth-covered buildings were equiped with safety chambers it would be unlikely a firestorm could destroy life, but no research was conducted on this topic. What is apparent, however, is that if the earth cover extended substantially over, say a 6- or 10-square city block area, that a firestorm would not likely penetrate into the area very far in a serious way.

Another aspect of the performance of earth-covered buildings under fire conditions has to do with material losses because of a fire inside the building. Such losses can include the 1) furnishings and furniture, 2) the partitions, ceilings, doors, etc., 3) electrical and mechanical systems losses, 4) documents, tools, etc., and 5) the structural shell. Earth-covered buildings offer no special benefits or disbenefits to these categories of loss with the exception of structural shell losses. It is widely agreed that monolithic reinforced concrete shells are difficult to damage by fire except for very hot and long fires which require substantial fuel. It is unlikely most dwellings would contain adequate fuel for such damaging fires, and many other building occupancies would likely be quite free of risk of loss of the basic building structure if it were monolithic reinforced concrete.

As regards the other four categories of material loss, astute selections of construction materials, utility systems, and furnishings can reduce the likelihood of extensive loss for any building. One could make a case that, because the buildings are long-lasting, the more expensive, fire-resistant systems and materials are justified. No one disagrees with the point that metal studs, fire alarm, smoke evacuation systems, sprinklers, and the like tend to make all buildings safer. However, there is the countervailing argument that it is wiser to purchase the sometimes more expensive earth-covered building shell and install less expensive furnishings with the expectation that a total remodeling would likely take place in 50 years, and the savings in operations costs over the intervening years could be used to purchase higher performance furnishings later. Perhaps there is no resolution to the debate these two perspectives pose, but it is clear that lifesafety engineering is a must for these and all buildings.

In summary then, lifesafety in <u>in</u>ternal fire conditions, while dependent on design, can be at least as good for most earth-covered buildings as for conventional (non-highrise) buildings, and lifesafety from <u>ex</u>ternal fires is probably considerably greater in earth-covered buildings.

Material losses of earth-covered buildings relate primarily to internal systems and contents of the buildings since most structural shells and earth cover are exceedingly fire resistant and long lasting. Conservation of the basic building shell from fire losses at the level expected from earth-covered buildings could be a major individual and social benefit. Reductions in losses to internal systems and contents, however, will come more from careful design and adequate budgets than the inherent fire resistance of the usual concrete shell. Even so, total long-term material losses to earth-covered buildings under fire conditions are expected to be significantly less than for conventional buildings and long-term life losses could be profoundly less with proper design and construction.

NUCLEAR RADIATION: There are three ways earth-covered buildings perform with respect to nuclear radiation: first, as potential radon containers, second, as shields from initial nuclear radiation from a nuclear explosion, and third, as shields from the nuclear radiation in the radioactive fallout resulting from a nuclear detonation.

The potential for earth-covered buildings to act as radon containers has been discussed in the literature and explored in great depth at the Lawrence Berkeley Lab. The gist of the issue is that radon, a naturally occuring radioactive gas, exists everywhere on earth in varying degrees. In some locations the concentration exceeds health standards. The problem is three-fold: first, if there is too much radon in the ambient air of the location, then all construction is probably contraindicated. Second, if there are high levels of radon in the existing terrain of buildings, then fresh air ventilation becomes more important and occasional monitoring may well be required. Third, some building materials containing raw materials from high radon-bearing areas can release radon into buildings; examples are concrete containing gravel with a high radon content or similar gypsum products. There is broad agreement that, 1) problems with radon can exist for all building types, 2) radon researchers say their understanding is as yet imperfect, and that it is difficult to state in advance that any particular building may have a radon problem, 3) that earth-covered buildings may bear special attention because the radon content of some soils and some concretes may pose problems, and because earth-covered buildings tend to have exceptionally low rates of air-infiltration and therefore acceptable rates of ventilation must be maintained.

It is difficult to say with confidence that radon is never a concern with properly ventilated buildings, but there is broad private agreement that such may be the case with rare exceptions; however, with earth-covered buildings, it is likely that the rare exceptions, while still rare, will be more frequent than for conventional buildings.

The other two nuclear radiation performance areas have to do with nuclear radiation from a nuclear explosion, particularly a low level air burst where the fireball contacts a large area of the earth's surface and produces large amounts of radioactive fallout. The two principal forms of radioactivity are the initial, line-of-sight immediate radiation impulse from the fireball, and the other is the radioactivity in the fallout blown downwind from the burst. In both cases, earth-covered buildings, particularly the kinds considered here, have extraordinary potential for effective shielding from these hazards; however, the effectiveness depends greatly on engineering design, preparations made before fallout falls, luck (bombs explode where predicted, etc.), cleaning activities in the recovery phase, and the proximity and size of explosions. All these aspects crucially influence the utility of earth-covered buildings during and after nuclear explosions.

In many cases, initial radiation may be less of a problem than air overpressures and temperatures, but certainly an earth-covered building with three feet of earth cover facing away from the explosion and beyond the zone of total destruction would likely perform well as a shield from initial nuclear radiation.

Perhaps more importantly, such earth-covered buildings in which fallout is the principal hazard would perform very well as shields in most cases, and could perform exceptionally well with minimal preparation. Three feet of earth cover attenuates even high levels of fallout exceedingly well, nearly 100%. If skylights and atria are covered and easily cleaned, and if windows and other openings are shielded so air and more particularly ground fallout can't "see" people in buildings, then cleanup operations can be simple and brief resulting in mimimal overall impact on inhabitants from most levels of fallout. Analysis of secondary effects of fallout, such as potential dangers to inhabitants from water supplies, are not included in this analysis.

ENERGY CONSUMPTION: Earth-covered buildings can reduce energy requirements for thermal tempering significantly in residential- and institutional-sized buildings in most regions of the United States. Reductions of 50 percent to 75 percent in residences are common as are 50 percent reductions for institutional-sized buildings. Such reductions are the result of the characteristically high thermal mass, limited exposure of the building envelope to external climatic conditions, and the high degree of air tightness attainable in most earth-covered buildings. Moreover, earth-covered buildings are adaptable to a wide range of climatic conditions and design variations.

Only individual dwellings and buildings the size of a public school (that is, probably less than 100,000 sq. ft.) were considered in the study because such structures constitute the bulk of the buildings in the United States.

There is no question that earth-covered buildings may not be suitable for all situations. We believe, however, the conclusions of the study apply to the majority of buildings in the United States, and that reductions in heating and cooling demands should be at least 40 percent to 55 percent across most of the country for most mid-sized buildings and dwellings and potentially 75 percent for dwellings (more in the American Southwest). Purchased energy reductions beyond these figures may occur by the attendant use of active or passive solar heating or cooling techniques or other alternatives.

The use of daylighting in buildings has not been specifically addressed in this report. Although daylighting is a major conservation tool, its impact on energy use is a result of design. Nevertheless, the potential for daylighting in earth-covered buildings and dwellings, as well as conventional buildings, is significant.

In terms of embodied energy, savings in day-to-day energy requirements can lead to short-term payback of the extra embodied energy cost of many earth-covered buildings. More efficient use of materials via technology development could reduce the embodied energy of earth-covered buildings.

COMPATIBILITY WITH SOLAR: There appears to be no incompatibility between earth-covered buildings and either passive or active solar energy designs. Indeed, there is every indication that earth-covered buildings' reduced sensitivity to energy supply interruptions makes them particularly amenable to solar energy, wind power, photovoltaics, and a host of resources which are intermittent in nature.

Earth-covered buildings can be ideally compatible with both active and passive solar techniques because such buildings have strong points that moderate the weak points of both solar approaches. First, earth-covered buildings tend to change internal temperatures very slowly, as a function of outside climatic conditions. Large daily temperature changes, a problem of many active solar designs because of the solar radiation during the day and its absence at night, fade to insignificance with the kinds of earth-covered buildings considered here. Smooth or constant energy demands are of great benefit to solar design, and earth-covered buildings present relatively constant demands.

Second, the demands for heating and cooling energy is characteristically less with earth-covered construction than in conventional structures. This suggests not only the use of smaller equipment and energy collection arrays, but higher equipment utilization. Thus, the life-cycle cost for solar energy use in earth-covered buildings may be particularly favorable.

Third, days without sun have little impact on much earth-covered construction, whereas conventional buildings with active solar systems could face hardship after only a few sunless days.

PEAK LOAD: Peak loads occur at several levels, primarily affecting the building itself and the energy supplier. Heating and cooling equipment in buildings must be designed to meet the occasional peak of high demand. The energy supplier (public utility or other) must also design supply capability to meet occasional, even if regularly occuring, extraordinary demands. Reductions in peak energy demands in earth-covered buildings have been observed in many locations and with many different designs. This can affect not only the selection and operating costs of mechanical equipment, but ultimately reduce and stabllize local utility demands.

LONG-TERM POTENTIAL: The long-term potential impact of earth-covered buildings, especially in terms of the United States residential energy sector transactions, can be significant. The construction of significant quantities of earth-covered buildings can lead to an overall reduction in energy consumed by buildings and result in long-term savings of several quads per year.

If energy demands for heating and cooling are stabilized and reduced, the sizing of systems can be reduced and attendant savings can be realized. This can benefit both individual building owners and society as a whole as utility costs are reduced.

The energy benefits of earth-covered buildings to energy suppliers, building owners, and society at large, however potentially large, will accrue only as significant numbers of earth-covered buildings and dwellings are built. With the existing housing and building stock in the United States (79 million dwellings, averaging 26 years of age), a few hundred or a few thousand earth-covered buildings have little impact on overall energy consumption. The United States, however, has a large demand for new and replacement structures. Because of this, even a modest introduction of earth-covered buildings could have a major impact within a generation.

Another aspect of the long-term potential benefits of earth-covered buildings has to do with their substantial independence from temporary power outages. Earth-covered buildings and dwellings could have significant social utility use in times of general energy crisis.

SOIL AND GROUNDWATER EFFECTS: Earth-covered buildings usually affect the ecological system less, for not only is more ground potentially available for plants (which cleanse the air), but also, the ground area available for natural rain water absorption increases dramatically. Such increases reduce pollution from storm runoff and improve the recharge rate of aquifers.

The food and fuel production capabilities of such green spaces are large and constitute a major social benefit, but one not considered here.

AIR AND CLIMATE EFFECTS: Earth-covered buildings require relatively little externally supplied energy for heating and cooling, and, in turn, proportionally less air pollution problems from energy suppliers, whether utility companies or fuel transporters.

The beneficial effects of vegetation on local air quality and climate are not quantified.

PSYCHOLOGICAL RESPONSE EFFECTS: Windowless buildings, whether earth-covered or not, affect people differently from "all glass" buildings. The range of buildings between these two extremes elicit varying responses. Because many earth-covered buildings provide views to the outside, the evidence indicates that earth-covered buildings pose no inherent psychological problems. Indeed, some approaches to earth-covered buildings have gained quite exceptional public support.

Note: Earth-covered buildings present an unusual opportunity for "open space" rooftop development, a major benefit for most communities.

The uses of open space include parks, playgrounds, food and fuel crops, gardens, walks, exercise areas, gathering areas, and so on. Many communities feel the need for more such space, and many earth-covered buildings provide that opportunity in ways quite unlike that of other building types.

Conclusions

Based on the trends of the last few years, it seems likely that there will be an increase in the construction of earth-covered residences and public buildings.

If earth-covered buildings are viewed as a quasi-traditional developing technology, then one can expect unit cost reductions as use becomes more widespread and one can expect increases in performance as well. While some see the earth-covered movement as a young and developing technology in competition with mature, rejuvenating and well-developed technologies, there is another view that this emerging technology has its niche. The future will, no doubt, prove the truth of both views.

The conclusion of this exploratory study is that well-designed earth-covered buildings (see footnote 1) have exceptional benefits regarding safety, efficiency, toughness, durability, and cost criteria. Moreover, public policy encouraging more efficient, safer, and more durable buildings would provide incentives to explore the use of earth-covered buildings.

The following statements by experts in the earth-covered field summarize their views regarding earth-covered buildings:

> Earth sheltering as a viable concept to save energy, to reduce maintenance, to improve land use, to provide secure environments from natural and manmade disasters as well as to provide a sensitive and visually satisfying result, is growing in popularity among the lay public, the professionals and the financial community.[2]
>
> David Scott

> As it becomes increasingly evident that conservation is the single most cost-effective strategy for responding to decreased energy availability, earth sheltering has taken its

place among the principal alternatives in building design. Its attributes, when properly applied, not only contribute to conserving energy, but can also facilitate other benefits, such as land conservation, increased open space on intensely developed urban sites, preservation of historic sites and building in close proximity to new development, increased security and protection from natural and man-made disaster. It should be remembered, however, that in respect to energy conservation, earth sheltered building design--like any other approach--is effective only for appropriate conditions of location, climate, geology, program and economics. Given these, its manifest benefits have already made it the subject of increasing attention from the building industry.

As with all of the new building design alternatives stimulated by the general interest in energy efficiency, the future of earth sheltering will be largely determined by two major considerations--the continued short supply of energy to meet demands and the success of earth sheltered buildings in satisfying the needs they have been designed to meet. As the first consideration becomes more critical and the second is successfully met, we may expect to see an increasing application of earth sheltered designs to a wide variety of building programs, accompanied by dramatic changes in construction technology and architectural design.[3]

David Bennett

Faced with a future of dwindling energy reserves, fallout from our own faulty power plants, and the possible consequences of struggle over international energy stores, we enter an era in which underground construction is certain to play an increasingly important role in all aspects of shelter. We must be careful, however, that we are not driven into the ground with paranoia, too willingly accepting lesser standards of accomodation than we demand for our surface structures. I am convinced that the most pressing issue in the development--and the desirability--of underground construction is quality of design. What good are efficient buildings, or protective buildings, if they themselves are banal or oppressive, inflicting their own subtle damage upon the mind and soul? If our clients and an anxious public turn to underground buildings solely as a vehicle for passage through troubled times, then we as architects have failed. The humanness of the species prevails only if underground alternatives are chosen because we have designed them well.[4]

Kenneth Labs

FOOTNOTES:

1. Perhaps an extended discussion of the term "proper" can be avoided by the definition: "proper" means that the buildings do not leak excessively, build up air pollutants, or have structural safety factors less than 2.0. Earth-covered buildings that satisfy these requirements exist throughout the U.S.

2. Personal correspondence with David Scott of Washington State University, June 1981.

3. Personal correspondence with Architect David Bennett with BRW, Inc. Architects, Minneapolis, June 1980.

4. Personal correspondence with Architect Kenneth Labs with Undercurrents, New Haven, Connecticut, April 1981.

PART II HAZARD ANALYSIS

HAZARD ANALYSIS

More than one billion dollars is spent annually in the United States to help disaster victims and their communities recover from major catastrophies ...[1]

Roy Popkin

INTRODUCTION

While there is a lack of precision in measurements of life and property losses caused by disasters, there is broad agreement that the losses are large. Professor Henry Lagorio (Berkeley) breaks down <u>partial</u> losses in Figure 1.

ANNUAL U.S. NATURAL DISASTER LOSSES			
Hazard	Injuries	Life Lost	Property Damage in Millions of Dollars
Hurricane	6,755	41	448.7
Tornado	2,091	124	180.0
Flood	610	62	388.5
Earthquake	112	28	102.7
Fire	N.A.	6,300	4,008.0
TOTALS	9,568	6,555	5,127.9

Source: Henry J. Lagorio, University of California, Berkeley

Notes: Fire data are based on 1978, data for all other hazards are based on 3-5 year averages and 1975 costs on an annualized national basis.

FIGURE 1

Note that Figure 1 does not include losses from such natural hazards as volcanoes, insects, or fungus (e.g., losses to wood rot). Potential losses caused by nuclear blast and radiation are also not included in the table; however, they are a concern for this study. The table also does not record losses related to the thermal performance of buildings, (e.g., economic and life losses caused by buildings not tempering the weather adequately; hot weather damage to buildings runs in the billions).

Professor Lagorio goes on to say:

> On a projected annualized basis under 1980 conditions, it is estimated that the total cost of losses due to the occurrence of natural disasters in urban areas within the United States will approach $12 billion, representing quite a drain on the national economy.[2]

This study explores the performance of earth-covered buildings in relation to hazards which affect the built environment: blast, storms, earthquakes, fire, nuclear radiation, and thermal radiation are explored.

Footnotes:

1. Popkins, Roy, "Executive Summary," in Reconstruction Following Disaster, edited by Haas, J., Kates, R., and Bowden M., The MIT Press, Cambridge, Mass., pp. XXV, 1980.

2. Correspondence with Professor Henry Lagorio at the University of California at Berkeley, April 1981.

STORMS

Introduction

For the purpose of this study, the term "storm" is taken to mean violent weather. Typically, tornadoes and hurricanes are the worst of storms. Because tornadoes are usually the more violent, they are discussed in detail.

Concerns for other storm effects, such as hail, ice formation, and snow accumulation are not explored because there is general agreement that earth-covered buildings would have minimal effects from them.

Tornadoes

> Earth-covered buildings can be expected to offer a significant advantage over normal above ground buildings if subjected to tornado winds. Their advantage lies in the fact that they are out of the path of the debris carried by the strong winds. Further, the roof must be strong to support the overlaying earth and therefore the potential for damage from tornadoes is lessened. One possible rule of thumb for considering the strength of the roof and the amount of overlaying material would be to design for a reduction in pressure of one-half atmosphere. This means that the combined weight of earth over the building and the structure of the roof should support an upward force of approximately 7.5 pounds per square inch. Such

> a construction should be strong enough to withstand the greatest pressure reduction within tornadoes. Thus, they could be considered very safe from the ever present threat of severe weather.[1]
>
> Joe R. Eagleman

Tornado Phenomenon

Tornadoes are among nature's most potent short-term phenomena. In a single year, over 100 people may die, thousands can become injured or homeless, and hundreds of millions of dollars of damage can result from tornadoes. Tornadoes usually occur in the spring, between 3:00 and 8:00 PM. They travel from the southwest, west, and south, 60%, 16%, and 6% of the time respectively. Wind speeds are usually less than 200 mph. Damage caused by tornadoes is divided into several categories: 1) wind pressure, 2) impact of flying debris, and 3) atmospheric pressure differentials.

In a discussion of earth-covered buildings under tornado stresses, Eagleman says:

> An average of 700 tornadoes strike the United States every year. More than 1,000 tornadoes have developed in each of several different years. Although some states are more prone to the tornado hazard than others, every state in the Union has been subjected to the impact of these storms. A frequent response to the threat of tornadoes is to construct storm cellars or other shelters.
>
> Damage surveys have verified that the lower stories of houses are safer than upper stories and below ground areas are generally safer areas than those above. Thus, the earth-covered building has the advantage of offering more protection from severe storms than conventional houses.

Earth-covered houses may be constructed with no opening in the roof or with small openings to furnish light from above. Other designs also include large openings. Those designs that have fewer and smaller openings could be expected to withstand the impact of a tornado much better than those with more and large openings; however, even those with atriums would not be expected to be destroyed in the same manner as a house located above the surface. When a tornado strikes a building the south and west walls are usually bombarded with strong winds carrying debris that may be composed of boards and other objects. With the very strong winds accompanying tornadoes, objects become missiles; but since the wind speeds are great such missiles do not travel in curved paths as long as they are within the strong winds. Therefore, they do not immediately fall into depressions. For that reason, ditches may offer some protection during a tornado. In the same way, an atrium would not be bombarded by as much debris as the south side of an above ground building although within an earth-covered house the atrium would not be the recommended place for seeking shelter from a tornado. A safer location would be in some part of the house that is covered by earth. Those houses with skylights may also be expected to perform well during a tornado for the same reason. The bombarding effect from debris could definitely be expected to be less. The reduction from damage due to flying debris is a significant factor in considering the reduced damage from tornadoes for earth-covered houses.

Some earth-covered buildings are constructed with one wall above ground. The orientation of such buildings is important. Damage surveys, for example Eagleman, et al, 1975, have shown that the orientation of houses is important in their ability to withstand tornadoes. Since the tornado carries a large amount of debris if it moves through a city or through a wooded area, the wind direction during a tornado is important. It has been observed that the strongest winds are in the direction that the tornado is travelling. This is normally from the

> southwest. Therefore, with an earth-covered house the best orientation for a window-wall would be with the opening toward the northeast. The worst orientation would be with the opening facing the southwest. In either case the rooms within an earth-covered house having a window-wall would be most unsafe adjacent to the window. Safer rooms would be those located farther away from the window-wall.
>
> Earth-covered houses are built with varying amounts of earth cover. The depth of earth over the building could be expected to influence the ability of the house to withstand a tornado. The deeper the covering, the more likely that a house will withstand the reduction in pressure and strong winds accompanying a major tornado. The strength of the roof structure is probably more important than the depth of covering. Since the submerged building is not subjected to the bombarding effect of the strong winds, the major impact of the tornado could be expected to come through the effects due to a reduction in pressure. The exact amount of pressure decrease accompanying a tornado is not known. In order to have damage in earth-covered houses the reduced pressure would have to be sufficient to overcome the weight of the earth of the roof as well as to destroy the roof itself. It is commonly found with above ground houses that the roof flies upward because of the reduced pressure. A tornado that moved over an earth-covered house would also provide an upward force because of the lower pressure above ground. This would be opposed by the weight of the earth over the building and, therefore, the amount of damage would be expected to be less.[2]

The wind velocity in a majority of tornadoes exceeds that of many hurricanes and are especially destructive because of turbulence. Wind pressures on walls and roofs are greater than many residential and institutional structures can resist, frequently on the order of 2-4 psi. Building failures occur when racking, buffeting and lateral forces weaken structural connections and topple load-bearing walls. Overhangs, corners, and windows are areas particularly susceptible to damage. Bursting forces occur when high-velocity, high-pressure air enters and then is contained inside a space, causing roofs and walls to dislocate.

Windblown debris is another tornado hazard. Small objects are capable of penetrating buildings, and flying autos may collapse whole structures. Flying debris tends to take a horizontal path so that walls are most susceptible to damage, but roof damage is common.

Abrupt changes in air pressure also cause damage from tornadoes. The air pressure within the vortex of a tornado is extremely low, particularly compared to the pressure existing just outside the vortex. The effect these differential air pressures have on buildings might best be described via the familiar balloon analogy. Imagine a weather balloon, inflated just enough to rise, and as it rises it grows in size as the gas inside it (small in volume at ground level pressures) expands because of decreasing atmospheric pressures around the balloon. A building passing into the vortex of a tornado reacts in much the same way as the balloon when the air pressure surrounding a building drops. A building adapts to a vortex in one of three ways: 1) venting the high-pressure air trapped inside the building, 2) withstanding the differential air pressure as a pressure vessel, or 3) "exploding," sometimes with a roof lifting off or walls blowing out.

This air-pressure differential can also be viewed as the vortex applying suction to the roofs or walls of buildings. In any case, the effect is not smooth, that is, vibrations are set up so that a building subjected to such loads is shaken and buffeted fiercely.

Experts disagree on the magnitude of hazard presented by air-pressure differential. Some attribute more potential damage to it than to the wind-pressure damage discussed earlier. FEMA assumes a 225 psf negative pressure results from wind (in the most destructive tornadoes) and 204 psf for air-pressure differential when no venting is assumed. Eagleman says that the air-pressure differential can be on the order of 950 psf.[3]

Earth-Covered Buildings and Tornadoes

Earth-covered buildings are less affected by tornadoes than conventional construction because of: 1) external mass and minimal building exposure, 2) structural toughness, and 3) resistance to flying debris.

Earth massing absorbs energy such as wind-pressure loading, debris impact, and uplifting pressures, and transmits only a fraction of incident loading to the building itself. Conventional buildings are literally shaken apart by the turbulent forces produced by tornadoes. Earth masses resist racking and lateral forces, thus protecting an earth-covered building. Structural connections designed to resist earth loading are particularly tough and will not easily fail under tornado loadings or the impact of flying debris.

Conventional construction exposes a large surface area which must resist tornado-induced wind pressures and penetration by debris. Earth-covered buildings, in contrast, usually present a minimum surface exposure. The profile of an earth-covered building permits high winds to pass with minimal resistance. Naturally, glazed areas are susceptible to damage and penetration by debris in any type of construction. Atrium and wall glazing may well be damaged in earth-covered buildings, but failure of other building elements should be minimal. Hardening of zones within earth-covered buildings should result in a predictably high occupant safety.

Earth-covered buildings have been recognized as a way to provide high-quality storm protection for institutional facilities. For example, 27 school buildings which are earth sheltered and at least 15 additional schools with earth berming have been constructed in Oklahoma.[4] Many of these schools, especially those with only earth berming and no earth cover, may not resist the uplift forces generated by a tornado vortex even though they may have adequate venting to relieve internal pressure. Those buildings with moderate spans, proper venting, and either a substantial concrete roof structure or a moderate depth of soil cover should withstand most tornado-related stresses.

Orientations most subject to tornado damage are south, southwest, and west. Perhaps few earth-covered buildings face west or southwest, but a southerly orientation is popular because of the energy-conservation potential of solar glazing, solar greenhouses, and attached sunspaces. A possible increase in property damage because of a southerly orientation does not necessarily increase the hazard for persons within an earth-covered building because they could move to protected parts of the building and face minimal risk of injury.

Footnotes:

1. Personal correspondence with Joseph R. Eagleman, July 1981.

2. This statement is from a statement prepared by Joseph R. Eagleman for Moreland Associates, See also: Eagleman, Joseph R., V. U. Muirhead, and Nicholas Willems. Thunderstorms, Tornadoes and Building Damage, Lexington Books, Lexington, Massachusetts, 1973. Eagleman, Joseph R., "Tornado Damage Patterns in Topeka, Kansas, June 8, 1966," Monthly Weather Review, 1967, pp. 370-374.

3. Wind-Resistance Design Concepts for Residences: Guidelines For Homeowners and Builders, TR-83, Defense Civil Preparedness Agency, November 1976.

4. A Case For Underground Schools, a report prepared by the Oklahoma State Department of Education in cooperation with the Oklahoma Civil Defence for the Defense Civil Preparedness Agency, 1980.

BLAST

Introduction

For purposes of this study, the discussion of blast as a hazard which affects life and the built environment will be limited to nuclear explosions although other blast sources may have similar effects. Damage attributed to nuclear explosions, beyond the immediate region of the fireball, can be isolated into the effects of: short-term atmospheric overpressure, atmospheric overpressure-induced ground shock, a pulse of thermal radiation, initial nuclear radiation, and radiation from fallout. Conventional construction does not offer significant occupant protection from such blast effects. Earth-covered buildings offer improved mitigation against each of these blast effects. The thermal and radiation effects are discussed under the Fire and Nuclear Radiation Sections of this study and the ground shock effects under the Earthquake Section. Short-term atmospheric overpressures are discussed in this section.

While these explosion effects are discussed in detail in separate parts of this study, it is helpful to begin discussion of nuclear explosions with an overview. To this end, Thomas Carroll prepared the following statement:

> The split-second blast of a nuclear weapon releases awesome amounts of energy into the

atmosphere. Energy so great that it is measured by comparison with the energy released by thousands or millions of tons of TNT (kiloton or megaton). The first manifestations of a nuclear explosion are the emission of x-rays and gamma radiation, causing the growth of a fireball which emits intense levels of thermal and nuclear radiation. Temperatures inside the fireball reach millions of degrees farenheit. In low altitude bursts the fireball may touch the ground, cratering the earth and vaporizing everything it engulfs.

In about the time it takes a thunderclap to follow a lightning bolt a blast wave moves out radially from the burst point, producing enormous shock pressures, and blast winds several times greater than hurricane strength. Meanwhile if the fireball touches the ground, the hot gasses generated by the vaporized material in the crater begin to rise rapidly, mixing with the radioactive byproducts of the nuclear reaction. Upon reaching the upper atmosphere, the gasses cool and solidify into particles which fall back to the earth. These fallout particles are radioactive by virtue of having the radioactive fission products adhering to them, or trapped inside. If the burst is so high that the fireball does not touch the ground, there will be no crater and fallout will not develop.

Aside from nuclear war, the possibility of a nuclear explosion through an accident or sabotage could pose similar hazards. The nuclear hazard is unprecedented, and protective measures pose new challenges to architects and engineers.

Ordinary buildings with combustible roofs and siding materials can be vulnerable to the thermal pulse of a nearby nuclear explosion. Thermal energy may be delivered in such intensities that ignition thresholds are exceeded for highly combustible materials such as paper, window curtains, leaves, dry grass, etc. Just as the sun shines through windows, the thermal pulse can ignite furnishings inside of buildings with unprotected windows. Major fires in and around buildings would develop as these materials provide the kindling for heavier combustible building materials.

Underground buildings would be spared many of the hazards of nuclear thermal pulse. The lack of combustible facades and roofs, along with small window areas sharply reduces the hazard. If consistent with the solar design, underground buildings with windows could be oriented such that the windows face away from likely target areas, thereby eliminating the thermal pulse load. To further reduce the fire hazard, windows and skylights could be covered with metallic blinds or glass fiber draperies which will shield combustible furnishings from the thermal pulse.

Underground buildings are also spared the devastating damage which the nuclear shock-wave and blast winds would cause to ordinary buildings. When the shock-wave hits an exposed vertical wall of any building, a reflection of the shock front occurs, creating reflected pressures several times greater than the incident overpressure. In ordinary construction walls are designed to resist loads that are only a fraction of that produced by the passage of a nuclear shock-wave. Walls designed to meet ordinary building codes for basement walls are several times more resistant to nuclear blast than walls of aboveground buildings.

The normal concrete slab over buried buildings goes a great way towards reducing the hazards posed by nuclear blast loads. Special detaining of the reinforcement and the addition of a few inches of concrete can dramatically reduce the hazards even further Skylights and exposed window walls in buried buildings can be fitted with blast-resistant covers to keep the blast wave out. Alternately, survival could be greatly enhanced by providing a small blast resistant area, perhaps a storage room, a laundry room, or a bathroom in one of the back corners of the underground building.[1]

Underground buildings provide many times more protection from hazardous fallout radiation than ordinary buildings. Each small radioactive fallout particle sends out hazardous gamma rays in all directions. The amount of protection which a building provides against fallout gamma radiation is expressed by the Protection Factor (PF). An occupant of a building with a PF of 40 would be exposed to 1/40 or (2½%) of the exposure he would be exposed to if his location was unprotected. Current government policy requires that fallout shelters for the general public should have a minimum PF of 40. A typical house would have a PF somewhere in the range of 1.5 to 2 on the first floor and 5 to 20 in the basement depending on the degree of exposure of the basement. Underground structures, by their nature, provide vastly improved levels of protection against fallout radiation. Gamma radiation penetrating any material is captured or stopped if there is sufficient material present. The walls and roof materials of ordinary buildings do not contain sufficient material to effectively reduce the exposure to safe levels. Very little, if any, radiation can pass through buried walls, and the combination of the structural roof slab and earthcover over underground structures can produce PF's greater than the minimum value of 40.

Protected areas of the building can be located such that occupants are not exposed to radiation entering through skylights and exposed window walls.

This report supports the statement that earth-covered buildings should perform exceptionally well in the hostile environment beyond the area of total destruction created by nuclear explosions.[2]

Thomas Carroll

Air Blast Overpressure

Upon detonation of a nuclear weapon, the air adjacent to the explosion compresses to form a shock-wave of increased atmospheric pressure which expands from the detonation point, like a tidal wave, moving outward in all directions from the point of detonation. The shock-wave strikes all objects in its paths, including the ground. Initially the air blast or shock-wave overpressure exceeds normal atmospheric pressure substantially[4] and travels much faster than the speed of sound. Shock-waves gradually slow down, lose pressure and become merely a sonic disturbance. High wind lasting several seconds follows immediately behind the shock front. The phenomenon constitutes a most potent blast hazard, air-blast overpressure.

The impact of a shock-wave on a building shell is nonsimultaneous, creating momentary stresses throughout the structure. In addition, upon impact with a building frontwall, short-term high-pressure-reflected shock-waves form, extending blast wave damage potential. Conventional construction fails at relatively low overpressures. For example, glass breaks at ¼ to ½ psi and curtainwalls will begin to be damaged at 1 psi and likely destroyed at 3 psi. Brick-veneer residential construction will begin to fail at 2 psi and collapse at 3-4 psi.[5] Massive load-bearing walls will begin to fail at 4 psi and collapse at 6 psi. Steel or concrete building frames can withstand up to 10 psi.[6] The median lethal overpressure (50% survival of occupants) has been estimated to be about 6 psi for conventional aboveground construction.[7]

Blast-generated winds following the shock-wave arrival differ in windspeed and duration according to shock-wave overpressure (Figure 1). High blast winds blow debris away from the blast center, and blown or falling debris is a major cause of building failure.

Blast Wave Characteristics			
Peak Overpressure PSI	Wind Velocity MPH	Wind Duration in Seconds	
		5 Megaton Burst	40 Kiloton Burst
1	35	9.5	1.9
2	70	8.5	1.7
5	160	6.8	1.4
10	290	6.0	1.2
20	470	5.8	1.1
30	670	5.6	1.1
Source: DCPA Attack Environment Manual, Chapter 2, 1973			

FIGURE 1

Air Blast Overpressure and Earth-Covered Buildings

Earth-covered buildings can be less affected by atmospheric overpressure than conventional construction if: 1) the external mass is designed to absorb and distribute stresses, 2) the building profile offers minimal resistance to the passage of the overpressure shock-wave, and 3) structural toughness is designed in. A related benefit of most earth-covered buildings is resistance to penetration by blast-overpressure-generated flying debris.

Masses of earth are able to absorb and diffuse energy pulses, thereby transmitting only a percentage of incident forces into the structure to reduce racking and bursting forces. Moreover, a limited building exposure creates a profile which the overpressure shock-wave will roll over (Figure 2), minimizing reflected blast-overpressure effects.

The transient air-blast-pressure fluctuations, created by the passing of atmospheric-overpressure shock-waves, will act on all exposed building surfaces, regardless of their orientation. In contrast, dynamic

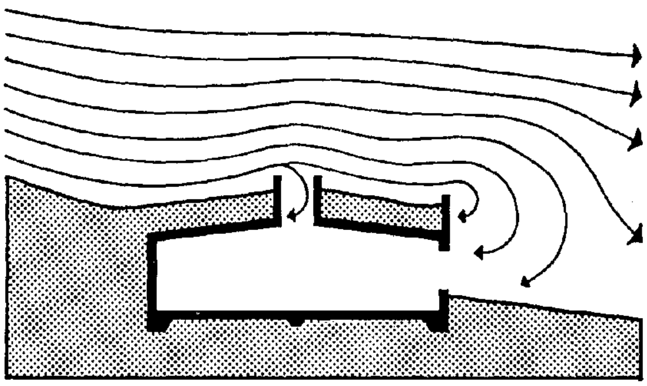


FIGURE 2 Blast-Generated Wind Patterns

pressures created by the brief, high-velocity winds (following the shock-wave front) are positive on the windward side and negative on the sidewalls, roof, and leeward side. Conventional construction is often stressed to the point of failure by these forces. Glazing or window glass is almost certain to be damaged in any building subjected to such loads; however, because of the toughness of most earth-covered buildings, other types of failure are less likely to occur at a given level of overpressure than in conventional construction.

In addition to pressure changes, the atmospheric-overpressure shock wave will also carry with it debris which can batter a building, block exits, and penetrate walls and glazing. Because shock-wave-generated winds are without the twisting turbulent uplift associated with tornadoes, blast-generated debris sources tend to be in line outward from the blast origin point. Conventional construction is both vulnerable to and the source of much debris in a blast. In contrast, many earth-covered buildings are resistant to debris damage. Moreover, they do not themselves contribute greatly to debris formation. Earth-covered buildings will tend to contain their own interior debris, regardless of the direction of the blast source. Moreover, earth-covered buildings will have few exterior components which can become debris. Earth masses are effective absorbers of debris impact, and earth-covered buildings have minimal exposures to be effected by debris. Debris accumulation can be many feet thick in a highly-builtup area after a nuclear explosion. Earth-covered buildings can be expected to support substantial accumulations of debris loading before collapse. Debris blockage of exits can occur in all buildings and some below-grade earth-covered buildings may have blockage problems similar to basement spaces of conventional buildings.

Bursting forces, present when a shock-wave enters a building and is suddenly trapped, are resisted in earth-covered buildings because of the lateral bracing of the adjacent soil, the dead load of earth cover, and the potential toughness of the structural shell. Structural shells are easily designed to be tough to such loadings, but they must be designed properly.

Definitive comments on the toughness of earth-covered buildings are tempered by uncertainties in testing and modeling the blast phenomenon. For example, the duration of a megaton-blast shock-wave is 4.25 greater than either the Hiroshima blast or known tests. The overpressure that can be tolerated by earth-covered buildings and not jeopardize occupant survival is difficult to estimate; however, performance should be similar to or better than the 12 psi median lethal overpressure DCPA assumes for basement spaces in its National Fallout Shelter Survey.[8] In the case of heavily earth-covered buildings, say those with 5 to 7 feet of earth cover, one could remove some of the earth cover, place the soil in front of windows, and thereby increase the blast and radiation resistance of the building, so long as 3 feet of earth were left on top.

Summary

Earth-covered buildings, when located beyond the area of total destruction, should provide significant shelter to occupants from the hostile environment created by nuclear explosion. Earth-covered-building earth mass can be designed to absorb and distribute stresses. Building profiles can offer minimal resistance to the overpressure shock-wave. Earth-covered buildings can be designed to be exceptionally tough and also to resist blast-generated flying debris.

Footnotes:

1. H. L. Murphy states that the cost of making an entire basement space blast-resistant during the construction phase is less than adding an interior blast-resistant wall to harden a space.

2. Statement prepared by Thomas Carroll for Moreland Associates.

3. This section is derived in part from information in the DCPA Attack Environment Manual, Chapter 2, Defense Civil Preparedness Agency, 1973.

4. For example, 50 psi overpressure can be found .51 miles from a 200 Kt yield surface burst and .37 miles from a 1 Mt yield surface burst according to the following report:

   H.L. Murphy, J.R. Rempel and J.R. Beck, Slanting in New Basements For Combined Nuclear Weapons Effects, Stanford Research Institute, Melno Park, California, 1976, pp. A-5.

5. Murphy, H.L., "Addendum, A Multiple Regression Analysis Approach," in Existing Structures Evaluation,

Part II: Window Glass and Applications, by J.H. Iverson, Stanford Research Institute Final Report, for U.S. Office of Civil Defense, December 1968.

6. DCPA Attack Environment Manual, Chapter 2, Panel 14. See also, Protective Construction, Vol. 4, Chapters 1 and 2, DCPA, 1977.

7. DCPA Attack Environment Manual, Chapter 2, Panel 2.

8. Wiehle, C.K., and Backholt, J.L., Blast Response of Five National Fallout Shelter Survey Buildings, Stanford Research Institute, 1971.

Additional Readings:

Design and Structures to Resist Nuclear Weapons Effects, A.S.C.E. Manual of Engineering Practice, No. 42, 1964.

The Effects of Nuclear Weapons, U.S. Department of Defense and U.S. Department of Energy, Third Edition, 1977, Superintendent of Documents, Washington, D.C. 20402.

Increasing Blast & Fire Resist in Buildings, DOD, DCPA TR-62, May 1976.

H.L. Murphy, D.E. Beck, Maximizing Protection In New EOCs From Nuclear Blast and Related Effects: Guidance Provided by Lecture and Consultation, Stanford Research Institute, Melno Park, California, 1976.

H.L. Murphy, J.R. Rempel, and J.E. Beck, Slanting In New Basements For Combined Nuclear Weapons Effects, 3 volumes, Stanford Research Institute, Melno Park, California, 1975.

Protection in the Nuclear Age, DPD, PDPA H-20, February 1977.

EARTHQUAKE

Ronald F. Scott

Introduction

Almost all of the United States is subject to some earthquake hazard, with perhaps 25% of the land facing serious threat, and another 25% moderate threat. Damage to buildings may result during earthquakes as a result of the dynamic motions of the soil or foundation material as the earthquake-generated ground waves pass through the site. The dynamic deformations of the structure develop because of its inertia. With motions larger than the design may have allowed for, column yielding and other damage may result. It is also possible that the foundations may be displaced as a result of the dynamic loads acting on them, because of yielding or even liquefaction of the supporting soil under the transient earthquake stresses. For these reasons, building codes place certain requirements on the design of structures in areas where seismic activity occurs.

Since footing failure or foundation damage is relatively rare, the two main considerations examined here have to do with the structural integrity of a shell under earthquake loading. They are: 1) the ability of the roof structure to withstand dynamic vertical displacement, and 2) the ability of the roof and its supporting walls and columns to remain a structural unit.

In the first case, the roof must be able to take the effect of additional dynamic loads applied repeatedly to the roof. The roof must sustain such loads without distress. In case two, the roof and column structures must remain securely attached to each other. The second point requires that beams and columns must be adequately connected.

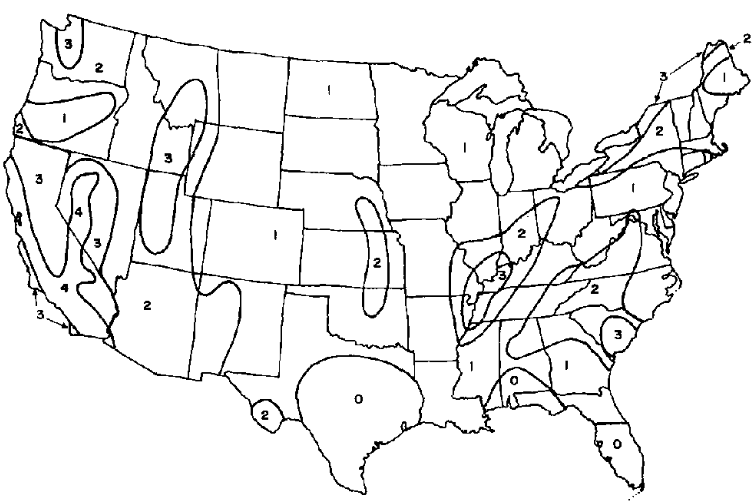
Building Code Requirements for Earthquakes

In the Uniform Building Code (1979 Edition), a figure sets out zones of seismic risk for the United States. Zones range from 0 (zero seismic hazard) to 4 (maximum seismic hazard). The figure is reproduced here as Figure 1. The Uniform Building Code establishes requirements for the minimum earthquake force for a structure as follows. Every structure is to be designed and constructed to resist at least a minimum total lateral seismic force in accordance with the following formula

$$V + ZIKCSW$$

where V is the total lateral force, Z is a numerical coefficient dependent upon the seismic zone in which the structure is located, I is an occupancy importance factor (equal to one for residential construction), and K, C, and S are all numerical coefficients set forth in Tables of the UBC. W is the total dead load of the structure.

For construction, the values of Z are given as follows: Zone 1, $Z = 3/6$; Zone 2, $Z = 3/8$; Zone 3, $Z = 3/4$; Zone 4, $Z = 1$. For residential construction, $K = 1.0$ is the usual case, although it could be argued



SEISMIC RISK MAP OF THE UNITED STATES

Zone 0 - No damage.
Zone 1 - Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 second; corresponds to intensities V and VI of the Modified Mercalli Intensity Scale (M.M. Scale).
Zone 2 - Moderate damage; corresponds to intensity of VII on the M.M. Scale.
Zone 3 - Major damage; corresponds to intensity VIII and higher of the M.M. Scale.
Zone 4 - Those areas within Zone No. 3 determined by the prozimity to certain major fault systems.

Source: The Uniform Building Code.

FIGURE 1

that the framing shown in the Moreland drawings for earth-covered housing could be considered a "box system," in which case K would equal 1.33. The coefficient C is a function of the building period and is determined in accordance with the formula

$$C = 1/15\ T$$

For earth-covered housing, the period of the structure varies from about 0.1 to about 0.3 sec so that C lies in the range of 0.2 (0.1 sec) to 0.12 (0.3 sec). The Building Code, however, restricts C to be less than 0.12 so that this value of 0.12 should be used. The value of S is obtained from a formula which relates it to the ratio of the building period to the "site" period. It is still a matter of controversy as to whether or not a site can have a natural period associated with it. Therefore, it is suggested that S be taken as unity. The product of the factors ZIKC and S, for an earth-covered house, ranges from about 0.02 (Zone 1) to 0.12 (Zone 4).

The lateral seismic coefficient, V, represents an equivalent static horizontal force applied to the structure. In the case of a larger structure, such as a hypothetical underground public building, the fundamental periods are likely to be in the same range since the structural members have more mass, but they are stiffer and the entire structure is more deeply embedded in the soil. Consequently, the lateral seismic coefficient in this case would have the same range of values.

Actual experience in earthquakes in San Fernando 1971 and El Centro 1979 indicates that structures built to The Uniform Building Code requirement may have inadequate earthquake resistance. For this reason instead of using Uniform Building Code-derived forces, an approximate dynamic analysis has been done for the underground structures and is discussed below.

Preliminary Calculations of Dynamic Behavior of Underground Structures

Two small structural shells were examined for this study, both composed basically of conventional steel-reinforced concrete. In both cases the foundations and walls were cast-in-place reinforced concrete. In one case, the roof structure was also cast-in-place; in the other case the roof was a composite structure made up of prestressed and precast reinforced hollow concrete planks with a cast-in-place concrete topping. The construction documents examined, both refering to residences, were provided by Moreland Associates. The basic design was for a house similar to Figure 2. Both shells were assumed to have an earth cover of three feet.

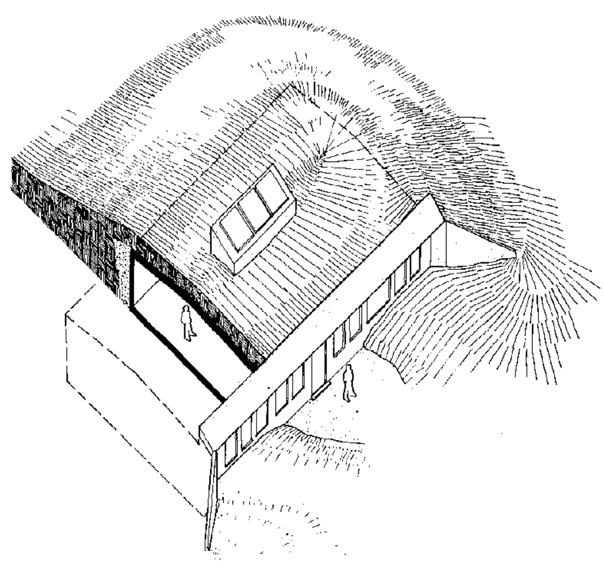


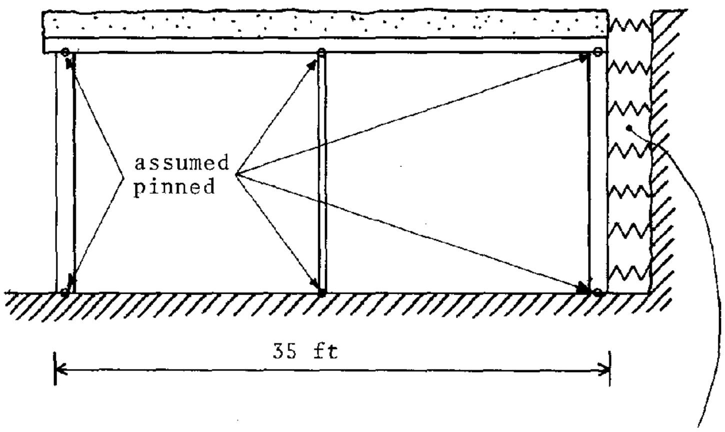
FIGURE 2 Hypothetical Earth-Covered Residence

The moment of inertia (I) of plank per 12-inch width was assumed to be 550 inches.[14] With this value the vertical fundamental frequency of such a plank along with the 3-foot depth of superimposed earth on a 16-foot span would be about 5 hz. This value was used to enter a vertical response spectrum curve for an earthquake with a 0.4g peak vertical acceleration. The ground motion from which this spectrum is derived might be considered to be that generated by a magnitude 6.5 to 7.5 earthquake with its origin within 10 to 20 miles of the housing site. Such an earthquake could occur in Zone 4 of Figure 1 and would be pertinent to much of California, for example. The results of the analysis indicate that the maximum vertical veolcity of the center of the roof plank would be about 8 inches per second; the maximum acceleration at the center about 0.6g, and the plank would undergo a central dynamic displacement under these loading conditions of about 0.3 inches. This would be superimposed on the existing static deflection of about 0.4 of an inch. Since the dynamic deflection is approximately 100% of the static deflection, it would be expected to double the stresses in the plank during the transient response. In these circumstances, some cracking of ceiling plaster might be expected, but adequate design should take care of the excess stresses involved.

The other concern lies with the horizontal motion of the structure, and this was analyzed for lateral vibrations in the direction from front to back. The structural model taken for the dynamic calculations is shown in Figure 3 in which are also shown the properties assumed to be associated with it. The two values for soil resistance represent loose and moderately well-compacted soils, respectively. For the values shown in Figure 3, the fundamental lateral frequency of the

The values for soil spring constant k are 50 tsf for loose soil and 200 tsf for well-compacted soil.

Beam + 3 ft soil cover = 500 lb/sq.ft.



Sketches are Not To Scale

Springs, k t/sq.ft.
Representing
Soil Backfill
Reaction can be
replaced by a
single spring

Assuming end wall is rigid and hinged at ends:

$K = \frac{kh}{3}$;

K = 150 t/ft (soft soil)

K = 600 t/ft (dense soil)

It is assumed that columns and end wall contributions to lateral spring resistance are negligible.

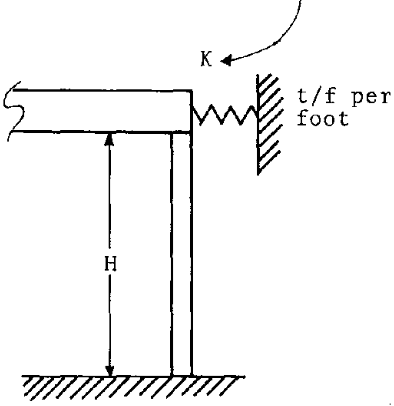


FIGURE 3

entire structure ranged from 3.7 Hz for the low soil-spring constant (loose soil) to 7.5 Hz for the high soil-spring constant (dense soil). Now the response spectrum for the horizontal ground motion associated with the earthquake discussed previously is used. It would have a peak horizontal acceleration of 0.6g. The following values were obtained for the indicated building periods:

Horizontal Component

	Low Soil Constant	High Soil Constant
Velocity, inches/sec	17	9
Acceleration, g	1.1	1.1
Displacement, inches	0.8	0.2

It can be seen that there are considerable advantages to compacting the soil behind the structure since it reduces the lateral dynamic displacement of the building. At the low soil-spring constant displacement of 0.8 of an inch, the possibility exists for some soil gapping at the rear wall of the house. For the same period, the results in the table apply both to underground housing and underground public buildings.

It is apparent under these conditions that careful attention should be paid to the joints where the roof elements meet the central columns and the rear wall of the house. In particular, cast-in-place beams should be mechanically linked to their supports, preferably by dowelling. Such beams and the precast planks require adequate lateral extent of support, say six inches, so that some lateral movement can be tolerated without the beams or planks slipping off their supports. Also, exterior walls and interior columns should have moment as as well as shear connections to the foundations and beams.

In the case of the second structure considered, an all cast-in-place, steel-reinforced concrete structure, all connections were moment connections, and the shell would sustain the expected earthquake loadings without distress.

Several general comments should be made regarding site and soil conditions.

1. As a general precaution, the seismic stability of the area for which underground structures are being considered should be checked. The possibility of slope failures or liquefaction taking place in the adjacent material requires assessment.
2. Drainage should be designed to evacuate water away from the exterior of the building if the site presents this need (and many do). A traditional French drain and drainage layers (coarse granular soil) are common techniques.
3. Attention should be paid to the possibility of erosion of the soil from the roof and around the sides of the wing retaining walls. Steep soil gradients and excessive rainfall may cause trouble before landscape materials have become effective.
4. Roofs should be drained so that water does not pond in the soil unless water retention is desired. It would usually be desirable to cover the roof with a gravel drain layer overlain with filter cloth before applying the compacted soil overburden.
5. Portal design should consider the extra loading the earth cover could present to parapet walls,

particularly if such parapets are also part of the roof support systems, if liquefaction is possible.

6. After the cutting and filling operations taking place in the course of site preparation, care should be taken that the various wall and column footings are not placed on materials of widely different strength or stiffness. For example, it may be convenient to form the rear walls of the structure on cut material, and the front on fill. This will inevitably result in differential settlements under static loading, and these will be enhanced during seismic motions.

A Note on Ground Shocks Induced by Nuclear Explosion

The detonation of a nuclear weapon, whether an air burst, near-surface burst, or surface burst, creates ground shocks which can be a hazard to shallow-buried structures such as earth-covered buildings. The following is a description of the phenomenon:

> The mechanics of ground motion (resulting from) nuclear explosion is much more complex than that of air blast (overpressure). Considering the wide variety of earth materials, variations in the mechanical properties of these materials, nonlinear behavior and inelastic behavior, it is understandable that there has been a lack of success in the prediction of ground motions on the basis of theoretical developments.
>
> The earth motions and associated earth pressures generated by a nuclear explosion are the result of direct-transmitted ground shock and air-blast induced ground shock. Direct-transmitted ground shock results from the conversion of thermonuclear energy into mechanical energy in the earth medium. Indirect, or air-blast induced, ground shock is associated with passage of the air-blast wave over the

ground surface. For distances from ground zero to points at which air blast overpressures are within the limits of this text, (i.e., less than 50 psi), the effects of direct-transmitted ground shock are small and are neglected...

The character of an air-blast-induced ground shock is a function of the weapon yield, air blast (shock wave) velocity and the velocity of the propagation of the compression waves in the earth. ...

The lateral pressures on the vertical sides of a buried rectangular structure may be considerably less than the pressures applied at the top surface of the soil, depending on the type of soil and the height of the water table. Static tests on soils have indicated that lateral earth pressure varies from 0.4 to 0.5 of the vertical earth pressure in sandy soils, and may become as large as the vertical earth pressure for soft clay soils. ... For design purposes, it is recommended that the lateral overpressure on vertical surfaces of rectangular buried structures be taken as the fraction K, (shown in Figure 4).[1]

Ratio of Horizontal to Vertical Soil Pressures	
Type of Soil	K Factor
Dry Cohesionless	.25
Medium Hard Cohesive	.5
Soft Cohesive	.75
Saturated	1
Source: Protective Construction, DCPA, 1977, p. 2-41.	

FIGURE 4

For earth-covered buildings with well-drained granular backfill, such as gravel, around their perimeter the lower values of K would be appropriate for most conditions. For air-blast-overpressure levels which could reasonably be resisted by earth-covered buildings and dwellings, i.e., less than 14 psi, lateral pressures would likely not be a controlling factor. Structurally, vertical walls generally span shorter distances than roofs and will likely withstand any ground pressures related to sustainable roof loading (which for shallow depths of cover is a function of air-blast overpressure). As in earthquake design, structural joints and roof-bearing points are areas which deserve close attention. Figure 5 lists approximate lateral loads vis-a-vis air-blast overpressure.

Lateral Earth Loads (PSI) As A Function of Soil Factor (K) and Air-Blast Overpressure				
Air-Blast Overpressure PSI	K = .25	K = .5	K = .75	K = 1
1	.25 psi	.5 psi	.75 psi	1 psi
5	1.25 psi	2.5 psi	3.75 psi	5 psi
10	2.5 psi	5.0 psi	7.5 psi	10 psi
15	3.75 psi	7.5 psi	11.25 psi	15 psi
Source: Derived from Protective Construction, Defense Civil Preparedness Agency, 1977.				

FIGURE 5

The Defense Civil Preparedness Agency Attack Environment Manual notes that "ground shock causes little damage in the low overpressure region with which civil defense planners are concerned. However, ... below ground portions (of buildings) can move suddenly for short distances, possibly causing injury to people if they are leaning against the basement wall."[2] The Manual also contains a caution about breaks in underground utility lines. This may be of concern to earth-covered buildings in the form of leaking of explosive gasses or flooding.

In summary, ground shock resulting from a nuclear blast is likely to have less destructive potential to earth-covered buildings than air-blast overpressure. Ground pressure is often significantly less than the air-blast overpressure. The hazard may be primarily limited to personal injury from wall movements and other earthquake-like damage.

Footnotes:

1. Protective Construction TR 20 (Vol. 4), Defense Civil Preparedness Agency, May 1977, p. 2-37 thru 2-41.

2. Attack Environment Manual, Defense Civil Preparedness Agency, 1973, Chapter 2, Panels 21 and 22.

Additional Readings:

Bolt, B.A., Horn, W.L., MacDonald, G.A. and Scott, R.F., Geological Hazards, Springer-Veslag, New York, Second Edition, 1977.

Bolt, B. A., Earthquake--A Primer, W. H. Freeman, San Francisco, 1977.

Chopra, A.K., Dynamics of Structures: A Primer, Earthquake Engineering Research Institute, Berkeley, California, 1981

Hudson, D.E., Reading and Interpreting Strong Motion Accelerograms, Earthquake Engineering Research Institute, Berkeley, California, 1979.

Leeds, David (editor), Earthquake Engineering Research Institute Newsletter, Los Angeles.

Newmakr, N.M., and E. Rosenblueth, Fundamentals of Earthquake Engineering, Prentice-Hall, New Jersey, 1971

Rosenblueth, E., (editor), Design of Earthquake Resistant Structures, Pentech Press, London, 1980.

Uniform Building Code, 1979 Edition, International Conference of Building Officials, Whittier, California.

FIRESAFETY ANALYSIS FOR EARTH-COVERED BUILDINGS

Robert Fitzgerald

Introduction

Firesafety design can be accomplished in one of two ways. First, it can have a building regulatory solution. In this way, the code and its administration and enforcement can assume the responsibility for the level of risk society--and the occupants--are expected to bear. This is the conventional method for fire design.

The second way is to design for fire in a manner analogous to other building design practices. Normally, the space planning and circulation for normal use is an architectural design function. The structural system is proportioned by a structural engineer to support applied loads. In a similar manner, the electrical and mechanical engineer consider the functional requirements of the problem in the design of the mechanical and electrical systems. Firesafety is of sufficient importance to warrant functional design attention.

Improved firesafety is often perceived to involve increased cost, which is not necessarily true. When firesafety is a conscious part of building design from the start of the building design process, as opposed to code compliance near the end of the design, costs in conventional construction are often reduced.

It is impossible to assess the firesafety risk for a building until the building is defined, at least in schematic. Therefore, this report will identify the components of a firesafety analysis of a building, and it will describe general observations and concerns for an earth-covered building.

Components of Building Firesafety

The major components of a building firesafety system are as follows:

I. Identification of objectives
    A. Life safety
    B. Property protection
        1. Contents
        2. Building structure
    C. Continued use of the building after a fire
        1. Time for reconstruction
        2. Time to return to normal operation
II. Prevention of serious fires
    A. Ignition prevention
    B. Initial fire control
III. Flame movement control (for a serious fire)
    A. Fuel control
    B. Manual (fire department) suppression
    C. Automatic suppression
    D. Barrier effectiveness
IV. Smoke movement control
    A. Natural movement
    B. Mechanical controls
V. Structural frame protection
VI. People protection
VII. Property protection
VIII. Continued use protection

Performance Concerns of Building Firesafety Components and Earth-Covered Buildings

I. Identification of Objectives.

This is an aspect that is implied in codes and seldom described in building design. It is analagous to "conceiving the project" part of a preliminary real estate development feasibility study.

It is important for an occupant to be aware of the relative risk to himself, his personal property, and his home. This might be related in general terms, such as "as safe as a usual single family detached house," "much less safe than an apartment." "much more safe than a modern office building," etc. Absolute safety is not possible, but a recognition of safety comparable to alternative designs is quite feasible. A numerical rating of the relative safety of specific designs is possible for some of the components. Subjective probability values are used in this case.

Setting objectives is the most difficult part of a firesafety design. Yet, addressing the proper questions is often a means of enhancing the total design at less overall cost.

II. Prevention of Serious Fires

This component addresses the ability or effort of an occupant to prevent fire that will begin to threaten the building and its firesafety objectives. Quality of equipment with regard to ignition prevention is a part of the component. The occupant attitudes and behavior is a more important part.

Normally in building design we assume that this component fails. When fire prevention fails, the building design for firesafety becomes important. Design decisions as early as the schematic phase now become critical.

III. Flame Movement Control, assuming a serious fire occurs.

A. Fuel Control

The building designer has relatively little to do with this component, except for a recognition of its impact on firesafety. The type of fire that can occur and the time durations for defensive action should be a part of the assessment for the earth-covered buildings.

We know that the building contents in the home are very different from those of a generation ago. Modern interior designs are generally more hazardous. Fires produce more smoke and faster fires than the earlier fuels. Interior finish remains a critical factor here, as does furniture construction material.

This problem can be serious in an earth-covered dwelling because the better insulation of rooms can create an "oven effect," causing faster fires. If ventilation is difficult and not well considered, severe smoke problems could result. If venting is automatic, this could further complicate the problem. Automatic ventilation would likely result in a faster fire. These comments would likely apply to most energy-efficient buildings.

B. Manual (Fire Department) Suppression.

A serious problem in fire suppression is access to the burning space. With some earth-covered designs, access to the rooms is limited. Ventilation can be a problem with some designs as well.

Building designers seldom realize that a fire department "extinguishes" a fire only when it is small. Fires larger than a critical size must be "pushed out" of a building. Thus, some below-grade earth-covered buildings, as in below-ground structures of any type, cause serious fire suppression difficulties.

Because firesafety in earth-covered buildings is critically dependent on building design, I would suggest that, in general, fire department aid be discounted for most earth-covered buildings. If a fire department is to be included, its inclusion should be only on a conscious, designed basis. Otherwise, the building and its occupants are left to their own resources.

C. Automatic Suppression.

Automatic suppression is seldom a part of single family home design, earth-covered or not. The unique suppression problems potential in some designs of earth-covered homes make it a consideration. Not only should automatic sprinklers be considered, perhaps with modifications, but also some unusual applications, such as high-expansion foam systems might be feasible. This might be one way to overcome the high firesafety hazards inherent in some designs of earth-covered buildings.

D. Barrier Effectiveness.

The normal fuel loading in a single-family home does not pose a significant problem with regard to the barrier effectiveness for conventional, unpenetrated barriers. However, if a fire is not suppressed within the room of origin, the spread to adjacent rooms by means of open doors, windows, grilles, poke throughs, etc. can be important. I might anticipate that any mechanical air movements could cause some problems with regard to flame movement beyond the room of origin. At this stage, this is speculation, but a concern that must be investigated.

IV. Smoke Movement Control.

A potentially serious problem with regard to earth-covered shelters is the quantity of smoke which could be more significant than in most buildings. The time duration for smoke logging the building may be even more so.

The people-protection component for earth-covered buildings will be extremely sensitive to the smoke problem. This will be addressed more in Section VI.

V. Structural Frame Protection.

This should not be a problem in earth-covered buildings, unless the frame is of timber. The structural framing should have little impact on the life-safety concern, but would influence building reconstruction after the fire.

VI. People Protection.

Unless careful design attention is given to fire-safety, the risk to people in earth-covered dwellings or buildings could be greater than in conventional design. One aspect involves alerting the occupants. This involves fire detection. The type and sensitivity of the detectors, their location and, above all, their reliability, both initially and over time, are important considerations in any building. Proper design of a detection system is a significant feature of any building design and requires experience.

Other concerns are the speed of flame movement and the amount of time before smoke blocks the means of egress, It may be reasonable to expect a maximum time of two or three minutes in many situations. This is not much time to awaken, decide action, help the very young or very old, and leave the building. Both of these concerns are crucially dependent upon ventilation design, egress design, and flame spread protection.

Architectural design with regard to circulation patterns is very important for all buildings. Fire departments may not be able to provide significant, or even any, assistance to some designs of buildings of this type. Emergency people movement with regard to reduced or no visibility, time duration, flame and heat blockages, and smoke blockages must be given careful attention.

VII. Property Protection.

Potentially reduced fire department effectiveness and the potentially greater flame, heat, and smoke problems in an earth-covered building may make the protection of property quite difficult. For any fire that the occupant cannot extinguish easily and quickly, total loss of contents can be anticipated unless attention to firesafety is a part of building design.

VIII. Continued Use Protection.

Relatively little structural damage would be expected in a major fire in an earth-covered building. The owner could redecorate, purchase new contents, and reuse the structure. Permanent structural damage, other than doors, windows, and partitions, should be minimal.

A Note on Thermal Radiation From Nuclear Explosions[3]

As radiation is being released by a nuclear detonation, x-rays are absorbed by the adjacent air to form a fireball which radiates a significant portion of its energy as infrared radiation and visible light. This pulse of radiation may last as briefly as twenty seconds for a five-megaton blast. The pulse is observably double peaked, with a brief flash interrupted by the formation of the blast shock wave, after which the pulse quickly peaks and gradually dies away.

The thermal radiation pulse contains a sufficient energy flux to: 1) cause fatal burns on unprotected persons who are in areas which are minimally affected by blast or gamma radiation, 2) ignite trash and dry vegetation adjacent to combustible exterior building components, and 3) pass through unshielded glass to ignite interior combustibles. Opaque surfaces provide effective shielding from thermal radiation for objects or persons behind them. No appreciable time elapses between detonation and arrival of the thermal pulse, thus effective protection must be in place at the time of blast.

Many materials capable of thermal radiation shielding may absorb sufficient energy to ignite. Fires thus caused are a primary post-blast hazard despite the fact that many such fires are extinguished or reduced to smoldering by the subsequent passage of the blast winds.

Earth-covered buildings are less affected by the thermal pulse of a nuclear blast than conventional construction because of their high external mass and minimal exposure of building materials. In addition, earth-covered buildings are less likely to be damaged by fires induced by thermal radiation because interior spaces are isolated from external fire and there are few aperatures for radiation penetration. Moreover, all buildings of reinforced concrete have an inherent resistance to fire.

The earth mass which surrounds most earth-covered structures can absorb large quantities of energy, including thermal energy, usually with little distress beyond the loss of surface vegetation. Unlike conventional construction, which presents a large surface area to external thermal radiation, earth-covered buildings expose a limited surface, thus fire defense is less demanding. An exterior fire caused by thermal radiation will not spread to the interior spaces of an earth-covered building as easily as in conventional construction because of usually tough and noncombustible structural shells, protection of the earth, and limited openings.

The low profile of most earth-covered buildings and the limited use of glazing tends to form a limited aperature of vulnerability to radiation penetration. This can be enhanced by orienting building glazing or windows away from probable blast origins burst points, if they can be reasonably assumed. Thermal radiation can be further excluded from interior spaces by closing metallic blinds or glass fiber curtains.

Conclusions

Some earth-covered buildings can pose a significantly greater fire risk than some conventional buildings. If fire protection is to be left to an adaption of current building codes, we should anticipate high losses both in people and in personal property from those designs. However, attention to firesafety in the design stage can make earth-covered buildings no greater a risk than conventional buildings and houses in these two of the three components of the loss concern. Indeed, some designs potentially could perform well from the point of view of fire egress, for instance, in dwelling designs where each habitable space (bedrooms and living areas) has direct egress to the outside.[2]

The major concerns of firesafety involve the time available for escape, architectural spatial patterns, and the ability of a fire department to be effective in suppressing a fire. Some designs of earth-covered buildings and houses pose serious problems in these regards. In addition, fire detection will require attention in design, particularly regarding type, reliability, and placement of the devices. On the other hand, earth-covered dwellings generally appear to have less fuel for fire than many conventional dwellings because of the usual concrete shell. Also, they can be difficult to ignite from the outside. Structural failures from fire should be far less, and means of egress can be exceptionally good. In the final analysis, concern for firesafety in the design stage of any building is required for firesafety performance, earth-covered buildings no less than others.

Property protection from fire loss is the dominate concern in fire codes. That fact, coupled with the natural protection from fire damage (particularly the buildings themselves) which most earth-covered buildings provide, results in less threat of property loss. Thus, in the component of fire loss concerns, the building itself, earth-covered buildings should perform exceptionally well.

Proper firesafety design for any building, earth-covered building no less, requires careful attention to emergency access and egress, smoke evacuation, ventilation, fire fuel reduction and isolation, suppression systems, and so on. High-rise buildings present their special problems, double-loaded corridors in low-rise buildings have their problems, frame buildings theirs, and earth-covered buildings theirs. In particular, large multistory buildings that are below grade can make emergency fire service with personnel most difficult if access to the lower floors is not available through smoke- and fire-free pathways. Also, use of earth completely around a building can make emergency access from the perimeter essentially impossible. Similarly, complete earth cover can present access problems. It is important, therefore, that the location, isolation, limitation and suppression of fire fuels within earth-covered buildings be well considered. While this is not a requisite peculiar to earth-covered buildings, it is always a substantial area for concern.

Summary

Earth-covered buildings should have superiod performance from threat of fire property losses because of reduced exposure. Moreover, the potential for earth-covered construction for lifesafety performance is exceptionally good, but safety engineering must be included in the design.[4]

Footnotes:

1. "Fire within the man-made environment (in the U.S.A.) is an $11.4 billion problem that claims 12,000 lives annually. The problem is particularly severe in housing, which accounts for approximately 70 percent of the annual one million building fires, between 85 and 90 percent of all fire deaths, and approximately 40 percent of all property losses," from Schodek, David L., "Fire In Housing: Research on Building Regulations and Technology," Working Paper Number 38, January 1976, Joint Center for Urban Studies of MIT and Havard.

   Professor Fitzgerald has noted that more recent estimates of lives lost in fires conclude 7500 may be true currently, but the categories of loss remain the same.

2. See also, Michael Muson (Princeton), "Fire Safety Characteristics of Earth-Covered Dwellings", in The Use of Earth-Covered Buildings, Moreland, editor, National Science Foundation, 1976.

3. Thomas Carroll and Moreland Associates prepared the section on fires caused by nuclear explosions.

4. Robert W. Fitzgerald, Professor, Worcester Polytechnic Institute, statement used by permission.

NUCLEAR RADIATION

Introduction

Three types of radiation are explored in this part: 1) initial radiation from a nuclear explosion, 2) radioactive fallout resulting from a nuclear explosion, and 3) radioactive elements common in the environment and human settlements. In each case, we explore how earth-covered buildings can reduce radiation hazards to inhabitants.

Initial Nuclear Radiation

The detonation of a nuclear device unleashes large amounts of initial nuclear radiation, composed primarily of gamma radiation and neutrons in megaton blasts, with neutrons becoming an increasingly important effect in smaller (kiloton) blasts. Because of atmospheric radiation attenuation, hazardous levels of initial nuclear radiation are confined to a three-mile radius of the detonation point. This holds true for large nuclear devices and decreases in radius only slightly with smaller weapon yields.

Figure 1 gives an indication of the relationship between air-blast overpressure and initial radiation for different weapon yields. For the 5 psi and 12 psi air-blast-overpressure levels, where moderate-to-severe blast damage to buildings is likely, the radiation exposure ranges from negligible to 10,000 REM. In low-kiloton yield weapons, initial nuclear radiation can become significant, perhaps controlling. For example, in the design of reinforced concrete in shelter spaces, the ratio of reinforcing steel to concrete may be very low so that extra concrete mass is available for radiation shielding at a given overpressure-resistance level.

Initial Nuclear Radiation as a Function of Surface Burst Weapon Yield and Overpressure		
Weapon Yield Blast Magnitude	Over Pressure PSI	Initial Nuclear Radiation (REM)
40 Kiloton	5	560
	12	10,000
	20	34,000
100 Kiloton	5	170
	12	5,500
	20	23,000
1 Megaton	5	---
	12	280
	20	3,600
Source: DCPA Attack Environment Manual, Chapter 5		

FIGURE 1

In comparison to fallout, initial nuclear radiation is a relatively brief phenomenon. According to DCPA:

> Initial nuclear radiation has been somewhat arbitrarily defined as that nuclear radiation emitted during the first minute following the detonation of a nuclear weapon. This time interval was initially chosen on the basis that by one minute the rising fireball and nuclear cloud would be too remote from the earth's surface to cause any significant effects. Actually, the main exposure to initial radiation occurs in a much shorter time.[2]

Moreover, initial nuclear radiation emanates from a single source rather than from an infinite horizontal plane (as assumed in fallout analysis). Initial nuclear radiation mitigation is less stressed in public literature than fallout protection. Again quoting DCPA "...initial nuclear radiation does not appear to be an important threat to life so long as large weapons ... constitute the major threat."[3] In the case of multiple small nuclear detonations, initial nuclear radiation becomes a major hazard. This hazard is especially significant in that most conventional buildings provide little shielding from initial nuclear radiation, just as they do for fallout.

Attenuation of initial nuclear gamma radiation is a function of mass, but neutron attenuation is a function of type of material as wells as mass. The atmosphere will attenuate nuclear radiation, but only over distances in the radius of thousands of feet. Building materials, such as those listed in Figure 2, provide various levels of radiation attenuation. It is obvious that radiation mitigation levels are related to the design and construction of buildings.

Earth-covered buildings provide shielding of occupants from initial nuclear radiation because their mass is made up of concrete and earth, both particularly effective against neutrons. Moreover, reduced openings are available for radiation penetration. The shielding effect of relatively small amounts of earth cover can be seen in Figure 2. In comparison, most conventional construction has much less mass to attenuate initial nuclear radiation and more apertures for radiation penetration. Therefore, under similar blast levels, earth-covered buildings can provide increased mitigation of initial nuclear and thermal radiation, as well as blast effects.

INITIAL NUCLEAR GAMMA RADIATION DOSAGE VS BUILDING SECTIONS			
Building Section	Weight PSF	Barrier Factor[1]	Dose (REM)[2]
Outdoors	0	1.0	8,000
Double-glazed window	2	.95	7,600
Brick veneer w/stud wall	45	.35	2,800
10" concrete wall	125	.055	440
Shingle roof	7	.85	6,800
Concrete roof[3] with 8" soil	146	.035	280
Concrete roof[3] with 18" soil	230	.006	48
Concrete roof[3] with 36" soil	380	.0003	3

Notes:

1. Barrier factor is the fraction of total initial radiation that is unshielded, that is, it passes through the material.
2. Dosage at a hypothetical point 2 miles from the detonation of a 40 kiloton contact surface burst. (10 psi ± overpressure).
3. 8" concrete hollow core plant with 2" concrete topping.

Source: Adapted from DCPA Attack Environment Manual, Chapter 6, DCPA TR-85, Building Design for Radiation Shielding Thermal Efficiency, 1977, pp. 25.

FIGURE 2

Both thermal and initial nuclear neutron radiation emanate from the detonation at similar speeds beginning at approximately the same time. Thermal radiation mitigation is applicable to initial nuclear radiation, including the topics of earth mass, low above-ground building profile, and few apertures. Initial nuclear radiation, however, is not attenuated by the opaque but very lightweight shielding used in thermal radiation mitigation.

Windows are a weak point for radiation penetration in many building types, including earth-covered. Window placement is critical to occupant radiation shielding, thus, initial nuclear radiation mitigation is design specific. Some general statements can be made, however, in regard to earth-covered building performance.

In many locations, probable blast origins can reasonably be assumed. One design alternative would then be to orient windows away from these probable critical radiation hazards. For earth-covered buildings in non-specific target areas and with windows on one side, the probability of initial radiation penetration is reduced to one-fourth of that in most other types of construction. Earth-covered buildings with windows oriented toward a central atrium will tend to be mutually shielded unless the burst height point is sufficient to "see" into the atrium. An example is shown in Figure 3.

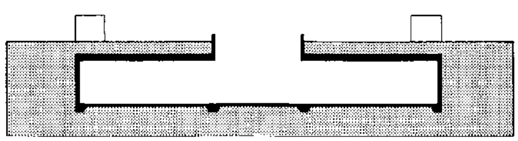


FIGURE 3 Cross Section through Hypothetical Earth-Covered Building

Earth-covered buildings with substantial areas of window glass may provide adequate shielding in all directions only if a radiation-hardened (high-mass) space is provided within the building.

Institutional-sized earth-covered buildings may provide high levels of initial nuclear radiation attenuation because of interior spaces remote from windows and entrances. Windows and entrances will probably be found on several sides.

The initial nuclear radiation possible from an air burst entering through skylights will be small unless the building is in the immediate area of the detonation, in which case blast effects would control design.

Emergency hardening of an earth-covered building for initial nuclear radiation can be achieved by shielding windows and entrances with temporary mass, such as sandbags. The shielding will remain intact long enough to provide radiation alternation, even if it is subsequently knocked down by the arrival of the air-blast overpressure or ground shock. Moreover, as opposed to fallout protection, initial nuclear radiation shielding is only necessary for less than one minute. Crouching behind a massive barrier could provide protection in many cases.

According to Carroll, a small hardened space, perhaps a laundry or storage room in a windowless corner, can offer a high level of occupant safety.[3]

Fallout

Fallout is the most pervasive nuclear-blast related hazard in terms of geographic area and population. According to a 1973 Defense Civil Preparedness Agency projection, for a full-scale attack, "Almost the whole (U.S.) population would be located less than 100 miles from at least one nuclear detonation."[4] One-half the population would experience some blast effects. The effects of fallout on the U.S. population during the first week, assuming shelter with selected overall protection factor (PF), are shown in Figure 1.

Distribution of Radiation Sickness Levels In the U.S. Population As A Function Of Available Shelter Protection Factor				
Radiation Sickness Levels	Selected Protection Factor			
	PF=2	PF=10	PF=40	PF=100
Negligible	20%	75%	85%	98%
Need Medical Care	42%	20%	14%	2%
Minimum Probable Deaths	38%	5%	1%	---
Note: Sickness levels are based on a one-week exposure to fallout radiation after a large nuclear attack and do not include injury from other blast-related effects or subsequent fallout radiation exposure.				
Source: Adapted from DCPA Attack Environment Manual, Defense Cicil Preparedness Agency, Chapters 1 and 13, Chapter 6, Panels 15 and 20.				

FIGURE 1

Clearly fallout protection available to a population is an important factor in survival. Other countries, including China, Sweden, Switzerland and Russia, have given shelter design and construction a high priority.[5]

Fallout is essentially fused soil particles, 50 to 2000 microns in diameter, which contain trace (.1 parts per million) fission products. The primary radiation from fallout is gamma radiation, which decays about tenfold for every sevenfold increase in time during the first two weeks, and at a faster rate beyond two weeks. Gamma radiation can be attenuated by mass, but it will travel many hundreds of feet in air with negligible attenuation. Gamma radiation (from an energy spectrum appropriate for early fallout particles) is the major focus of this section. Beta and alpha particles, also emitted by fallout, are attenuated by very little mass and travel only short distances, in the order of 10 feet, through the air.

The visible mushroom cloud from a surface nuclear weapon detonation contains fallout particles. These particles are formed as a consequence of the fireball contacting the earth, and they are dispersed by prevailing winds. The particles are precipitated by gravity, and return to the earth after a period lasting from 20 minutes to many days or weeks after detonation. According to wind speed and direction, fallout will spread out over several hundred square miles with a detectable gradient of accumulation density, that is, edge or fringe areas will have nonlethal doses, and a limited area near the detonation point will have dose rates that exceed tolerable levels in less than one hour. Fallout will not itself make other materials radioactive; however, surfaces on which fallout particles accumulate are said to be contaminated. A visible accumulation of fallout particles is indicative of a significant hazard.

A building protection factor, PF, is an indication of the relative safety of a location, and is the summation of the radiation attenuation potential of a specified location with reference to the dose on a flat uniformly contaminated smooth plane. Actual dose rates are usually lower than the theoretical. For example, fallout particle accumulation on rough ground surfaces has a PF of 2.5 from the roughness alone; that is, the gamma radiation hazard is only 50%. Gamma radiation emitted by fallout particles is attenuated by mass, with the relationship being exponential, a doubling of mass more than doubling radiation attenuation. Thus the mass in a building envelope, intermediate partitions, and the geometry of window placement determine PF. Spaces which commonly provide a high PF are subways, basement spaces, and interior rooms on floors around the midheights of tall buildings. The latter provides fallout protection by being remote from the two principal planes of contamination (the ground and roof).

Earth-Covered Buildings and Fallout

Earth-covered buildings can provide significant attenuation of fallout radiation, in comparison to conventional construction, by use of envelope mass and small areas of windows and entrances. Earth-covered buildings present greater mass in most configurations than do conventional residences or institutional structures, according to Figure 2.

Increasing mass has an expotential effect on nuclear radiation attenuation. For instance, the 10-inch concrete wall and the concrete roof with 18 inches of earth cover--an extra 100 pounds of mass--reduces the nonattenuated radiation by a factor of 10. The

FALLOUT RADIATION DOSAGE VS BUILDING SECTIONS			
Building Section	Weight psf	Barrier Factor[1]	Dose (REM)
Outdoors	0	1.0	11,000[2]
Double-glazed window	2	.95	10,830
Brick veneer w/stud wall	45	.35	3,990
10" concrete wall	125	.055	627
Shingle roof	7	.85	9,690
Concrete roof[3] with 8" soil	146	.035	398
Concrete roof[3] with 18" soil	230	.006	68
Concrete roof[3] with 36" soil	380	.0003	4

Notes:

1. Barrier factor is the fraction of total fallout radiation which passes through a material.
2. One week dosage at a hypothetical point 30 miles downwind (15 mph) of a 5 megaton surface burst if shielded by specific materials.
3. 8" concrete hollow-core plank with 2" concrete topping.

Source: DCPA Attack Environment Manual, Chapter 6, Panel 15. DCPA TR-85, Building Design for Radiation Shielding Thermal Efficiency, 1977, pp. 25.

FIGURE 2

barrier factor of windows indicates that spaces which have a good daylighting potential provide less protection against fallout. Many earth-covered buildings have windows in primary spaces for daylighting and views, but also have spaces which are well shielded or easily shielded. Earth-covered institutional structures, because of increased areas remote from windows, provide high-quality fallout shelter. An estimate by Moreland Associates of typical building blast resistance and PF range is given in Figure 3.

BUILDING BLAST AND FALLOUT ATTENUATION RANGES		
Building Type	Relative Blast Vulnerability	Approximate PF Range
Residential abovegrade	Severe	1.5 - 4
Residential basement	Moderate	4 - 20
Institutional abovegrade	Moderate	10 - 60
Institutional basement	Moderate-light	20 - 150
Earth-covered residential	Moderate-light	10 - 100
Earth-covered institutional	Moderate-light	20 - 200

FIGURE 3

In the brief period between a distant nuclear detonation and the arrival of downwind fallout, building occupants can harden a space to a higher PF by placing sand bags part way up a window wall so that contaminated surfaces within approximately 200 feet cannot "see" the occupied shelter space.[8]

The profile of a building will have some effect on the level of incident radiation. Primary radiation sources for an earth-covered building are fallout particles on the earth cover and on surfaces which view the shelter space through windows, entrances, and skylights. Areas shielded by earth masses should have a 50-100PF range, while interior locations which can directly view the contaminated exterior plane have a PF closer to 10. Sloping exterior surfaces downward away from windows, as well as baffling entrances or installing temporary radiation barriers adjacent to windows and doors, will increase the interior PF to the 25-80 range.[9]

Fallout radiation contributed by skylights is primarily a result of the fallout which collects on the skylight itself. Thus, areas below the skylights will be less acceptable than most areas remote from skylights. Periodic cleansing of the skylight by broom or water spray will, however, dramatically reduce the hazard. Large skylights and atriums pose a special fallout radiation hazard. An atrium or damaged skylight will allow fallout to collect within a building, and according to the quantity, the PF of nearby spaces can be lowered unless they are shielded. Repairs to damaged skylights may be more effective than similar time spent on damaged window areas.

A Note

As background for this report, Thomas Carroll estimated the protection factor provided by several configurations of earth-covered dwellings and institutional-sized buildings. Each structure was assumed to contain a designated shelter area (separated by a 60 lb. per square foot barrier wall). Calculations have been made for locations both inside and outside the shelter. The figures represent the results.

With respect to each of the buildings, the protection factor assumes a worst-case situation, i.e., that nothing can or will be done by the occupants to remove fallout, or otherwise upgrade the shelter area. Decontamination of affected surfaces by removal of fallout particles or covering of particles with soil would improve the building protection factor significantly. Fallout particle radiation contribution is primarily through windows, entrances, and skylights (which have collected fallout particles). In the atrium configuration, particles in the atrium are comparable to the contribution through non-atrium windows. According to Carroll, decontamination activities would likely be worth any radiation penalty imposed. In addition, some or all work involved in shielding windows and entrances with extra mass could be undertaken before the arrival of fallout.

The calculations assume little or no blast-related damage, although one might speculate that, short of structural collapse, these buildings would loose little of their initial protection factor. This characteristic would be especially useful in areas of moderate blast-damage probability. In some cases, essential people could be given shelter close to their respective post-blast work areas, thus reducing transportation requirements and improving productivity.

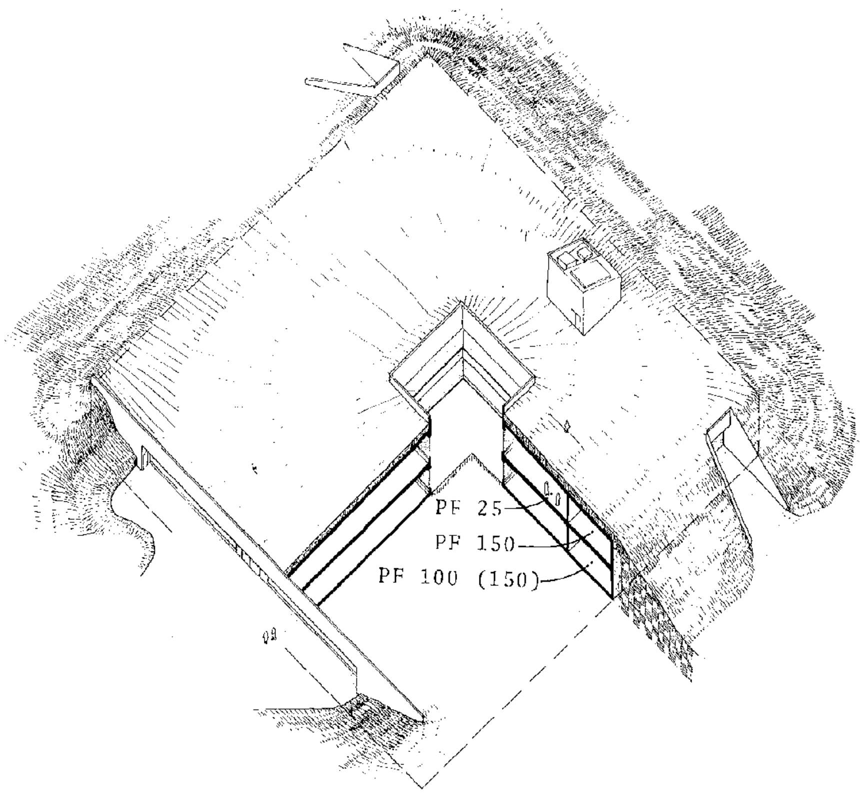


FIGURE 1 Two Level Institutional Sized Building
( ) indicates probable PF after
decontamination of atrium

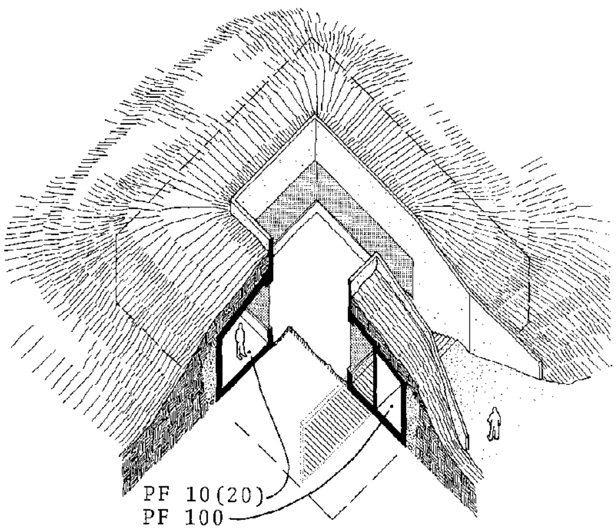


FIGURE 2 Atrium Dwelling
( ) represents probable
PF after decontamination
of the atrium

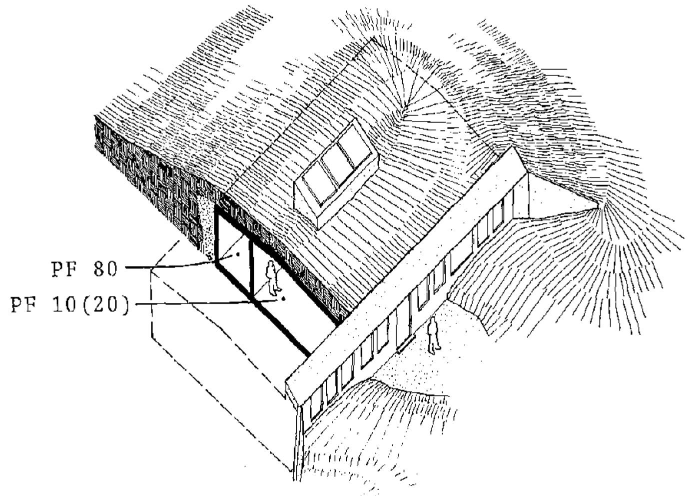


FIGURE 3 Single Window-Wall Dwelling
( ) represents probable PF
after exterior shielding added

Radon

> The element radon is a noble gas which has three naturally occurring isotopes with mass numbers of 219, 220, and 222. All three are radioactive and have short halflives ...The three radon isotopes (or progeny) occur in nature as intermediate decay products in the three radioactive series headed by the long-lived primordial radionuclides ...[10]
>
> R. Colle

The occurrence of radon in buildings has been of scientific interest the past few years, perhaps more noteable at the National Bureau of Standards and at the Lawrence Berkeley (LBL) and Oak Ridge Labs. Radon in Buildings,[11] an NBS publication, several publications from LBL,[12] and consultants' review constitute the basis for this part. For a detailed analysis of radon as a phenomenon, please review the citations. The following extensive quotation summarizes the field:

> For a given radon input into a structure the radon and progeny concentrations[13] in that structure are highly dependent upon the ventilation and infiltration (henceforth called ventilation) rates within that structure as shown in Figure 1. The magnitude of these rates is a function of wind speed, pressure difference between inside and outside, type of construction, workmanship, condition of the building and the activities of the occupants.
>
> The most common method of determining ventilation rate is by releasing a tracer gas into the structure and measuring its concentration as a function of time. A literature survey of published data was performed by Handley and Barton. They found the average

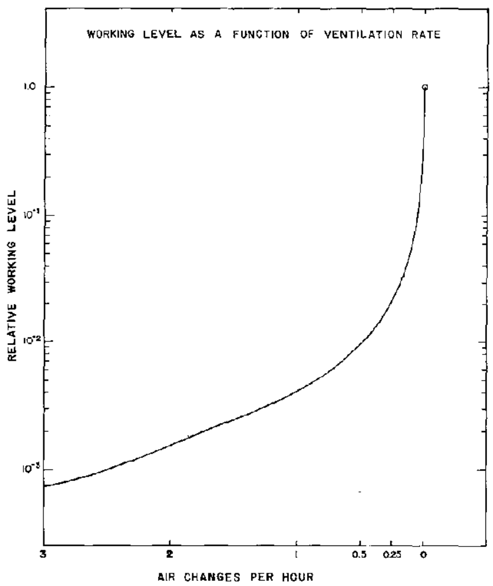


FIGURE 1 Working Level of Radon Daughters as a Function of Ventilation Rate

annual ventilation rate of most occupied single-family houses falls in the range 0.5 to 1.5 air changes per hour.

Ventilation measurements made in a modern test house, constructed to minimize infiltration, indicate ventilation rates from 0.22 to 0.4 air changes per hour, depending on wind speed (Haywood, et al). The test house was unoccupied; however, utility usage was simulated. Other unpublished measurements on similarly constructed "energy-conservative" houses indicate ventilation rates of from 0.1 to 0.2 air changes per hour.

Occupancy factors must not be ignored when making ventilation measurements or in using some published value for calculation purposes. For example, in a test house in Florida, the central air-conditioning fan was allowed to operate continuously for three hours. There was a subsequent reduction in working level by a factor of ten and a reduction in radon by a factor of five from that, of a closed, unoccupied condition. This represented an effective ventilation rate change from 0.5 to 2.5 air changes per hour.

A study funded by the Colorado Department of Health evaluated radon progeny control measures including dilution by ventilation, air cleaning with HEPA filters and air cleaning by electrostatic precipitation (Carr, et al). This report concluded that dilution by ventilation provides the most cost-effective method for radon progeny reduction, closely followed by elastrostatic precipitation.

This paper has attempted to review the literature on the factors that affect the radon and progeny levels in structures. Although a seemingly large volume of data is available on this subject, it falls far short of being sufficient, in this author's opinion. We know only in a qualitative sense the deterministic factors affecting these levels. We are not able to answer the principal question: "What will be the radon progeny concentration in a structure constructed of given materials, in a given manner on a known location?"[14]

Phillips, Windham, Broadway

Radon is a gas that occurs naturally in the environment, often coming from solid materials such as rock. Once airborne, radon at high levels makes use of any building a problem. All soils and rocks contain radon in varying concentrations. Just as there are some soils on which conventional buildings should not be built because of radon buds there are also soils into which earth-covered buildings should not be built. It it likely that there are more soils contraindicated for earth-covered buildings because of radon concerns than there are for conventional construction, at least for some designs, but more testing is needed for accurate evaluation.

Radon from building materials and radon from the earth can accumulate to dangerous levels in buildings unless adequate ventilation with outside air is provided, given that the outside air has only normal amounts of radon. Ventilation dilutes radon accumulations and sweeps radon out. As ventilation causes outside air to move through a building, it also introduces outside pollutants as well as air requiring thermal tempering. Thus, the level of ventilation required is important to the design of earth-covered buildings and all energy-efficient buildings. The following quote summarizes the issues:

> The problem of indoor air pollution is just beginning to receive the attention that it requires. Such pollution exposes itself in the form of short term and long term human health problems. Pollutants under examination include, but are not limited to: CO, NO, NO_2, CO_2, ozone, aldehydes, lead, and radon with daughter products. Presently, controlled ventilation is the only acceptable residential method of minimizing such pollutants in the indoor environment, assuming that the outdoor air quality is better than the indoor air quality. It appears that 12 total air changes per day (.5 ACH) can keep indoor pollutants below critical long term exposure levels.[15]
>
> Martin R. Lunde

Passive means of providing positive draft for ventilation are often old and generally well known, such as the thermal and wind chimneys of ancient Iran. Many recent earth-covered buildings have used modern versions of these.[16] Figure 2 is a sketch of one.

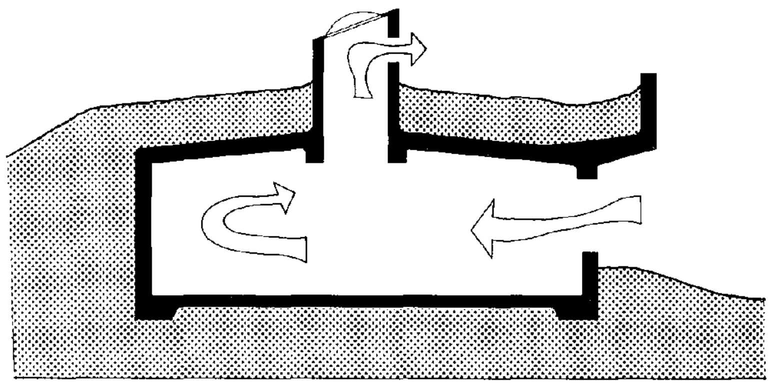


FIGURE 2 Cross Section Through a Thermal Chimney in an Earth-Covered Dwelling

The following quote summarizes the magnitude of Radon hazard in earth-covered buildings:

> The limited data on earth-sheltered structures suggests that radon levels in well-constructed earth-shielded homes are not significantly higher than those reported for conventionally constructed (i.e., above-ground) houses. However, architects and engineers involved in design and construction of earth-sheltered structures--as well as other energy-conserving buildings with relatively low air exchange rates--must design these structures so as to minimize the exposure of their occupants to possible sources of harmful radiation effects.[17]
>
> Harold May

Radiation Summary Statements

Initial Nuclear Radiation

In earth-covered buildings, earth mass and limited windowed or glazed areas tend to provide significant attenuation of initial nuclear radiation. Although window areas are always a weak point for radiation penetration, earth-covered buildings have compensating beneficial characteristics including: 1) reduced possibility of glazing facing a blast origin, 2) substantial self-shielding in several earth-covered building designs, and 3) a high probability of safety in spaces remote from windows and entrances, especially in institutional-sized earth-covered buildings.

Emergency hardening for initial nuclear radiation is compatible with mitigation of other blast effects. Because initial nuclear radiation is a short-term phenomenon, only temporary shielding is required rather than the more stringent requirements imposed for fallout protection for occupant-related shelters. In most cases, increased hazard mitigation is associated with the availability of an interior, radiation-and-blast-hardened space. Thus, earth-covered buildings can provide attenuation of the initial nuclear radiation that emanates from nuclear explosions.

Fallout

Earth-covered buildings can provide significant attenuation of fallout radiation as a result of their earth mass and limited area of windows. Earth-covered buildings provide sufficient mass in most configurations to reduce fallout radiation by a factor of 25 to 200. Institutional-sized earth-covered buildings, because of the high probability of finding spaces remote from entrances and glazing, may provide a higher level of fallout protection than an average earth-covered dwelling.

Short-term upgrading of the building Protection Factor, by adding mass to window areas and entrances, is possible in many earth-covered building configurations. Specific zones of increased fallout safety within earth-covered buildings appear to be a reasonable design strategy. This is especially true in view of the overall blast-effects resistance of earth-covered buildings. Thus, high levels of fallout protection are easily attainable in most earth-covered buildings.

Radon

Radon is a concern for all buildings, including earth-covered ones. If the soil around a building contains radon, care must be taken that it does not leak into the building. Also, any radon from building materials must be removed. Ventilation adequate for ordinary air quality is usually adequate for radon control, and there are efficient and cost-effective means of providing such ventilation for all buildings. Nevertheless, radon evaluation is an important consideration for earth-covered buildings.

Footnotes:

1. DCPA Attack Environment Manual, Chapter 5, Panel 8, Defense Civil Preparedness Agency, 1973.

2. Ibid.

3. Personal correspondence with Thomas P. Carroll of Carroll Associates, Consulting Engineers, Bethesda, Maryland, 1980.

4. DCPA Attack Environment Manual, Chapter 1, Defense Civil Preparedness Agency, 1973.

5. Walter Murphey has written:

   > Today, Switzerland's cornerstone of defense is the development of subsurface shelter against nuclear attack. For instance, Switzerland has more hospital beds per capita underground than the U.S. has per capita aboveground. Switzerland does not accept the view that preparedness is useless or provocative.
   >
   > The U.S. neglected civil defense: the Soviets did not. Evidence that the Soviet Union has persevered in building a total civil defense since the Second World War abounds in Soviet publications and in Western analyses.

   Walter Murphey, "Civil Defense: A 1981 Appraisal", Underground Space, Vol. 5, No. 6, pp. 356, 1981.

6. Effects of Nuclear Weapons, Revised Edition 1964, Edited by Glasstone, Government Printing Office.

7. DCPA Attack Environment Manual, Chapter 6, Panel 16, Defense Civil Preparedness Agency, 1973.

8. Correspondence with Thomas Carroll.

9. Correspondence with Thomas Carroll.

10. R. Colle, The Physics and Interaction Properties of Radon and Its Progeny, in Radon in Buildings, edited by R. Colle and Preston E. McNall, Jr., National Bureau of Standards, June 1980.

11. DCPA Attack Environment Manual, Chapter 5, Panel 8, Defense Civil Preparedness Agency, 1973.

12. C. D. Hollowell and others, *Impact of Energy Conservation in Buildings on Health*, Lawrence Berkeley Laboratory, 1979.

    Jeffrey Kessel, "Building Ventilation and Indoor Air Quality Program," in *Energy and Environment Division Annual Report 1978*, Lawrence Berkeley Laboratory, 1979.

    J. V. Beck and others, *The Effects of Energy Efficient Ventilation Rates on Indoor Air Quality at a California High School*, Lawrence Berkeley Laboratory, 1979.

    Harold May, "Ionizing Radiation Levels in Energy-Conserving Structures" in *Underground Space*, Vol. 5, 1981.

13. One measure of radon concentration is "working level" as defined in *Radon in Buildings* and depicted in Figure 1 of this section.

14. C. R. Phillips, S. T. Windham, and J. A. Broadway, "Radon and Radon Daughters in Buildings: A Survey of Past Experience," in *Radon In Buildings*, Edited by R. Colle, National Bureau of Standards, 1980.

15. Martin R. Lunde, "Interfacing Residential HVAC Systems With Earth Sheltered Construction," presented at the Underground Space Conference and Exposition, Kansas City, June 1981.

16. See Henryk Orlowski, "Thermal Chimneys and Natural Ventilation", in *Earth Covered Buildings: Technical Notes*, Ed. Moreland, Higgs, Shih, Department of Energy, 1979.

17. Harold May, "Ionizing Radiation Levels in Energy-Conserving Structures," in *Underground Space*, Vol. 5, 1981, p. 384.

Additional Readings:

Nero, A. V., Airborne Radionuclides and Radiation in Buildings, Berkeley, Lawrence Berkeley Laboratory, LBL-12948, 1981

Nero, A. V., Indoor Radiation Exposures from Radon and Its Daughters: A View of the Issue, Berkeley, Lawrence Berkeley Laboratory, LBL-70525, 1981.

Nataroff, W. W. and others, "The Use of Mechanical Ventilation with Heat Recovery for Controlling Radon and Radon Daughter Concentrations in Houses," in Atmospheric Environment, Vol. 15, pp. 263-270, 1981.

SUMMARY

The performance of earth-covered buildings and dwellings has been explored with relation to several broad categories of hazards including storms, earthquake and blast, fire, and radiation. Flood--certainly a serious hazard condition--deserves comment in this section even though flood hazards and the performance of earth-covered buildings are crucially dependant on design.

Flood

The flood-protection potential of earth-covered buildings is very particular to building and land-form design, the geometric character of the flood basin, soil characteristics, and so many other considerations that no general statement can be made about the relative safety of earth-covered buildings in a flood. Although many kinds of earth-covered buildings would suffer less physical damage than conventional buildings, their relative safety depends on too many variables for a blanket conclusion. Some earth-covered building designs (Figures 1 and 2), however, would fare at least as well as conventional buildings would under raging, swift-water flooding conditions because of the protection of the earth mass to the sides of bermed, earth-covered buildings. Safety for both earth-covered buildings and conventional buildings depends on an early warning system. Because of warning limitations down river from major dams, they might be early candidates for earth-covered developments designed for expected flooding conditions.

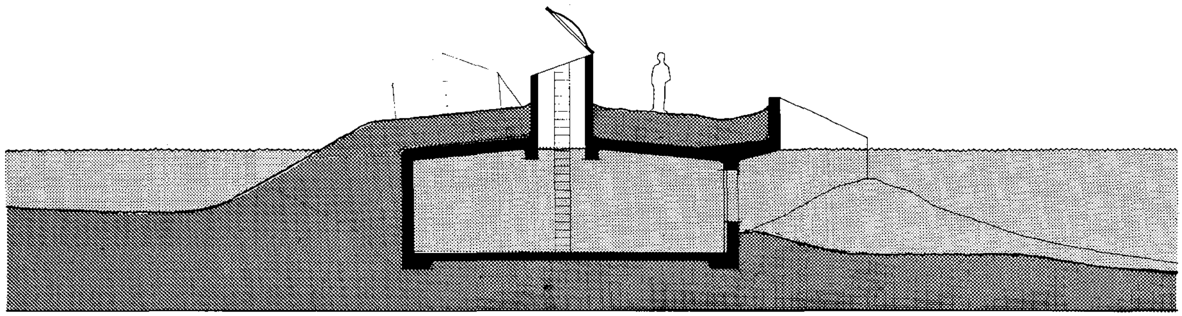


FIGURE 1 Cross Section of Earth-Covered Dwelling Under Flood Conditions.

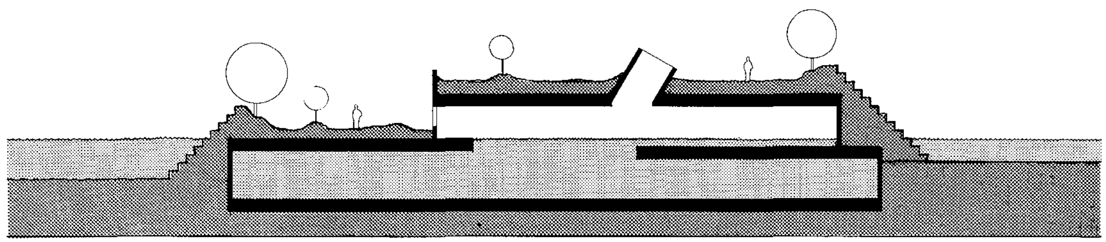


FIGURE 2 Cross Section of Earth-Covered School Under Flood Conditions

Storms

Tornadoes, which have the most violent characteristics of storms, cause damage primarily because of the air-pressure stress imposed on structures and because of flying debris generated by high speed and turbulent winds. The earth mass and structure of most earth-covered buildings can absorb large impact loads. The generally low profile of earth-covered buildings is more likely to deflect than resist wind-generated forces. The building's structural toughness and the stability of earth masses combine to resist the buffeting of abrupt air pressure changes. The general characteristics of tornadoes suggest that damage from wind and flying debris is reduced if major window areas are oriented away from the south and southwest. Moreover, the provision for a shelter space within earth-covered buildings offers an exceptionally high degree of protection from storm effects. Indeed, earth-covered buildings are being used in increasing numbers in areas of high storm damage probability.

Hurricanes, which are less turbulent if longer lasting than tornadoes, would likely cause far less damage to earth-covered buildings than to conventional buildings. The flooding which often accompanies such storms is likely to be less destructive to earth-covered buildings. Hail damage, which can result in significant damage to conventional buildings, will have little or no effect on earth-covered buildings.

Earthquake and Blast

Violent shaking, as well as the high pressure and temperature stresses which accompany blast, can cause the collapse of buildings. Some of the approaches to earth-covered buildings examined in this study, however, would likely fare better under many earthquake and blast conditions than would conventional structures. Slanting of structures for blast resistance, either during construction or as a temporary hardening, can result in significant levels of shelter safety. Earth-covered buildings effectively absorb and distribute blast-related stresses, offer minimal resistance to airblast overpressure, and are resistant to blast-generated flying debris.

Fire

Some approaches to earth-covered buildings can pose problems for firefighters and occupants because fires spread upward through openings. This is especially true in large multilevel earth-covered buildings. However, most earth-covered buildings can, with the application of firesafty engineering, be designed to provide convenient and safe exits for occupants and access for fire-control personnel and equipment, as many examples show.

In addition, earth-covered buildings are for the most part very fire resistant because of the use of reinforced concrete structures. Moreover, earth-covered buildings can be difficult to ignite from the outside because of the reduced area of exposure and because the structural shell forms an effective barrier to the migratio of fire into or out of an earth-covered building.

Nuclear Radiation

Nuclear radiation associated with fallout particles and the emissions from a nuclear burst have several properties of particular interest in building design: first, they travel in straight lines, do not ricochet much (but may change direction when passing through a mass), and second, nuclear radiation is effectively absorbed by the combination of reinforced concrete and earth mass characteristic in earth-covered building construction. Earth-covered buildings have great potential for providing high-quality shelter from both initial nuclear radiation and fallout particle radiation. This is particularly true if openings and earth cover are properly designed or if a temporary hardening of the building is carried out.

Radiation hazard from radon accumulation in earth-covered buildings is not markedly different from that of any other type of building. Ventilation adequate for air-quality control is usually adequate for radon control and is easily provided in most earth-covered buildings.

Earth-covered buildings have been shown to be generally high in hazard performance, with the comments noted. Societal costs for this improved performance appear to be especially moderate. Earth-covered buildings are an exceptionally tough and adaptable form of construction. Additional research and improvements can lead to further reductions in loss of life and property in most hazard situations.

PART III ENERGY ANALYSIS

ENERGY ANALYSIS

> We now find ourselves faced with the startling fact that our buildings alone consume about twice the electricity that was used twenty-five years ago for all purposes.
>
> Taking every aspect into account, buildings are responsible for over 40 percent of the energy used in the United States. The greater part of this usage is predetermined by architectural decisions. Energy is consumed in the complete process of making and assembling buildings' components, to operate the various systems during the useful life of buildings, in the transportation systems predetermined by decisions on how buildings are grouped together, and to demolish buildings or to dismantle the shells of buildings that have been destroyed in other ways.[1]
>
> Richard G. Stein

INTRODUCTION

In the last three decades there has been a fundamental shift in expected levels of thermal comfort in buildings. Until recently this was manifested in an increasing reliance on mechanical systems to alter ambiant conditions of light, temperature, air motion, and humidity. Serious questions regarding the energy required by such building systems remained largely unasked until the prices of energy increased and its future supply was in doubt.

Moreover, the implicit reliance on an uninterrupted energy supply, for even minimal habitability in many conventional buildings, places additional burdens on society in the event of power supply interruptions resulting from storms, earthquakes, flooding, fire, or nuclear blast. Not only are such buildings less appropriate as shelter in many instances, they can themselves become life-safety hazards, i.e., during severe weather conditions. The recovery from a natural or man-made disaster, depends on the distribution of scarce commodities. One of the primary shortfalls will be energy. Buildings with minimal demands or which are ammenable to service interruptions will be an advantage at such times.

The life cycle of buildings is long relative to most other energy consuming parts of the economy, thus current architectural design decisions will have an impact on future energy-use patterns. The introductory quote by Richard Stein focuses attention on the importance of energy consumption by buildings. According to the American Institute of Architects, the energy used to heat and cool, illuminate, and generate hot water in the United States residential and commercial sectors accounts for 15% and 10%, respectively, of all United States energy transactions, or 25% in total.[2] This agrees well with a Solar Energy Research Institute (SERI) study[3] which, after including refrigeration and cooking, estimates that buildings require almost one-third of all United States energy transactions.[4]

The energy embodied in buildings during their manufacture, a factor which is included in Stein's analysis, is more difficult to determine. A major portion of the industrial and commercial sectors is involved in construction, and Stein estimates that almost six percent of all energy transactions in 1967 were building-construction related.[5] A breakdown by building type is shown in Figure 1. The six-percent figure, when combined with the 33-percent figure from SERI for building-related

1967 Energy Embodiment Per Square Foot of Building					
	Total S.F. In Millions	Percent of Total	Total Energy Embodiment in Quads*	Percent of Total	Energy Embodiment (1000 BTU/ Sq. Foot
Residential	1443	54	1.343	35	708
Hotels - Dormitories	78	32	.127	4	1268
Industrial Buildings	364	13	.521	17	926
Office Buildings	158	6	.258	8	1641
Retail Buildings	250	9	.287	9	1008
Educational Buildings	204	7	.437	14	1386
Religious Buildings	41	1	.068	2	1257
Hospital	66	2	.117	4	1722
Libraries/Museums	18	1	.030	1	1744
Farm	NA	NA	.087	3	NA
Miscellaneous	72	3	.068	2	938

*Quads = 10^{15} BTU

Interpreted From: R.G. Stein, Atchitecture and Energy, Anchor Press, Garden City, New York, 1977, pp. 299

FIGURE 1

energy use, results in approximately 40 percent of all energy transactions in the United States accounted for by its building sector.

Changes in building-related energy use can have a significant impact on energy consumption in the United States. Earth-covered buildings have reduced requirements for energy, thus their widespread use could influence energy consumption. The specific nature of the variation in energy use and energy embodiment between conventional buildings and earth-covered buildings is discussed in the Energy Requirements section. Next, the compatibility of earth-covered buildings and solar energy use will be discussed. This is followed by a section on the peak energy demands of earth-covered buildings. Finally, changes in long-term energy consumption resulting from the introduction of earth-covered buildings is explored.

Footnotes:

1. Stein, Richard G., Architecture and Energy, Anchor Press/Doubleday, Garden City, New York, 1977, pp. 2, 4.

2. Daly, Leo A., Energy and the Built Environment: A Gap in Current Strategies, American Institute of Architects, 1975.

3. "Energy Conservation: The Debate Begins", Science, Volume 212, No. 24, April 1981, page 424.

4. This energy is equivalent to 26 quads (26 x 10^{15} BTU).

5. Stein, Richard G., Architecture and Energy, Anchor Press/Doubleday, Garden City, New York, 1977, pp. 298.

ESTIMATES OF ENERGY REQUIREMENTS

Energy-Use Characteristics of Buildings

Tempering the climate within buildings is done one of two ways; 1) by appropriating naturally occurring energies or, 2) by the use of mechanical systems. In either case, the physical properties of building materials and their placement determine the flow of light, heat, and air. In both cases, the energy required to maintain the usual comfort range is crucially dependent on climatic conditions.

Conventional construction in the United States today is characterized by minimal mass and substantial exposure of building envelopes to the weather. Many conventional structures appear to ignore the outside environment, and instead rely on mechanical systems to maintain acceptable interior environments. Climate-caused thermal loads in conventional structures are characterized by extreme peaks and minimal time lags (the time it takes external thermal conditions to be felt inside). With conventional construction, failure of mechanical systems can result in swiftly deteriorating interior conditions, often creating life-safety risks.

Past energy costs and economic conditions have encouraged construction of buildings that use increasing quantities of purchased energy to provide thermal comfort and illumination. This has led to a trend that is costly to maintain in light of current energy prices and uncertain supplies.

Earth-covered buildings have demonstrated an ability to reduce energy requirements for environmental tempering. These reductions are related to several characteristics of earth-covered buildings, including the use of significant thermal mass, control of air infiltration, and limited exposure of the building envelope to weather.

Earth-covered buildings are adaptable to varying climatic conditions, and once adapted, they provide comfortable shelter with minimal application of purchased energy. In fact, earth-covered buildings have been used throughout history in many different regions of the world, some with notably harsh environments.

After being designed to fit local materials and labor, adaptation of earth-covered buildings to different climates had primarily come through manipulation of thermal mass, insulation, orientation of glazing, and provisions for ventilation. Because of their significant thermal mass, earth-covered buildings tend to follow long-term climatic conditions. Their mass tends to damp out extremes in the outside environment and it also imparts a time lag to the passage of thermal energy. An example plot of likely temperatures in North Texas is shown in Figure 2. These characteristics are of particular value in reducing peak load requirements of mechanical systems (see section on Peak Load). Reduced peak loads are evident both on a daily and seasonal basis. This reduction can allow the use of smaller equipment, often operating under more efficient conditions.

Thermal time lag inherent in earth-covered buildings implies a reduced sensitivity to energy supply interruptions. Changes in interior thermal conditions

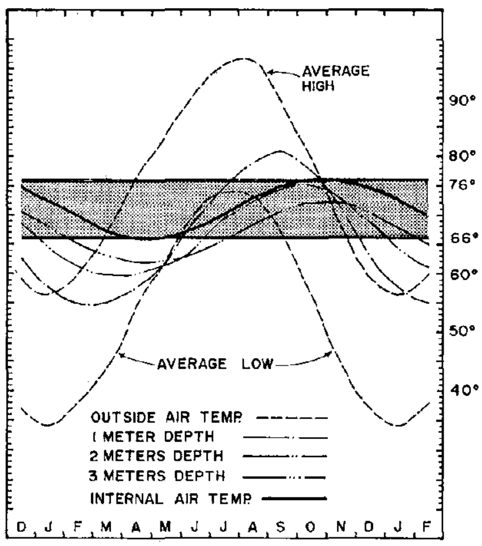


FIGURE 2 Estimate of Probable Earth and Interior Air Temperatures for Earth-Covered Buildings in North Central Texas.[1]

will occur very slowly, over a period of days, should mechanical systems fail. Thus, power and equipment failures can be viewed as less an emergency and more as an inconvenience which poses less life-safety threat. This reduced sensitivity to energy supply interruptions makes earth-covered buildings amenable to solar energy, wind power, photovoltaics, and a host of alternative resources which are intermittent in nature.

Site-Specific Characteristics of Earth-Covered Buildings

Energy use in buildings is very much dependent on site conditions. One site condition is the range of ground temperatures that occur at a given site. Recent studies by Kenneth Labs on the thermal constraints for different regions of the United States, indicate that, with the exception of some areas on the Gulf Coast, suitable ground temperatures exist for earth-covered structures throughout the country.[2]

Earth-covered buildings are especially effective in climates with well-defined seasons and average yearly temperatures near the thermal comfort range. According to Labs this includes the bulk of the United States.

Different types of designs of earth-covered buildings are required for optimal performance in diverse climates. Where heating is a primary concern, structures tend to be open to the sun and be thermally isolated from the adjacent earth mass. The structural surface-to-interior volume ratio tends to be small. These characteristics enhance passive heat gains while limiting heat losses.

In regions of moderate earth temperatures and yearly average temperatures near thermal comfort, an increased coupling of structural thermal mass and earth mass can result in exceptionally comfortable interior conditions with little or no purchased power. The ratio of structural surface-to-building volume may be increased to maximize contact with the beneficial ground temperatures.

Where cooling is a dominant need, shading of the earth cover and building facade will reduce heat gains. Increasing the earth cover can also delay the arrival of thermal pulses until either ventilation or minimal purchased power tempers the air adequately.

Approaches to Thermal Tempering In Earth-Covered Buildings

There are several ways of approaching thermal tempering in earth-covered buildings. One approach is to consider that while the earth-covered design will reduce heating and cooling loads, additional tempering will be supplied by a reduced size (but possibly a more sophisticated) mechanical system.

Because of the thermal time lags inherent in most earth-covered buildings, it would be possible to predict and eventually provide controlled reactions to impending thermal pulses. System failure might lead to brief excursions beyond optimal thermal comfort, but seldom provoke life-safety questions.

A different approach, which appears to have been taken by many owners of earth-covered residences, is to view mechanical systems as backups which are seldom used.[3] For instance, in many regions of the United States, mechanical assistance is used only for specific functions, such as dehumidification in especially humid climates. In other locations, backup mechanical systems are not required, given that changes in clothing, ventilation, and adjustments in passive systems can suffice. Wood heaters, direct solar gain through fenistration, earth-to-air heat exchangers (often called earth tubes), natural or forced ventilation, and building shading are techniques which have been used to provide heating and cooling in earth-covered dwellings.

Thermal Tempering Systems

Thermal tempering systems in earth-covered buildings may be different from those in conventional buildings because of the earth-covered building's reduced peak

Energy Reductions for Institutional-Sized Earth-Covered Buildings Compared to Similar Conventional Buildings* in Several Climates.

Location	Annual Heating Reductions %	Peak Heating Reductions %	Annual Cooling Reductions %	Peak Cooling Reductions %
Boston	55	65	28	18
Washington	54	58	39	46
Jacksonville	58	58	21	48
San Diego	46	80	7	29

*Assuming the same size building with added windows, in the same location, with similar internal loads.

Source: Interpreted from Meixel, "Energy Uses of Non-Residential Earth Sheltered Buildings", in The Potential of Earth Sheltered and Underground Space, Editor, Holthusen, pp. 227-257, 1981.

FIGURE 3

thermal loads, resistance to air infiltration, and the thermal stability of earth berms and cover. Figure 3 is an example of the differences between thermal tempering demands in earth-covered buildings and conventional buildings.

Heating reductions are uniformly greater than those of cooling, but Meixel notes that because of computer limitations, cooling estimates are conservative.

The peak and annual thermal tempering requirements for residential-sized earth-covered buildings have been recorded or estimated for several regions of the United States.[4] Davis computed that an earth-covered building in the North Texas area with eight feet of earth cover would have energy reductions for heating and cooling of approximately 80%.[5] Actual energy use from a North Texas earth-covered dwelling with three feet of earth cover, shows an average <u>total</u> energy use reduction of 52% with the breakdown shown in Figure 4.[6] That reduction is in comparison to a utility company survey of similar-sized conventional dwellings 45 miles from the earth-covered dwelling.[7]

Estimates before construction placed thermal tempering reductions at 65% in comparison to conventional dwellings in the area. This level of reduction was predicted on three feet of cover and mature vegetation. Adjusting for differences in climatic conditions (between the earth-covered residence data and the time of the utility company survey data which is the basis for the comparative conventional dwelling), Figure 4 indicates energy-requirement reductions of 62% were achieved in the earth-covered buildings. It is anticipated that after a ground cover is established, summer and winter thermal tempering requirements will drop even further.

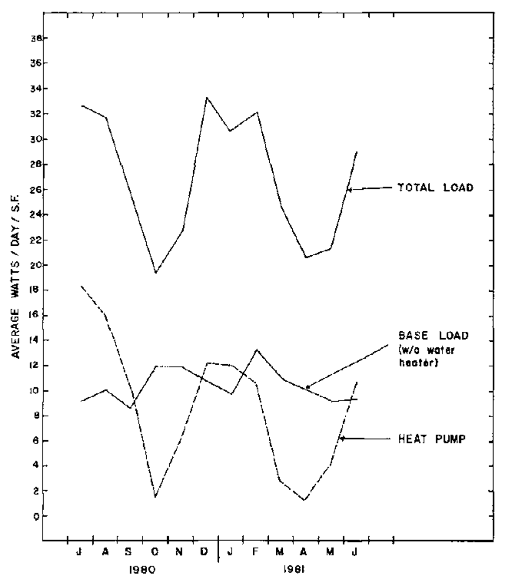
Comparative Energy Consumption of Earth-Covered VS Conventional Dwellings in North Central Texas					
	Conventional		3' of Earth Cover		
	KW/SF/Yr	% of Total	KW/SF/Yr	% of Total	Percent Reduction
Heating	5.99*	29	1.30	13	78
Cooling	5.32	2.6	2.02	20	62
Total Dwelling Consumption	20.71	100	9.85	100	52

*Note: The energy demand of the conventional dwelling has been adjusted to account for differences in climatic conditions between the time periods that data were collected. The total dwelling consumption includes all energy demands. Both conventional and earth-covered dwellings are all-electric.

FIGURE 4

The distribution of electrical energy use in the dwelling is: heating, 13%; cooling, 20%, water heating, 28%; and all other uses, 38%. Cooling demand has been computed to be .508 watt-hours per square foot of building per cooling degree day. Heating demand has similarly been computed to be .549 watt-hours per square foot of building per heating degree day.[8] A plot of energy use patterns is shown in Figure 5. An analysis of Figure 5 indicates that thermal tempering varied between 6% and 56% of the total energy demand.

A survey of Oklahoma earth-covered dwellings found a 41% reduction in total energy use, in comparison to conventional dwellings, for earth-covered dwellings built before 1978.[9] Computations also showed reductions of winter heat loss and summer heat gain in earth-covered



Note: The summer of 1980 was the worst on record, with 70 days over 100°.

Source: Data from electrical sub-meters compiled by Moreland Associates.

FIGURE 5 Energy Use For Earth-Covered Dwelling In North Central Texas

dwellings of 51% and 67% respectively, in comparison to conventional structures designed according to the ASHRAE 90.75 energy code.[10]

An example of the winter heat loss from an earth-covered dwelling in Minnesota is shown in Figure 6. Because heat loss through the earth-covered portions

Winter Heat Loss in a Prototype Minnesota Earth-Covered Dwelling			
Roof	16.2	Windows	45.7
Below-grade walls	10.4	Doors	1.3
Floors	5.3	Front Wall	3.5
Perimeter footing loss	7.2	Infiltration	10.4
	39.1%		60.9%
Source: Lunde, Martin R., Interfacing Residential HVAC Systems With Earth-Sheltered Construction, paper given at the Underground Space Conference and Exposition, Kansas City, Missouri, June 1981			

FIGURE 6

of the dwelling are minimal, the windows have become the dominant heat loss, i.e., losing nearly 10% more heat than all other building surfaces combined. In a conventional dwelling, the windows might account for roughly one-third of the heat loss.

For earth-covered dwellings, Lunde recommends mechanical systems which differ from those usually found in dwellings.[11] One is a low-temperature (100°) forced air system with an integral fresh-air cycle and whole-house ventilator. The other system is a low-temperature (75° - 95°) radiant floor system which incorporates a small fresh-air distribution system. The moderate temperatures of the air and radiant-heat sources are compatible with temperatures generated by low-cost solar collection systems.

According to an analysis of earth thermal mass by A. F. Emery and C. J. Kippenham, the following conclusions have been derived about the performance of massive and light weight building sections:

1. Earth masses are a substantial improvement over lightweight walls, even when both have equal steady state U valves.
2. Earth masses are most effective when average temperature differences between interior and exterior environments are large, such as during a hot summer or cold winter.
3. Earth masses are most effective in summer periods, particularly in comparison to the usual lightweight wall (by a factor of 2 when there is considerable solar radiation falling on their respective surfaces).[12]

Air Infiltration

One source of heating and cooling load in buildings is air infiltration, the volume of air that leaks into and out of a building over time. Reduction of air infiltration is a major technique for energy-use reduction, as evidenced by its inclusion in several energy-saving building techniques. For instance, Scandinavian buildings, which are widely known for their energy efficiency, are designed for extreme conditions and have only .25 air changes per hour as the result of air infiltration.[13]

Earth-covered buildings have reduced air infiltration because of the reduced area of building surface which is exposed, and the tightness of construction demanded to protect against moisture. In earth-covered dwellings infiltration rates of .5 air changes per minute should be commonly attained. As shown in Figure 6, the air infiltration rates of .5 air changes per hour should be commonly attained. Again, refering back to Figure 6, the air infiltration heat loss was roughly 10% of the building heat loss. Conventional dwellings in the same region, built before 1973 were estimated to have as much as 75% of their winter heat loss through infiltration.[14]

Infiltration rates are strongly dependent on the outside windspeed. A doubling of windspeed caused the variance in air infiltrations for conventional dwellings in Figure 7. A 23% increase in cooling load results under the conditions listed, whereas a negligible increase in air infiltration would occur in the earth-covered building. Summertime infiltration can be especially important if large quantities of moisture in the air must be removed to provide for thermal comfort.[15]

Figure 8 lists the range of winter air-infiltration loads for a number of locations. The data demonstrate the effect of low air infiltration.

There has been concern that earth-covered and other tightly constructed buildings have so little air infiltration that if no other ventilation is provided, internal pollutants will build up to toxic levels, and odors will not be adequately removed. According to Lunde,[16] a 50% (.5) ACH is adequate to maintain acceptable low levels of indoor polluntants, including CO and radon.[17] Positive ventilation can be provided through a heat exchanger which reduces unwanted heat gains or loss.

Ventilation in Earth-Covered Buildings

Ventilation in earth-covered buildings may be mechanically assisted and can also rely on prevailing breezes and building configuration for air movement. Most earth-covered buildings have no inherently different ventilation characteristics from conventional buildings, with the exception that if no ventilation is desired, they can often be closed tighter than a conventional

Peak Cooling Load As a Function of Variation In Air Infiltration**						
Load Source	Earth-Covered Building		Range For Conventional Dwelling*			
	.5 ACH***		.7 ACH		1.0 ACH	
	KBTU/Hr	%	KBTU/Hr	%	KBTU/Hr	%
Infiltration-Latent	1.25		1.8		2.5	
Infiltration-Sensible	3.45		4.8		6.9	
Infiltration-Total	4.7	29	6.6	37	9.4	45
Internal Loads	7.5	47	7.5	42	7.5	36
Envelope Loads	3.6	22	3.6	20	3.6	17.5
Total Loads	15.8	98	17.7	99	20.5	98.5

*Variation in outside wind speed from 10 MPH to 20 MPH assumed cause change in infiltration from .7--1.0 air changes per hour (ACH).

**Base Assumptions Conventional dwelling conforms to 1977 California energy code standard. Peak internal load assumed at 6 P.M. Simulations Specifics - 6 P.M. Miami on July 14.

***ACH = Air Changes per hour

****KBTU/hr = 1000 BTU per hour

Source: G. D. Roseme, Air to Air Heat Exchanges: Saving Energy And Improving Indoor Air Quality, Lawrence Berkeley Laboratory, 1979.

FIGURE 7

Annual Air Infiltration Heating Load (Million BTU)

City	Degree Days Base (65°)	0.75 ACH (Base Case)	0.5 ACH*	Energy Saving (Million BTU)
Atlanta	2961	15.82	5.80	10.0
Washington	4224	23.09	8.46	14.6
Chicago	5882	36.16	13.26	22.9
Minneapolis	8382	57.17	20.96	36.2

*Includes .2 ACH air infiltration and .3 ACH fresh air brought in via an air-to-air heat exchanger. Assumed to represent the typical performance of an earth-covered building. ACH stands for air changes per hour.

Source: G. D. Roseme, Air to Air Heat Exchangers: Saving Energy and Improving Indoor Air Quality, Lawrence Berkeley Laboratory, 1979.

FIGURE 8

building. Earth-covered buildings which are below grade and have a few external openings often have to rely on forced ventilation.

In most cases it is possible to design earth-covered buildings with adequate natural air circulation. For example, an earth-covered building with windows only on one side can be effectively ventilated by including an air shaft in the center, or center rear of the structure. A skylight and operable vents combination could be designed to function as a thermal chimney, such as shown in Figure 9. According to Orlowski, a thermal chimney increases the volume of air flow by using solar energy to warm the air, thereby creating a thermal draft within the chimney.[18]

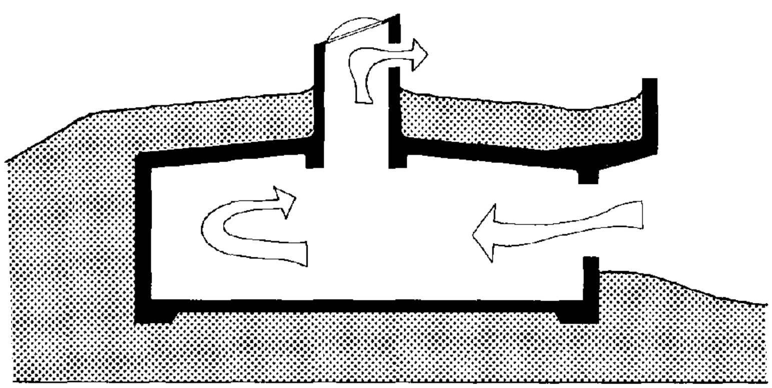


FIGURE 9 Thermal Chimney in Dwelling

In windy areas, earth-covered buildings might successfully use wind scoops and wind towers similar to those in Iran described by Bahadori. According to Bahadori:

> In Iran certain traditional building designs achieve more than a flattening of the temperature curve; they circulate cool air through the building and can even keep water cold and ice frozen from the winter until the height of the long, hot summer of the country's arid central and eastern plains. They do so without any input of energy other than that of the natural environment; hence they can be characterized as passive cooling systems.[17]

In the United States, large conventional buildings such as institutional structures do not generally provide forced ventilation for thermal tempering, and rarely are designed for natural air movement. Large earth-covered buildings may, however, also benefit from mechanical ventilation, particularly ventilation during cool nights in warm climates.

The energy needed to temper incoming ventilation air can be reduced by the use of special heat exchangers, sometimes called "heat wheels." Such devices transfer the energy in the outgoing or exhaust air (in winter) to the incoming air without mixing the two air streams.[20]

Provisions for natural ventilation are especially helpful in the case of power interruptions that occur during hot weather or in the case of a natural or man-made disaster. If an earth-covered building were to be used as a shelter space, natural ventilation would ensure that high levels of internal heat and humidity would be unlikely.

Embodied Energy

A significant percentage of the annual energy flow in the United States, about 6%, is bound into buildings during their construction.[21] This embodied energy, the summation of all the energy used to transform raw materials into the built environment, is recovered only partially and then only when building materials are recycled. A comparison of the energy requirements of earth-covered buildings and conventional buildings is given increased accuracy by taking into account embodied energy.

To compare the embodied energy of earth-covered buildings to conventional buildings, two hypothetical structures, each containing 1600 square feet (gross) are compared. One structure assumes the aggregate embodied energy characteristics of the residential construction sector, as described by Stein and the Center for Advanced Conputation.[22] Another structure, similar in characteristics but earth-covered, is compared to the Stein analysis. The earth-covered dwelling has concrete shell, waterproofing, and excavation energy included. Figure 10 lists the energy embodiment of the two structures.

An example of the differences in embodied energy between the earth-covered building and the conventional can be found in a comparison of typical wall sections. The conventional has a brick veneer over an insulated wood stud wall with gypsum sheeting and embodies 1.26×10^5 Btu/ft^2. A 10-inch cast-in-place concrete wall with waterproofing and interior gypsum sheeting on wood furring strips embodies 1.77×10^5 Btu/ft^2. Moreover, one cubic yard of earth can be excavated for about the embodied energy of one brick, (eight bricks embody the

Embodied Energy Components of an Earth-Covered and and Conventional Dwelling				
Division	Conventional Dwelling		Earth-Covered Dwelling	
	%	Million BTU	%	Million BTU
Refined Petroleum	11.3	126.9	8.1	126.9
Utilities	0.9	10.1	0.6	10.1
Sawmill Products	10.7	120.1	0.77	12.3
Wood Flooring	0.5	5.6	0.07	1.1
Millwork	2.7	30.3	1.9	30.3
Plywood	2.5	28.0	0.36	5.6
Paint	1.26	14.1	0.28	4.4
Concrete Paving	0.22	2.4	0.07	1.1
Asphalt - W/P	3.1	34.8	9.05	140.3
Bricks	4.4	49.4	0	0
Ceramic Products	1.8	20.2	1.3	20.2
Concrete Block	2.2	24.7	0	0
Concrete/Cement	10.6	119.0	26.76	415.0
Gypsum Products	2.2	24.7	1.08	16.8
Stone Products	0.9	10.1	0.5	7.8
Plumbing	0.3	3.3	0.21	3.3
Plumbing Fixtures	1.9	21.3	1.36	21.3
HVAC Equipment	0.9	10.1	0.32	5.0
Sheet Metal	6.6	74.1	2.74	42.6
Structural Steel	1.2	13.4	16.57	226.8
Transportation	3.4	38.1	2.43	38.1
Wholesale Trade	3.0	33.6	2.17	33.6
Retail Trade	4.5	50.5	3.25	50.5
Professional Svcs.	2.2	24.7	1.8	28.0
Other	20.2	226.9	14.63	226.9
Excavation/Earth	0	0.0	2.74	42.6
Total	100.0	1116.4	100.0	1510.6
Source: Center For Advanced Computation, Document # 228, 1977 for the Conventional dwelling with additional data from Moreland Assoc. for the earth-covered dwelling.				

FIGURE 10

energy equivalent of one gallon of gasoline).[23] The earth-covered dwelling is assumed to look similar to Figure 11.

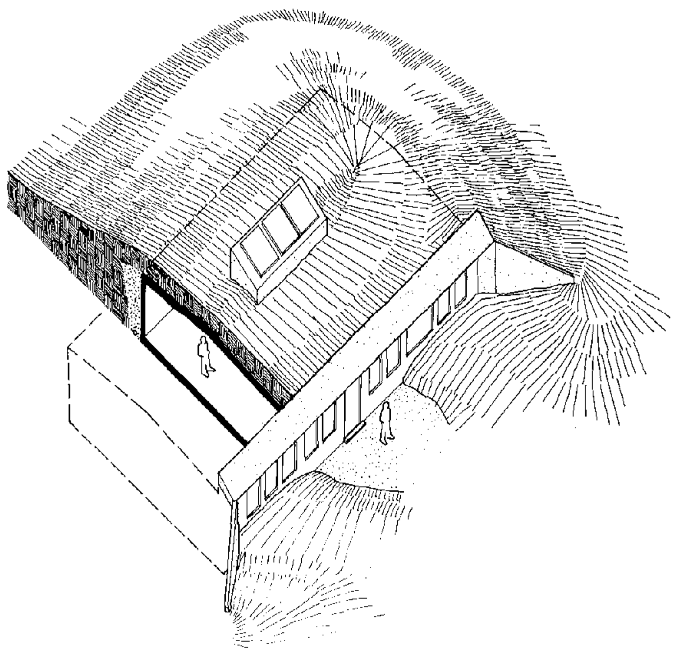


FIGURE 11

In the case of earth-covered buildings, embodied energy is effectively paid back with savings in operating energy and a reduced need for maintenance and replacement. Referring to Figure 9, the conventional structure embodies 1.12 billion BTU, while the earth-covered building embodies 1.55 billion BTU, a difference of 427 million BTU, or 27%, given current technology. Assuming an 80.3

billion BTU energy savings per year for the earth-covered building, based on data in the life-cycle cost section of this report, the energy payback is approximately 5.34 years. For an initial energy embodiment expenditure, the earth-covered structure will remain substantially intact for many times conventional construction. In comparison, the conventional structure would have to be replaced at roughly 60-year intervals, resulting in a much higher energy expenditure over time. For example, at 80 years the total energy expenditure (including embodied energy) of the conventional dwelling is 14.8 billion BTU, while the earth-covered dwelling is 8.9 billion BTU. The difference is 5.0 billion BTU or 50%. At 300 years the conventional dwelling, which by this time will have been rebuilt 5 times, has expanded 58.02 billion BTU. The earth-covered dwelling, in comparison, has necessitated the expenditure of only 20.75 billion BTU. The difference being 29.29 billion BTU or 50%.[24] Of course, new technologies, for instance curved shell concrete structures, might reduce the amount of embodied energy in earth-covered buildings still further.

There remains the embodied energy of large commercial and institutional earth-covered structures. In conventional construction, the energy embodiment of institutional structures is typically twice that of residential construction.[25] That such a ratio will exist between institutional and residential-scale earth-covered buildings is unlikely, given the similarities in materials and design. To calculate the energy embodiment of an institutional structure is beyond the scope of this study, but if the residential comparison is accurate, it would imply that energy payback for institutional structures is likely to be attractive in both the marketplace and in terms of the overall United States energy balance.

Summary

Earth-covered buildings can reduce energy requirements for thermal tempering in residential and institutional-sized buildings in most regions of the United States. Such reductions are the result of the characteristically high thermal mass, limited exposure of the building envelope to external climatic conditions, and the high degree of air tightness attainable in most earth-covered buildings. Moreover, earth-covered buildings are adaptable to a wide range of climatic conditions and design variations. In terms of embodied energy, savings in day-to-day energy requirements can lead to short-term payback of the embodied energy cost of earth-covered buildings.

Footnotes:

1. Moreland, Frank L., "An Alternative to Suburbia," in Alternative In Energy Conservation: The Use of Earth-Covered Buildings, U.S. Government Printing Office, 1976, pp. 197-204.

2. Labs, Kenneth, "Regional Suitability of Earth Tempering," Earth Shelter Performance and Evaluation, L.L. Boyer, editor, Oklahoma State University, Stillwater, Oklahoma, 1981

3. Boyer, L. L. et al, Energy and Habitability Aspects of Earth Sheltered Housing in Oklahoma, Oklahoma State University, Stillwater, Oklahoma, 1980.

4. For instance, in the north Texas area Moreland Associates has collected data; Oklahoma State University has collected data on a number of dwellings; and the Underground Space Center has instrumented several dwellings in Minnesota. Others have also contributed to a growing data base on the

performance of earth-covered buildings. Space limitations preclude covering more than the few listed below:

Boyer, L.L. et al, Energy and Habitability Aspects of Earth Sheltered Housing in Oklahoma, Oklahoma State University, Stillwater, Oklahoma, 1980.

Goldberg, L. F., and Lane, Chavler, A., "A Preliminary, Experimental, Energy Performance Assessment of Five Houses in the MHFA Earth-Sheltered Housing Demonstration Program," in the Proceedings of the Underground Space Conference and Exposition, Kansas City, Pergamon Press, 1981.

5. Davis, William B., "Earth Temperature: Its Effect On Underground Residences", Earth-Covered Buildings: Technical Notes, editors, Moreland, Higgs, Schih, National Technical Information Service, Springfield, Virginia, 1979, p. 205.

6. Figures 4 and 5 are based on an ongoing monitoring of a 2100 gross square foot single family dwelling in rural north central Texas. The dwelling, which is occupied by three persons, faces slightly to the west of north to fit the site topography and take advantage of a view to a wooded creek area. The house has submetering of the heat pump compressor, HVAC blower, hot water, base load (all miscellaneous outlets, appliances, and lighting), total dwelling demand and peak demand. This report includes data from June of 1980 through May of 1981. This includes the summer of 1980 which has been the worst on record, with 65 days over 100°. The dwelling, during that summer had 2 inches of insulation on the roof, 2 feet of earth cover and no vegetation. In October of 1980, one foot of topsoil was added to bring the earth cover to the design specification of three feet.

7. Casey, Elizabeth Ellen, The Impact of Solar Energy Usage in Simple Family Residences on an Electric Utility Company, Thesis, University of Texas at Arlington, 1978.

8. This figure was derived by adding all the heat pump and blower energy use in the cooling mode and dividing this by the tempered area of the dwelling

and the number of cooling degree days recorded for that location. A similar calculation has been done for heating energy.

9. Boyer, L.L. et al, Energy and Habitability Aspects of Earth Sheltered Housing in Oklahoma, Oklahoma State University, Stillwater, Oklahoma, 1980

10. Energy Conservation in New Building Design, ASHRAE Standard 90-75, by the American Society of Heating, Refrigeration and Air Conditioning Equipment, 1975.

11. Lunde, Martin R., Interfacing Residential HVAC Systems With Earth Sheltered Construction presented at the Underground Space Conference and Exposition, Kansas City, Missouri, June 1981

12. An analysis performed by A. F. Emery and C. V. Kippenham for Moreland Associates on a hypothetical earth-covered building located in north Texas.

13. Roseme, G. D., "Mechanical Ventilation Systems Using Air to Air Heat Exchanges," in Building Ventilation and Indoor Air Quality, edited by Jeffrey Nessel, Lawrence Berkeley Laboratory, Berkeley, California, 1979.

14. Clovis Heimsath Associates, Energy Conservation in the Single Family House, Houston, Texas, 1976.

15. Roseme, G. D., "Mechanical Ventilation Systems Using Air to Air Heat Exchanges," in Building Ventilation and Indoor Air Quality, edited by Jeffrey Nessel, Lawrence Berkeley Laboratory, Berkeley, California, 1979.

16. Lunde, Martin R., "Interfacing Residential HVAC Systems With Earth Sheltered Construction," presented at the Underground Space Conference and Exposition, Kansas City, Missouri, June 1981,

17. A discussion of ventilation values is included in the Radiation section of this report.

18. Orlowski, Henryk, "Thermal Chimneys and Natural Ventilation," in Earth Covered Buildings: Technical Notes, Edited by Moreland, Higgs, Shih, National Technical Information Service, Springfield, Virginia, 1979.

19. Bahadori, Mehdi N., "Passive Cooling Systems in Iranian Architecture," Scientific American, 238, February 1978, p. 144-154.

20. Roseme, G. D., et al, Air to Air Heat Exchangers: Saving Energy and Improving Indoor Air Quality, a paper presented at the International Conference on Energy Use Management, Los Angeles, 1979.

21. Stein, Richard G., Architecture and Energy, Doubleday, Garden City, New York, 1977.

22. Stein, Richard G., and the Energy Research Group, Energy Use For Building Construction, Energy Research Group, Center for Advanced Computation, University of Illinois at Urbana-Champaign, 1977.

23. Brick data from Center for Advanced Computation Document 228. Earth excavation computed from manufacturers' performance data on mid-sized excavation equipment.

24. Assuming earth-covered dwelling uses 9.002×10^7 BTU/dwelling/year and the conventional dwelling uses 17.1×10^7 BTU/dwelling/year. The life span for the earth-covered dwelling is over 300 years and the conventional 60 years. Additional discussion can be found in the Life-Cycle section of this report.

25. Stein, Richard G., and the Energy Research Group, Energy Use For Building Construction, Energy Research Group, Center for Advanced Computation, University of Illinois at Urbana-Champaign, 1977.

COMPATIBILITY WITH SOLAR ENERGY SYSTEMS

In most climates, there will be only minimal heating and cooling requirements in earth-covered buildings because of the moderating force of mass of the surrounding earth and structure.[1] One thermal tempering alternative is the application of solar design techniques. In this report, active solar design is assumed to incorporate flat-plate or concentrating solar collectors in conjunction with either liquid or solid-mass thermal-storage systems. Mechanical force is assumed to be required to transfer heating and cooling to occupied spaces. Passive solar design is the specific manipulation of building materials and building design to affect an optimum flow of naturally occurring thermal energy through a building.

Solar energy used with earth-covered buildings is important because there is a natural fit between them. It is not surprising that earth-sheltered construction has paralleled that of solar energy use in history.[2] There is every indication that solar energy used with earth-covered buildings is a promising form of construction.

An example of the use of passive solar techniques with earth-covered buildings in colder climates is seen in the many dwellings which orient glazing to the south, varying the area of glazing in proportion to the passive heat gain desired. Two-story designs are common, with large sun spaces being integral with the living space. In other climates, where cooling is the primary constraint, structures tend to have a larger surface-to-volume ratio, more earth-cover, and glazing which can be well shaded in summer. To minimize heat gain, glazing may face north, with baffles and berms to protect from winter winds. Obviously, while passive solar design techniques require care in application to earth-covered buildings because the thermal demands and rhythms can be different, these techniques hold much potential.

In earth-covered buildings in some climates the use of solar greenhouses is appropriate. Transfer of warmth from a greenhouse to interior spaces can be accomplished in many ways, some passive. The additional humidity created by a greenhouse may need to be periodically isolated from other living spaces in some climates. During summers, additional shading and venting of greenhouses may be necessary to reduce heat gains.

Solar energy use has long been focused on the heating of spaces and water. Solar design techniques can also reduce heat gain, for example, the choice of light-colored surfaces, sun-shading techniques, and use of thermal mass to delay the passage of heat. Beyond these techniques, earth-covered buildings have an inherent capacity to reduce moderating affect on local climate. Additionally, there are low-energy cooling means which may be used to augment the cooling effects of earth thermal masses. For instance, ventilation may be enhanced by the use of thermal chimneys, tempered fresh air may be supplied via earth tubes, shading by trees and ground cover may lessen the buildup of heat in the earth mass, evaporative cooling may be used in some climates, as may radiative cooling to the cool night sky.[3] Each of these resources is intermittent and earth-covered buildings tend not to be significantly affected by such transient sources. In contrast, lightweight conventional buildings are more difficult to cool by these means.

It should be noted that integration of active solar design with earth-covered buildings requires: 1) the ability to predict energy required, 2) an appropriate link between collector, storage and building, and 3) adequate thermal storage. Of these, the prediction of energy needed is likely to be the most difficult, primarily because of a lack of experiential data. Computer modeling, to be accurate, is a complex transient analysis to which few designers have access.

Energy demands for heating and cooling by earth-covered buildings are usually without defined peaks, and the buildings are forgiving of transient loss in supply. This allows for a decrease in the area of solar collectors and thermal storage, and thus improves the cost effectiveness of solar systems. Requirements for backup systems may be relaxed, given the improbability of major temperature excursions during a system failure. This alone could add greatly to the cost effectiveness of a solar system in an earth-covered building.

The use of solar-powered absorption cooling in earth-covered buildings is perhaps most appropriate for such equipment. This is because of the moderate, non-peak demands of earth-covered buildings and their ability to accept transient energy sources. Collector area and thermal storage requirements would be lessened in most cases. One current difficulty with such equipment is the unavailability of small units for single-family installation. The use of absorption cooling in dwelling clusters or for institutional projects may be more likely

Photovoltaic and wind systems are also solar-energy systems and suited to earth-covered buildings or dwellings.

The heating-, cooling-, and illumination-demand characteristics of earth-covered buildings result in a very cost-effective application for wind and photovoltaic power. Demands of several kilowatt hours per day can be met with increasingly moderate costs.[4] The economic justification extends beyond remote sites, where such alternative power systems are often found, to areas within a utility grid which has abundant wind and sunshine.

Institutional earth-covered buildings present a special opportunity. First, because of the size and thermal requirements of institutional buildings, active solar systems tend to be complex. Because the control systems also tend to be complex, there is an exciting potential to use semi-intelligent (computer-based) environmental controls.[5] Such controls accept environmental data and, taking into account a building's thermal characteristics, give controlled responses. Control of ventilation and natural lighting in many separate building zones is possible now. There could evolve controls for mechanical systems which take into account a building's thermal characteristics, and in conjunction with current climatic data, provide anticipatory rather than reactive thermal tempering. Cooling is likely to be a prominent requirement in institutional earth-covered structures because of the characteristically higher level of internal heat generation in institutional buildings. In fact, internal heat gains could preclude the need for any supplemental heating in some climates.

Summary

Not only does there appear to be no incompatibility between earth-covered buildings and either passive or active solar energy design, there is every indication that earth-covered buildings reduced energy requirements and their insensitivity to energy supply interruptions makes them most compatible with solar energy systems, wind power, and photovoltaics.

Footnotes:

1. The quantity of reduction depends on a number of factors, such as soil-temperature range, placement of insulation, earth mass, glazing, and climatic variations. There are times when interior conditions will provide thermal comfort without the use of purchased energy. At other times, and in particular regions, additional tempering will be required.

2. Kennedy, R., and Col, R.S., "Passive Solar: Lessons from the Past," in Underground Space, Volume 6, Number 1, 1981.

3. Hand, J.W., "Integration of Sky Vault Cooling in a 115m^2 North Texas Residence" in Proceedings of the 5th National Passive Solar Conference, Ed. by Hays and Snyder, ASIES, Newark, Delaware, 1980, pp. 722-726, and

   Hand, J.W., "Integration of Sky Vault Cooling in a 115m^2 Owner-Built Resisdence in North Central Texas," Proceedings of the International Conference on Energy Resources and Conservation Related to Built Environment, Ed. Oktay Ural, Miami, Florida, International Institute for Housing and Building, 1980.

4. Miles C. Russell, "An Apprentice's Guide to Photovoltaics," Solar Age, July 1981, pp. 32-26.

   Schoen, Richard, "Solar Photovoltaics," in Progressive Architecture, Volume 4, 1981, pp. 182.

   Lange, Frederic S., "Energy out of Thin Air," in New Shelter, Volume 1, Number 8, 1980, pp. 24.

5. Interview with Forrest S. Higgs, associate editor of Energy and Buildings, 1980.

IMPACT ON PEAK LOAD

Peak loads are the highest instantaneous energy flux required by an energy user. In the case of buildings, a peak load can occur as the result of the simultaneous electrical appliance demands, but is most often associated with the onset of severe climatic conditions. In most cases, exceptionally high heating and cooling energy demands occur for only a small percentage of the year, although there are exceptions.[1] Thermal tempering equipment is sized to meet the anticipated peak demand for a particular building. Moreover, some utility rates and electrical generating capacity are determined by peak demand.[2] It is obvious that peak loading conditions affect building equipment costs, operating costs and societal costs for utility generation equipment.

Reductions in peak heating and cooling loads in earth-covered buildings are the result of several phenomena. One influence is the usually mild and stable temperatures surrounding a large portion of most earth-covered buildings. A related phenomenon is the slow and moderating manner in which thermal energy travels through earth (as opposed to through typical conventional building sections) which dampens the effects of extreme climate changes. Moreover, the normally reduced levels of air infiltration in earth-covered buildings reduces air tempering loads.

Conventional buildings expose a large surface area to climatic forces. Climatic conditions are likely to be skewed from the human comfort range much of the year, with peak excursions during the summer and winter. Even though these excursions usually occur for a small percentage of the year, they form the basis for sizing mechanical equipment. In contrast, earth-covered buildings expose much less of their surface to the elements and, instead, remain in contact with the more stable influence of the earth. Figure 2 in the Energy Requirements section of this report shows that, at even minimal depths below the surface, the amplitude of yearly temperatures is reduced 60% from the average outside air temperatures. At three meters below the surface, the amplitude is reduced 85%. Figure 1 lists a range of probable temperature differences (Δt) between the surrounding soil and desired temperatures for different regions.

Moderation of Climatic Extremes and Peak Demands				
	Earth-Covered		Conventional	
	Summer Δt*	Winter Δt	Summer Δt	Winter Δt
Northern Tier States	0-10°F	20-30°F	20-30°F	60-90°F
Southern States	10-20°	0-15°	20-30°	40-60°
*Δt is the temperature difference between inside and surrounding air.				

FIGURE 1

The Underground Space Center at the University of Minnesota points out the effectiveness of earth mass against substantial shifts in climatic conditions.[3] They compared a conventional roof (made of 8-inch precast concrete planks with 4 inches of rigid foam insulation) to a roof with 18 inches of earth (over the same structure with 3 inches of rigid insulation). In the event of a five-day cold snap of 10° below normal, the nonearth-covered roof's mechanical equipment would have to respond quickly to the thermal pulse. If it failed during its five days, considerable discomfort would occur. In contrast, the earth-covered building's mechanical equipment would have one day before the first effects of the cold snap arrived and four days before the thermal pulse were fully developed. The simulated peak load arrived six days after the onset of the climatic change. The peak in the earth-covered roof was 79% of the less massive roof (reductions caused by walls were not included). Moreover, a large percentage of the earth-covered building's recovery time was during more favorable weather. With even more mass, the peak demand would be further reduced and delayed longer.

In the Underground Space Center study, when the thermostat in the less massive building registered the need for heating, the cold would have arrived at the interior. Under such conditions, equipment must be used extensively to keep the internal thermal conditions comfortable until a weather change pumps in some warmth. In comparison, an earth-covered building could begin an anticipatory tempering response long before the need were critical.

Reduction in air infiltration attainable in most earth-covered buildings is the result of the limited area of exposure of building elements to wind and the tightness of construction necessary to protect against external moisture. This reduction can also assist in reducing peak energy demands. For example, peak heating demand in winter is often related to blizzard conditions.

Cold winds can both remove warmth from a structure via convection and by the introduction of untempered air into living spaces. The inflow of humid air in hot and humid regions can accentuate cooling demands.

Meixel predicts that substantial peak-load reduction can be found in institutional-sized earth-covered buildings, in comparison to conventional buildings (Figure 2). Generally, he found greater heating-load reductions than cooling-load reductions. Meixel notes that his cooling-load calculations are conservative because of the computer simulation assumptions.[4] Additionally, internal heat generation is very much a factor in institutional-sized buildings and tends to elevate cooling demands and reduce winter heating demands.

Conclusion

Earth-covered buildings have two effects on peak loads: reduction in the magnitude of demand and a time shift in the occurence of peak demand, some in the order of months. These effects have several important economic consequences for building owners: Lowering the unit rate at which energy is purchased, reducing the size (and cost) of equipment and its housing, and more efficient operation without extreme demands.

Earth-covered buildings have unusually stable energy needs which tend to smooth out peak demands for heating and cooling. Earth-covered buildings also reduce air-infiltration-related peak loads. Thus earth-covered buildings can use smaller sized mechanical equipment and have moderate power requirements for thermal tempering. If earth-covered buildings are built in increasing numbers, the demand for peak generating

Peak Heating and Cooling Load Reductions
In Institutional-Sized Earth-Covered Buildings*

	Boston	Washington	Jacksonville	San Diego
Heating Degree Days	5791	4333	1243	1574
Peak Heating Load Red.	65%	58%	58%	80%
Cooling Degree Days	1000	1500	3200	1500
Peak Cooling Load Red.	18%	46%	48%	29%

*In comparison to a similar building above ground at the same location, with similar interval loads and more windows. Based on a computer simulation which the author says is conservative in regards to cooling load reductions.

Source: G. P. Mixel, "Energy Use of Nonresidential Earth-Sheltered Buildings In Five Different Climates" in The Potential of Earth Sheltered and Underground Space, Ed. Holthusen, Pergamar Press, New York 1981.

FIGURE 2

capacity of electric utilities would be reduced primarily because summer cooling demands would be reduced. Peak demands on energy sources for heating could be reduced even more. A discussion of these and other long-term potential impacts is covered in the following section.

Footnotes:

1. For example, during the summer of 1980, the Dallas-Fort Worth area had more than 70 consecutive days over 100°F, with 113° the maximum and many days near that figure. Most years average 8 to 10 days reaching 100°, with one day peaking to 105°.

2. See the discussion related to Figure 6 in the "Energy Requirements" section of this report.

3. Earth Sheltered Housing Designs: Guidelines, Examples, and References, The Underground Space Center, University of Minnesota, 1978, pp. 55-58.

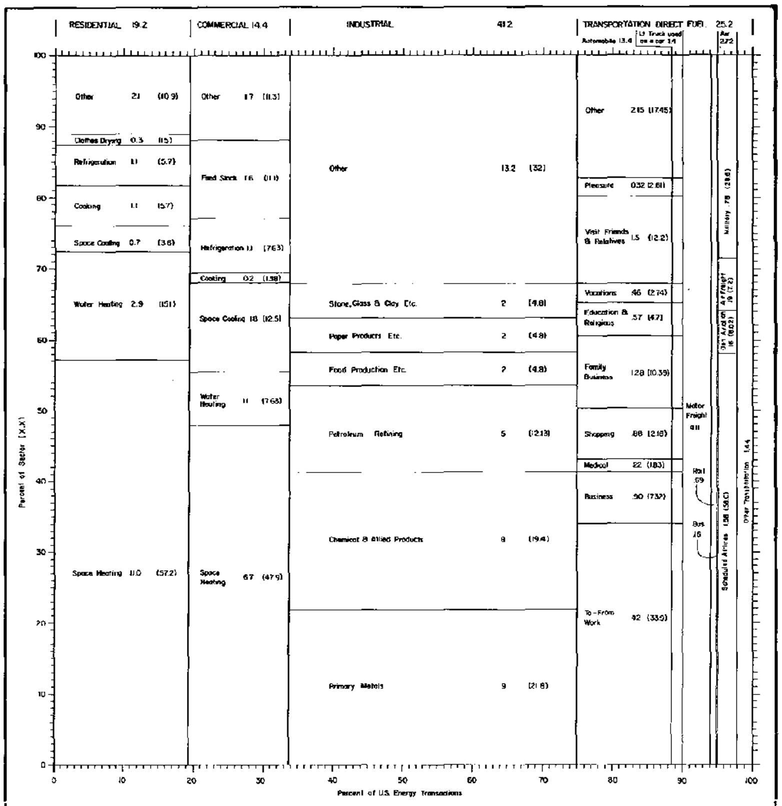
4. Meixel, G.P., "Energy Use of Nonresidential Earth-Sheltered Buildings in Five Different Climates," The Potential of Earth Sheltered and Underground Space, edited by Holthusen, Pergamon Press.

LONG-TERM POTENTIAL IMPACT

> Since America's buildings consume approximately 40 per cent of the energy used in this country, it is clear that architects through energy-conscious design can have a significant effect in reducing America's dependence on non-renewable sources of energy while at the same time providing a built environment not of less, but of better. Nowhere is the opportunity and achievement more visible than in the area of earth sheltered design.[1]
>
> R. Randall Vosbeck

The change in energy consumption in the United States which could result from the construction of large numbers of earth-covered buildings is dependent on the energy transaction matrix (Figure 1) of which the construction and operation of buildings are a part. With respect to the construction of buildings, many sectors of the matrix are affected,[2] while ongoing energy use is primarily centered in the residential energy sectors. Perhaps two-thirds of all energy transactions occur in cities, and forty percent[3] of all energy transactions are related to the construction and operation of buildings.

Figure 2 breaks down the specific distribution of energy in the residential sector, according to various estimates. The last column on the right represents the



Sources:

Stanford Research Institute, Patterns of Energy Consumption in the U. S.
R. C. Harkness, "Energy Implications of the Telecommunications/Transportation Trade Off," Energy Use Management Vol. I PP. 674-689.
The American Institute of Architects, Energy and the Built Environment: A Gap in Current Strategies, 1973.

FIGURE 1: U.S. Distribution of Energy End Uses in 1967

Estimates of Residential-Sector Energy Use				
Consumption Section	AIA[a] 1968	Eccli[b] 1975	ASHRAE[c] 1975	Assumed[d] Conventional
Space Heating	57.3	50	67.6	50
Space Cooling	3.6	10	5.6	15
Waterheating	15.1	15	11.5	15
Lighting	7.0			7
Cooking	5.7	5		5
Refrigeration	5.7	5		
Other	5.6	15	15.2	8
Total	100 %	100 %	100 %	100 %

Sources:

a. The American Institute of Architects, Energy and the Built Environment: A Gap in Current Strategies, 1973. Uses data from the Stanford Research Institute reflecting 1968 consumption estimates.

b. Hartman, David L., "Ways to Save When Using Heating and Cooling Equipment," in Low-Cost Energy Efficient Shelter, Edited by Eccli, Rodale Press, 1976, p. 222. 1975 U.S. energy-sector consumption estimates.

c. ASHRAE, Energy Conservation in New Building Design, An Impact Assessment of ASHRAE Standard 90-75, 1975. Data for typical conventional residential construction. End point electric energy use only, does not include source energy, but is weighed by region. Based on computer simulations by Wind Lindquist, Inc.

d. Energy use in conventional dwelling assumed by Moreland Associates for purposes of this study.

FIGURE 2

right represents the energy distribution for conventional dwellings assumed in this report. The higher consumption for cooling acknowledges a trend toward more widespread summer tempering, and population growth in areas of traditionally higher cooling requirements.

To illustrate the range of future United States energy demands which might result from the construction of earth-covered buildings, a simplified model of the dwelling unit stock of the United States has been created. Data on the number of dwelling units, their replacement rate, new dwellings constructed, energy embodiment and ongoing energy use distribution were taken from several sources. The base data are primarily for the year 1975.

In order to model the introduction of earth-covered dwellings in terms of energy use, all conventional dwellings are assumed to have the same distribution of energy demand as the residential energy sector and each conventional dwelling is assumed to consume an equal portion of the residential energy sector demand. The earth-covered dwelling is represented in the model as a variation of the embodied energy and operational energy demand of the conventional dwelling (Figure 3). The embodied energy of the conventional dwelling and earth-covered dwelling has been calculated in the Energy Requirements section of this report. Earth-covered dwellings might, as the result of improvements in technology, reduce their embodied energy requirements to the level of conventional construction.

The reductions for energy use in the earth-covered dwelling listed in Figure 3 are representative of the United States as a whole.[4] No life-style changes or changes in other energy use are included in Figure 3. There is, however, some justification to believe that reductions in other energy use are widespread in earth-covered dwellings.[5]

Several possible futures dealing with the introduction of earth-covered buildings have been explored. Figure 4 is a plot of long-term trends in

Comparative Energy Use of Conventional And Earth-Covered Dwellings In The United States			
Consumption Sector	Conventional Dwelling	Earth-Covered Dwelling 3' Earth Cover	
	Energy Units Used	Energy Units Used	Percent Reduction Assumed
Heating	50	15	70%
Cooling	15	5	70%
Hot Water	15	15	0%
Lighting	7	7	0%
Cooking	5	5	0
Misc.	8	8	0
Total	100	55	
Source: From Figure 2 and estimates by Moreland Associates.			

FIGURE 3

dwelling unit stocks assuming earth-covered dwellings are introduced into the new building inventory in increasing numbers. Figure 5 is a plot of possible energy use resulting from the introduction of earth-covered dwellings. The following assumptions have been made with regard to Figures 4 and 5:

a. The introduction of earth-covered dwellings into the new construction follows an "S" curve with a slowly increasing percent of market followed by a mid-range of high yearly increase, tapering off as a market saturation of 75% is achieved.
b. The gross number of dwelling units is assumed to increase 1% per year until the 45th year at which time a no-growth period begins.
c. The replacement of conventional dwellings is 3.3% of the total dwelling unit stock until the zero-growth

period, wherein the conventional dwelling stock is maintained consistant with a 60-year life span. Earth-covered dwellings are assumed to have a life span of 300 years, therefore no replacement earth-covered dwellings are needed for a considerable time period.

d. The 1975 stock of dwelling units is approximately 79 million.[6]

e. The residential energy sector consumed 13.6 quads in 1975.[7]

f. Each conventional dwelling unit consumes 171 million BTU per year and embodies 1.127 billion BTU. Each earth-covered dwelling unit consumes 94.05 million BTU per year and embodies either 1.127 billion BTU or 1.55 billion BTU.[8]

Assuming the higher embodied energy derived in the Energy Requirements section of this report, the energy use in earth-covered dwellings is such that at 17 years the cumulative operational savings have paid back the additional embodied energy of the earth-covered building construction. At 35 years, the yearly energy savings are sufficient to create a reduction in the entire residential energy sector. If, as a result of improvements in construction technology, earth-covered dwellings energy embodiment roughly equals that of similar sized conventional dwellings (beginning at the five-year point), the cumulative operational savings will recoup the cumulative embodied energy on the sixth year. At 28 years, the yearly energy savings with earth-covered dwellings is sufficient to create a reduction in the residential energy sector. Figure 6 is a listing of the yearly and cumulative energy savings.

During the zero-growth phase the yearly savings are approximately 9 quads, partially as the result of the embodied energy consumed in rebuilding the then existing conventional dwelling unit stock. As an indication of the magnitude of energy reductions which might take place, the yearly savings at 15 years for the lower embodied energy option in Figure 6 is .5 quad, which is roughly equal to the output of 24 one thousand-megawatt nuclear power plants.[9]

Energy savings at the consumption endpoint frees up additional primary energy for other uses or for reserve. For example, according to the United States Bureau of Mines, 24% of the endpoint energy use in the residential sector is electrical energy which requires 45% of the

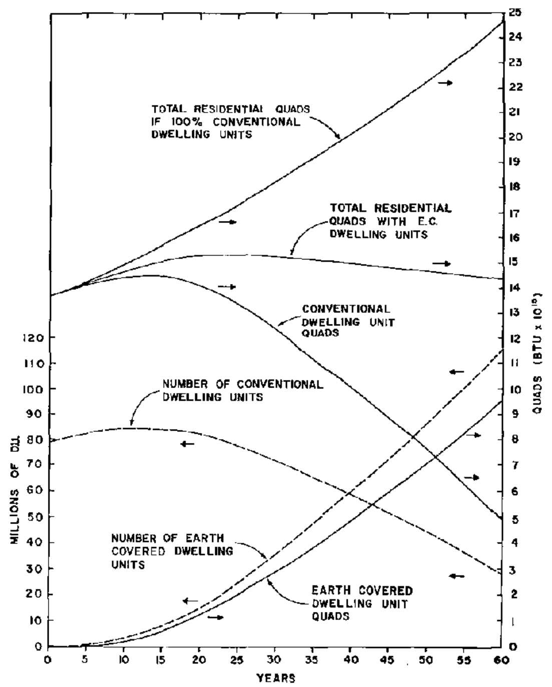
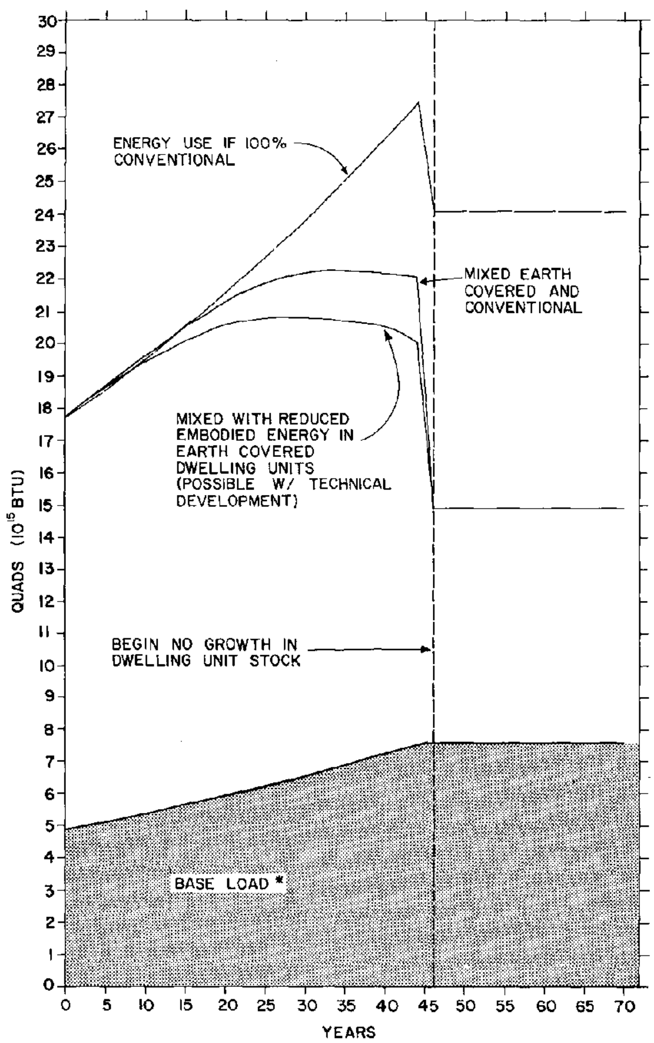


FIGURE 4 Introduction of Earth-Covered Dwelling Units into the Residential Stock



*Note: Base load includes hot water, lighting, cooking, and appliances.

FIGURE 5: Energy Impact of the Introduction of Earth-Covered Dwellings Into the Residential Sector

Quads of Energy Saved By The Introduction of Earth-Covered Dwellings*				
Year	E-C Dwellings With High Embodied Energy		E-C Dwellings With Low Embodied Energy	
	Quads Per Year	Quads Cumulative	Quads Per Year	Quads Cumulative
0	-0.009	-0.009	-0.009	-0.009
5	-0.036	-0.142	0.048	-0.057
10	-0.026	-0.319	0.194	0.572
15	0.065	-0.199	0.500	2.383
20	0.303	0.730	1.073	6.482
25	0.862	3.752	1.957	14.385
30	1.740	10.593	3.086	27.468
35	2.686	22.571	4.423	46.833
40	4.238	40.985	5.878	73.286
45	5.683	66.484	7.761	108.968
50	9.199	112.481	9.191	154.935
75	9.199	342.456	9.193	384.767
100	9.199	572.431	9.193	614.605
*Note: All other factors being equal. Includes both operating and embodied energy.				

FIGURE 6

primary energy attributable to the residential sector. One quad of energy is equivalent to the energy requirements of 5.8 million conventional dwelling units. That same quad of energy would operate approximately 11-million earth-covered dwellings.

In summary, changes in energy consumption related to the construction of dwellings and their subsequent energy use is a slow process, and one which can yield substantial energy savings. In the case of earth-covered dwellings, near term decisions will influence construction practices and energy use for time periods in the order of centuries.

Footnotes:

1. Vosbeck, R. Randal, FAIA, "Wombar Tomb? The Designers Role in the Energy Crisis," in The Potential of Earth Sheltered and Underground Space, edited by Holthusen, Pergamon Press, 1981.

2. This is illustrated clearly in Figure 10 of the Energy Requirements section of this report.

3. Stein, Richard, G., FAIA, Architecture and Energy, Doubleday, Garden City, New York, 1977, --. 2, 4.

4. This figure is based on interviews with a number of researchers across the nation including: Dr. Charles Kippenham at the University of Washington; Kathleen Vadnais the editor of Earth-Shelter Digest and Energy Report, who maintains a nation-wide data bank on earth-sheltered dwellings and buildings; Henryk Orlowski, a solar engineer with experience in prediction of thermal loads in earth-covered buildings. Additional references to the current research literature in the Energy Requirements section of this report also tend to support the position that with careful design and construction, such reductions are a conservative estimate.

5. Lester Boyer in his survey of earth-covered residences in Oklahoma, found that many occupants were content with reductions in heating and cooling energy use and did not modify any other energy use. Others did "live better on less" and had lower overall energy requirements. Moreover, earth-covered dwellings are often viewed as an alternative shelter type which attracts occupants who choose a less energy-intensive life style. Periodicals geared to low-energy lifestyles contain many ads for earth-covered dwellings or books about earth-covered dwellings.

6. Based on 1975 estimates of dwelling unit stocks in the Statistical Abstract of the United States, 1978 Edition.

7. From the Statistical Abstract of the United States and the sources listed in Figure I.

8. Based on calculations set out in the Embodied Energy subsection of this report. The variation in embodied energy in earth-covered dwellings is the result of speculation about the possible technology improvements which might take place in the near future.

9. This assumes a 70% duty cycle and does not take into account the energy embodied in the power plant itself or the difference in expected life spans between earth-covered buildings and nuclear generating facilities.

SUMMARY

Earth-covered buildings can reduce energy requirements for thermal tempering significantly in residential and institutional-sized buildings in most regions of the United States. Reductions of 50% to 75% in residences are common as are 50% reductions in institutional-sized buildings. Such reductions are the result of the characteristically high thermal mass, limited exposure of the building envelope to external climatic conditions, and the high degree of air tightness attainable in most earth-covered buildings. Moreover, earth-covered buildings are adaptable to a wide range of climatic conditions and design variations.

In terms of embodied energy, savings in day-to-day energy requirements can lead to short-term payback of the embodied energy cost of earth-covered buildings. More efficient use of materials via technology development could reduce the embodied energy of earth-covered buildings.

There appears to be no incompatibility between earth-covered buildings and either passive or active solar energy designs. Indeed, there is every indication that earth-covered buildings' reduced sensitivity to energy supply interruptions makes them amenable to solar energy, wind power, photovoltaics and a host of resources which are intermittent in nature.

Reductions in peak energy demands in earth-covered buildings have been observed in many locations and with many different designs. This can affect not only the

selection and operating costs of mechanical equipment, but ultimately reduce and stabilize local utility demands.

The long-term potential impact of earth-covered buildings, especially in terms of the United States residential energy sector transactions, can be significant. The construction of significant quantities of earth-covered buildings can lead to an overall reduction in energy consumed by buildings and result in long-term savings of several quads per year.

Additional Readings

Baca, R. G., I. P. King and W. R. Norton, "Finite Element Models for Simultaneous Heat and Moisture Transport in Unsaturated Soils," in Finite Elements in Water Resources, Pentech Press, London, England, 1978.

Baggs, S. A., "The Lithotecture of Australia with Special Reference to Use Health Factors," in Proceedings, Earth Sheltered Building Design Innovations Conference, Oklahoma City, Oklahoma, 1980.

Barnes, Paul R. and Hanna Shapira, "Passive Solar Heating and Natural Cooling of our Earth Integrated Design Proceedings," in Proceedings, Earth Sheltered Building Design Innovations Conference, Oklahoma City, Oklahoma, 1980.

Bligh, T. P., "Energy Conservations by Building Underground," Underground Space, 1,1: 48-62, 1976

Brownell, L. E., R. E. Isaacson, J. P. Sloughter and M. D. Veatch, Moisture Movement in Soils on the Hanford Reservation (Washington), NTIS, Springfield, VA, 1976.

Cary, J. W., "Soil Moisture Transport Due to Thermal Gradients, Practical Aspects," Soil Science, 30: 428-33, 1966.

Cary, S. W. and S. A. Taylor, "The Interaction of the Simultaneous Diffusion of Heat and Water Vapor," Soil Science, 26: 413-6, 1962.

Dempsey, B. J., "A Mathematical Model for Predicting Conference Heat and Water Movement in Unsaturated Soils," Geomechanics, 2: 19, January, 1978.

Diamond, S. C., B. D. Hunn, and T. E. McDonald, "Verification Methodology for the DOE-1 Building Energy Analysis Computer Program," Proceedings of the Conference on Systems Simulation and Economic Analysis for Solar Heating and Cooling, San Diego, California, pp. 186-189, June 1978.

Eagleson, T. S., "Climate Soil and Vegetation, Part 3, A Simplified Model of Soil Noisture Movement in the Liquid Phase," Water Resources Research Journal, 4: 722, October 1978.

Eckert, E. R., T. P. Bligh, and E. Pfender, Energy Conservation by Subsurface Construction. First Annual Report NSF-RA-760431, July 1976.

Eckert, E. R., T. P. Bligh, and E. Pfender, "Energy Exchange Between Earth Sheltered Structures and the Surrounding Soil," Proceeding of the Earth Sheltered Building Design Conference, Oklahoma City, April 18-19, 1980.

Eckert, E. R., E. Pfender, "Heat and Mass Transfer in Porous Media With Phase Change," Proceedings of 6th International Heat Transfer Conference, Toronto, Vol. VI, 1978.

Emery, A. F., et al., "The Optimal Energy Design of Structures by Using the Numerical Simulation of the Thermal Response with Emphasis on the Passive Collection of Solar Energy," Energy and Buildings, 1: 367-382, 1977.

Jury, W. A. and E. E. Miller, "Measurement of the Transport Coefficients for Coupled Flow of Heat and Moisture in a Medium Sand," Soil Science, 38: 551-557, 1974.

Kemper, W. D., W. R. Walker and J. Sabey, "Trans-seasonal Storage of Energy in Moist Soils," DOE Solar Energy Options Conference Proceedings, San Antonio, Vol. 1, pp. 155, March 1979.

Kirkham, D. and W. L. Powers, Advanced Soil Physics, Wiley Interscience, 1972.

Kusuda, T., "NBSLD, The Computer Program for Heating and Cooling Loads in Buildings," NBS Building Science Series 69, 1976.

Kusuda, T., "Thermal Response Factors for Multi Large-Structures of Varoius Heat Conduction Systems," Transaction ASHRAE No. 2180, Vol, 75, Part I, 1969.

LaRosa, R., "Local Soil Warming by Solar Energy," Proceedings of the Miami International Conference On Alternate Energy Sources, December 1977.

Lytton, R. L. and Ramesh Kher, Prediction of Moisture Movement in Expansive Clays, Research Report #RR-118-3 University of Texas, Austin, pp.226, May 1970.

Penrod, E. B. et al., "Earth Heat Pump Research Part I," University of Kentucky Engineering Experiment Station Bulletin, Vol. 4, No. 14, pp. 1-64, December 1949.

Penrod, E. B., "Measurement of the Thermal Diffusivity of a Soil by the Use of a Heat Pump," Journal of Applied Physics, Vol. 21, No. 5, pp. 425-427, May 1950.

Penrod, E. B., J. M. Elliott, and W. K. Brown, "Soil Temperature Variation," Soil Science, 90: 5, pp. 275-283, November 1960.

Rose, C. W., "Water Transport in Soil With a Daily Temperature Wave, Theory and Experiment, Analysis," Australian Journal of Soil Research, 6: 31-57, 1968.

Schlosser, K., and T. Bjorn, "A Mathematical Simulation of a Solar Assisted Heat Pump System Using the Ground for Energy Storage," Energy and Buildings, 2:1, p.37 January 1979.

Stephenson, E. G. and G. P. Mitalas, "Calculation of Transient Heat Flow Through Walls and Roof," ASHRAE Transactions, 74: Part II, 1968.

Wistinghausen, N., "Ground House, A Low Cost Solar Home," Proceedings of Annual Conference of The Solar Energy Society of Canada, Vol. 1, Paper 8.3.4, August 1978.

PART IV ENVIRONMENTAL QUALITY

ENVIRONMENTAL QUALITY

Douglas Cargo

> In theory, the use of earth-covered buildings would dramatically alter the energy budget of a city by increasing the vegetation cover, and thus the capture of somatic energy by green plants; and by making use of the atmospheric energy captured by the earth, to modify the need for extra-somatic energy to heat and cool buildings. Energy budget studies on this scale are essential to understanding the overall impact of alternative patterns of urban development.[1]
>
> Royce LaNier

INTRODUCTION

The advent of earth-covered buildings as an alternative to traditional building options occurred during the mid 1970s. There are many reasons that earth-covered building alternatives have become a reality. Historically, when a person thought of earth-covered buildings, the ideas of basements, storm cellars or bomb shelters often came to many minds.[2] Likewise, the concept of a basement or earth embankment around building walls in the Southwest did not gain acceptance until just a few years ago.

New architectural designs, coupled with some examples of earth-covered buildings, have changed many people's minds concerning such alternatives. With these changes came the removal of the "cave concept." The "cave concept," as I will call it, was the stereotypical image that popped into people's minds when discussions regarding earth-covered housing (buildings) took place. They pictured a tunnel-like structure with no windows, gray, stone walls, and a cold, dark and damp environment. This "cave concept" is now passe, and it does not apply to the alternatives discussed in this study nor the facilities such as department stores, shopping centers, office buildings, houses, parking garages, subways, or libraries which are earth-covered (i.e. underground) and which are used on a regular daily basis by thousands of people.

Earth-covered buildings are not just "pipe dreams" not futuristic plans of space writers. They are a realistic alternative to traditional building design.

Further, earth-covered buildings have had renewed interest because of their obvious benefits in terms of disaster and hazard protection. Tornadoes such as the one which devastated Wichita Falls, Texas, in 1979 and in other areas, have helped focus attention towards housing alternatives.

The environmental decade of the 1970s and its attention towards conservation, materials shortages and price increases, life-cycle cost, open space, and pollution problems all help to show how well-suited earth-covered buildings really are.

One of the biggest pushes in the use of earth-covered buildings, however, came as a result of energy shortages and dramatic increases in the costs of energy. Indeed, some of the first strong interest in earth covered buildings and houses came as a direct reaction to these increases and concerns regarding energy.[3]

The purpose of this part, however, is not to justify earth-covered buildings for the reasons of energy, efficiency or safety. The purpose here is to evaluate earth-covered buildings as they effect, both positively and negatively, the quality of the environment. Several major environmental areas will be discussed. These include: ground and ground water effects, air and climate effects, and vegetation effects. Most of the comments will be addressed to entire subdivisions or larger developments of earth-covered buildings.

SOIL AND GROUNDWATER EFFECTS

Because of the nature of earth-covered buildings and their designs, the effects upon the landscape (ground soil) surface and subsurface water (groundwater) is significant. That is not to say, however, that it is anymore significant than traditional aboveground development. Both kinds of developments have similar impact effects during the construction phase. However, earth-covered building becomes environmentally more sound during the life of the structure than does traditional aboveground developments. To this end, both construction phases and developed phases will be discussed.

Many of the ground and groundwater effects of earth-covered buildings have been discussed by Foute and Cargo.[4] Figure 1 from their paper summarizes some of the potential problems that could be anticipated at both "construction" and "development" phases. It should be noted, however, that all that is presented in the table could also be problems for traditional modes of building. It is clear that both earth-covered building and traditional-building types would vary in amount of runoff, leading and soil transport, during construction and development phases. The overall considerations of time during both construction and development, however, would place earth-covered buildings at a much lower loading rate than traditional housing types. In terms of soil and ground water effect, earth-covered buildings would be better able to control the sediment loads to surrounding streams.

SOME ENVIRONMENTAL PROBLEMS OF EARTH-COVERED HOUSING	
Construction Phase	Developed Phase
<u>Drainage and Slope</u>	
1. Slope Changes a. Direction of slope b. Slope length c. Number of slope faces 2. Infiltration 3. Natural Drainage Ways Disrupted 4. Increased Runoff	1. Possible Water Accumulation 2. Nutrient Runoff 3. Natural Drainage Ways Disrupted 4. Changes in Peak Flow Characteristics 5. Increased Runoff
<u>Soils</u>	
1. Disrupted and Piled 2. Leaching 3. Soil Transport (wind; water) 4. Horizon Loss	1. Reduced Fertilities 2. High Energy Maintenance a. Fertilizers b. Pesticides and Herbicides c. Mowing
<u>Landforms</u>	
1. Site Limitation a. Too wet b. Too rocky c. Too steep d. Too-shallow soils 2. Site Configuration Changed (geometric)	
Source: Foute, Steven J., and Cargo, Douglas B., "Earth Covered Housing: Hydrologic and Pollution Consideration", <u>Earth Covered Buildings and Settlements</u>, Frank Moreland ed. U. S. Government Printing Office, 1978.	

FIGURE 1

While each specific site undergoing development has its own unique set of circumstances relative to soil, geology, slope, vegetation, water and climate, some general comments can be made which would reflect the desirability of an earth-covered building.

There is no doubt that, overall, earth-covered buildings would minimize the negative effects upon the natural environment. To this end, Figure 2 provides a partial list of those positive effects which could be anticipated from earth-covered buildings. Figure 2 highlights four major areas: Drainage and Waterways, Landform and Vistas, Soil, and Groundwater. Other typical areas could be itemized as well. These might include some of the typical water pollution problems such as presented in Figure 3. Figure 3 compares and contrasts typical water problems that might be anticipated from earth-covered building and other traditional building options. A quick review of Figure 3 would suggest that in terms of water-pollution potential, earth-covered building ranks much better environmentally than traditional building types.

Moreland's discussion of "An Alternative to Suburbia," discusses some of the "mildly technical" soil considerations of earth-covered buildings.[5] While he does not address pollution per se, he does discuss the effects of cooling that the surrounding soil has and its moderating effects upon the temperature that can be anticipated inside an earth-covered building. He states "...the soil surrounding an earth-covered building serves to reduce radically external climate heating and cooling demands for the building."[6] Little discussion was provided regarding the effects that different soil structure (i.e., clay, loam, sand, etc.) might have upon the earth-covered building site. In Moreland's defense, however, I am not sure any work has been done in this area.

POSITIVE SOIL AND GROUND WATER EFFECTS OF EARTH-COVERED BUILDINGS

Drainage and Waterways

1. Less runoff
2. Less non-point pollution
3. Less artificial drainage needed (culverts)
4. Waterways dynamics change very little (i.e. volume and velocity of water)

Landform and Vistas

1. Views are not disrupted by above ground buildings
2. Tendencies to smooth and terrace landscape lessened
3. Overall slope gradient remains the same
4. More natural looks, less cultural manmade look
5. No mass clearing for development

Soil

1. Soil moisture retained
2. Less area-wide soil disruption
3. Soil horizons and fertility maintained
4. Less soil displacement (fill and backfill)

Ground water

1. Aquifers recharge possible
2. Soil moisture retained
3. More surface area, therefore water retention

Source: Compiled by author.

FIGURE 2

COMPARISON OR EARTH-COVERED AND TRADITIONAL BUILDING AREAS TO TYPICAL WATER PROBLEMS		
TOPIC	EARTH-COVERED	TRADITIONAL
Impervious Surface Area	>5% most surface is pervious	25-35% typical suburban home (i.e. roof, drive, sidewalk, patios)
Slope Faces	Many in several directions. Different gradients.	Uniform - one general direction. Same gradient.
Run-off	Very little	Great because of impervious surface area
Non-point	Very little run-off; therefore, no non-point. (Possible if heavy quantities of fertilizer are applied.	Very great. Large amounts of run-off surface
Streams	Retain natural conditions	Often dredged, straighten, concrete lined
Erosion and Sediment	Smaller than traditional housing types because of fewer streets and more pervious surfaces	Varied - Large street non-point source load.
Source: Compiled by author.		

FIGURE 3

Possibly more than any other component of the material environment, the earth (i.e., ground, soil) that constitutes the site of an earth-covered building will influence the degree of environmental quality factors to be considered both during construction and after development of the site.

Soils vary greatly in a relatively short horizontal distance. Their slope, depth, permeability, structure, plasticity and shrinkswell potential all can play a vital role in the development of an earth-covered building. It is suggested that a soil scientist be consulted during the design phase of an earth-covered building so that any problems which might arise can be accomodated and resolved.

The Soil Conservation Service usually has the detailed information about soils in a local area. The kinds of data available are partially illustrated with Figure 4, Soil Survey Interpretations, which list not only the physical properties of a soil series in Northeast Texas called Woodtell, but also the best and poorest uses of the soil for certain kinds of activity.

In summary, the potential for soil and groundwater effects and problems with earth-covered building needs to be better considered and reviewed before and during construction. The total effect or impact of earth-covered building may be less than traditionally developed areas, but the site and local conditions are often the determining factors.

TX0145 S O I L   I N T E R P R E T A T I O N S   R E C O R D

MLRA(S): 85, 81 BRACKETT SERIES
REV. GEL,FLG, 10-70
TYPIC USTOCHREPTS, LOAMY, CARBONATIC, THERMIC, SHALLOW

THE BRACKETT SERIES CONSISTS OF WELL DRAINED, GENTLY SLOPING TO STEEP, SHALLOW SOILS ON UPLANDS. THE SOIL FORMED IN INTERBEDDED LIMESTONES AND MARLY EARTH. IN A REPRESENTATIVE PROFILE, THE SURFACE LAYER IS LIGHT BROWNISH GRAY LOAM ABOUT 6 INCHES THICK. BELOW THE SURFACE LAYER AND TO A DEPTH OF 16 INCHES IS PALE YELLOW LOAM. THE LOWER LAYER FROM 16 TO 50 INCHES IS THINLY BEDDED WEAKLY AND STRONGLY CEMENTED LIMESTONE AND PALE YELLOW CALCAREOUS CLAY LOAM. SLOPE RANGES FROM 1 TO 20 PERCENT.

ESTIMATED SOIL PROPERTIES (A)

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLAS-TICITY INDEX
0-16	L, CL, GR-CL	CL, SC, GC	A-6, A-4, A-7-6	0-20	70-100	60-100	54-95	40-85	28-45	9-26
16-60	WB									

DEPTH (IN.)	CLAY (PCT <2MM)	MOIST BULK DENSITY (G/CM3)	PERMEA-BILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND EROD. GROUP	ORGANIC MATTER (PCT)	CORROSIVITY STEEL	CONCRETE
0-16	15-35		0.2-0.6	0.10-0.20	7.9-8.4	-	LOW	.32	2	4L	<1	HIGH	LOW
16-60													

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			20.0			-		10-20	SOFT	-		C	-

SANITARY FACILITIES (B)

SEPTIC TANK ABSORPTION FIELDS	1-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK,SLOPE
SEWAGE LAGOON AREAS	1-7%: SEVERE-DEPTH TO ROCK 7+%: SEVERE-DEPTH TO ROCK,SLOPE
SANITARY LANDFILL (TRENCH)	1-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK,SLOPE
SANITARY LANDFILL (AREA)	1-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK,SLOPE
DAILY COVER FOR LANDFILL	1-15%: POOR-AREA RECLAIM,SMALL STONES 15+%: POOR-AREA RECLAIM,SMALL STONES,SLOPE

BUILDING SITE DEVELOPMENT (B)

SHALLOW EXCAVATIONS	1-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK,SLOPE
DWELLINGS WITHOUT BASEMENTS	1-8%: MODERATE-DEPTH TO ROCK 8-15%: MODERATE-SLOPE,DEPTH TO ROCK 15+%: SEVERE-SLOPE
DWELLINGS WITH BASEMENTS	1-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-DEPTH TO ROCK,SLOPE
SMALL COMMERCIAL BUILDINGS	1-4%: MODERATE-DEPTH TO ROCK 4-8%: MODERATE-SLOPE,DEPTH TO ROCK 8+%: SEVERE-SLOPE
LOCAL ROADS AND STREETS	1-15%: SEVERE-LOW STRENGTH 15+%: SEVERE-LOW STRENGTH,SLOPE
LAWNS, LANDSCAPING AND GOLF FAIRWAYS	1-15%: SEVERE-THIN LAYER 15+%: SEVERE-SLOPE,THIN LAYER

CONSTRUCTION MATERIAL (B)

ROADFILL	POOR-AREA RECLAIM,LOW STRENGTH,THIN LAYER
SAND	IMPROBABLE-EXCESS FINES
GRAVEL	IMPROBABLE-EXCESS FINES
TOPSOIL	1-15%: POOR-AREA RECLAIM,SMALL STONES 15+%: POOR-AREA RECLAIM,SMALL STONES,SLOPE

WATER MANAGEMENT (B)

POND RESERVOIR AREA	1-8%: SEVERE-DEPTH TO ROCK 8+%: SEVERE-DEPTH TO ROCK,SLOPE
EMBANKMENTS DIKES AND LEVEES	SEVERE-THIN LAYER
EXCAVATED PONDS AQUIFER FED	SEVERE-NO WATER
DRAINAGE	DEEP TO WATER
IRRIGATION	1-3%: DEPTH TO ROCK 3+%: DEPTH TO ROCK,SLOPE
TERRACES AND DIVERSIONS	1-8%: LARGE STONES,DEPTH TO ROCK 8+%: LARGE STONES,SLOPE,DEPTH TO ROCK
GRASSED WATERWAYS	1-8%: LARGE STONES,DEPTH TO ROCK 8+%: LARGE STONES,SLOPE,DEPTH TO ROCK

REGIONAL INTERPRETATIONS

FIGURE 4

RECREATIONAL DEVELOPMENT (B)

CAMP AREAS	1-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-SLOPE,DEPTH TO ROCK	PLAYGROUNDS	1-6%: SEVERE-SMALL STONES,DEPTH TO ROCK 6+%: SEVERE-SLOPE,SMALL STONES,DEPTH TO ROCK
PICNIC AREAS	1-15%: SEVERE-DEPTH TO ROCK 15+%: SEVERE-SLOPE,DEPTH TO ROCK	PATHS AND TRAILS	1-15%: SLIGHT 15-25%: MODERATE-SLOPE 25+%: SEVERE-SLOPE

CAPABILITY AND YIELDS PER ACRE OF CROPS AND PASTURE (HIGH LEVEL MANAGEMENT)

CLASS-DETERMINING PHASE	CAPABILITY		OATS (BU)		WHEAT (BU)		IMPROVED BERMUDAGR. (AUM)									
	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.	NIRR	IRR.
1-5% L,CL,GR-CL	4E		20		10		2.0									
5-8% GR-CL,GR-L	6S		-		-		-									
8-30% GR-CL,GR-L	7S		-		-		-									

WOODLAND SUITABILITY

CLASS-DETERMINING PHASE	ORD SYM	EROSION HAZARD	EQUIP. LIMIT.	SEEDLING MORT'Y.	WINDTH. HAZARD	PLANT COMPET.	COMMON TREES	SITE INDX	TREES TO PLANT
							NONE		

MANAGEMENT PROBLEMS: EROSION HAZARD through PLANT COMPET.; POTENTIAL PRODUCTIVITY: COMMON TREES, SITE INDX

WINDBREAKS

CLASS-DETERMINING PHASE	SPECIES	HT	SPECIES	HT	SPECIES	HT	SPECIES	HT
	NONE							

WILDLIFE HABITAT SUITABILITY (C)

CLASS-DETERMINING PHASE	GRAIN & SEED	GRASS & LEGUME	WILD HERB.	HARDWD TREES	CONIFER PLANTS	SHRUBS	WETLAND PLANTS	SHALLOW WATER	OPENLD WILDLF	WOODLD WILDLF	WETLAND WILDLF	RANGELD WILDLF
	POTENTIAL FOR HABITAT ELEMENTS								POTENTIAL AS HABITAT FOR:			
1-5% L,CL,GR-CL	FAIR	GOOD	FAIR	-	-	FAIR	POOR	V. POOR	FAIR	-	V. POOR	FAIR
5-8% GR-CL,GR-L	POOR	POOR	FAIR	-	-	FAIR	POOR	V. POOR	POOR	-	V. POOR	FAIR
8-30% GR-CL,GR-L	V. POOR	V. POOR	FAIR	-	-	FAIR	V. POOR	V. POOR	V. POOR	-	V. POOR	FAIR

POTENTIAL NATIVE PLANT COMMUNITY (RANGELAND OR FOREST UNDERSTORY VEGETATION) (D)

COMMON PLANT NAME	PLANT SYMBOL (NLSPN)	1-8%	8-30%			
		PERCENTAGE COMPOSITION (DRY WEIGHT) BY CLASS DETERMINING PHASE				
LITTLE BLUESTEM	ANSC2	40	30			
SIDEOATS GRAMA	BOCU	8	10			
TALL GRAMA	BOPE*	7	10			
TALL DROPSEED	SPAS	3	5			
INDIANGRASS	SONU2	5	10			
SILVER BLUESTEM	ANSA	5	5			
PURPLE THREEAWN	ARPU9	2	-			
SLIM TRIDENS	TRMU	2	5			
FALL WITCHGRASS	LECO	2	-			
HAIRY GRAMA	BOHI2	1	5			
OTHER PERENNIAL GRASSES	PPGG	5	-			
OTHER PERENNIAL FORBS	PPFF	10	5			
OTHER TREES	TTTT	6	15			
OTHER SHRUBS	SSSS	4	-			
POTENTIAL PRODUCTION (LBS./AC. DRY WT):						
FAVORABLE YEARS		4,000	3,000			
NORMAL YEARS		3,200	2,200			
UNFAVORABLE YEARS		1,800	1,500			

FOOTNOTES

A ESTIMATES BASED ON ENGINEERING TEST DATA OF 2 PEDONS FROM TRAVIS AND BOSQUE COUNTIES, TEXAS. GR-L IS ALSO TEXTURE.
B INTERPRETATIONS BASED ON NATIONAL SOIL HANDBOOK,PART II,SEC.403,MAR.1978.
C WILDLIFE RATINGS BASED ON SOILS MEMORANDUM-74,JAN.1972.
D 1-8%:ADOBE;8-30%:STEEP ADOBE RANGE SITE.

FIGURE 4 (continued)

AIR AND CLIMATE EFFECTS

Any changes in the surface configuration of any areas, whether the changes are buildings, trees, concrete, grass or lakes, have the effect of changing the amount of heat which is absorbed or reflected by the surfaces, the flow of horizontal movement of the air (i.e., wind), and changes in humidity. Many of these factors, when analyzed over a large urbanized area such as Chicago or Los Angeles, play a very important role in the day-to-day weather events, and most probably effect the longer term climatic effects as well. Singularly, each effect may cause so little change that no notice of change can be measured. Collectively, however, they produce very noticeable change. It is not clear, however, that a subdivision or two will make changes in the surrounding atmosphere to have very dramatic effects upon the local weather or climate regime. What is clear, however, is that changes do occur. These changes, no matter how significant or insignificant, are the basis of this discussion.

Plants Control Solar Radiation

The amount and kind of plant cover help to control unwanted or excess solar radiation in at least four ways:

1. Absorption
2. Reflection

3. Radiation
4. Transmission

As earth-covered housing areas usually have larger total amounts of vegetation (i.e., trees or grass) than hard surfaces such as concrete, sidewalks, drives and streets, wood walls and roofs, the amount of solar radiation absorbed, reflected, and radiated varies considerably from traditional housing developments.

Vegetation absorbs larger amounts of solar radiation than is reflected. The canopy of trees or other vegetation can reduce solar radiation by a very large percentage, providing a cooling effect on the ground surface. The interception of solar energy by vegetation may completely block the sun's rays or filter them.

Albedo, or the reflectivity of a surface, varies greatly depending on the surface itself. For example, the percent of reflection of fresh snow is about 80-95% whereas the albedo (reflectivity) of meadows and fields is about 15-25%. Such reflections have an impact upon the local temperatures of the surroundings, the ground and buildings. Since earth-covered housing usually has very few high reflective surfaces and because the incoming solar radiation will be absorbed by vegetation, earth-covered building areas would tend to be cooler as the amount of evaporation and its associated cooling effects. The effects of shading would also tend to keep the surroundings cooler. In terms of micro-climate in urban areas, "heat islands" effect might be reduced.

Earth-covered building areas would retain moisture at a much higher rate than would conventional housing developments. In doing so, the rates of transpiration and evaporation would normally be much higher and thus tend to moderate surrounding temperatures--humidity extremes.

Wind

Anytime a barrier is placed such that horizontal movement of air is changed, a potential for micro-climatic changes also exists. Buildings, trees, hills, valleys, all will intercept and divert air movements. As interception occurs, wind can be decreased or increased in velocity. A wind-shelter area might be created. The configurations of all trees, buildings, and other natural or manmade obstacles combined to make the associated wind and air current patterns. Each situation is different. In cold regions, as wind speed is decreased, air temperatures would be inclined to increase a few degrees. The converse to this would be a decrease in temperature where wind velocities increase. Much of the temperature change is dependent on the rate of evaportranspiration that takes place. Some earth-covered buildings would tend not to block the flow of air as other surface buildings might, thus the overall velocity of the wind would tend to be less effected. This, however, would vary according to the amount of vegetation in an area, thus wind-temperature effects would be designed in.

The principal uses of vegetation and their resulting effects on the air and micro-climatic areas of earth-covered buildings can be summarized in six ways:

1. Large and small trees and shrubs may be used to screen out undesirable winds; conifers should be used to control winter winds.

2. Trees may be used to channel winds, to increase ventilation in specific areas.
3. Plantings will reduce the accumulation of snow on the ground, and so may be used to shield a solar collection unit.
4. Vegetation, especially needle-leaved trees may be used to capture fog, and thus increase sunlight reaching the ground or the collector unit.
5. Deciduous trees will screen out direct sunlight during the summer, to reduce required cooling loads, but allow it to pass through in the winter, reducing required heating loads.
6. Planted areas will be cooler during the day, and experience less heat loss at night.[8]

Summary

There is no doubt that overall, earth-covered buildings have much more positive environmental effects than negative. The positive environmental effects are far and above any similar effects which traditional single-family housing has.

Footnotes:

1. Royce LaNier, "Earth-Covered Buildings and Environmental Impact," The Use of Earth-Covered Buildings, edited by Moreland, National Science Foundation, 1976.
2. For a more detailed historical discussion of earth-covered buildings, consult Kenneth Labs' article, "The Use of Earth Covered Buildings Through History" in Alternative in Energy Conservations: The Use of Earth Covered Buildings, The University of Texas at Arlington, Texas, 1975, pp. 7-20.
3. See: Alternatives in Energy Conservation: The Use of Earth Covered Buildings, The University of Texas at Arlington, Texas, 1975.
4. Steven J. Foute and Douglas B. Cargo, "Earth Covered Housing: Hydrologic and Pollution, Considerations," Earth Covered Buildings and Settlements, editor Frank L. Moreland, Department of Energy, National Technical Information Source (CONF-7805138-p2), Springfield, Virginia, 1979, pp. 108-124.
5. Frank Moreland, "An Alternative to Suburbia," The Use of Earth Covered Buildings, The University of Texas at Arlington, Texas, 1975, pp. 197-204.
6. Ibid, p. 197.
7. Gary O. Robinette, Plants/ People/ and Environmental Quality, U.S. Department of the Interior, National Parks Service, Washington, D.C., 1972.
8. Landscape Planning for Energy Conservation, Gary O. Robinette, editor, American Society of Landscape Architects Foundation, Environmental Design Press, Reston, Virginia, 1977.

References:

Leopolad, Aldo, A Sand County Almanac, Ballentine Books, New York, Ninth Printing, 1976.

Moreland, Frank L., (editor), Earth Covered Buildings and Settlements, Department of Energy, NTIS (CONF-7805138-p2), Springfield, Virginia, 1979.

Moreland, Frank L., Alternative in Energy Conservation: The Use of Earth Covered Buildings, The University of Texas at Arlington, Arlington, Texas, 1975.

Robinette, Gary O., (editor), Landscape Planning for Energy Conservation, American Society of Landscape Architects Foundation, Environmental Design Press, Reston Virginia, 1977.

Robinette, Gary O., Plants/People/and Environmental Quality, U.S. Department of the Interior, National Parks Service, Washington, D.C., 1971

PSYCHOLOGICAL RESPONSE TO EARTH-COVERED HOUSING

Robert B. Bechtel

Although underground housing has a long history in several countries of the world such as China, Morocco and Turkey,[1] the concept is seen as new and untried in the United States. From a psychological point of view, any new concept presents the problem of public acceptance. Any innovative way of doing such traditional things as designing and building houses requires a basic level of public acceptance that goes beyond any technical requirement. The product may be technically superior and economically desirable, but if it is not accepted by the intended public, it stands as a failure. The psychological acceptance of underground housing, then, is potentially more critical than the technical feasibility or energy-saving potential.

Research on the acceptance of underground housing has been scarce. To date, (1981), only four studies bear directly on acceptance of underground housing, two in the United States, and two in Australia. Yet even these few studies point in certain directions that help define the parameters of the problem. These parameters seem to lie in four areas: 1) The image of underground housing in the public mind, 2) The problem of windowless space, 3) The social class associations with underground housing, and 4) The conflicting criteria between engineering and human factors requirements.

The Image of Underground Housing

By all indications, the phrase underground housing seems to have negative connotations. Dictionary definitions and library classifications associate underground dwellings with cave dwellers and crude human conditions. Morocco and China look upon their native troglodytes as backward types who must be upgraded in both housing and cultural life.

An example of this stereotyping is Bligh's questioning of 80 workers in an underground department store.[2] When asked if they would like to work in a subterranean environment, the majority said they would not like it; but when it was pointed out that 30 were already working below the surface, the workers changed their minds. Sommer found that people who work underground reported feeling like "moles."[3]

These two studies illustrate the negative image of underground dwelling, but the Bligh study at least demonstrates that the fact of underground dwelling shows some promise of alleviating that negative stereotype. In any case, it appears that the use of the term underground as a verbal cue sets off many negative associations, yet terms such as earth-covered or earth-insulated, may not evoke the same negative responses. There is some further evidence for this conclusion in the later studies cited below.

Windowless Space

Research done on environments without windows provides data that are useful for considering responses to underground environments that are themselves windowless. Of course, since most underground housing will not be windowless, these data do not apply. It is, nevertheless, instructive to reinforce the conclusions about why underground housing should not be windowless.

Earlier research on windowless schools show that children suffer no ill effects from learning in such schools.[4] Lutz reports favorable results on children in New Mexico who attended an underground school with windowless classrooms.[5] Generally, however, the findings are that windowless environments become troublesome to occupants in direct relationship to the amount of leisure time. The more activity required, the less troublesome was the lack of windows. These results suggest that housing, where occupants can be completely inactive at times, should not be windowless. This suggestion is supported by data collected from three sites. One study was done for the U.S. Navy anticipating earth-covered housing at two Naval Air Stations, Yuma, Arizona, and Fallon, Nevada.[6] Given choices of the four housing types illustrated in Appendix A, respondents chose the ranch-type house they were most familiar with and overwhelmingly rejected a windowless, totally underground structure (Figure 4). However, 44% in Yuma and 40% in Fallon picked a partially underground house (Figure 2) as their first choice. McKown and Stewart report similar results in a non-random survey of persons attending an open house for an underground dwelling in South Carolina. Respondents showed interest in a courtyard design that permitted light to enter all rooms of the house (similar to Figure 3).[7]

It is also worth noting that both the Chinese and Tunisian underground plans show individual or group houses facing a courtyard.[8]

Given the present state of the art, which is not voluminous, the available evidence would point to a partially below-grade design that permitted the maximum amount of natural light as an approach that could gain public acceptance.

Social Class and Underground Living

At certain locations in the world where wood and stones were not convenient for building, underground housing became a viable mode for human dwelling. Unfortunately, since these dwellings preceded modern technology, they became associated with backward, "lower class" populations. The Mamata of Tunisia, for example, are being forced to evacuate their underground homes for "upgraded" aboveground dwellings. And recent attempted negotiations with Chinese scientists to study the millions of people living underground in Kansu Province have not succeeded because the Chinese regard them as something of an embarrassment.

Fortunately, in the United States, underground housing has become associated with upper-class, prestige dwellings. The average underground house is seen as more expensive than the average house.[9] This means that underground houses do not suffer from a negative image in the specific sense and are not necessarily subject to the negative image of the verbal cues if they are labeled earth-sheltered, etc. Probably the biggest stumbling block at present is the unwillingness of financial institutions to loan money for their construction because of a lack of experience in resale markets.[10] Nevertheless, the fact that earth-sheltered housing is associated with middle- and upper-class status is a decided advantage for promotion of any new concept.

Engineering vs Human Factors Requirements

The first designs for housing to be built by the U.S. Government were in a demonstration project in Minneapolis. Results from this study are not yet available and do not include psychological acceptance.

The second demonstration of underground housing sponsored by the U.S. Government was the meso-quadraplex housing at the two Naval stations mentioned previously. These designs were intended to conform to human needs from the beginning. The architects generated eight different prototypes for the quadraplex, incorporating the knowledge available for energy-savings, construction-savings on cost and human factors. These eight prototypes were then rated independently by three architect/engineers who were conversant with energy and construction costs, and by three social scientists who had considerable experience in evaluating housing for human needs. The correlation between the mean ranks given by the architect/engineers and the social scientists was -.8, indicating a statistically significant difference.[11] In other words, the two groups rated the eight prototypes in opposite ways; the architect/engineers would pick designs which were energy conserving and cheaper to build but lack privacy and other features. The social scientists would do the opposite and pick designs that emphasized privacy and other features but which were not energy conserving and were more expensive to build.

The final design for the quadraplex was a compromise that permitted an energy savings of 45% without sacrificing privacy and other human requirements. This is an important principle to keep in mind while designing underground dwellings: the final design may be a compromise between these two competing needs, the engineering efficiency vs the human factors. The preference for partially underground housing, as opposed to totally underground, is the best example of such a compromise.

Human factors considered in the Yuma and Fallon studies were as follows:

1. Garage near door of most common entry (presumably the kitchen).
2. Patio or courtyard for children's play.
3. Outdoor space for socializing (barbecue, parties, etc.)
4. Large kitchen, large bathroom with storage space, large living room.
5. Separate utility room.
6. Separate storage room.
7. Entrances without blind spots (presumably to see who is coming).
8. Water heaters away from entrances.
9. Back entrance not going through the kitchen.
10. Windows for fresh air and sunlight.
11. Trees and landscaping.

Prospective occupants also mentioned such hardware items as good screen doors, good door locks, insulating glass, protective film on glass, ceiling lights in every room, non-accordion type closet doors, smoke alarms, stairs with bannisters and a non-stucco outside finish. The final prototype attempted to incorporate all of these features.

It must also be noted that human needs can differ with time and experience. Baggs' recent study illustrates that the preference for aboveground housing may be altered by the experience of living in underground housing.[12] Baggs took the same illustrations from Appendix A used in the Yuma and Fallon studies and asked the same preference questions of 48 Australians living underground in Coober Pedy.[13] The Australians also picked house Number 3 in the same ratio as the United States respondents. 48% made it their first choice. But 44% picked house number 1, the ranch house, as their last choice because it was seen as too hot, needing air conditioners and the fact that it was aboveground. The Coober Pedy residents lived in soft limestone "dug-outs" which could be quite elaborate, and even included swimming pools. They did not require air conditioning even in the extreme heat of the Australian desert because the completely underground dwellings provided a relatively constant climate that was cool enough for human comfort. It may not be possible to understand all the reasons the Australians differed from the United States subjects in their negative preference for the ranch house type, but what is important is that such a difference exists. Just as the Australians learned to prefer their dugouts, it may be possible that the preference for the ranch house was also learned and that the experience of living underground may change these preferences. Obviously, these are too few studies to permit drawing definitive conclusions, but they do point toward an acceptance of underground dwellings beyond the stereotypes.

Partially Below-Grade Earth-Covered Houses with Windows

To date, research on earth-covered dwellings is overwhelmingly in favor of the house with windows. The South Carolina study and the Yuma and Fallon studies previously mentioned involved dwellings that had windows. In the South Carolina study, the visitors went through a model house with windows and stated their preferences. In the Yuma and Fallon studies, the residents made a final selection from among three prototypes presented in scale model form. These models were constructed after residents answered questions about the four housing types presented in Appendix A. Each of the three prototypes had windows and the differences were largely in floor plan arrangements. The significant thing about all three studies was the assumption that windows were a necessary part of any earth-covered housing design.

One aspect that may be lost when windows are introduced is pointed out by Baggs.[14] While investigating the underground community of Coober Pedy, he found that the fully underground dwelling creates an air pressure that acts to keep out dust. In places such as hot deserts where there is a severe differential between outside and inside temperatures (in Australia this can be 72° vs. 150°), the cooler interior air is denser and creates a pressure which resists dust blowing inside. Baggs convincingly demonstrates this by dropping handsful of dust at the dugout entrance and showing that the dust always blows away from the opening.

The use of windows and other openings tends to mitigate against this effect but exactly how much is not known and more research is necessary. Nevertheless, it is clear that partially earth-covered houses with windows are the preferred design.

Notes on Community Design

The majority of United States residents prefer a separate single-family house to any other living combination. This preference is so strong that Bechtel and Ledbetter found residents would choose older, smaller dwellings, rather than live in larger apartments or housing combinations.[15] The reasons given were largely concerned with privacy. The preference for single-family dwellings creates problems of too little density. Greater density is more economical for construction cost, land use, transportation and energy consumption. Yet greater density is anathema to privacy. Nevertheless, careful design can go a long way toward reducing density without loss of privacy. Howroyd, in his design of Shay Gap was able to place the single-family houses within twelve feet of each other without residents being aware of the proximity.[16] This was accomplished by judicious use of yard fences for screening and placement of windows so that privacy was not compromised. Having a central air conditioning unit so that all windows could not be opened also helped.

The Yuma and Fallon studies involved quadraplexes which were designed so that each dwelling faced outward. With all windows in the house facing in one direction, as in the community designs suggested by Moreland, greater densities would be possible without violating privacy because visual access and accoustical intrusions are blocked by placement of windows, orientation of houses, and the sound-insulating properties of earth.[17] So far, all studies report that residents feel underground dwellings would be quieter. Hillsides would accommodate even greater densities because of the vertical placement of houses.

Some concern needs to be stated for the concept of informal surveillance. Oscar Newman promoted the principle of defensible space as a method of improving the security of neighborhoods. This concept need not be contradictory to privacy. It means that the anonymous spaces in a community be eliminated and that all property in a neighborhood be clearly understood as belonging to some resident and visible to that resident from his home. This also requires a careful arrangement of windows and house placement so that the top of the partially underground house is not a total blind spot.

.The automobile is a critical element in designing underground houses. Because exhaust gases would accumulate, it would not be practical to have underground garages for each house. Residents in the Fallon and Yuma studies expressed a preference for having the automobile parked beside the kitchen or side entrance. This is similar to preferences in earlier studies.[18] Fulfilling this preference may place constraints on saving space in underground housing since one space-saving strategy would be to park the automobile overhead. Such a strategy would go against most residents who want to be able to see the automobile.

Cul-de-sacs are the most desired form of street arrangement for houses.[19] This preference is strongest among families with children and seems to be related to a concern for children's safety. Shay Gap is the extreme example of a community design with children's safety in mind.[20] The community was designed to limit automobile penetration to a perimeter road from which residents would have to walk to their houses. This strategy was so successful that parents worried their children would not develop sufficient fear of the automobile when they moved to less protected environments.

The use of a cul-de-sac makes strangers more visible. A strange automobile is more easily discerned where neighbors have a chance to become familiar with each others' cars and do not see passing traffic. The cul-de-sac is probably the most efficacious compromise between a residential grid pattern and the total auto prohibition of Shay Gap.

Two other less well understood elements of community design are relevant. One is the centrality of services, and the other is the behavioral focal point.

It is an accepted principle of community design to locate services so that they have maximum access to all residents. Usually this means locating services in the center of a community. Shopping malls, department stores and other facilities strive to obtain central locations. Indeed, real estate values are almost always directly located to centrality of location. However, the central location of facilities can interrupt a community when those services are intended to attract customers from outside the community itself. The result can be an invasion of strangers so that community relations become more strained. This is especially critical when a homogeneous community of elderly, for example, is invaded by younger families, or when a middle-class community is invaded by working-class people. A careful analysis of all the service components must be made prior to planning so that if certain services are intended to attract outside customers, then these services can be located on the community edge, thereby eliminating the necessity for transit through the community.

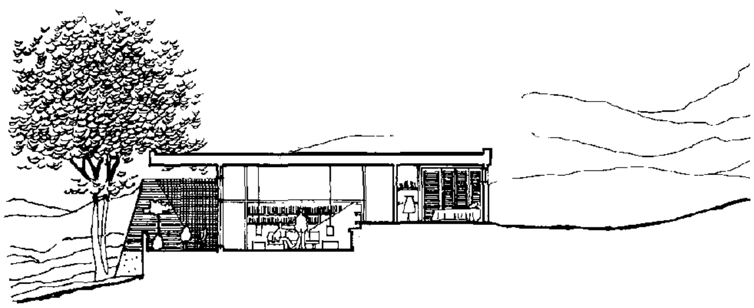
A behavioral focal point[21] is a geographical place where every member of the community has an opportunity to meet every other member of the same community face to face. It cannot be merely an empty space but must have some function that will attract people on a daily basis. A restaurant, drug store, post office, even a laundromat can serve the purpose. Small towns organize themselves socially around such focal points. They must have certain critical elements. There must be a physical building where the focal point can be accommodated. Services and facilities must be such that they provide anyone an excuse to go there at any time or at certain times when most people can go there. A regular flow of residents is necessary to make a behavioral focal point work. The residents should be able to meet face to face over coffee, shopping, or some other function. Weekly markets fulfill this purpose in old world villages. Drug stores and post offices often fulfill the purpose in Small Town, U.S.A.

In order for a community to function as a social entity, it must have a behavioral focal point designed to suit that community's needs. Good examples of behavioral focal points are the shopping center at Shay Gap,[22] and the light-well area of the Cape Lisburne Radar Station in Alaska.[23] The needs for a community of earth-covered houses are very nearly the same as those of a community of conventional housing. Privacy, access to facilities, safety and ability to function as a social entity are the basic requirements. However, special attention must be given to the placement of automobile spaces in the earth-sheltered community because visual access is more difficult. Nevertheless, placement of windows and use of hillside spaces seem especially suited to partially underground housing and may permit greater densities without violating any of the principles stated above.

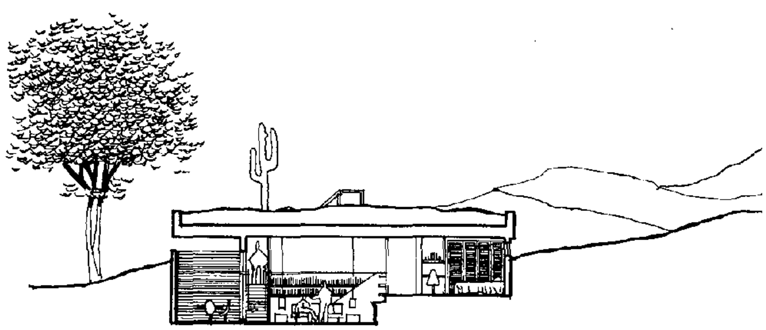
Conclusions

Although there does not exist a large and finally conclusive body of research on psychological acceptance of underground housing, the evidence does seem stable over several locations, and at least one other culture, to point to a clear preference for the partially below-grade earth-covered house that permits maximum natural light. Privacy and other human needs force a compromise between strict energy-saving and cost-saving requirements, and these compromises can result in designs that serve both sets of requirements.

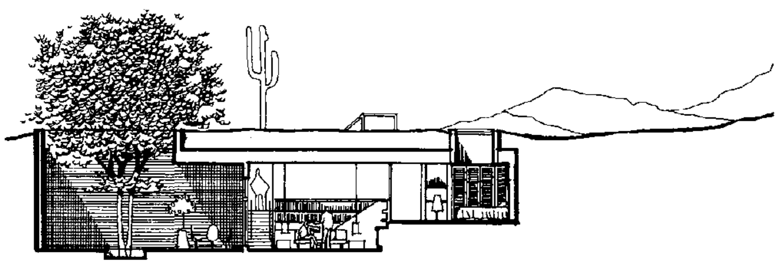
Appendix A



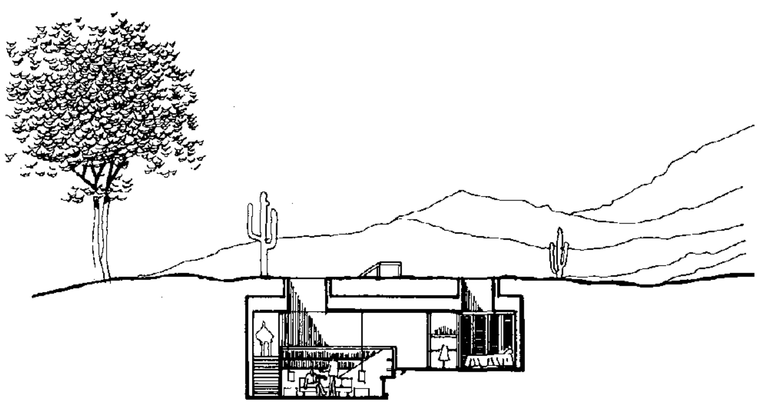
1. RANCH STYLE HOUSE



2. PARTIALLY EARTH COVERED



3. EARTH COVERED WITH COURTYARD



4. TOTALLY EARTH COVERED

Footnotes:

1. Labs, K., The Architectural Underground, Underground Space, Vol. 1, pp. 1-8, 1976.

2. Gorman, J., The Earth's the Ceiling, The Sciences, Vol. 16, pages 16-20, 1976.

3. Sommer, R., Tight Spaces, Prentice-Hall, 1974.

4. Larsen, T., (editor), SER 1, Environmental Abstracts, University of Michigan, 1965.

5. Lutz, F., Studies of Children in An Underground School, Alternatives in Energy Conservation, 1975.

6. Research on the Fallon and Yuma sites are from work done under contract to Earl K. Chann, architect, of Tucson, Arizona for the Department of Navy, Western Division Naval Facilities Engineering Command, Contract No. N62474-77-C-2788 and has not been published previously. Fifty families at each site were randomly selected. For each question answered there were varying numbers of persons answering because both wives and husbands responded at various homes. Each question was calculated for the exact number that responded.

7. McKown, C. and Stewart, K., Consumer Attitudes Concerning Construction Features of an Earth Sheltered Dwelling, Underground Space, Vol. 4, No. 5, pages 293-296, 1980.

8. Labs, K., The Architectural Underground, Underground Space, Vol. 1, pp. 1-8, 1976.

9. Earth Sheltered Housing Design: Guidelines, Examples and References, University of Minnesota, 1977.

10. Korell, M. L., Financing Earth-Sheltered Housing: Issues and Opportunities, Underground Space, Vol. 3, No. 6, pages 297-302, 1979.

11. The correlation coefficient was rho, the rank order correlation coefficient and the difference in mean ranks between the two groups was significant at the .05 level.

12. Baggs, S. A., Direct Survey of a Coober Pedy S. A. Sample, Personal Communication to the Author, November 28, 1978.

13. The Coober Pedy study by Baggs was done and reported solely to the author and these results also have not been previously published.

14. Baggs, S.A., Direct Survey of a Coober Pedy S. A. Sample, Personal Communication to the Author, November 28, 1978.

15. Bechtel, R., Ledbetter, C. B., Cummings, N., Post Occupancy Evaluation of a Remote Australian Community: Shay Gap Australia, Cold Regions Research and Engineering Ltd., 1980, Handover, New Hampshire.

16. Bechtel, R. B., Enclosing Behavior, Dowden, Hutchinson and Ross, 1977.

17. Moreland, Frank L., An Alternative to Suburbia in The Use of Earth-Covered Buildings, Moreland, editor, National Science Foundation, 1976.

18. Bechtel, R. B., Enclosing Behavior, Dowden, Hutchinson and Ross, 1977.

19. Bechtel, R., Ledbetter, C. B., Cummings, N., Post Occupancy Evaluation of a Remote Australian Community: Shay Gap Australia, Cold Regions Research and Engineering Ltd., 1980, Handover, New Hampshire.

20. Bechtel, R. B., Enclosing Behavior, Dowden, Hutchinson and Ross, 1977.

21. Ibid.

22. Bechtel, R., Ledgetter, C. B., Cummings, N., Post Occupancy Evaluation of a Remote Australian Community: Shay Gap Australia, Cold Regions Research and Engineering Ltd., 1980, Handover, New Hampshire.

23. Bechtel, R. B., Enclosing Behavior, Dowden, Hutchinson and Ross, 1977.

PART V ECONOMIC ANALYSIS

ECONOMIC ANALYSIS

Introduction

Present value analysis, as an approach to examining investment options, can be particularly useful in analyzing capital intensive and long-term investments such as building investments, and it is the basic perspective of this part of the study. Present value analysis begins by adding up the benefits and costs to be incurred over the expected life of a building. In summary of benefits and costs, future costs (and benefits) are "discounted," that is, they are not included at face value, but are reduced in value by an agreed upon sliding scale. The sliding scale reduces the value of future benefits and costs to the time of accrual in the future. Thus, future benefits or costs count less in the discounted present value analysis than do near-term benefits or costs.

The sliding scale used to reduce values of costs and benefits that accrue to future generations is called a discount rate. The selection of a particular discount rate constitutes a decision regarding the relative importance of the future for the purpose of analysis. A low number, for example 2.7, is thought of as a rate favorable to the concerns of future generations, while a rate of 9 is the opposite.

One popular formulation of discounted present value analysis is:

$$PV_o = \frac{B_1 - C_1}{1 + r_1} + \frac{B_2 - C_2}{(1+r_1)(1+r_2)} + \ldots\ldots + R$$

Put into words, this means that the present value of a project, as seen at a particular decision time (time 0), is the sum of all the net annual benefits (B_1) and costs (C_1) over the time of development and use, with future net benefits and costs taken to be increasingly less important over time. In theory, the discount rate, r, could be a different number in each time period; however, a single number is usually chosen. At the end of the equation there is a "+R", that is, any value remaining in the project or building at the time the analysis stops must be added. This value is known as the residual value (R) or as the salvage value.

This form of present value analysis includes as key elements the following ideas:

1. A time horizon: the period of time spanned by the analysis. The expected life span of the buildings under examination need not equal the time horizon, but long-time horizons are appropriate to long-lived capital-intensive projects, such as buildings. Long-term analysis is needed to put the stream of benefits and costs into perspective.
2. A discount rate: a rate used to reduce the importance of future benefits and costs to the present generation.
3. Inflation: included in the analysis by exogenously increasing the costs and benefits over time. Indeed, by specifying that the inflation rate for particular costs, for instance energy costs, be different from that of the general rate, one can explore the consequences of changes in relative prices as

well as overall inflation.

4. Benefits: In commercial structures, market value rents usually constitute the benefits. In some public projects, implied monetary values are used as benefits (see public policy literature for disaster shelters and public parks). In private housing, monetary benefits are often ignored in present value analysis, with the exception of residual value.
5. Costs: Costs are included as monetary requirements for construction, operation, and maintanance. The cost of physical damage insurance can be included as an estimate of such damage over the time of analysis. Taxation is usually included, but external or social costs are seldom examined.

Public policy enters the analysis most directly as taxation, with the results of alternative public policies made obvious.

NOTE: In capital-intensive and long-lived projects, one can find that alternatives with high initial costs may have an advantageous present value if the costs for maintenance and operation (M & O) are low. The present value calculations for such projects are particularly sensitive to the discount rate and time horizon.

Only the present value of housing is examined in detail in this study. There are two reasons for this: 1) to gather data in the sector of commercial buildings would exceed the resources available and would have to focus on many building types; and 2) to analyze buildings in the public sector, e.g., schools, would require inclusion of their social benefits in dollar terms, such as the social use of shelter space, and that is beyond this study. One can, nevertheless, make general observations about large earth-covered buildings in the public sector.

1. In actual cases, the initial costs for institutional earth-covered buildings have roughly equaled or have not exceeded the costs for conventional construction.[1]
2. There have been significant reductions in the operating, repair, and maintenance costs associated with actual earth-covered buildings.[2]

These two points indicate that the present value of public-sector earth-covered buildings can be economically favorable. Moreover, adding the benefits of shelter protection and long-term building life to the analysis may make the case for earth-covered buildings in the public sector compelling, subject to local conditions (see the building highlight section of the Introduction).

Because the peak energy load of earth-covered buildings will likely be both smaller and occur later in the day or season than that of conventional buildings, larger earth-covered buildings may also have lower energy-cost rates in some communities. Moreover, these buildings will generally require less air tempering equipment than their conventional counterparts have, and therefore, lower initial equipment cost and lower maintenance and operating costs. It is likely then that a detailed analysis of larger earth-covered buildings here would concur with the analysis of others.[3]

While the life-cycle cost (LCC) for many public buildings is usually very favorable, the LCC case regarding housing, particularly single-family detached dwellings, has been less sure. Therefore, a detailed LCC analysis for single-family detached dwellings was undertaken.

AN EXAMPLE: ECONOMIC ANALYSIS OF EARTH-COVERED DWELLINGS

The Ehrenkrantz Group (TEG) conducted an analysis of earth-covered dwellings for this study. For the purpose of this exploratory analysis, their study was limited to the examination of earth-covered dwellings in North Central Texas. Most of the data required for analysis were made available by Moreland Associates, consultants and practitioners. Other locales and other technologies will produce different data, and future research should explore them in detail. The TEG study compared conventional tract houses to earth-covered houses in the Central Texas region.

Two related approaches to analysis are used, the well-known Present Value Criterion (Method I) and the Internal Rate of Return (Method II). Both methods employ an after-tax, discounted cash-flow economic model, with Method I yielding the Present Values and Method II yielding internal rates of return (numbers comparable to stock earnings rates or profit rates).

Both methods count the residual or salvage value as the only benefit, which is typical for analysis of owner-occupied housing. Both methods include a summary of the costs associated with building, construction, and use; and the costs are discounted (increasingly devalued) over time. Both methods require that any residual value remaining in a building at the end of the time horizon be devalued the most, a point not favoring long-lasting buildings.

The economic model behind both of the methods assumes the following:

1. Initial (Capital or Construction) Costs:
   Building costs are normalized to a \$/sq. ft. base using an average building size of 1627 sq. ft. High- and low-cost tract houses are compared to two earth-covered houses.
   The low-cost tract house (\$38/sq. ft.) was compared to an earth-covered house with three feet of earth cover (\$52/sq. ft.). The higher cost tract house (\$42/sq. ft.) was compared to an earth-covered house with seven feet of earth cover (\$60/ sq. ft.). (See Appendix IV).
2. Energy Consumption:
   Energy consumption for heating and cooling in the earth-covered houses are assumed to be less than those in the conventional tract houses. Specifically, 65% less for the house with three feet of earth cover, and 85% for the house with seven feet of cover. These percentages were applied to an average fuel consumption for 39 metered conventional homes in the Fort Worth, Texas area. NOTE: The electrical rate was assumed to be the then current 2.8 cents/kwh (1980).[4]
3. Insurance Costs:
   Insurance rates for earth-covered houses are available with rates 25% lower than conventional homes,[5] a fact that tends to offset the often greater cost of earth-covered dwellings. The additional cost for insurance is based on a cost-per-dollar valuation of properties. Thus, an additional \$3.00/year will be spent to insure the more expensive 3 ft. option and an additional \$33.00/year for the 7 ft. option, even though the rates are 25% less.

4. Maintenance Costs:
   Maintenance costs for earth-covered houses are assumed to be less than for tract houses, specifically, 1.5% of the building value per year for the tract house, and 0.5% for the earth-covered dwelling.
5. Mortgages:
   At the time of analysis (1980), twenty-year mortgages at 11% interest with a 15% down payment were available in the Fort Worth area, and they are used in one analysis run. Also, two low-interest mortgages for the earth-covered dwellings are examined as an exploration of the impact of this traditional means of providing incentives (the rates are 5% and 8.25%). Another form of incentive, a 90-year mortgage, is investigated in the long-term analysis of the earth-covered houses.
6. Residual of Salvage Value:
   In the 30-year economic analysis period: Tract house salvage value is equal to half of the inflated cost of the tract house at the end of the analysis, less one-third for interior furnishings. Earth-covered house salvage value is equal to the inflated cost of the underground house at the end of the analysis, less one-third for interior furnishings. For Method II, salvage value is equal to the difference between the tract house and the underground house salvage values.

   In the 80-year economic analysis period: Tract house salvage value is equal to two-thirds of the inflated cost of the repurchased tract

house at the end of the analysis, less one-third for interior furnishings.
Earth-covered house salvage value is equal to the inflated cost of the underground house at the end of the analysis, less one-third for interior furnishings. For Method II, salvage value is equal to the difference between the repurchased tract house and the earth-covered house.

7. Economic Environments:
Fuel cost inflation rates are assumed to be:
20% for 5 years, 11% for 25 years for the third-year economic analysis period.
15% for 15 years, 10% for 65 years for the 80-year economic analysis period.
Discount rates of 5% and 8% are investigated:
General inflation rates are: 8% for the 30-year economic analysis period and 5% for the 80-year economic analysis.
The tax bracket for the homeowners is assumed to be 25%. Commercial and investor tax rates are not used since these homes are assumed to be owner occupied.

NOTES ON THE METHOD OF ANALYSIS:

The first method is a comparison of Present Value Totals for the earth-covered and tract houses. This model takes into account all of the major costs to the home buyer over 30- and 80-year economic analysis periods. The Present Value Totals for the earth-covered buildings are compared directly to the totals for the tract houses. The difference between the values indicates the relative benefit of choosing one building over another. This method acknowledges the need to replace the tract house after its 60-year estimated life.[1]

The second method treats the choice of building an earth-covered house as an option which will add an additional cost to the purchase of a home. This cost will be offset by savings produced by the option in energy and maintenance. All costs and savings have been normalized to a $/square foot basis. This method results in a Payback Period for the option and an Internal Rate of Return on the investment in an underground house.

Three different mortgage structures, two discount rates and long- and short-term analysis are investigated in these comparisons. In Method II, the capital cost is the difference between the cost of the earth-covered house and the tract house. In Method I, the entry under ENERGY SAVINGS is input as a negative number, therefore it becomes a COST. The entry under MAINTENANCE COST is input as a negative value in Method II, therefore, it becomes a SAVINGS.

RESULTS:

The results of the TEG analysis are presented in the following figures. In the cost-comparison curves in Figure 1 through Figure 4, the 30-year and 70-year costs of conventional tract housing are compared to costs of the custom-built earth-covered dwelling construction.[7] The curves are plotted on log-graphs.

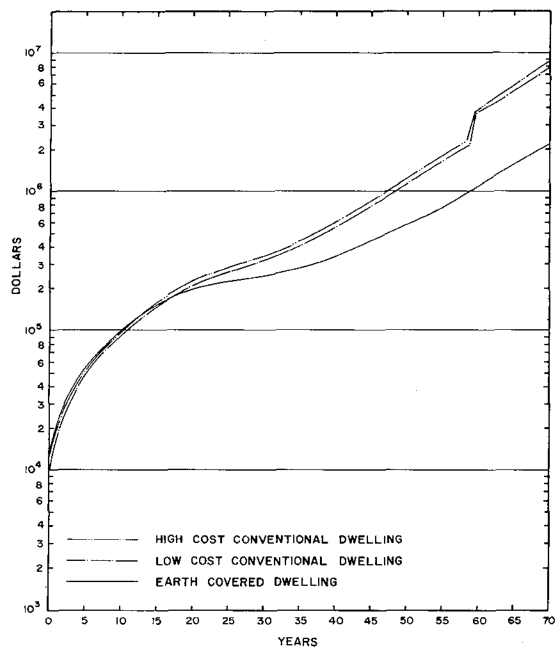


FIGURE 1

Yearly Costs, Noncumulative
11%, 20-yr. Mortgages & No Discounting

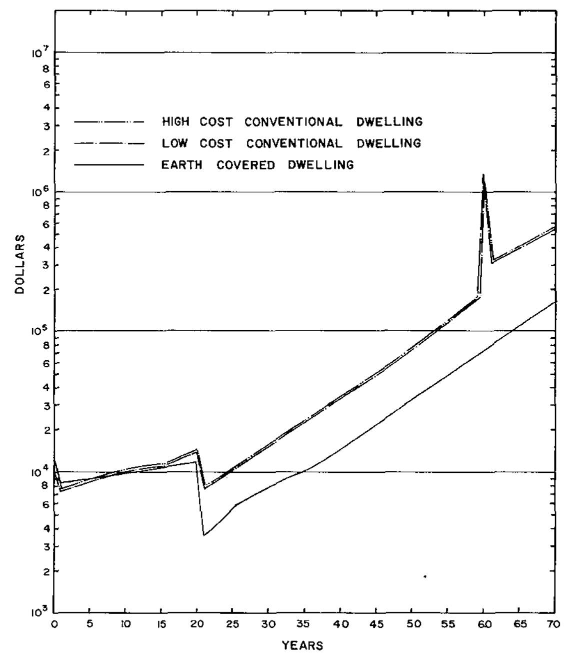


FIGURE 2

Yearly Costs, Cumulative
11%, 20-yr. Mortgages & No Discounting

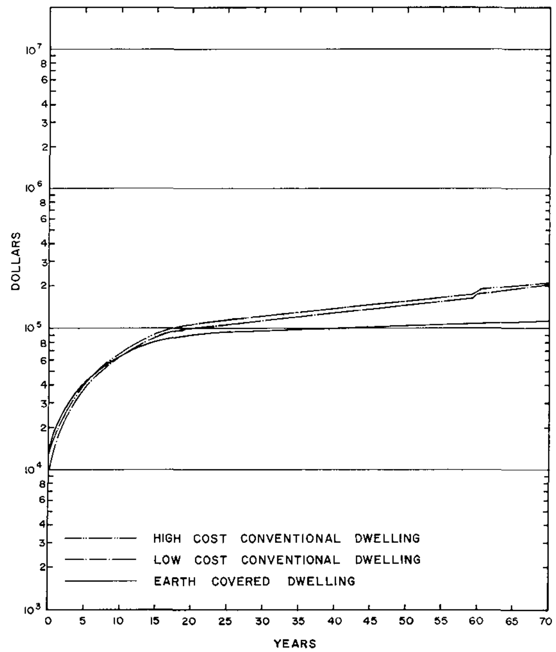


FIGURE 3

Cumulative Costs With 8% Discount Rate
11%, 20-yr. Mortgages

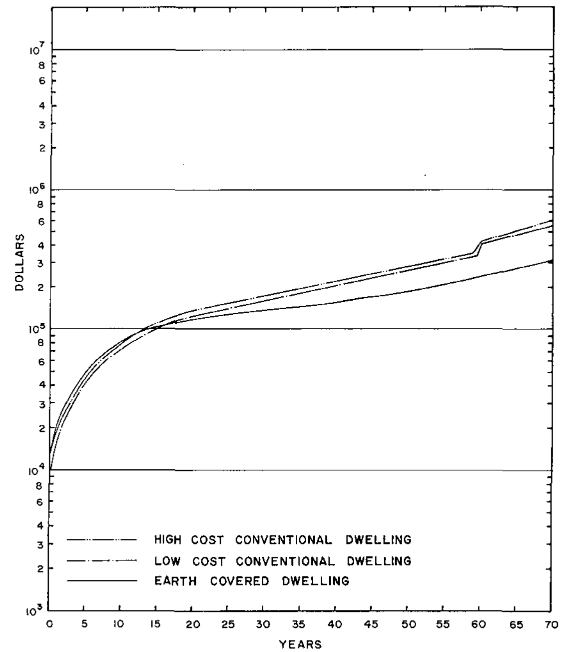


FIGURE 4

Cumulative Costs With 5% Discount Rate
11%, 20-yr. Mortgages

Sensitivity analysis on the variables would help bracket the range of benefits expected. For instance, the electricity rate is very low and could increase more rapidly than assumed. Indeed, in Fort Worth the price per kwh increased in 1981 at least 50% over the 1980 price. Also, one would expect construction costs for earth-covered dwellings to decrease as the number of units produced increases. And, construction technology development will likely result in decreased construction costs for earth-covered dwellings. Such changes would favor the earth-covered dwelling in analysis.

SUMMARY

From the preceding analysis for part of the American Southwest, earth-covered dwellings have a favorable life-cycle cost relative to conventional construction. The longer the time horizon one takes, the more favorable is the life-cycle cost. Similarly, the less one discounts the importance of costs and benefits to future generations, the more favorable are the life-cycle cost. The last two points would be true for any locale.

While the analysis presented here is for the Southwest, other regions which normally face extreme weather (such as the northern tier of states and much of the Midwest) will likely have similar analytical results. Regions of temperate weather or those which habitually have warm and humid weather, however, may have different results. All cases could not be addressed in this study, but it seems that the major places where earth-covered housing has been developing are the places where such housing makes exceptional climatic sense. It may also be that some of the benefits of earth-covered dwellings, for instance overall safety or aesthetics, account for their appearance in zones other than those of maximum climatic benefit. Such benefits are difficult to establish and are, therefore, not included in the economic analysis. Quoting from the Ehrenkrantz Group study:

> The results of this analysis indicate that building earth-sheltered homes, with both 3 ft. and 7 ft. of earth cover, is a cost-effective choice based on the assumptions outlined above. These results indicate that the underground buildings, in all cases, are less costly to operate than the tract houses. The investment becomes more attractive if low interest mortgages

are available for the underground buildings. A 5% discount rate is most favorable to the underground buildings.

The underground house is an attractive investment in all the situations investigated.

For a brief cost analysis of larger buildings, please see the introduction to this part of the report and main introduction.

Footnotes:

1. We know of no well-developed estimate of the life span of earth-covered buildings. If periodic updating of the interior of an earth-covered dwelling is done, then the life of the structural shell is the main element determining the expected life. Thus, estimates of the life span of waterproofing techniques and structural shells must be developed. Crude estimates can be approximated; for instance, well-designed reinforced concrete shells are thought to last an indefinitely long time. Dr. August Komendant, a structural engineer of international renown, gave an offhand estimate of "forever" for shells he had reviewed. Concrete is among the longest lasting materials used by man, with several thousand years of use known to be possible. For the purposes of this report, 300 years is taken as lifespan for shells.

   The lifespans of various waterproofing approaches and the success of patching techniques are difficult to estimate. Some waterproofing techniques are known to last well in ground conditions, but data are sparse at best. Also, some structures are more easily and successfully patched from the inside than others. Moreover, new materials and techniques are being developed at a rapid rate. It is not reaching to assume that cost effective and high performance waterproofing technologies can be developed to meet market demands.

PART VI PUBLIC POLICY

PUBLIC POLICY

By their public policies on habitat building, societies demonstrate their aspirations for the future, their knowedge of the past, and their economic and social conditions. The laws of land use, taxation, and construction practices have resulted in cities and buildings being the way they are. Land-use laws, for instance, set the physical patterns of transportation systems, public utilities, and buildings. Laws on taxation and construction practices determine, to a large extent, how things are built. In addition, capital funding practices, which have the force of public policy, exert a major influence over what is built.

Enlightened public policy for habitat building today would consider at least the following:

1. Capital funding systems
2. Ecological impact on the built environment
3. Construction technology and its development
4. Pollution reduction alternatives
5. Energy-resource reduction alternatives
6. Material-resource reduction alternatives
7. Safety

One interpretation of the preceding list of concerns is that societies are attentive to cross-generation distributions of the benefits and costs of habitat building. For instance, public policy may encourage current investment in order to secure future benefits.

In general, it can be said that earth-covered buildings would fit well with public policies that:

1. Encourage durable, long-lived structures
2. Encourage energy efficiency
3. Encourage hazard design
4. Encourage ecological fit
5. Encourage technology development
6. Encourage exploratory funding

There are many combinations of specific public policies that could result in effective measures, with the following policy alternatives of particular interest:

a. Link capital funding terms to expected useful life
b. Provide reduced interest financing to projects with significant social benefit
c. Link capital funding to hazard design

In general, the use of earth-covered buildings, like all approaches to building, will depend in large measure on public policy. Short-term policy regarding demonstration projects may help explore the opportunities available via earth-covered buildings, but long-term policies regarding habitat building will tell the tale. Earth-covered projects will be, and are being, explored in the United States. Whether the use of earth-covered buildings flourishes, and whether all the potential benefits are gained, will probably depend more on public policy than on simple market development. It is our judgment that earth-covered buildings would not, in the long-term, require special public policy consideration, given policies that encourage long-lived, durable, safe and efficient buildings. However, many public policies today do not encourage these things. We cannot review here the literature of public policy in city building, but such policy is known to be flawed in serious ways.

Thus, there may be warrant for new policy.[1]

There are several areas where policy decisions regarding earth-covered buildings merit discussion.

First, research to define the parameters for the design and engineering of earth-covered buildings (primary research related to heat transfer) is important to their development. The National Science Foundation and the Office of Civil Defense funded much of the early research in this regard. The Department of Energy is continuing research in this area, and the Department of Navy has funded a design manual for earth-covered shore facilities. Yet there is broad agreement that we need to know more, particularly about heat exchange between the buildings and the earth. When one compares the data and techniques available for the design of conventional buildings to the data and techniques for earth-covered buildings, the point is obvious.

Funding for technology development and dissemination is another policy alternative. The two areas mentioned most often in this regard are 1) development of less costly structures and 2) broader knowledge of effective waterproofing methods. There are many other areas for development, and there is widespread feeling that the construction technologies appropriate for earth-covered buildings are not so well developed as those for conventional construction, and that the existing technologies are not always well known throughout the construction industry.[2]

Another approach in public policy views the long-term utility to the nation of a stock of earth-covered dwellings as warranting some reimbursement. That is, the society as a whole stands to gain enough from such a stock that it could reimburse for part of their construction. Some see the long-term savings in materials and energy resources as the main reason for such a policy. Others see pollution reduction as sufficiently important. Others look to the survivability of such structures as their reason. At any rate, many people in the earth-covered field feel that there should be more consideration given to the broad social utility of a reasonable stock of earth-covered buildings and dwellings.

A more conservative policy view would advocate that earth-covered dwellings be built by the society at large for public use during crisis. Perhaps a variety of leasing arrangements could provide for use of the dwellings in non-crisis times.

The following figures are helpful in policy consideration in construction; they are derived from the 1978 U. S. Fact Book.

NEW CONSTRUCTION IN THE USA 1965 - 1975 average (in million sq. ft. per year)		
		Percent
Educational and Science	190	7.1
Hospital	66	2.4
Public Buildings	37	1.3
Recreational and Social	48	1.8
Commercial	451	17.0
Manufacturing	207	7.8
Residential	1,644	62.2

FIGURE 1 (Source: U.S. Fact Book, p. 771)

1975 STOCK OF DWELLING UNITS IN U.S.A.		
New Units	3.18% of stock	2.518 Mil./ yr.
Demolition	.55 - 1.37% of stock	1.05± Mil./ yr.
Net Growth	2.63% of stock	2.083 Mil./ yr.

FIGURE 2. (Source: U.S. Fact Book p. 777)

AGE OF HOUSING STOCK IN USA 1975		
Average of housing:	Non Farm	26 yrs.
	Farm	46 yrs.
	Apartments	16-18 yrs.
	Mobile Homes	6 yrs.

FIGURE 3. (Source: U.S. Fact Book p. 777)

New construction in public buildings has already shown early and substantial use of earth-covered buildings, and many of the newer earth-covered public buildings are widely known to have exceptional economic performance, energy efficiency and public acceptance. This sector also represents a relatively small part of all new construction, thus perhaps no new public policy, beyond an informational program, need be considered. This is true for educational, science, hospital, and recreational buildings as well.

The second and third largest sectors of new construction, commercial and manufacturing (24.8% combined) are not in the usual sense the direct concern of public policy at the Federal Government level, although various tax and other economic considerations play a major role in their design. This report does not consider breaking new policy ground in this area.

However, Federal Government policies do play a direct and profound role in housing. The Federal Housing Administration's minimum property standards are adopted by many locales as a local housing construction ordinance. Moreover, the loan insurance programs of FHA and VA are benchmarks for the industry, with the second tier of the mortgage investment market, for instance FNMA, supporting the standards of FHA and VA without question. Thus, the private sector looks to the Federal Government for setting its standards and for investment guidance.

VA and FHA currently consider loan insurance requests for earth-covered dwellings routinely, whereas only a few years ago special consideration was required. Thus, earth-covered dwellings meet construction standards acceptable to VA and FHA.

Public policy is also expressed in funding programs. To explore one policy alternative (reduced rate and long-term financing of earth-covered dwellings) the figures on the following pages were developed. For instance, the effect of reduced rate mortgages on costs in a 50-year period is shown in Figure 6. This suggests that earth-covered dwellings might do well in a market with such financing available. In effect, long-term benefits and energy efficiency play a more important role in price determination. The more expensive, but longer lasting and more efficient, earth-covered dwelling comes to parity with conventional construction. Naturally, any general reduction in the costs of earth-covered construction, or greater increases in the relative prices of energy than invisioned here, would tend to work in the favor of earth-covered dwellings in the market place.

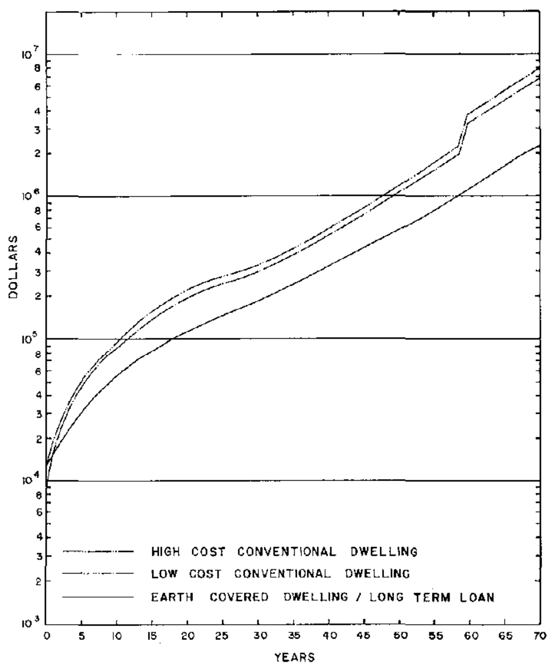


FIGURE 4. CUMULATIVE COSTS WITHOUT DISCOUNTING
Note: 11%, 20 yr. mortgages for conventional and 5.25%, 90 yr. mortgage for earth covered.

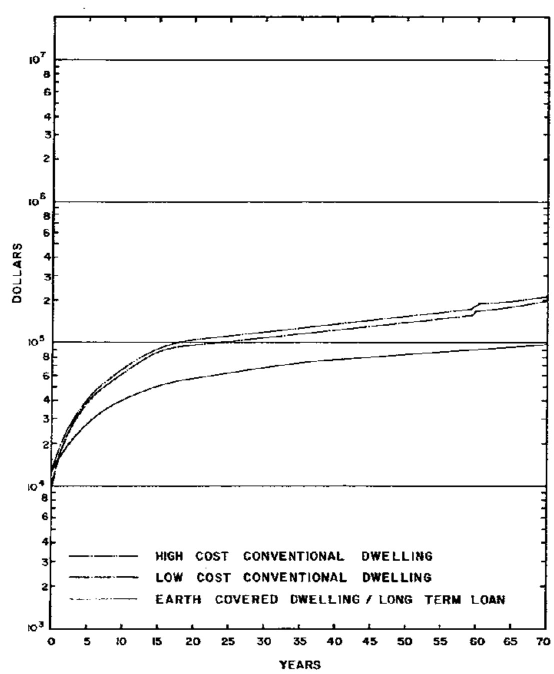


FIGURE 5. CUMULATIVE COSTS WITH 8% DISCOUNT

Note: 11%, 20-year mortgage for conventional and 5.25%, 90-year mortgage for earth-covered

COST COMPARISONS*		
30-Year Term and 5% Disount Rate		
Tract House (Low Cost)	Earth-Covered House	Difference
11% Mortgage	11% Mortgage	
$ -169,221	$ -32,052	$ 137,169
	8.25% Mortgage	
	$ -17,744	151,477
	5% Mortgage	
	$ -2,423	166,799
*Note: Cost Comparisons are based on the following two tables.		

FIGURE 6

SPECIFIC ASSUMPTIONS (A)	Tract House Higher Cost 5% Discount Rate	Tract House Higher Cost 8% Discount Rate	Tract Houst Lont Term 5% Discount Rate	Tract Houst Long Term 8% Discount Rate	Underground - 7 Ft. 5% Discount Rate 11% Mortgage	Underground - 7 Ft. 5% Discount Rate 8.25% Mortgage	Underground - 7 Ft. 5% Discount Rate 5% Mortgage	Underground - 7 Ft. 8% Discount Rate 11% Mortgage	Underground - 7 Ft. 8% Discount Rate 8.25% Mortgage	Underground - 7 Ft. 8% Discount Rate 5% Mortgage	Underground - 7 Ft. Long Term 5% Discount Rate	Underground - 7 Ft. Long Term 8% Discount Rate
Economic Analysis Period	30	30	80	80	30	30	30	30	30	30	80	80
Project Life, years	60	60	60	60	300	300	300	300	300	300	300	300
Capital Cost, $	68334	68334	68334	68334	97620	97620	97620	97620	97620	97620	97620	97620
Mortgage Rate, %	11	11	11	11	11	8.25	5	11	8.25	5	5	5
Mortgage Term, years	20	20	20	20	20	20	20	20	20	20	90	90
Down Payment, %	15	15	15	15	15	15	15	15	15	15	15	15
Energy Savings, $	-548	-548	-548	-548	-82	-82	-82	-82	-82	-82	-82	-82
Maintenance Cost, $	1025	1025	1025	1025	490	490	490	490	490	490	490	490
Insurance Cost, $	386	386	386	386	419	419	419	419	419	419	419	419
Salvage Value, $	114604	114604	2257800	2257800	655000	655000	655000	655000	655000	655000	3225500	3225500
General Inflation Rate, %	8	8	5	5	8	8	8	8	8	8	5	5
Fuel Cost Inflation, %	20	20	15	15	20	20	20	20	20	20	15	15
Fuel Cost change year	5	5	15	15	5	5	5	5	5	5	15	15
Fuel Cost Inflation, 2nd,%	12	12	10	10	12	12	12	12	12	12	10	10
Discount Rate, %	5	8	5	8	5	5	5	8	8	8	5	8
Tax Bracket, %	25	25	25	25	25	25	25	25	25	25	25	25
Present Value Total	-179587	-131212	-782481	-235913	-22786	-6277	-11401	-66019	-53173	-39468	-158542	-91612
Present Value-Difference					156801	173310	168186	65193	78039	91744	623939	144301

SPECIFIC ASSUMTIONS (A)	Tract House Low Cost 5% Discount Rate	Tract House Low Cost 8% Discount Rate	Tract House Low Cost, Long Term 5% Discount Rate	Tract House Low Cost, Long Term 8% Discount Rate	Underground - 3 Ft 5% Discount Rate 11% Mortgage	Underground - 3 Ft. 5% Discount Rate 8.25% Mortgage	Underground - 3 Ft. 5% Discount Rate 5% Mortgage	Underground - 3 Ft. 8% Discount Rate 11% Mortgage	Underground - 3 Ft. 8% Discount Rate 8.25% Mortgage	Underground - 3 Ft. 8% Discount Rate 5% Mortgage	Underground - 3 Ft. 5% Discount Rate Long Term	Underground - 3 Ft. 8% Discount Rate Long Term
Economic Analysis Period	30	30	80	80	30	30	30	30	30	30	80	80
Project Life, years	60	60	60	60	300	300	300	300	300	300	300	300
Capital Cost, $	61826	61826	61826	84604	84604	84604	84604	84604	84604	84604	84604	84604
Mortgage Rate, %	11	11	11	11	11	8.25	5	11	8.25	5	5	5
Mortgage Term, years	20	20	20	20	20	20	20	20	20	20	90	90
Down Payment Percentage	15	15	15	15	15	15	15	15	15	15	15	15
Enerty Savings, $	-548	-548	-548	-548	-192	-192	-192	-192	-192	-192	-192	-192
Maintenance Cost, $	927	927	927	927	425	425	425	425	425	425	425	425
Insurance Cost, $	386	386	386	386	389	389	389	389	389	389	389	389
Salvage Value, $	103710	103710	2042800	2042800	570000	570000	570000	570000	570000	570000	2800000	2800000
General Inflation Rate, %	8	8	5	5	8	8	8	8	8	8	5	5
Fuel Cost Inflation, %	20	20	15	15	20	20	20	20	20	20	15	15
Fuel Cost change year	5	5	15	15	5	5	5	5	5	5	15	15
Fuel Cost Inflation,2nd, %	12	12	10	10	12	12	12	12	12	12	10	10
Discount Rate, %	5	8	5	8	5	5	5	8	8	8	5	8
Tax Bracket, %	25	25	25	25	25	25	25	25	25	25	25	25
Present Value Total	-169221	-122740	-757666	-224540	-32052	-17744	-2423	-64569	-53437	-41559	-247845	-103277
Present Value Difference					137169	151477	166799	58171	69303	81181	509821	121263

Public Sector Construction Alternative

Another policy option is the construction of earth-covered buildings and dwellings by a public body, such as a city, state or federal agency, with subsequent leasing to the private sector for peacetime use. Some argue that a minimum policy would include the use of earth-covered communities for the security of civilian populations located near major military facilities, and perhaps several non-military facilities. An expanded policy could include any specific geographic area up to the country as a whole. This approach would have the society-at-large, through one or many public instruments, purchase a stock of earth-covered settlements. The settlements would then be leased or sold to the private sector. Many settlements might be leased or sold subject to the condition that the settlements would be available for public use under specified conditions.

While concern for emergency or crisis may be the reason for early exploration of such policy, the development of earth-covered communities could become attractive for other reasons as well, as has been pointed out repeatedly in the literature.

One variation to the approach of construction or ownership by society-at-large would have the society-at-large only partially contribute to their construction. Conditions on the use of public resources for such purposes could also attend this approach, again with crisis accessibility being of particular interest to FEMA.

Another policy option lies in the area dealing with the structures which are built to replace those lost to disasters. R. L. Meier, University of California at Berkeley, argues[3] that in many cases, it makes sense to rebuild with better structures than those that were lost.

In many cases, earth-covered buildings, as replacement buildings, would make large future losses from disaster less likely.

The range of policy options for such concerns is very wide. For instance, one could, as U.S. Representative Williams of Montana has, propose to "construct or acquire underground structures for use as public buildings unless the use of such structures is demonstrably inappropriate for the proposed function of such buildings."[4]

While a thorough exploration of policy instruments for replacement facilities lies beyond the scope of this report, an ongoing exploration would be most useful. In developing this report we have repeatedly found the people and organizations we consulted have a serious interest in a coordinated effort to study policies which might lead to more durable and safer buildings.

Footnotes:

1. Consider the following two quotes:
First from Heimsath Associates, Inc., Houston in their report to the LBJ Space Center in 1976.

> As an illustration of the benefit attainable through widespread implementation of energy conserving design in residential and commercial buildings, an estimate was made based on the projected national energy consumption.
>
> Assumptions:
> Attainable energy savings for new construction, 30%, based on results of previous studies conducted with Urban Systems Project Office.
> Attainable energy savings through retrofitting, 20%, based on projections in Project Independence: Residential and Commercial Energy Use Patterns, 1970-1990.
>
> Replacement rate of existing buildings 1.5% per year. Projected rate of all new construction 1.8% per year. Degree of penetration of energy conserving technology into new construction market - 80%.
> Extent of retrofit implementation in existing buildings - 50%.
> Unit energy demand is assumed to be constant.
> Based on 1975 implementation projected to 2000.
>
> Based on the above assumptions, the total number of buildings will increase 156.2% from 1975 to 2000. 29.6% of the buildings existing in 1975 will still exist in 2000. The remaining 81% will be new buildings constructed since 1975.
>
> 7.5% of the total buildings will be old buildings that were retrofitted with energy conserving modifications, accounting for a 1.5% savings in residential/commercial energy consumption.
>
> 64.8% of the total buildings will be new buildings built with energy saving technology. This will account for a 19.4% savings in residential/commercial energy consumption.

Second, from Thomas Bligh in "A Comparison of Energy Consumption in Earth Covered vs. Non-Earth Covered

Buildings" in The Use of Earth Covered Buildings, ed., F. L. Moreland, National Science Foundation, 1976.

> The National Bureau of Standards, Building Environment Division, has calculated potential cost savings over the next 25 years if thermal transmission characteristics of new and existing housing units are upgraded. They predicted that the then 60 million dwelling units would increase to about 100 million if, of the existing stock, 3% are built and 1% are retired each year for 25 years. If heat transmission could be reduced by 50% in all new houses and by 10% in all existing houses, savings in energy and cost for the next 25 years . . .could be substantial.
>
> According to a recent ERDA publication, "...during the 1975-85 period, 40% of all space that will be in place in 1985 will be constructed." And in "The Nation's Energy Future," they estimate that if half the new buildings built each year were to incorporate energy conserving designs which result in a 40% savings in consumption (a figure easily attainable in underground buildings) a savings of 15% of the present total U.S. consumption would be realized at the end of ten years. The potential for energy conservation by earth-covered buildings, therefore, is very large indeed.

2. To date its major centers for information have been,

    1) The Underground Space Center at the University of Minnesota, Directed by Ray Sterling. At the same location is the headquarters of the American Underground Space Association and the journal Underground Space.

    2) The Clearing House for Earth-Covered Buildings, P.O. Box 9428, Fort Worth, Texas 76107.

    3) The School of Architecture at the Oklahoma State University, Professor Lester Boyer.

    4) The Innovative Shelter Program of the Department of Energy at Oak Ridge National Laboratory, Bob Wendt, program manager.

5) Professor David Scott, the University of Washington.

6) Professor Ernest Kiesling, Texas Tech University.

7) Professor James W. Scalise, College of Architecture, Arizona State University, Tempe, Arizona.

8) Professor Nolan B. Aughenbaugh, University of Missouri at Rolla.

9) Earth Shelter Digest and Energy Report, WEBCO Publishing, St. Paul, Minnesota.

3. Meier, R. L., "Catastrophe Theory and the Acceptance of Underground Space," in Earth Covered Buildings and Settlements, ed. Frank L. Moreland, 1978.

4. H. R. 4270, July 24, 1981, A Bill "Requiring the Use of Underground Structures for Public Buildings Whenever Appropriate."

Additional Readings:

The following readings in Public Policy appear in Alternatives in Energy Conservation: The Use of Earth Covered Buildings, Frank L. Moreland, editor, Government Printing Office, 1976.

Hamburger, Richard, "Strategies for Legislative Change"

Horsburg, Patrick, "Urban Geotecture: The Invisible Features of the Civic Profile"

LaNier, Royce, "Earth Covered Buildings and Environmental Impact"

Moreland, Frank L., "Alternatives to Suburbia"

Tarlock, Dan, "Property Rights Considerations"

The following readings appear in Earth Covered Buildings and Settlements, Frank L. Moreland, editor, United States Department of Energy, 1979.

Davidoff, Linda, "Social Issues in Community Planning for Earth Covered Shelter"

Green, Melvyn, "Building Codes and Underground Buildings"

Hamburger, Richard, "Public Policy Considerations and Earth Covered Settlements"

Higgs, Forrest S., "Integrating Earth Covered Housing Into Existing Energy Efficient Codes Structures"

Isakson, Hans, "Institutional Constraints on the Marketing and Financing of Earth Covered Settlements"

Meier, Richard L., "Catastrophe Theory and the Acceptance of Underground Space"

Moreland, Frank L., "Notes on Earth Covered Settlements"

The following readings appear in The Potential of Earth-Sheltered and Underground Space, T. Lance Holthusen, editor, New York, Pergamon Press, 1981.

Browne, Forrest R., "The Role of the Real Estate Developer in the Future of the Underground Industry"

Chester, C. V., "Incorporating Civil Defense Shelter Space in New Underground Construction"

Muir Wood, A. M., "Underground Space: Its Contribution to the Sustainable Society"

The following readings appear in Underground Space, The Journal of Underground Space Association, published bi-monthly by Pergamon Press, Elmsford, New York.

Korell, Mark, "Financing Earth Sheltered Housing: Issues and Opportunities," Vol. 3, #6.

LaNier, Royce, and Moreland, Frank L., "Earth Sheltered Architecture and Land Use Policy," Vol. 1, #4.

Murphey, Walter, "In the Event of Catastrophe," Vol. 5, #6.

Murphey, Walter, "Civil Defense: A 1981 Appraisal," Vol. 5, #6.

Parker, Harvey W., "Underground Technology can Advance Through Government, Industry Cooperation," Vol. 4, #4.

Sisson, George W., "Underground for Nuclear Protection," Vol. 4, #6.

Swenson, Gregory, "Zoning Ordinances As Obstacles to Earth Sheltered Housing: A Minnesota Perspective," Vol. 3, #4.

Thomas, William S., "Ownership of Subterranean Space," Vol. 3, #4.

Vasatka, Richard J., Editorial Comment, Vol. 4, #3.

Winqvist, Torbjorn, "How Can Society Encourage Appropriate Use of Subsurface Space?" Vol. 5, #4.

The following books also contain material pertaining to Public Policy:

Earth Sheltered Housing: Code, Zoning and Financing Issues, Ray Sterling, Roger Aiken, and John Carmody. The Underground Space Center, University of Minnesota, 1980.

Earth Sheltered Housing Designs: Guidelines, Examples, and References, The Underground Space Center, New York, Van Nostrand Reinhold, 1979.

Public Policy: Appendix A

A Statement by Richard Hamburger

Policy has been defined as a definite course of action selected from among alternatives and a set of decisions designed to carry out the chosen course of action. Public policy is thus policy enunciated and set in action by the body politic. Public policy reflects the judgment that a given goal or goals are in the interest of society. Public policy may be enunciated by legislative action, by court decisions, through administration procedures, or by the conscious decisions of legislators to let precedent stand.

Thus for there to be a public policy, there must be a judgment that there is a public good, and a judgment on who pays for implementation. On the payment part there are really only two choices: individual or society. There may, of course, be some combination of these. The following outline illustrates how these choices may be implemented:

A. Individual
   1) No action--Let the market place decide.
   2) Zoning--e.g., Do not build on the flood plain.
   3) Regulations--Fuel economy (passed through).

B. Society
   1) Direct payment--e.g., Education, mass transit.

2) Indirect Payment--e.g., Tax incentives such as energy tax credit.

That there is a public good in encouraging the construction of earth-covered buildings is the conclusion of this document. Energy conservation has already been enunciated as a public goal. The reduction of loss of life and monies which result from natural or man-made disasters is certainly a worthwhile public goal. If not formally enunciated as public policy, that goal is understood by most people as a proper function of government. Thus we have here two public goods which can both be accomplished by the use of earth-covered buildings.

Disaster mitigation is a public objective. As noted in the quote on the first page of part 2: "More than one billion dollars is spent annually in the United States to help disaster victims and their communities recover from major catastrophies...". To this must be added the loss to community and individuals of the loss of life (not directly measurable in dollars). Thus, the United States has an interest in having as many disaster shelters as can be built. If these shelters can have the dual purpose of being buildings which are useable for normal daily activities, there would appear to be a better chance that they would be built (not as shelters but for their normal use). To encourage such buildings is also a worthwhile public goal.

It must be recognized that these goals may be accomplished by means other than earth-covered buildings. Within the realm of public policy it is the goals which are paramount and actions used to accomplish goals should be performance-oriented not specification-oriented. Earth-covered buildings used as shelters would have to demonstrate their superiority for energy conservation and disaster mitigation.

Illustrations of actions which might be taken to further these goals are discussed below:

No Action--Let the market place decide. This is not always an option with public goods where purchases must be made collectively.

Zoning--Some zoning ordinances which make sense for conventional construction do not provide for the full benefits of earth-covered buildings. Examples of such ordinances are set-back requirements and maximum lot-coverage requirements. Zoning ordinances should be modified to encourage energy conservation and disaster mitigation. The cost of complying with such ordinances is borne by the owner, but the benefits are to both the owner and to society.

Regulations--Most building codes are designed for conventional construction and are specification codes. For instance, most building codes, for firesafety reasons, require that sleeping rooms have windows or doors leading directly to the outside. During a tornado, this would be the worst place to have the sleeping quarters. Other designs could provide maximum protection during a tornado and still provide safe exit in case of fire. Performance codes would permit such designs and should be encouraged. As above, the cost would be borne by the owner, and the benefit is to both the owner and to society.

Direct Payment--There is a need for technology development and for research. Technology development could include learning how to build less costly structures. Further research is needed on heat transfer, especially as it related to earth-covered buildings. The construction industry needs to become educated about existing technologies for the safe and sound construction of earth-covered buildings. Education is a proper function of government, especially when the result of that education rebounds to society.

Indirect Payment--The government already provides some payment, through the tax system, to home owners who install certain energy conservation systems. As noted before, each building has an embodied energy budget. If destroyed by a tornado, the embodied energy of a building is essentially lost and must be reinvested. Thus disaster mitigation and one form of energy conservation go hand in hand. Considering the large sums of public monies spent annually to help disaster victims, it should make good economic sense to provide tax incentives to people who build structures which would resist these destructive forces. To the extent that this reduces the cost of society of disaster relief, the government is ahead.

Two public policies (encourage energy conservation and disaster mitigation) are identified. Several actions to implement and pay for those policies have been discussed as illustrations.

APPENDIX I THE EARTH-COVERED BUILDING MOVEMENT: A PERSPECTIVE

By Kenneth Labs

THE EARTH-COVERED BUILDING MOVEMENT: A PERSPECTIVE

Kenneth Labs

Reference is frequently made to the underground "movement." Beyond the word play, the expression itself raises an interesting question: can underground construction activity of the recent past, or the spate of increasing activity in the present be characterized as a movement? A simple definition of the word requires: 1) an organized activity directed toward 2) a common end. A shared ideology or some specific cause is implicit in the definition, which also subsumes that the achievement of the end produces some good for the society as a whole, or some sector thereof, rather than simply the collective good of a disparate group of members of society. One can assume that a movement requires a consciousness among both leaders and followers of their desire and deliberate purpose to effect change. Without pursuing the semantics of discussion any further, let us begin by asking, "Why are underground buildings built, and whom do they serve?"

It is clear from reviewing the history of numerous buildings constructed during the past three decades[1] that the decision to build underground usually has been made either to satisfy some programmatic issue in service to the occupant or owner (such issues hereafter will be referred to as "internal" in origin) or to satisfy some broader or higher purpose usually fully unrelated to the occupants' immediate or future interests or needs (therefore, described here as "external" issues). Internal and external determinants for underground placement may be further partitioned as shown in Figure 1. These subcategories will be discussed later.

Internal	Pragmatic
	Experiential
External	Circumstantial
	Deontological

FIGURE 1 Categories of Underground Building Motives

Among the prime occupant- or owner-serving reasons for underground placement have been radiation and fallout shielding, storm protection, and energy conservation through reduced heating and cooling loads. Multiple internal purposes are often served in the same building by underground construction. An interesting example is the Lake Worth Junior High School, near Fort Worth, Texas, where acoustical isolation was the primary consideration, and a fallout shelter was a significant fringe benefit (Figure 2). The coincidence of the two purposes is especially poignant, since the need for acoustical isolation derives from the school's situation under the flight path of Carswell Air Force Base where bomber pilots practiced touch-and-go's at 30-second intervals during the war in Viet Nam. As another example, the Oklahoma State Department of Education

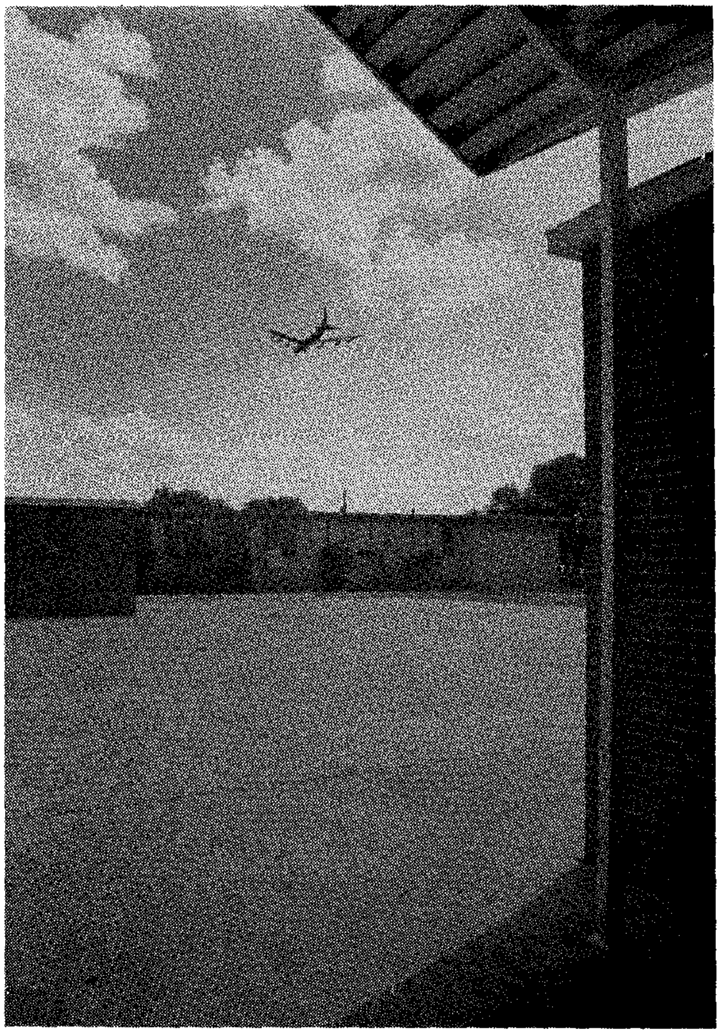


FIGURE 2. Because of interruptions caused by landing B-52 bombers passing over existing schools (background, and across the street) in Lake Worth, Texas, architect Preston Geren designed the new junior high school completely underground, beneath a concrete slab play area (foreground).

recently sponsored a workshop in cooperation with Oklahoma Civil Defense on the subject of underground schools. Energy conservation and protection from tornadoes and vandalism are additional considerations in new school construction in the Midwest.

Protection from winds and fallout, and reductions in energy costs are pragmatic reasons for underground construction: these ends can be served by other means, but underground placement is often the most effective, if not the most immediately economical, solution. Pragmatic considerations alone, however, are poor critera for a decision to build underground. There are few buildings or building types in which the successfulness of serving the users can be judged without considering the experiential qualities of the enclosure, including daylighting, views to the out-of-doors, outdoor air ventilation, and other environmental stimuli relating to the above surface. The importance of experiential quality is greater for some building types than others, as is the ease of opportunity for making the interface between the inside and outside. Different characterizations of need for undersurface-surface relationships can be made for example:

1) the isolated underground environment offers some unique spatial-psychological opportunity. Modern examples of this are rare, although the ceremonial Pueblo Indian kivas of the Southwest are a good case in point. Architect Philip Johnson articulates his perception of the effect in reference to his berm-surrounded art gallery in the back yard of his estate in Connecticut: "Oh yes, everyone likes caves... People get a positive pleasure going into my gallery. Going into a building that isn't there, they get a feeling of 'Where are we going?' Since every room is about ten times bigger than they expect, there's a positive element of surprise and romance. Caves are probably an atavism of some kind; people enjoy being enclosed."[2]

2) no significant relationship is necessary between indoors and out, so there is no sacrifice in building below ground. Many building types fall in this category, some common, some highly specialized. Included are theaters, parking garages, assembly plants, grocery stores, recording studios, convention centers, museums, and department stores. Some would place schools in this grouping.

3) the need for visible indoor-outdoor relationships is not important throughout much of the building, so that the satisfactoriness of an underground solution is largely a matter of siting and architectural design. Schools, libraries, and houses are examples.

4) the need for strong indoor-outdoor relationships is important throughout most of the building, so that acceptable underground solutions are inherently difficult to achieve. Office buildings and hotels are prime examples, and many would include various forms of housing.

The fact that some building types do not require strong indoor-outdoor relationships explains in part why so few building types (libraries, schools, museums, parking garages) account for the majority of existing underground structures.

External Issues

Among the external reasons for underground placement are those which are 1) circumstantial in character, being related to specific conditions at a given site, and 2) what might best be described as deontological in character, springing from a designer's and client's beliefs about the place of architecture in the twentieth century. There exist several recurring sets of circumstances which have been responsible for the underground placement of numerous significant buildings. One of the most common of these is the lack of acceptable building sites on college campuses. A typical example is the

Pusey Rare Book Library, a three story building located beneath a portion of Harvard's sacred yard (Figure 3). Another recurring theme is that of the addition to an existing building of monumental or landmark status. An award-winning case in point here is the annex to the Jefferson Memorial, a Beaux Arts building located on the periphery of Forest Park in midtown St. Louis. A completely below-grade addition to the existing structure was built to extend the gallery space of the Missouri Historical Society (Figure 4). Still another theme is the building which by function or size cannot readily be integrated into the context of its surroundings. Examples include libraries in historic residential neighborhoods (Figure 5), and range to all sorts of structures in both wilderness and urban parks (Figure 6).

In circumstantial cases of underground buildings, the site either imposes constraints or offers opportunities in such a way that an underground structure is the most appropriate solution to the context. A contributing factor must be that the experiential needs of the occupants can satisfactorily be met.

Although many architects have found an underground building to be the best solution to some set of site and programmatic circumstances encountered in their practice, few of them would describe themselves as having a particular commitment to the idea itself. There are, however, some designers who may be said to be predisposed to underground architecture, because they believe the practice satisfies a broader perceived need to build in consonance with the natural environment, rather than lording over it. "Deontological" is used here to describe this sense of obligation to a higher ideal than merely meeting the programmatic requirements of the client.

Perhaps the first promotion of underground alternatives in the name of environmental quality was made by

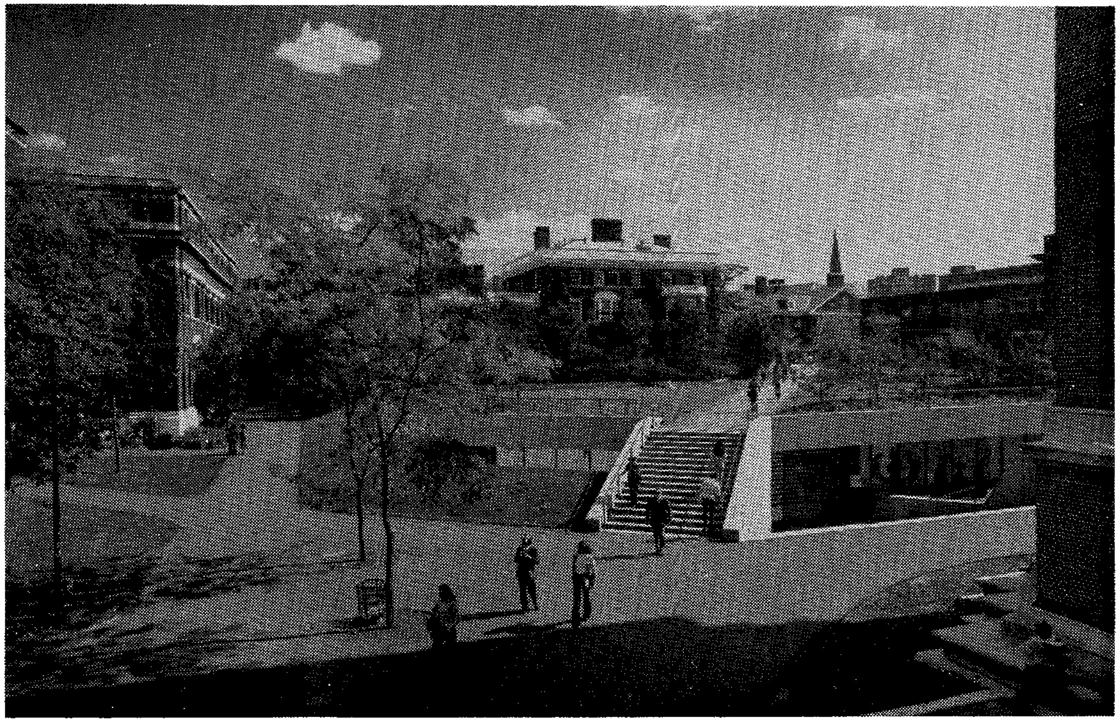


FIGURE 3. Harvard's Pusey Library was built underground to preserve open space in Harvard Yard (Hugh Stubbins & Associates, Architects).

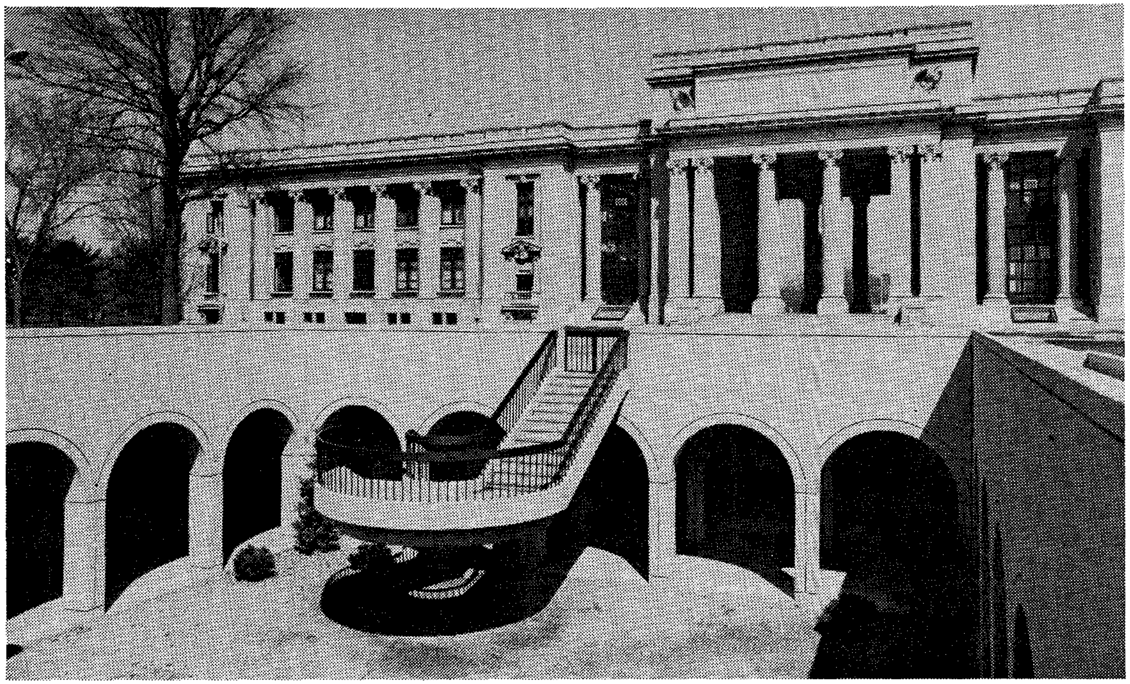


FIGURE 4 Underground placement of the Missouri Historical Society's annex to the Jefferson Memorial in St. Louis preserves the view of all four facades of the monumental old structure (Sverdrup & Parcel, Architects).

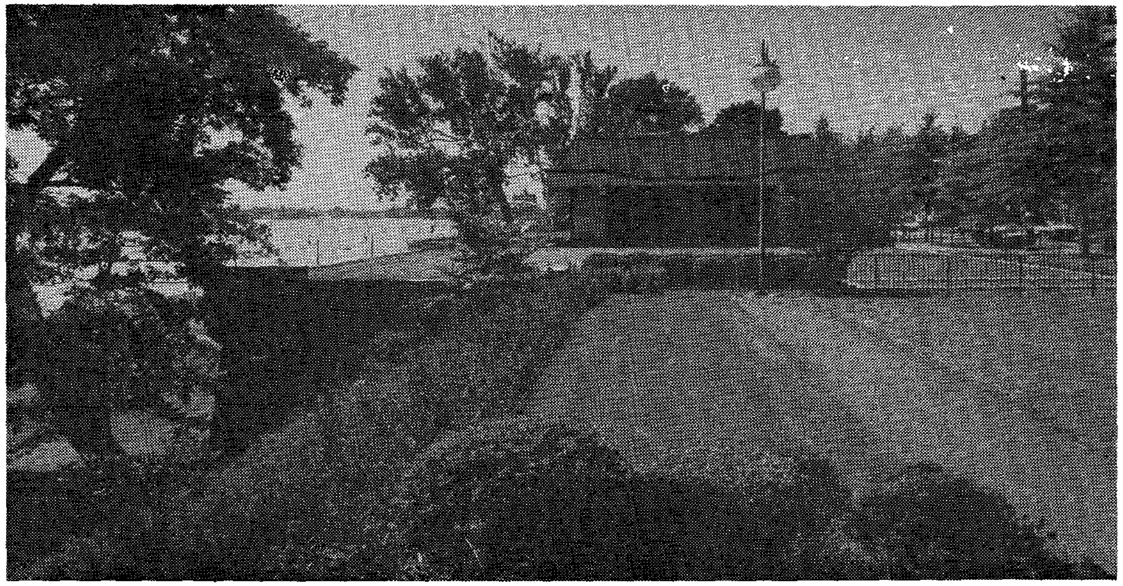


FIGURE 5. Carroll, Grisdale and Van Alen's (now J. Roy Carroll, Jr. and Partners) design for the Grundy Memorial Library in Bristol, minimizes the bulk of the building at street level, since it is located in an old residential neighborhood. The entry pavilion at the sidewalk is flanked by lawns, under which are located the library stacks.

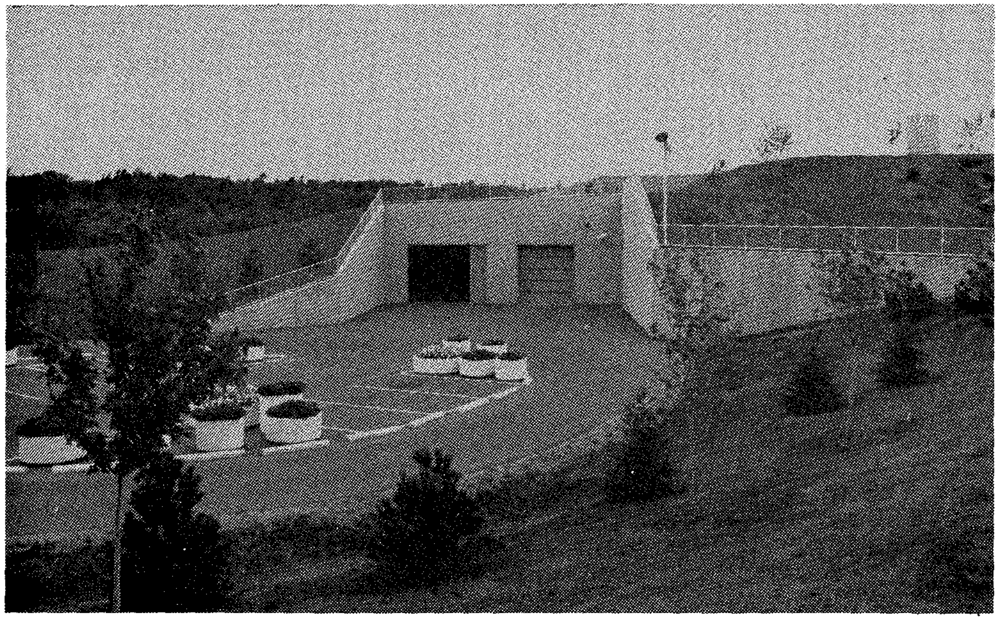


FIGURE 6. The Lorne Park Water Treatment Plant is located beneath the surface of an 84-acre site adjacent to Lake Ontario, in Mississagua, Canada. The sub-surface location allows continued use of the site by neighboring residents as a park (Shore, Tilbe, Henschel, Irwin, Architects; photo by W. G. Labs).

architects Mort and Eleanor Karp, who in 1960 envisioned an "Ecological City" in which houses, factories, and other edifices were imagined as largely underground: "...the forms of buildings should be the forms of the world in which they exist, so that, instead of obtruding, they will be a continuous part of the landscape, indistinguishable and integral."[3] Like much of the environmental consciousness of the 1960s, the Karp's objectives were very much aesthetic in their basis, as a reaction against the homogenizing spread of suburban development.

Not long after the Karps' article appeared, a somewhat similar vision was described in a better publicized article by Malcolm Wells, entitled "Nowhere to go but Down."[4] Although superficially seeming much the same in content as the Karps, Wells instead argued for conservation of the ecologic community, rather than preservation of visual landscape character. Although there is overlap between these concerns, a distinction can be seen between what may be called a landscape aesthetic on one hand, and a nature ethic on the other, or a difference between form and process. Very few buildings were actually built underground in the name of either cause, mostly for lack of interest on the part of both architects and clients. The handful of buildings which were built underground for environmental reasons, were largely done so by architects who subscribed to such beliefs with themselves as clients (Figure 7).

Movements?

Little is heard these days of "conservation architecture." "architecture of little presence," "architecture of little impact," "nonbuildings," and the

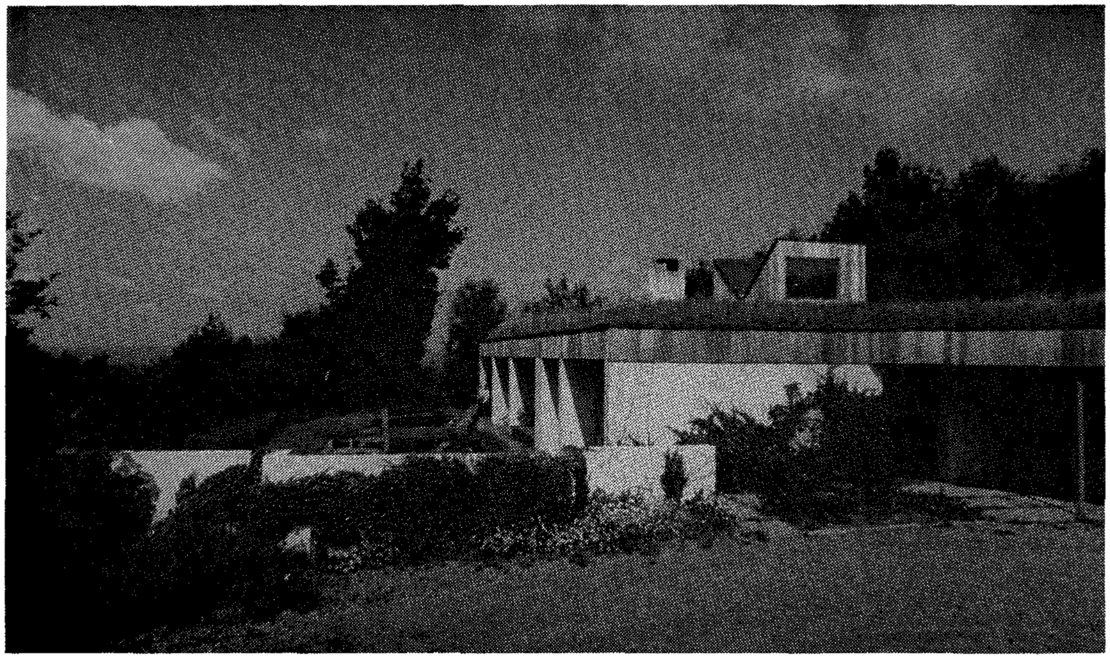


FIGURE 7. Architect Don Metz designed and built Winston House in 1971-1972 on speculation on a site he owned near Lyme, New Hampshire. Tucking the house into the grow of the hill minimizes its disturbance of the landscape.

like, as the immediate concern for energy conservation has diverted attention from issues of environmental quality. The major interest in underground building thus far in the 1980s is individually motivated, and for individual benefit: owner-builders are eagerly burrowing into hillsides all over the country with the belief that they will find energy savings as extraordinary as their own departure from the suburban stereotype. The present generation of underground houses for the most part, is built on large rural lots with gardens which are worked with an aim of self-sustenance. Apart from this intention of independence from utilities and manufactured foods is a more purely survivalist appeal of underground building. It is perhaps no more clearly evident than in a proposed 266 unit underground condominium called "Terrene Ark I," developed by Survive Tomorrow, Inc., in La Verkin, Utah. "This will be a safe retreat," Survive Tomorrow President Robert Boutwell is quoted as saying.[5] "Of course we would hope that everybody would know how to use a gun to defend what he has." There is no issue here of the common good: self-preservation is the appeal.

In returning to the original question as to whether we have ever experienced an underground movement, it can be said that at no time during the past three decades have underground buildings been built in noteworthy numbers for the cause of some common good. Although many buildings have been built underground, most of these have found their way beneath the surface as a result of circumstances at the site (in the case of nonresidential buildings), or in immediate service to the occupant for purposes of energy conservation and/or survival shelter (in the case of residential buildings). It is an irony that the only concepts of underground development that might have been movements--landscape preservation or nature conservation--have had no appreciable following. This is also a saddening fact, for only in these deontological scenarios has the quality of design and of the living environment in general been a central issue in the idea of an underground future. In the present rush to dig in for energy dollars, the quality of design is too often too willingly sacrificed. And, unfortunately, it is mostly this generation of underground buildings that will be judged as to what underground architecture is.

Footnotes:

1. A sampling of these are discussed in Kenneth Labs, "The Architectural Underground, Part II," Underground Space, Vol. 1, Number 2, Pergramon Press, July/August 1976.

2. Progressive Architecture, April 1967, p. 181.

3. Mort and Eleanor Karp, "The Ecological City," Landscape, Autumn 1963, pp. 4-8; the article is based on an unpublished manifesto written in 1960.

4. Malcolm Wells, "Nowhere to go but Down," Progressive Architecture, February 1965, pp. 174-179.

5. Ray Vicker, "Underground Condominium Offers Haven for Pessimists," Underground Space, Vol. 5, Number 6, Pergamon Press, May/June 1981, pp. 356-357 (reprinted from an article appearing in the Wall Street Journal).

APPENDIX II EARTH FORMING AND PLANT SELECTION FOR EARTH-COVERED BUILDINGS

By Dr. Geoffrey Stanford

EARTH FORMING AND PLANT SELECTION FOR EARTH-COVERED BUILDINGS

Introduction

Local or regional independence in food production, that is local self-sufficiency, has great social and economic value. In most regions, local agricultural systems compromise high-quality produce while reducing the dollar and energy costs of transportation. In a similar way, local small-scale renewable energy production can assist in reducing dependence on finite fuels.

During natural and man-made disasters, regions experience disruption in the flow of goods and services. Shortages in fuel and food supplies are apt to be the most critical. Local production of food and fuel crops would form a cushion against such catastrophic events.

Dr. Geoffrey Stanford has been asked to explore the implications of food and fuel crop production in clusters of earth-covered dwellings and buildings. Notes on land forming to lessen soil and storm water pollution, and the recycling of household wastes to improve food and fuel crops are included. These topics can become important societal issues in the event of long-term disruptions of community services.

Earth-Forming and Plant Selection For Earth-Covered Buildings

Geoffrey Stanford

Plantings over and around earth-covered dwellings can provide increased acreage for food crops, reduce albedo, provide a renewable source of fuel, and keep the soil in place against the forces of wind, rain, and scrambling children. Plantings can also provide a habitat for wildlife, absorb household wastes, improve the thermal performance of the dwellings they cover, add color, variety, and improve the quality of life in the neighborhood. These needs should be carefully considered, so that implementation will be smooth, and balanced conditions result.

The topography in earth-covered settlements may preclude the use of large-scale equipment for crop management. Nonetheless, the quality and quantity of crops should equal or exceed that of urban, suburban, and some rural areas. The absence of mechanization indicates that output will reflect the time and effort put into crop management by the residents. Several levels of effort are possible, for instance, with minimal husbandry, grasses, groundcovers, and coppice can become established and be virtually self-sustaining. With more intensive husbandry, a mixture of vegetables and fruit trees can be added. Careful land forming and irrigation can improve the quantity and quality of food and fuel crop production, especially if some or all of the irrigation water is recycled grey water from showers, kitchen, and laundry.

Land Forming

Most soils are in layers (strata). Water tends to drain along strata as well as through them. Earth berms around earth-covered buildings do not have that layered structure; and their soil has little cohesion, to that irrigation and rainstorms may wash gullies. Forming berms into horizontal terraces can minimize that; sloping the terraces into hills as in Figure 1 and 2 will be a further improvement. Service walkways should be at the same angle, and each terrace should be connected to the ones above and below by steps, not by sloped ramps. Drains can be placed under the walkways. The terraced walls can be brick, flat rocks, or railway ties, preferably arranged so that the walls slope against the hill, and that the brick or rock also tilts into the hill. Plants can be put in between as building progresses. Figure 2 shows this in exaggerated form.

Most plants have two series of roots: the surface feeders, in the top 2-3 inches, and the deep water-seekers, which can go down many feet and even tens of feet. Planning of the land form must arrange that rainfall and irrigation drains away from the house structure, otherwise deep roots may get into and under the foundation in search of water and then cause cracking. Ordinary agricultural drainage pipe should be laid about two-feet deep along berms at 10-foot intervals.

Since tree roots follow the same pattern, tall trees can be planted and grown on top of the roof. Most trees are stabilized against strong gales by their spring-like form, and need only light anchoring on their windward side as shown in Figure 3.

The actual growth in food and fuel crops will depend very much on the level of irrigation that is provided.

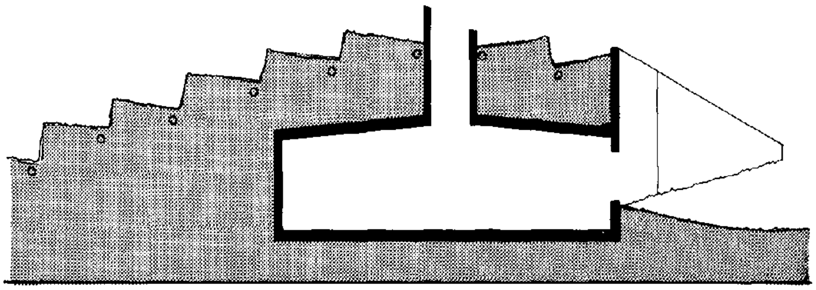


FIGURE 1 Earth terracing

If the terraces have been properly made at the start, each level can be flooded once every 14 days in the summer to about a 2-inch depth. Much of the water will flow into the drainage pipes and can be diverted to holding ponds where it can be pumped to other terraces.

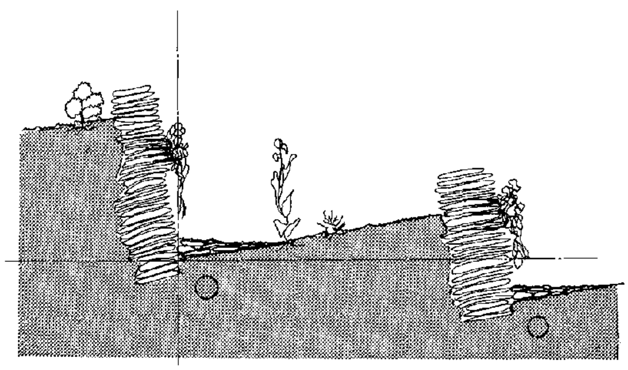


FIGURE 2 Detail of earth terracing

Low-Intensity Husbandry

Native grasses and ground cover serve several important functions, including control of erosion, reducing storm water pollution, altering the temperature of the earth, and providing forage for wildlife and domestic animals. Deep-rooting native species should be selected. These will be adapted to the local climate and will need little attention. A long grass will shade the soil in summer, form an insulating "fur" in winter, and a protective thatch in a driving rain. Mowing equipment should be modified to cut the grass at an 8-inch height. Whenever the tip-growth reaches above 12 inches, it can be mowed. This will likely be at

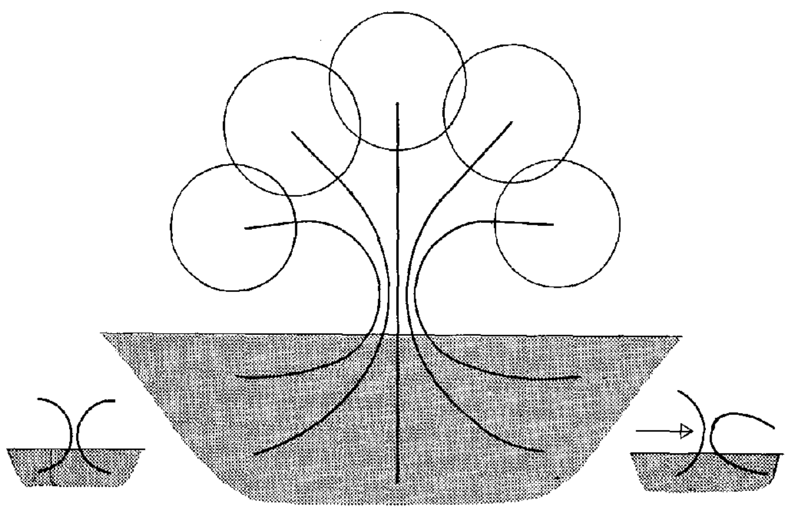


FIGURE 3 Anchorage of trees

6- to 10-week intervals. Under this regime, many native plants will seed themselves, and there will be an unending succession of colors.

Intensive Management

Under intensive management and care (that is, hard work) enough vegetables for a family of four for the whole year can be grown on a 30' x 40' plot. This does not include potatoes or grain, nor does it include fruit and nut trees. To get that level of production requires an average of one hour's work in the garden each day, and another hour, on average, in the kitchen each day during the summer.

Nut and fruit trees can be grown either as free-standing trees or trained as cordons against the walls of the terracing.

Fuel Crops

Steep slopes, which cannot easily be terraced, and transition spaces between public and private space, can be planted with coppice, a managed miniforest which is harvested at short intervals about every 5 to 7 years. The first harvest does not give much firewood, perhaps 5 to 8 tons per acre per year; but the second and subsequent harvests will give 12 to 20 tons per acre per year of dry wood to burn.[1] During each winter one-seventh to one-fifth of the woodland is cut, and the next spring new shoots grow from the stumps.

Coppice can be grown on top of earth-covered buildings if the weight of the trees is taken into consideration and a minimal depth of earth cover is provided. Because coppice is a dense growth, the root systems will intertwine. This will reduce the stresses on individual trees and danger of overturning in strong winds. Placement of coppice can help channel beneficial breezes and shelter buildings from harsh winter winds. Care must be taken to ensure that the trees do not block the winter sun or beneficial breezes from neighboring buildings.

Coppice is valuable because all the organic household refuse can be put onto its soil raw without composting. In the shaded ground, the refuse rots quickly and gives tremendous growth to the trees. Coppice will also absorb and cleanse tub, shower, and kitchen wastewaters throughout the winter, contrary to vegetable gardens. These are important advantages when public services break down.

The fuel harvest from a earth-covered dwelling cluster in which 30% of the land is used for coppice will supply the majority of the heating requirements for many parts of the country. This is true even if the density is 4 or even 5 dwelling units per gross acre.

Summary

From the community point of view, the value of this kind of land management can be seen in several areas. First, the approaches explored here require little or no fossil fuel; they are self-sufficient. Second, they provide food grown locally, for eating locally without the expense of long distance transportation. Third, they use land very productively: crops planted and managed by hand yield, on average, about twice as much per acre as field-grown crops that are managed by machines. In England, during World War II, yard food production was encouraged by the government.[2] It was found that the total yield per acre per year was as great from the suburbs, with their substantial areas devoted to homes and roads, as the same farm acreage. Not only did the people grow their crops more intensively and productively, but they also grew two or more crops on the same patch each year. There is no reason to believe that earth-covered dwelling clusters could not equal or better this. Fourth, if food needs for the winter are grown and stored locally, there will be less need for reliance on emergency food supply systems. Last, produce tastes better and is more heathful if freshly picked. Eating locally grown or home-grown food provides a sense of achievement, security, and satisfaction that is not quantifiable, but is nonetheless real.

Footnotes:

1. One ton of wood contains 16 million BTU. At present prices of about $5.00 per million BTU, this represents $1,000 to $1,500 per acre harvested each year from a seven acre plot.

2. Report of the Departmental Committee of Inquiry into Allotments; Her Majesty's Stationery Office, 1969, 470 pp.

3. A plot of 52 x 52 feet yielded about $200 of produce in 1969 dollars, ibid., p. 225.

APPENDIX III EXURBAN EARTH-COVERED SETTLEMENTS

By Frank L. Moreland

EXURBAN EARTH-COVERED SETTLEMENTS

Frank L. Moreland

> The paradoxical nature of civil defense preparedness is that if you have it you are unlikely to need it; if you don't have it, then you are more likely to need it. Incorporating shelter space in new underground construction built for other purposes is one way of improving civil defense preparedness and survival capability while making the most efficient use of resources.
>
> C. V. Chester

Earth-covered settlements can be particularly beneficial near military targets or zones of extreme natural hazard. For instance, small communities built principally with earth-covered buildings can provide emergency or surge housing in times of disaster or disaster threat. Such communities, or settlements, can be located an appropriate distance from areas of known potential hazard.

The DFW (Dallas-Fort Worth) metropolitan area, for example, is a well-known military target because it: 1) is a major population center (2.7 million), 2) has major military-manufacturing and high-technology installations, 3) has a SAC base, and 4) is a major transportation center. In the relocation phase of an expected nuclear attack, earth-covered settlements

---

Note: this appendix was developed out of discussions with Ralph Garrett, and many of the ideas here are rooted in his.

located 20 miles from the major target areas could provide significant protection to a large population. A warhead of one megaton, detonated three miles from an 9 psi resistance building, will not likely damage the structure beyond use. Earth-covered structures with an overall P.F. of 150+ and a 8 psi resistance can be provided with today's technology.

Civil defense documents of the Fort Worth-Tarrant County Office of Civil Defense 1977 Civil Defense Emergency Plan suggest that the nearest major crisis relocation center to Fort Worth be 29 miles away from the city center, with the average being 103 miles away, and the farthest being 290 miles away. Earth-covered structures at closer locations might perform equally as well as these centers. While the exact distance is not known, earth-covered structures at a distance of 4-20 miles beyond the zone of expected explosions would likely be useful.

The amount of surge housing required at this distance is difficult to estimate. Current relocation plans suggest that 40% of the population relocate more than 100 miles away, with 4% remaining in the DFW centers and 30% at 30 miles from them. As an intuitive guess, perhaps 35% would wish to relocate to earth-covered structures within the 20-mile distance. At 10 sq. ft. per person and an average available sq. ft. per house of 1400, 1035 houses would be needed to house 35% of the DFW population. This number might be reduced if community, commercial, and public buildings near the houses also provide shelter space. Figure 1 gives more calculations.

To put this in perspective, the two counties containing Dallas and Fort Worth add 6,000 units to the housing stock annually. Roughly 2,000 dwelling units are added each year to the 15- to 30-mile "doughnut"

SHELTER SPACE ESTIMATES			
Percent Population (Number)	Space Allotment S. F. per Person	Number of Houses Required	Average Occupancy People Per House
25% (145,000)	10	1,035	140
35% (204,000)	10	1,463	140
25% (145,000)	20	2,071	70
35% (204,000)	20	2,914	70
25% (145,000)	40	4,142	35
35% (204,000)	40	5,828	35

FIGURE 1

surrounding the major population centers. It is apparent, then, that earth-covered dwellings could make a significant contribution to surge housing programs with relatively modest introduction rates. For instance, if 25% of housing starts were earth-covered, 1000 to 1400 such houses could exist in the area by 1990.

The shelter opportunity would increase dramatically with the use of such dwellings in the small towns surrounding Dallas-Fort Worth beyond 20 miles. For instance, there are eleven towns with populations in excess of 15,000 within 45 miles of the metropolitan centers, and each of these towns is growing at rates equal to or greater than Dallas-Fort Worth proper.

The design of such settlements would require data and design criteria specially for their locations. While further research is required for their design, Figure 2 suggests how they might look.

Figures 3 through 6 show more examples of earth-covered settlements.[2]

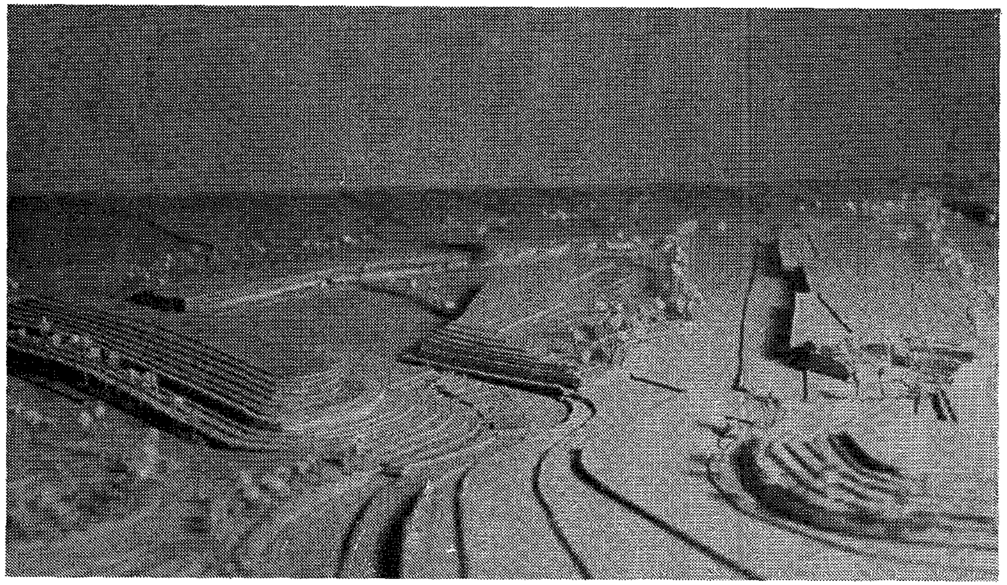


FIGURE 2 Model of an Earth-Covered Settlement (containing roughly 60 houses)

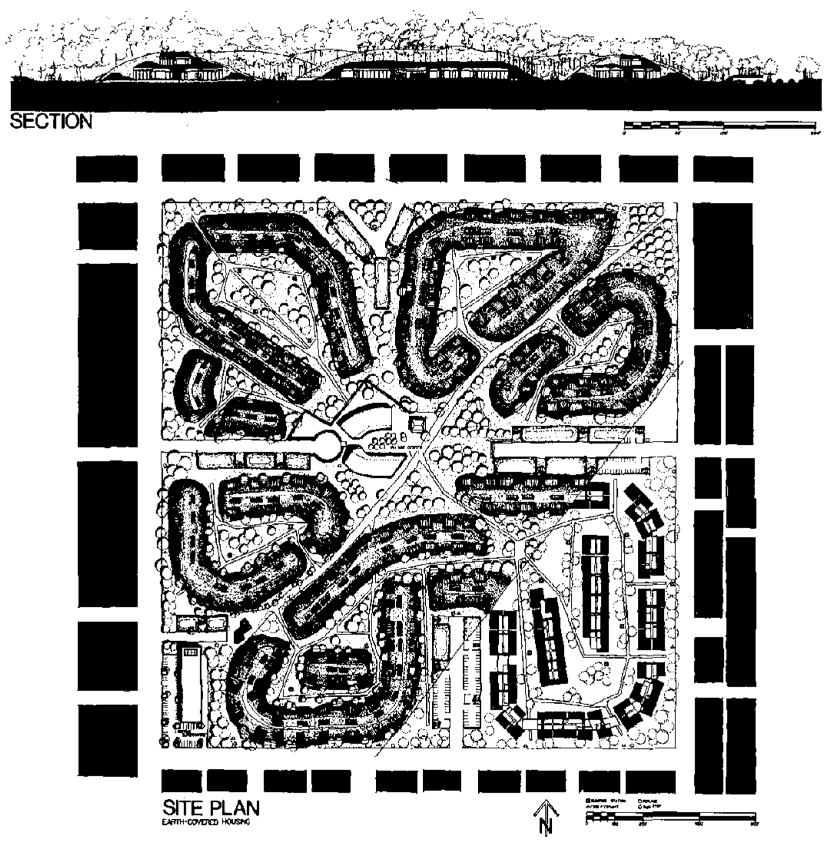


FIGURE 3


SITE PLAN
LEGEND
BUS STOP
PUMP ROOM
GARBAGE
SCOTT
MEADOWBROOK PARK
MEADOWBROOK
BEACH
LANCASTER
N
0 50 100
500
1000

FIGURE 4

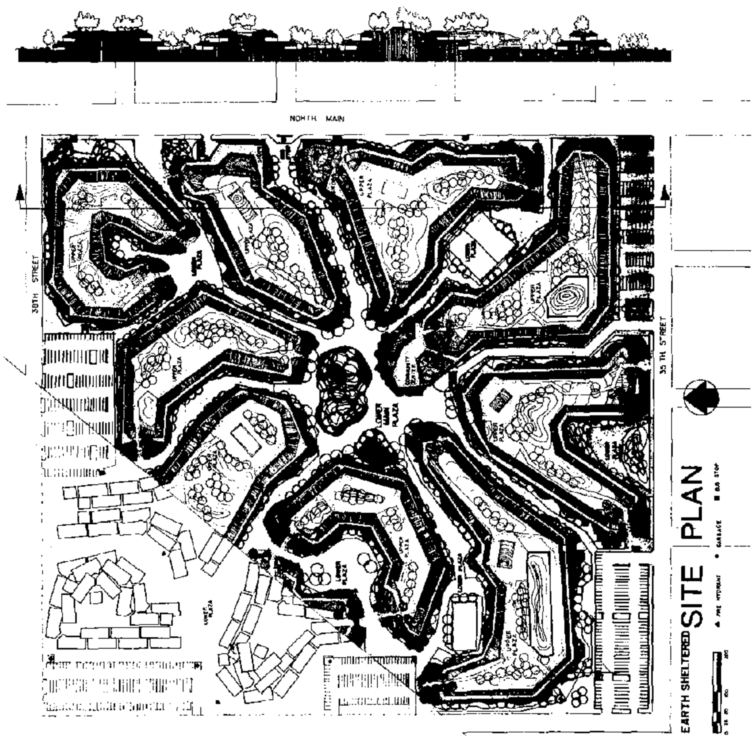

NORTH MAIN
38TH STREET
35 TH STREET
EARTH SHELTERED SITE PLAN

FIGURE 5

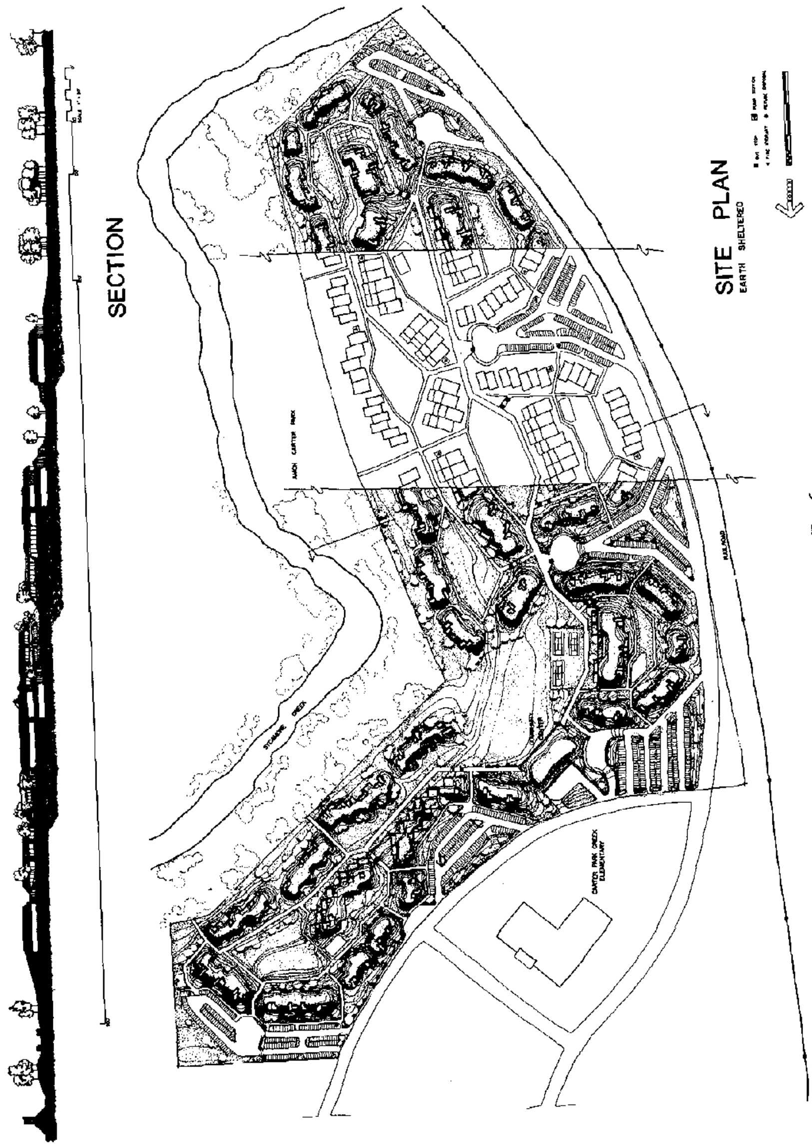


FIGURE 6

To put the costs of such a program in perspective, Figure 7 was constructed. If 7000 earth-covered dwellings were built in the DFW area over a three-year period, the range of costs might be:

EARTH-COVERED DWELLING COST PERSPECTIVE CIRCA 1981
7000 e-c dwellings @ 100,000 ea. = 700 million
7000 e-c dwellings @ 80,000 ea. = 560 million
7000 e-c dwellings @ 70,000 ea. = 490 million
7000 e-c dwellings @ 60,000 ea. = 420 million

FIGURE 7

If the 7000 earth-covered dwellings were part of the housing stock added in the doughnut of land lying between 8 and 20 miles from the central parts of DFW, then the additional cost of the construction program would be any additional construction costs associated with the earth-covered dwellings. Assuming land costs balance out, the earth-covered dwellings might cost more to construct than conventional;[3] however, it is difficult to say what the costs might be given research technology development. One should note that such research and development has already taken place over a long period of time in conventional housing, and Figure 8 gives the approximate range of their costs.

CONVENTIONAL DWELLING COSTS CIRCA 1981
7000 Conventional Dwellings @ 70,000 = 490 million
7000 Conventional Dwellings @ 50,000 = 350 million
7000 Conventional Dwellings @ 30,000 = 220 million

FIGURE 8

Using these figures we find the additional costs for the earth-covered dwellings to be as in Figure 9.

Unit Cost Differences between Earth-Covered and Conventional Dwellings			
Earth-covered Construction	Conventional Construction $30,000	$50,000	$70,000
$100,000	70,000	50,000	30,000
$ 80,000	50,000	30,000	10,000
$ 60,000	30,000	10,000	-10,000

FIGURE 9

For Fort Worth, $10,000 to $30,000 is the expected range, with $20,000 a median figure to use for comparison. Using that figure the additional construction cost for the program might be $140 million.

FOOTNOTES:

1. Haaland, C. M., C. V. Cester and E. P. Wigner (1976), Survival of the Relocated Population of the U.S. After a Nuclear Attack, ORNL-5041, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

2. The examples shown in Figures 2 through 6 are student projects. For a more thorough discussion of them, see Frank L. Moreland, Notes on Earth-Covered Settlement, in Earth-Covered Buildings and Settlements, Moreland, editor, Department of Energy, 1980 (NTIS)

3. The earth-covered dwellings might fit more per acre than conventional housing, reducing unit land costs, but there may be additional site development costs.

A Note in Collaboration with Jon Hand

Combining information from several parts of this report brings to light interesting possibilities for food and fuel production. Applying the food and fuel estimates provided by Dr. Stanford in Appendix II to the energy requirement assumptions of the Long-Term Potential Impact section, it appears that a significant percentage of heating demands of earth-covered dwellings could be met with on-site (renewable) fuel crops with similar results in food crop production. For the country as a whole, earth-covered dwellings have been assumed to consume an average of 94 million BTU of energy equivalents each year with about 26 million BTU allocated to heating. Mature coppice (fuel crop) production can range from 12 to 20 tons of wood (190-320 million BTU) per acre per year. Since fuel crops can be grown above and around earth-covered dwellings, a housing density of 4 and possibly 5 dwelling units per gross acre could have food and fuel crops each year sufficient to supply the majority of the produce and heating requirements of their neighborhood in most regions of the United States.

APPENDIX IV COST/BENEFIT ANALYSIS: EARTH-COVERED HOUSE

By the Ehrenkrantz Group

COST/BENEFIT ANALYSIS: EARTH-COVERED HOUSE

The Ehrenkrantz Group

INTRODUCTION

The economic benefit of choosing to build an underground home is the subject of this study. Two earth-covered buildings--one with three feet of earth and one with seven feet of earth--are compared to tract houses common to the Fort Worth area. This analysis employs a discounted after tax cash-flow economic model, a series of assumptions about the buildings being compared and an economic environment which acknowledges benefits for buyers of underground buildings.

METHOD OF ANALYSIS

Two methods of comparison have been used to take into account as many economic aspects of the buildings as possible.

The first method is a comparison of Present Value Totals for underground and tract houses. This model takes into account all of the major costs to the home buyer over 30- and 80-year economic analysis periods. The Present Value Totals for the underground buildings are compared directly to the totals for the tract houses. The difference between the values indicates the relative benefit of choosing one building over another. This method acknowledges the need to replace the tract house after its 60-year estimated life.

The second method treats the choice of building an underground house as an option which will add an additional cost to the purchase of a home. This cost will be offset by savings produced by the option in energy and maintanance. All costs and savings have been normalized to a $/square foot basis. This method results in a Payback Period for the option and an Internal Rate of Return on the investment in an underground house.

Three different mortgage structures, two discount rates and long and short term analysis are investigated in these comparisons.

ASSUMPTIONS

Capital Cost

Building costs have been normalized to a $/sq. ft. base using an average building size of 1627 sq. ft. High- and low-cost tract houses were compared to two underground houses.

The low-cost tract house, $38/sq. ft., compared to the underground house with three feet of earth cover, $52/sq.ft., and the higher cost tract house, $42/sq.ft., compared to the underground house with seven feet of earth cover, $60/sq.ft.

Energy Savings

Estimates of energy consumption in the underground house show potential savings of 65% for three feet of earth cover and 85% for seven feet of earth cover. These percentages were applied to an average fuel consumption for 39 metered conventional homes in the Fort Worth area. The then current electrical rate of 2.8 cents/Kwh produces savings of $356 in the first year for the 3 ft. option and $465 in the first year for the 7 ft. option.

Insurance Costs

The additional cost for insurance is based on a Cost/$ Valuation of the Property that is 25% lower than the tract house. Thus, an additional $3.00/year will be spent to insure the 3 ft. option and an additional $33.00/year for the 7 ft. option.

Maintenance Costs

The entry under MAINTENANCE COST is input as a negative value, therefore it becomes a SAVINGS.

Mortgages

Twenty-year mortgages at 11% interest with a 15% down payment percentage are available in the Fort Worth area. Two low-interest mortgages, 5% and 8.25%, are investigated for the underground house in addition to the 11% interest rate. This assumption is made to reflect possible incentives offered by banks or government to the buyers of underground homes. A 90-year mortgage at 5% interest is investigated in the long term analysis of the underground houses.

Salvage Value

In the 30-year economic analysis period:

*Tract house salvage value is equal to half of the inflated cost of the tract house at the end of the analysis, less one third for interior furnishings.

*Underground house salvage value is equal to the inflated cost of the underground house at the end of the analysis, less one third for interior furnishings. For the second method, salvage value is equal to the difference between the tract house and the underground house salvage values.

In the 80-year economic analysis period:

*Tract house salvage value is equal to two-thirds of the inflated cost of the repurchased tract house at the end of the analysis, less one-third for interior furnishings.

*Underground house salvage value is equal to the inflated cost of the underground house at the end of the analysis, less one-third for interior furnishings. For the second method, salvage value is equal to the difference between the repurchased tract house and the underground house salvage values.

Economic Environment

Fuel Cost Inflation Rates are assumed to be:

*20% for 5 years, 12% for 25 years for the third year economic analysis period.

*15% for 15 years, 10% for 65 years for the eighty-year economic analysis period.

Discount rates of 5% and 8% are investigated.

General inflation rates are: 8% for the 30-year economic analysis period and 5% for the 80-year economic analysis period.

The tax bracket for the home owners is assumed to be 25%. Commercial and investor tax rates are not used since these homes are assumed to be owner occupied.

The results of this analysis indicate that building earth-sheltered homes, with both 3 feet and 7 feet of earth cover, is a cost-effective choice based on the assumptions outlined above. The results are presented in two formats. The first is a comparison of the Present Value Total for the tract house and underground house in Group A. For Group B, the Payback Period and Internal Rate of Return are given for each option studied. The second format is a presentation of the specific assumptions made for each test along with the results produced in the analysis. The computer printouts for the economic analysis runs are presented in Appendix A and B. These printouts show the cash flows in each year of the economic analysis period, the assumptions made and the results of the analysis.

RESULTS

GROUP A

Tract House	Underground House	Difference
$38/sq', 5% discount rate 11% mortgage -169,221	3 Ft., 5% discount rate 11% mortgage -32,052	$137,169
	3 Ft., 5% discount rate 8.25% mortgage -17,744	$151,477
	3 Ft., 5% discount rate 5% mortgage - 2,423	$166,799
$38/sq', 8% discount rate 11% mortgage -122,740	3 Ft., 8% discount rate 11% mortgage -64,569	$ 58,171
	3 Ft., 8% discount rate 8.25% mortgage -53,437	$ 69,303
	3 Ft., 8% discount rate 5% mortgage -41,559	$ 81,181
$38/sq', 5% discount rate long term -757,666	3 Ft., 5% discount rate long term -247,845	$509,821
$38/sq', 8% discount rate long term -224,540	3 Ft., 8% discount rate long term -103,277	$121,263
$42/sq', 5% discount rate 11% mortgage -179,587	7 Ft., 5% discount rate 11% mortgage - 22,786	$156,801
	7 Ft., 5% discount rate 8.25 mortgage - 6,277	$173,310

Tract House	Underground House	Difference
	7 Ft., 5% discount rate 5% mortgage - 11,401	\$168,186
\$42/sq', 8% discount rate 11% mortgage -131,212	7 Ft., 8% discount rate 11% mortgage - 66,019	\$ 65,193
	7 Ft., 8% discount rate 8.25% mortgage - 53,173	\$ 78,039
	7 Ft., 8% discount rate 5% mortgage - 39,468	\$ 91,744
\$42/sq', 5% discount rate long term -782,481	7 Ft., 5% discount rate long term -158,542	\$623,939
\$42/sq', 8% discount rate long term -235,913	7 Ft., 8% discount rate long term - 91,612	\$144,301

These results indicate that the underground buildings--in all cases--are less costly to operate than the tract houses. The investment becomes more attractive if low interest mortgages are available for the underground buildings. The underground house with 7 Ft. of earth cover produces greater savings than the house with 3 Ft. of earth cover. A 5% discount rate is most favorable to the underground buildings.

Group B

Underground House, 3 Ft. of Earth Cover

Option	Discounted Payback Period	Internal Rate of Return
5% discount rate:		
11% mortgage	19.82 years	17.85%
8.25% mortgage	16.83 years	19.22%
5% mortgage	13.46 years	21.09%

Option	Discounted Payback Period	Internal Rate of Return
8% discount rate:		
11% mortgage	21.73 years	17.84%
8.25% mortgage	19.03 years	19.25%
5% mortgage	15.07 years	21.06%
Long Term		
5% discount rate:		
11% mortgage	22.27 years	14%
8.25% mortgage	19.24 years	15.23%
8% discount rate:		
11% mortgage	25.52 years	14%
8.25% mortgage	21.81 years	15.22%
5% discount rate:		
90 year, 5% mortgage	7.75 years	23.13%
8% discount rate:		
90 years, 5% mortgage	8.5 years	23.13%

Underground House, 7 Ft. of Earth Cover

Option	Discounted Payback Period	Internal Rate of Return
5% mortgage rate:		
11% mortgage	21.17 years	16.8%
8.25% mortgage	18.9 years	18.09%
5% mortgage	15.44 years	19.73%
8% discount rate:		
11% mortgage	23.49 years	16.78%
8.25% mortgage	21.03 years	18.06%
5% mortgage	17.41 years	19.75%
Long Term		
5% discount rate:		
11% mortgage	23.72 years	13.46%
8.25% mortgage	21.05 years	14.51%

Option	Discounted Payback Period	Internal Rate of Return
8% discount rate:		
11% mortgage	27.74 years	13.47%
8.25% mortgage	23.85 years	14.5 %
5% discount rate:		
90 years, 5% mortgage	8.84 years	21.25%
8% discount rate:		
90 year, 5% mortgage	9.73	21.25%

If the internal rate of return is greater than the discount rate, an option is judged cost-effective.

The underground house is an attractive investment in all the situations investigated. The house with 3 Ft. of earth cover produces a slightly better return on investment than the house with 7 Ft. of earth cover. An underground house with a conventional 11% mortgage at 8% discount rate will produce returns on investment of 17.84% for 3 Ft. of earth cover and 16.78% for 7 Ft. of earth cover in the short term. When a long term, low interest mortgage is available, the investment has a payback period of less than 10 years with returns on investment of 23.13% and 21.25% for the 3 Ft. and 7 Ft. of earth cover, respectively.

Typical Listing of Economic Assumptions (1 of 22)

```
THE EHRENKRANTZ GROUP ECONOMIC ANALYSIS PROGRAM


PROJECT TITLE  TRACT HOUSE  LOW COST  5% DISCOUNT RATE
ECONOMIC ANALYSIS PERIOD  30
PROJECT LIFE  60
CAPITAL COST OF THE OPTION  61826
MORTGAGE RATE  11
MORTGAGE TERM (YEARS)  20
DOWN PAYMENT PERCENTAGE  15
NET ENERGY SAVINGS IN YEAR 0   548
MAINTENANCE COST IN YEAR 0  927
INSURANCE COST IN YEAR 0 386
STRAIGHT LINE DEPRECIATION SCHEDULE (YEARS)  0
SALVAGE VALUE AT THE END OF THE PROJECT LIFE  103710
SALVAGE VALUE AS CAPITALIZED CASH FLOW (YES OR NO)NO
GENERAL INFLATION RATE  8
FUEL COST INFLATION RATE  20
DOES THE FUEL COST INFLATION CHANGE DURING THE ECONOMIC ANALYSIS PERIOD(YES OR NO)  YES
IN WHAT YEAR DOES THE INFLATION RATE CHANGE  5
WHAT IS THE SECOND FUEL COST INFLATION RATE  12
DISCOUNT RATE, (AFTER TAX)  5
HOME OWNERS TAX BRACKET (IF BUILDING IS COMMERCIAL PROPERTY INPUT 0)  25
INVESTMENT TAX CREDIT RATE  0
CORPORATE INCOME TAX RATE  0
CORPORATE CAPITAL GAINS TAX RATE  0


MORTGAGE PAYMENT PER YEAR OF TERM
6599.26


SALVAGE VALUE    PRESENT VALUE OF THE SALVAGE VALUE
103710           23996.16

TOTAL            PRESENT VALUE TOTAL
-327047.99       -169220.92
```

THE EHRENKRANTZ GROUP *** DISCOUNTED AFTER TAX CASH FLOW ANALYSIS

PROJECT TITLE: TRACT HOUSE LOW COST 5% DISCOUNT RATE

YEAR	ENERGY SAVINGS	DEPRECTN	MORTGAGE PRINCL PD	INTRST PD AFT TAX	CAPITAL COST	MAINT COST	INSURANCE COST	YEAR TOTAL	SIMPLE TOTAL	PV TOTAL
0	0	0	0	0	-9273.9	0	0	-9273.9	-9273.9	-9273.9
1	-657.6	0	-818.53	-4335.55	0	-1001.16	-416.88	-7229.72	-16503.62	-16159.35
2	-789.12	0	908.57	-4268.02	0	-1081.85	-450.23	-7497.19	-24000.81	-22959.52
3	-946.94	0	-1009.51	-4193.06	0	-1167.75	-486.75	-7802.52	-31803.34	-29699.64
4	-1136.33	0	-1119.45	-4109.86	0	-1261.17	-525.15	-8151.96	-39955.3	-36406.28
5	-965.76	0	-1242.59	-4017.51	0	-1362.07	-567.16	-8155.09	-48110.39	-42796
6	-1081.65	0	-1377.27	-3914.99	0	-1471.03	-612.53	-8459.49	-56569.87	-49100.6
7	-1211.45	0	-1530.99	-3801.2	0	-1588.72	-661.54	-8793.9	-65363.78	-55358.26
8	-1356.83	0	-1699.4	-3674.89	0	-1715.81	-714.46	-9161.4	74525.17	-61559.06
9	-1519.65	0	-1886.34	-3534.69	0	-1853.08	-771.62	-9568.37	-84090.55	-67724.98
10	-1702	0	-2093.84	-3379.07	0	-2001.32	833.35	-10009.58	94100.13	-73869.99
11	-1906.25	0	-2324.16	-3206.33	0	-2161.43	-900.01	-10498.17	-104598.3	-80008.06
12	-2134.99	0	-2579.82	-3014.59	0	-2334.34	-972.01	-11035.75	-115634.05	-86153.18
13	-2391.19	0	-2863.6	-2801.75	0	-2521.09	-1049.77	-11627.41	-127261.46	-92319.44
14	-2678.14	0	-3178.59	-2565.5	0	-2722.78	-1133.76	-12278.77	-139540.23	-98521.05
15	-2999.51	0	-3528.24	-2303.27	0	-2940.6	-1224.46	-12996.08	-152536.31	-104772.39
16	-3359.46	0	-3916.34	-2012.19	0	-3175.85	-1322.41	-13786.25	-166322.56	-111088.03
17	-3762.59	0	-4347.14	-1689.09	0	-3429.92	1428.21	-14656.95	-180979.5	-117482.81
18	-4214.1	0	-4825.32	-1330.45	0	-3704.31	-1542.46	-15616.65	-196596.16	-123971.85
19	-4719.79	0	-5356.11	-932.36	0	-4000.65	-1665.86	-16674.78	-213270.94	-130570.63
20	-5286.17	0	-5945.28	-490.49	0	-4320.71	-1799.13	-17841.77	-231112.72	-137298.01
21	-5920.51	0	0	0	0	-4666.36	-1943.06	-12529.93	-243642.65	-141792.53
22	-6630.97	0	0	0	0	-5039.67	-2098.5	-13769.15	-257411.8	-146499.51
23	-7426.69	0	0	0	0	-5442.85	-2266.38	-15135.92	-272547.71	-151427.33
24	-8317.89	0	0	0	0	-5878.27	-2447.7	-16643.86	-289191.57	-156508.06
25	-9316.04	0	0	0	0	-6348.54	-2643.51	-18308.08	-307499.66	-161994.49
26	-10433.96	0	0	0	0	-6856.42	-2854.99	-20145.37	-327645.03	-167660.18
27	-11686.03	0	0	0	0	-7404.93	-3083.39	-22174.36	-349819.39	-173599.55
28	-13088.36	0	0	0	0	-7997.33	-3330.06	-24415.75	-374235.14	-179827.85
29	-14658.96	0	0	0	0	-8637.11	-3596.47	-26892.54	-401127.68	-186361.3
30	-16418.04	0	0	0	0	-9328.08	-3884.19	-29630.31	-430757.99	-193217.08

Typical Listing of Yearly Data (1 of 22)

Typical Listing of Economic Assumptions (1 of 22)

```
THE EHRENKRANTZ GROUP ECONOMIC ANALYSIS PROGRAM


PROJECT TITLE  UNDERGROUND HOUSE  3FT OF EARTH COVER  OPTION 1
ECONOMIC ANALYSIS PERIOD  30
PROJECT LIFE  300
CAPITAL COST OF THE OPTION  22778
MORTGAGE RATE  11
MORTGAGE TERM (YEARS)  20
DOWN PAYMENT PERCENTAGE  15
NET ENERGY SAVINGS IN YEAR 0  356
MAINTENANCE COST IN YEAR 0  -502
INSURANCE COST IN YEAR 0 .3
STRAIGHT LINE DEPRECIATION SCHEDULE (YEARS)  0
SALVAGE VALUE AT THE END OF THE PROJECT LIFE  466290
SALVAGE VALUE AS CAPITALIZED CASH FLOW (YES OR NO)NO
GENERAL INFLATION RATE  8
FUEL COST INFLATION RATE  20
DOES THE FUEL COST INFLATION CHANGE DURING THE ECONOMIC ANALYSIS PERIOD(YES OR NO)  YES
IN WHAT YEAR DOES THE INFLATION RATE CHANGE  5
WHAT IS THE SECOND FUEL COST INFLATION RATE  12
DISCOUNT RATE, (AFTER TAX)  5
HOME OWNERS TAX BRACKET (IF BUILDING IS COMMERCIAL PROPERTY INPUT 0)  25
INVESTMENT TAX CREDIT RATE  0
CORPORATE INCOME TAX RATE  0
CORPORATE CAPITAL GAINS TAX RATE  0


MORTGAGE PAYMENT PER YEAR OF TERM
2431.31


SALVAGE VALUE   PRESENT VALUE OF THE SALVAGE VALUE
466290          107888.99

TOTAL           PRESENT VALUE TOTAL
579225.71       137169.06


SIMPLE PAYBACK  16.86  YEARS
DISCOUNTED PAYBACK  19.82  YEARS
INTERNAL RATE OF RETURN  17.85  %
```

THE EHRENKRANTZ GROUP *** DISCOUNTED AFTER TAX CASH FLOW ANALYSIS

PROJECT TITLE: UNDERGROUND HOUSE 3FT OF EARTH COVER OPTION 1

YEAR	ENERGY SAVINGS	DEPRECTN	MORTGAGE PRINCL PD	INTRST PD AFT TAX	CAPITAL COST	MAINT COST	INSURANCE COST	YEAR TOTAL	SIMPLE TOTAL	PV TOTAL
0	0	0	0	0	-3416.7	0	0	-3416.7	-3416.7	-3416.7
1	427.2	0	-301.56	-1597.31	0	542.16	-3.24	-932.75	-4349.45	-4305.04
2	512.64	0	-334.74	-1572.43	0	585.53	-3.5	-812.49	-5161.94	-5041.99
3	615.17	0	-371.56	-1544.81	0	632.38	-3.78	-672.61	-5834.55	-5623.01
4	738.2	0	-412.43	-1514.16	0	682.97	-4.08	-509.5	-6344.05	-6042.18
5	627.39	0	-457.8	-1480.13	0	737.6	-4.41	-577.34	-6921.39	-6494.54
6	702.68	0	-508.15	-1442.37	0	796.61	-4.76	-455.99	-7377.38	-6834.81
7	787	0	-564.05	-1400.44	0	860.34	-5.14	-322.29	-7699.67	-7063.85
8	881.44	0	-626.1	-1353.91	0	929.17	-5.55	-174.95	-7874.62	-7182.27
9	987.22	0	-694.97	-1302.26	0	1003.5	-6	-12.5	-7887.12	-7190.33
10	1105.68	0	-771.41	-1244.92	0	1083.78	-6.48	166.65	-7720.47	-7088.02
11	1238.36	0	-856.27	-1181.28	0	1170.48	-6.99	364.3	-7356.17	-6875.01
12	1386.97	0	-950.46	-1110.64	0	1264.12	-7.55	582.44	-6773.73	-6550.69
13	1553.4	0	-1055.01	-1032.22	0	1365.25	-8.16	823.26	-5950.47	-6114.1
14	1739.81	0	-1171.06	-945.19	0	1474.47	-8.81	1089.23	-4861.24	-5563.96
15	1948.59	0	-1299.88	-848.57	0	1592.43	-9.52	1383.05	-3478.19	-4898.69
16	2182.42	0	-1442.86	-741.33	0	1719.82	-10.28	1707.77	-1770.42	-4116.34
17	2444.31	0	-1601.58	-622.3	0	1857.41	-11.1	2066.74	296.33	-3214.63
18	2737.63	0	-1777.75	-490.17	0	2006	-11.99	2463.72	2760.05	-2190.9
19	3066.14	0	-1973.3	-343.5	0	2166.48	-12.95	2902.87	5662.92	-1042.14
20	3434.08	0	-2190.37	-180.71	0	2339.8	-13.98	3388.83	9051.75	235.08
21	3846.17	0	0	0	0	2526.98	-15.1	6358.05	15409.8	2517.25
22	4307.71	0	0	0	0	2729.14	-16.31	7020.54	22430.34	4917.22
23	4824.64	0	0	0	0	2947.47	-17.61	7754.5	30184.84	7441.86
24	5403.59	0	0	0	0	3183.27	-19.02	8567.84	38752.68	10098.48
25	6052.02	0	0	0	0	3437.93	-20.55	9469.41	48222.09	12894.82
26	6778.27	0	0	0	0	3712.97	-22.19	10469.05	58691.14	15839.14
27	7591.66	0	0	0	0	4010.01	-23.96	11577.7	70268.84	18940.21
28	8502.66	0	0	0	0	4330.81	-25.88	12807.58	83076.42	22207.34
29	9522.98	0	0	0	0	4677.27	-27.95	14172.3	97248.72	25650.45
30	10665.73	0	0	0	0	5051.45	-30.19	15687	112935.71	29280.07

Typical Listing of Yearly Data (1 of 22)

Typical Listing of Economic Assumptions (1 of 22)

```
THE EHRENKRANZ GROUP ECONOMIC ANALYSIS PROGRAM

PROJECT TITLE  UNDERGROUND HOUSE  3 FT OF EARTH COVER  5% DISCOUNT RATE  11% MORTGAGE
ECONOMIC ANALYSIS PERIOD  30
PROJECT LIFE  300
CAPITAL COST OF THE OPTION  84604
MORTGAGE RATE  11
MORTGAGE TERM (YEARS)  20
DOWN PAYMENT PERCENTAGE  15
NET ENERGY SAVINGS IN YEAR 0  -192
MAINTENANCE COST IN YEAR 0  425
INSURANCE COST IN YEAR 0 389
STRAIGHT LINE DEPRECIATION SCHEDULE (YEARS)  0
SALVAGE VALUE AT THE END OF THE PROJECT LIFE  570000
SALVAGE VALUE AS CAPITALIZED CASH FLOW (YES OR NO)NO
GENERAL INFLATION RATE  8
FUEL COST INFLATION RATE  20
DOES THE FUEL COST INFLATION CHANGE DURING THE ECONOMIC ANALYSIS PERIOD(YES OR NO)  YES
IN WHAT YEAR DOES THE INFLATION RATE CHANGE  5
WHAT IS THE SECOND FUEL COST INFLATION RATE  12
DISCOUNT RATE, (AFTER TAX)  5
HOME OWNERS TAX BRACKET (IF BUILDING IS COMMERCIAL PROPERTY INPUT 0)  25
INVESTMENT TAX CREDIT RATE  0
CORPORATE INCOME TAX RATE  0
CORPORATE CAPITAL GAINS TAX RATE  s
?REENTER
CORPORATE CAPITAL GAINS TAX RATE  0


MORTGAGE PAYMENT PER YEAR OF TERM
9030.57


SALVAGE VALUE    PRESENT VALUE OF THE SALVAGE VALUE
570000           131885.15

TOTAL            PRESENT VALUE TOTAL
252177.73        -32051.86


SIMPLE PAYBACK  0  YEARS
DISCOUNTED PAYBACK  0  YEARS
INTERNAL RATE OF RETURN  3.73  %
```

THE EHRENKRANTZ GROUP *** DISCOUNTED AFTER TAX CASH FLOW ANALYSIS

PROJECT TITLE: UNDERGROUND HOUSE 3 FT OF EARTH COVER 5% DISCOUNT RATE 11% MORTGAGE

YEAR	ENERGY SAVINGS	DEPRECTN	MORTGAGE PRINCL PD	INTRST PD AFT TAX	CAPITAL COST	MAINT COST	INSURANCE COST	YEAR TOTAL	SIMPLE TOTAL	PV TOTAL
0	0	0	0	0	-12690.6	0	0	-12690.6	-12690.6	-12690.6
1	-230.4	0	-1120.1	-5932.86	0	-459	-420.12	-8162.47	-20853.07	-20464.38
2	-276.48	0	-1243.31	-5840.45	0	-495.72	-453.73	-8309.68	-29162.76	-28001.51
3	-331.78	0	-1380.07	-5737.87	0	-535.38	-490.03	-8475.13	-37637.88	-35322.65
4	-398.13	0	-1531.88	-5624.02	0	-578.21	-529.23	-8661.47	-46299.35	-42448.46
5	-338.37	0	-1700.39	-5497.64	0	-624.46	-571.57	-8732.43	-55031.78	-49290.54
6	-378.97	0	-1887.43	-5357.36	0	-674.42	-617.29	-8915.48	-63947.25	-55943.41
7	-424.45	0	-2095.05	-5201.64	0	-728.38	-666.68	-9116.19	-73063.45	-62422.12
8	-475.38	0	-2325.5	-5028.8	0	-786.65	-720.01	-9336.35	-82399.79	-68741.32
9	-532.43	0	-2581.31	-4836.95	0	-849.58	-777.61	-9577.88	-91977.67	-74915.31
10	-596.32	0	-2865.25	-4623.99	0	-917.54	-839.82	-9842.93	-101820.6	-80958.01
11	-667.88	0	-3180.43	-4387.61	0	-990.95	-907.01	-10133.87	-111954.47	-86883.07
12	-748.03	0	-3530.27	-4125.22	0	-1070.22	-979.57	-10453.31	-122407.78	-92703.87
13	-837.79	0	-3918.6	-3833.98	0	-1155.84	-1057.93	-10804.14	-133211.93	-98433.54
14	-938.33	0	-4349.65	-3510.69	0	-1248.31	-1142.57	-11189.54	-144401.47	-104085.02
15	-1050.92	0	-4828.11	-3151.84	0	-1348.17	-1233.97	-11613.03	-156014.5	-109671.08
16	-1177.04	0	-5359.2	-2753.53	0	-1456.03	-1332.69	-12078.48	-168092.98	-115204.37
17	-1318.28	0	-5948.72	-2311.39	0	-1572.51	-1439.31	-12590.2	-180683.18	-120697.44
18	-1476.47	0	-6603.08	-1820.62	0	-1698.31	-1554.45	-13152.93	-193836.11	-126162.75
19	-1653.65	0	-7329.41	-1275.87	0	-1834.17	-1678.81	-13771.91	-207608.02	-131612.77
20	-1852.09	0	-8135.65	-671.19	0	-1980.91	-1813.11	-14452.95	-222060.97	-137059.93
21	-2074.34	0	0	0	0	-2139.38	-1958.16	-6171.88	-228232.85	-139275.28
22	-2323.26	0	0	0	0	-2310.53	-2114.81	-6748.6	-234981.45	-141582.29
23	-2602.05	0	0	0	0	-2495.37	-2284	-7381.42	-242362.88	-143985.47
24	-2914.3	0	0	0	0	-2695	-2466.72	-8076.02	-250438.89	-146489.58
25	-3264.01	0	0	0	0	-2910.6	-2664.06	-8838.67	-259277.56	-149099.67
26	-3655.69	0	0	0	0	-3143.45	-2877.18	-9676.33	-268953.89	-151821.04
27	-4094.38	0	0	0	0	-3394.93	-3107.36	-10596.66	-279550.55	-154659.34
28	-4585.7	0	0	0	0	-3666.52	-3355.94	-11608.17	-291158.72	-157620.51
29	-5135.99	0	0	0	0	-3959.84	-3624.42	-12720.25	-303878.96	-160710.85
30	-5752.31	0	0	0	0	-4276.63	-3914.37	-13943.31	-317822.27	-163937.01

Typical Listing of Yearly Data (1 of 22)

<u>FEMA DISTRIBUTION LIST</u>

Federal Emergency Management Agency Mitigation and Research ATTN: Adiministrative Officer Washington, D.C. 20472	60
Assistant Secretary of the Army (R&D) ATTN: Assistant for Research Washington, D.C. 20301	1
Chief of Naval Research Washington, D.C. 20360	1
Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	12
Oak Ridge National Laboratory ATTN: Librarian P.O. Box X Oak Ridge, Tennessee 37830	1
Los Alamos Scientific Laboratory ATTN: Document Library Los Alamos, N.M. 87544	1
The RAND Corporation ATTN: Document Library 1700 Main Street Santa Monica, CA 90401	1

Earth-Covered Buildings: An Exploratory Analysis For Hazard And Energy Performance, by Frank L. Moreland, et al. UNCLASSIFIED, Moreland Associates, Fort Worth, Texas 76107, November 1981, FEMA Contract # 81-600091, Work Unit # 4411E.

Abstract

The performance of earth-covered buildings is examined regarding storms, nuclear detonations, earthquakes, fire, nuclear radiation, energy consumption, compatibility with solar energy systems, peak-load effects, soil and groundwater effects, air and climate effects, occupant evaluation, and resource management. Potential long-term benefits are assessed, including the areas of economic benefits, community benefits, and security benefits.

Earth-Covered Buildings: An Exploratory Analysis For Hazard And Energy Performance, by Frank L. Moreland, et al. UNCLASSIFIED, Moreland Associates, Fort Worth, Texas 76107, November 1981, FEMA Contract #81-600091, Work Unit #4411E.

Abstract

The performance of earth-covered buildings is examined regarding storms, nuclear detonations, earthquakes, fire, nuclear radiation, energy consumption, compatibility with solar energy systems, peak-load effects, soil and groundwater effects, air and climate effects, occupant evaluation, and resource management. Potential long-term benefits are assessed, including the areas of economic benefits, community benefits, and security benefits.

Earth-Covered Buildings: An Exploratory Analysis For Hazard And Energy Performance, by Frank L. Moreland, et al. UNCLASSIFIED, Moreland Associates, Fort Worth, Texas 76107, November 1981, FEMA Contract #81-600091, Work Unit #4411E.

Abstract

The performance of earth-covered buildings is examined regarding storms, nuclear detonations, earthquakes, fire, nuclear radiation, energy consumption, compatibility with solar energy systems, peak-load effects, soil and groundwater effects, air and climate effects, occupant evaluation, and resource management. Potential long-term benefits are assessed, including the areas of economic benefits, community benefits, and security benefits.

Earth-Covered Buildings: An Exploratory Analysis For Hazard And Energy Performance, by Frank L. Moreland, et al. UNCLASSIFIED, Moreland Associates, Fort Worth, Texas 76107, November 1981, FEMA Contract #81-600091, Work Unit #4411E.

Abstract

The performance of earth-covered buildings is examined regarding storms, nuclear detonations, earthquakes, fire, nuclear radiation, energy consumption, compatibility with solar energy systems, peak-load effects, soil and groundwater effects, air and climate effects, occupant evaluation, and resource management. Potential long-term benefits are assessed, including the areas of economic benefits, community benefits, and security benefits.