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JHS

DETAILING THE EARTH SHELTERED BUILDING

Rodney Wright and Sydney Wright
The Hawkweed Group, Ltd.

OSSECO, WI

At Hawkweed Group, we only design buildings that are solar heated. These buildings are designed to be very thermally efficient and are, therefore, frequently earth sheltered--wholly or partially.

We think the key to successful earth integration lies in careful detailing. Let's look at the considerations in detailing a building that are peculiar to earth sheltered structures.

We probably don't need to mention that an earth sheltered building should not be built in a swamp! If costs are high for waterproofing the building and stabilizing of the structure in unfavorable soils, the site is a poor choice.

Reinforcing helps to provide structural integrity for footings, foundations, walls and slabs, tying them all together. For this reason, it is necessary to extend rods into footings and to key them into walls. In footings, rods should be set up on chairs, so they will not slip, ending up at the bottom of the footing when the concrete is poured. All bars must be tied together in an even manner, properly spaced, with all reinforcing keyed throughout.

For a wood foundation, all members must be treated wood to withstand below ground conditions. Plywood must be butted tightly and caulked carefully. The plate should be at least its own depth below the finished slab.

Roofs that will be covered with earth should be designed to carry a load of six-hundred pounds per square foot.

Berms must be designed for stability, with the angle of repose calculated so that the earth will not slide away. Planting and riprap will also help to hold the berm in place.

For berms, dampproof with two coats of sprayed-on pitch, before the drain tile is placed, all the way to the bottom of the wall.

For an earth covered building, use a material designed to waterproof on the outside of the walls and roof. A roofing membrane will not provide adequate protection. Use bitumen, a membrane material or Bentonite, a natural clay product. A protective board is required for most of these materials and insulation may be placed over this prior to backfilling.

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Drain tile should be used to take water away from the building perimeter, with a foot of gravel placed over it.

At parapets, the waterproofing should lap up the wall, with another lap laid over the first for a good seal, in order to prevent water from moving and entering the building through capillary action.

Stacks and monitors must be adequately caulked and waterproofed. The best choice is to pour them of concrete, carefully formed for a good seal. Waterproof with cant strips, eased up over the face of curbs, not at a 90 degree angle.

Windows in monitors should be placed high enough so they will not be snow covered in winter, as this would increase the possibility of leakage. Triple glaze these windows, except at the south elevation, where solar gain dictates double glazing for maximum benefit.

If a vapor barrier is used as an added waterproofing membrane, follow the prescribed method of installation, with a band board placed over it.

Try to avoid conduction heat loss through the concrete walls without destroying the continuity of structure. Although it is difficult to provide the necessary thermal break to avoid this, we have covered concrete with another envelope, this one of wood, to achieve the desired effect.

Condensation is affected by a combination of air flow, temperature and humidity level. Place storage rooms on the north wall, where the greatest temperature variation would be anticipated. Detail the building to provide for good air flow throughout to evaporate moisture. Insulate on the outside of the walls to reduce temperature variation.

If the building is made of poured concrete and if doors will be required at concrete walls, be sure to provide for jambs at the openings. Either nailing strips, anchoring for a metal system or, a jamb, cast in the wall must be detailed. The alternative would be to cast the jamb itself into the wall. In this case, the detail should show the jamb securely anchored to the wall.

If you want to use a thermosiphon solar heat method, you can provide a heat sink under the slab. Begin with well-compacted level insulation over the fill. Next, place concrete block as a plenum, with the openings lined up to permit continuous air flow. All of this would be placed beneath a four inch concrete slab.

When construction begins, you need to be very sure that contractors follow the drawings precisely. Careful detailing is worthless without accompanying careful construction.

Beginning with the first steps of construction, the excavation must not be over dug, as footings and foundations should not be placed on disturbed soil.

Reinforcing must be rigidly inspected to be sure that it is tied together in an even manner and that it is keyed as required.

Waterproofing or dampproofing should go on before drain tile is placed so that the wall will be covered to the very bottom. Care must be taken to avoid puncturing a waterproof membrane or a vapor barrier, for moisture can enter through these breaks.

Even though it is difficult to effect a tight fit between pieces of rigid insulation, it is important to insist on careful fitting since heat loss will occur at each gap. One way to improve the situation is to use two layers of rigid insulation, with staggered joints. A tight construction sequence is important, with backfilling occurring as soon as insulation has been placed and inspected, since the material is quite fragile, easily damaged by other construction activity, and needs careful protection. Do not place berms, however, until the roof is framed, providing strength to support the earth.

In our experience, earth sheltering of buildings can be accomplished with success, creating structures that are thermally efficient, cozy, light and bright.

In buildings as diverse as a community center built into a south-facing hill, with roof and three walls fully earth integrated; and our own Wisconsin house built on a one-hundred year old earth sheltered barn foundation, we are using these techniques. Also, two houses in north central Wisconsin, and others in Wauconda, Illinois and Bryan, Ohio are built in south-facing slopes. In addition, we use the technique of berming at north and west sides whenever this is feasible, always keeping the south face open to the sun.

In fact, at the new town center at Soldiers Grove, Wisconsin, we have included encouragement of earth berming as a part of the design standards promulgated for the project as a strategy to enhance thermal efficiency of the buildings.

The Hawkweed Group, Ltd.
Box 97
Osseo, WI 54758
715/597-2300

OR: 4643 N. Clark St.
Chicago, IL 60640
312/784-5025

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AN EARTH INTEGRATED DESIGN:
OFFICE DORMITORY FACILITY*

H. B. Shapira and P. R. Barnes
Solar and Special Studies Section
Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

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* Research sponsored by the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

AN EARTH INTEGRATED DESIGN:
OFFICE DORMITORY FACILITY*

H. B. Shapira and P. R. Barnes
Solar and Special Studies Section
Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

1. Introduction

The need for a combination office-dormitory facility for the Joint Institute for Heavy Ion Research (JIHIR) provided an opportunity for the solar applications group at ORNL to demonstrate the effectiveness of the designs we have been developing to incorporate earth-sheltering and passive solar features into new structures. Several modifications of the design concept were required to satisfy all of the various requirements of the users and to maximize the advantages of the innovative features before a final scheme was adopted. This paper describes the evolution of the design and reflects the importance of understanding the relationship between architectural considerations and the energy consumption characteristics in obtaining the maximum in energy conservation.

2. User and Site Requirements

The Holifield Heavy Ion Research Facility (HHIRF), now being built at ORNL will be completed in the near future. When it starts operating, many guest scientists will come to Oak Ridge to conduct short experiments. The demanding schedule in such "runs" will require that living and sleeping quarters be provided on site. JIHIR (construction to begin April 1980) will provide such quarters.

The building design requirements called for:

1. Approximately 409 m² (4400 ft²) interior space.
2. The structure should house three defined activities:
 - a. office area with eight offices, mechanical room, storage, computer terminal and xerox machine;

* Research sponsored by the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

- b. lounge, dining room, and kitchen (for use both by visiting scientists and Physics Division personnel for special activities); and
 - c. work and sleep rooms for visiting scientists as well as sleeping alcoves for local researchers on long experimental shifts.
3. The structure must be located within the Physics Division complex.
 4. The unconventional sleep and work schedules need to be considered in the design process.

Site restrictions require that JHIR be very close to a heavily travelled road (Bethel Valley Rd., on the north). It will be located on a stretch of land which extends the park-like scenery from Swan Lake to the east (Fig. 1).

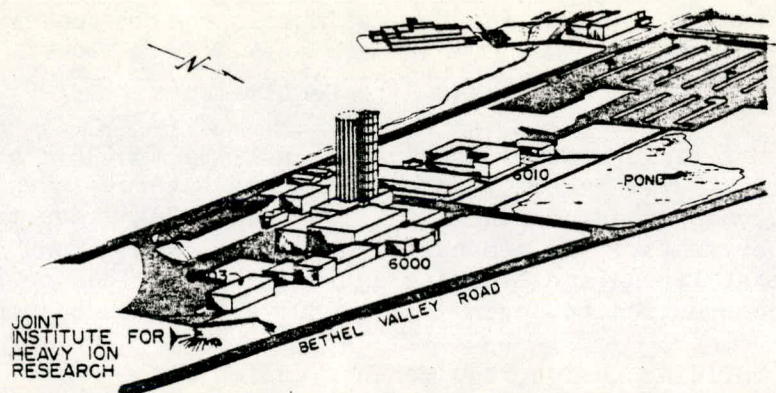


Fig. 1. Aerial View Indicating JHIR's Siting.

Only an innovative approach such as earth-sheltering could preserve the "green" image as well as screen the parking lot and partially hide Building 6003 from Bethel Valley Road. Careful attention was given to the shading pattern produced by Building 6003. The occupants of JHIR should find the psychological as well as the acoustical isolation from the main traffic artery advantageous.

3. Design Objectives

JHIR provides an opportunity to evaluate experimentally the benefits of earth-sheltering and passive solar heating. The combination of large south-facing windows and the high mass normally associated with earth-sheltering could be designed to become an effective collecting and storing mechanism of passive solar energy. Additional energy savings can be expected due to the benign temperature environment provided by earth-sheltering; this results from the fact that the diurnal as well as seasonal temperature fluctuation of the earth are lower than that of the ambient air. Figure 2 depicts the mean daily air temperature and earth temperature at depths of 1.5 m (5 ft) and 3.0 m (10 ft) for Oak Ridge, Tennessee. Earth-sheltering provides a favorably tempered "envelope" that will reduce energy loss.

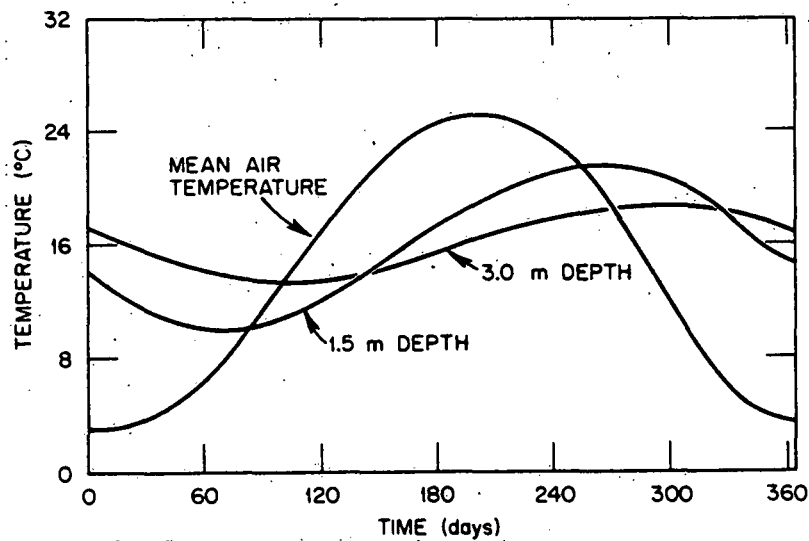


Fig. 2. Approximate Mean Daily Temperatures for Oak Ridge, Tennessee.

4. Office/Dormitory Design Development

4.1 Initial Design

The 409-m² (4400-ft²) Scheme I design called for the east, north and west walls to be completely bermed by earth with a 45-cm (1.5-ft) earth cover on the roof. The windows, which are on the south face of the building, have a total glazing of approximately 43 m² (460 ft²). During the winter, the sun is low enough that its warmth can penetrate to the interior spaces through the windows. The excess heat is absorbed by the thermal mass and during cooler

hours is radiated back into the interior space. The skylight at the rear allows additional solar gain and admits natural light. Excess heat from front spaces can be transferred to deeper interior areas by air circulation through the hollow cores in the prefabricated ceiling planks (e.g. Spandek). At night the windows are insulated, thus ensuring reduction of heat loss. In the summer an extendable overhang¹ shades the south-facing windows and thus reduces the cooling load. An opening in the skylight can be used to increase ventilation. Nighttime cool air flushing was planned for cooling. The materials selected are described in Table 1.

The floor plan in Fig. 3 reflects our desire to locate as many offices and living spaces as possible in the south portion of the building. This provides the occupants with the psychological and physiological benefits of an external view.² Spaces that house mechanical equipment, copying machine, computer terminal, and the cooking facility, all of which generate internal heat, were placed at the back of the structure. Fig. 4 shows a cross section of Scheme I.

4.2 Problems and Their Solution

4.2.1 Glare Reduction. The direct-gain windows in the offices introduced the disadvantages of glare from the direct sunlight and the restricted flexibility in furniture arrangement common to small offices--problems that could result in occupants' discomfort. Our solution was the development of Reflective Insulating Blinds (RIB). A description of RIB, which provides both nighttime window insulation and deflection of direct sunlight to the ceiling, is provided in Section 5.2.

4.2.2 Cost and Comfort. Refinements and revisions to the initial design were necessitated by high costs as well as conflicts between user needs and passive solar heating requirements. These are detailed below:

- a. The high cost of the skylight seemed unjustified for a structure utilizing forced-air circulation.
- b. The extendable overhang¹ was not cost-effective for a custom commercial application; also, the client was concerned about the maintenance it would require.
- c. There is a likelihood that the dormitory rooms will be frequently used in a manner precluding direct-gain space heating. For example, a person sleeping during the daytime, if not requiring darkness, will at least need privacy which can be obtained only by reducing or completely blocking window openings.
- d. The cost estimate dictated a 10% space reduction.

Table 1. Materials for Schemes I & II

Scheme I			Scheme II	
Unit	Materials	Dimension	Materials	Dimension
Exterior Walls	North: Poured in place concrete, reinforced Styrofoam insulation on exterior Waterproofing 1/16 Butyl Sheeting	30 cm 12 in. 7.5 cm 3 in.	North: Poured in place concrete, reinforced Styrofoam insulation Waterproofing, Bituthene by W. R. Grace	25 cm 10 in. 7.5 cm 3 in.
	East: "	" "	East: North of exit door - same as above. South " " " concrete block wall Finish: Dryvit System	20 cm 8 in. 7.5 cm 3 in.
	West: "	" "	West: Concrete Block Wall Dryvit System Finish	20 cm 8 in. 7.5 cm 3 in.
	South: Poured in Place Reinforced load columns Poured in place Lintel & Base Dryvit Finish over Insulation Windows - Awning Double pane with thermal break. Extend between columns	30x30 cm 12x12 in. 30 cm wide 12 in. 7.5 cm 3 in. 1.5 m 5 ft	South: Steel Columns and Steel Load bearing beams Under windows East wing - Trombe Wall Central & West wing concrete blocks Dryvit System Finish	20 cm 8 in. 7.5 cm 3 in.
Roof	Prestressed, precast concrete planks w/hollow cores (Spandek) Skylight with operable window Waterproofing 1/16 Butyl Sheeting Insulation Styrofoam Earth Cover	12 in. 91 cm deep 3 ft 7.5 cm 3 in. 46 cm 1.5 ft	Spandek 7.22 - wide planks Waterproofing - Bituthene by W. R. Grace Styrofoam Boards Earth Cover - sloping	30 cm 12 in. 7.5 cm 3 in. 76 to 46 cm 2.5 to 1.5 ft
Floor	Concrete Slab Poured in place Insulation Styrofoam Vapor Barrier .006 Polyethylene Sheeting	10 cm 4 in. 7.5 cm 1 in.	Same as Scheme I	
Interior Partitions	Concrete Blocks, sand filled	6 to 8 in.	North of Corridor: Metal studs & Sheetrock South of Corridor: Concrete Blocks	15 to 20 cm 6 to 8 in.

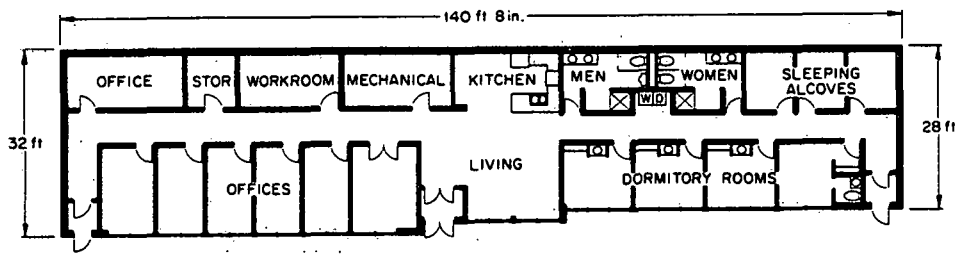


Fig. 3. Joint Institute for Heavy Ion Research - Scheme I.

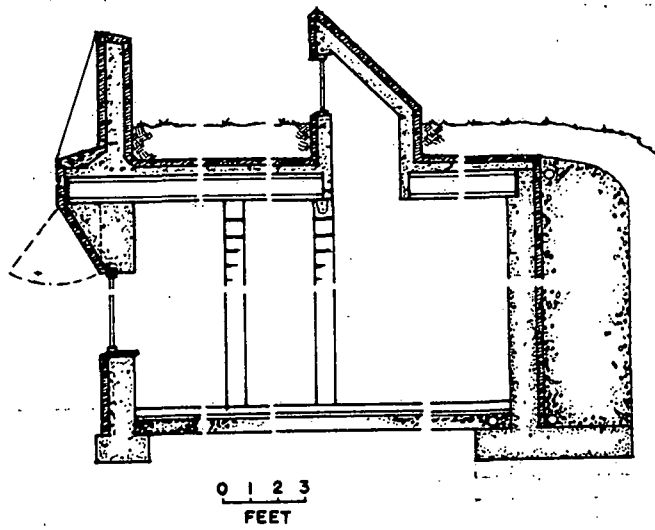


Fig. 4. Cross Section - Scheme I.

4.3 Final Design

Figures 5 and 6 depict the final design. The building will be constructed during 1980, with completion expected early in 1981. The basic design strategy and floor layout have not changed; the building size, however, was reduced to 373 m² (4010 ft²). Much of the space reduction was obtained by eliminating the wing vestibules and moving the exterior penetrations to the east and west walls. The reduced energy savings resulting from the increased fraction of envelope exposed to ambient air were offset by reductions in construction costs due to the decreased interior area wasted on corridors and shorter linear footage of retaining wall. The decision to partially expose east and west walls also improved the building's appearance by adding visual depth (Fig. 7).

The skylights were eliminated and the extendable overhang was replaced by a compromise fixed overhang. The dormitory area has a combined direct-gain/Trombe wall passive solar design, which is

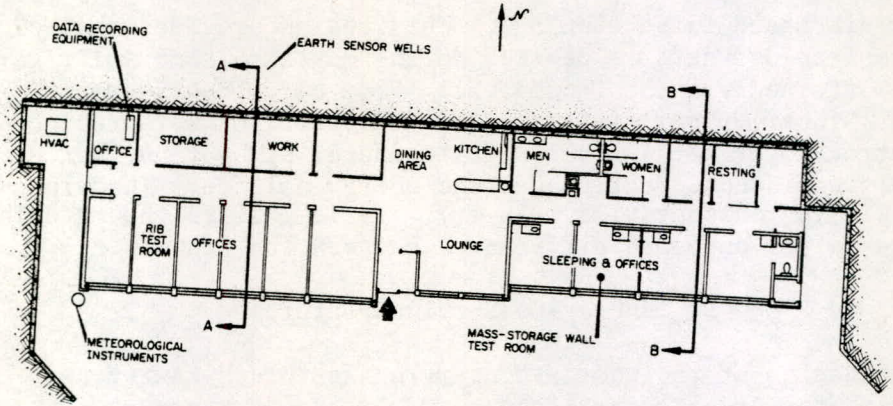


Fig. 5. Scheme II - Floor Plan.

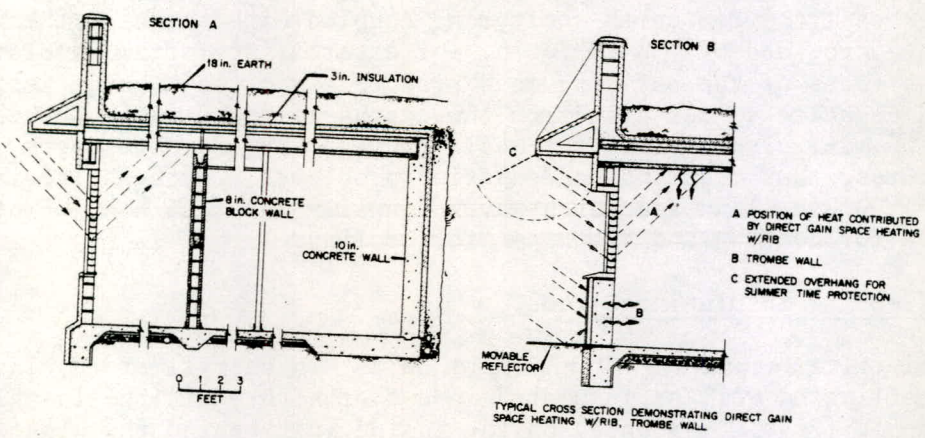


Fig. 6. Typical Cross Section.

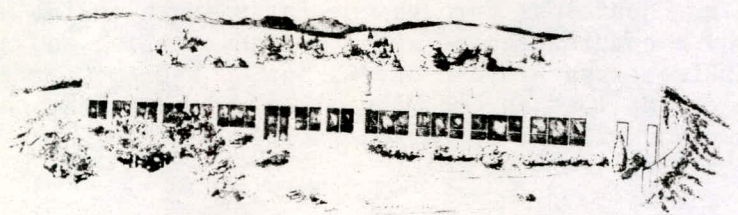


Fig. 7. Scheme II - Facade.

further discussed in Section 5.3. This design provides that even when complete darkness is desired during daytime, some solar gain will be attained via the Trombe wall (Fig. 6). The 15 cm to 20 cm (6-8 in.) interior partitions north of the corridor were replaced by sheetrock over metal studs after computer simulation indicated that this would not greatly hurt the energy balance. The window height was increased to 1.8 m (6 ft). Table 1 lists the materials used and points out some differences between the schemes.

5. Energy-Conserving Features

The design of the energy-conserving features was refined along with the architectural changes. Extensive energy analyses and simulations were performed.³ The following is a brief description of these features and the expected energy savings.

5.1 Earth-Sheltering

The benefits from earth-sheltering coupled with the high thermal resistance provided by 7.6 cm (3 in.) of external styrofoam insulation and the effects of the building mass produce a very low winter heat loss and negative summer gain from the earth-sheltered walls. The insulation will also prevent the walls from cooling down to earth temperatures, thus reducing condensation problems. Earth-sheltering in the Oak Ridge, Tennessee area saves annually about 25 kWhr/m² of wall area for heating and 8 kWhr/m² for cooling.

5.2 Reflective Insulating Blinds

Reflective Insulating Blind (RIB) units, which reflect insolation to the ceiling as well as insulate windows at night, will be installed.⁴ The RIB unit (Fig. 8), mounted on the inside just behind the window glass, operates much like a venetian blind. In the winter daytime mode, direct radiation striking the reflective surface of each slat is directed to the ceiling. The slats are curved so that frequent changes in the slant are not necessary. The problems of glare, fading and bleaching of materials, and spot overheating, common to direct-gain designs, are thus reduced. In the winter nighttime mode, the slats, which have an insulating body, are tilted closed to form an insulative shutter. Heat loss through the large south-facing windows is thus reduced by a combination of slats, window glazing and air gap. In the Oak Ridge area RIB can save about 80 kWhr/m² for a heating season by reducing heat loss through the windows. Contributions to cooling load reduction will be discussed in 5.4.

* Windows will be donated by Anderson Windows. Perma Shield awning was selected.

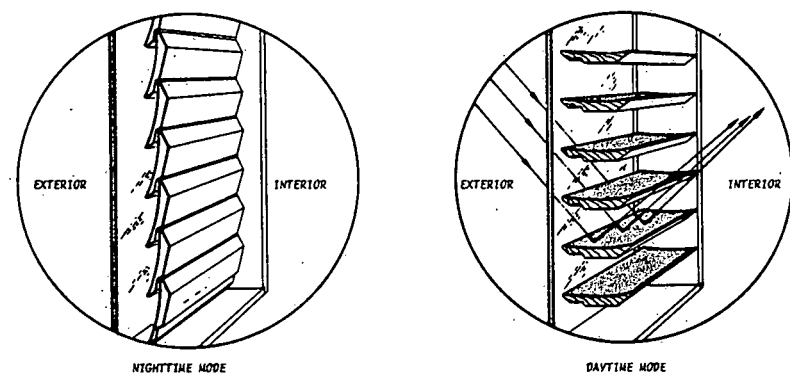


Fig. 8. Reflecting-Insulating Blinds.

5.3 Passive Solar Heating

Direct gain space heating (Fig. 6, Section A) will be utilized in the office and lounge sections. A wall unit combining direct gain and mass storage was designed for the dormitory section (Fig. 6, Section B). The unvented wall (B) is a 30-cm (12-in.) thick concrete wall extending to a height of 1.07 cm (3 ft 7 in.). Figure 9 depicts the comparison between the heating contribution of mass storage wall, direct gain without nighttime window insulation and direct gain with nighttime window insulation. The solar heating fraction for the Trombe wall will be increased by the use of a reflector (Fig. 6, Section B) and the application of selective coating. A reflector can be used to shade the mass storage wall during the summer.

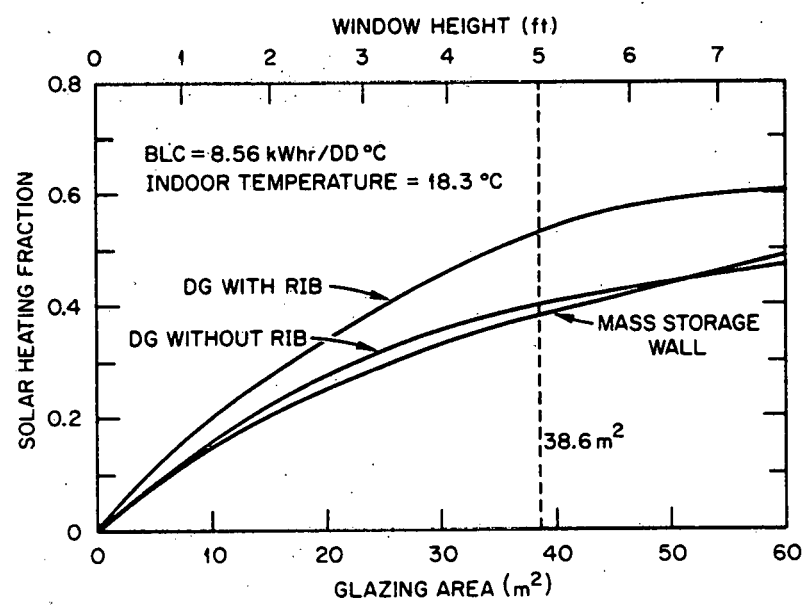


Fig. 9. Solar Heating Fraction as a Function of Glazing Area.

A heat pump with approximately 3 tons capacity will augment the passive solar systems by providing additional heating (or cooling) as required for the building. The mean monthly auxiliary energies required during the heating season for the different designs are shown in Fig. 10. For comparison purposes, a standard building design is also shown. The standard building design is an above-ground building with windows on all four sides comprising 13% of the wall area. The wall, including the windows, and the ceiling of the standard building both have an insulative value of $1.76 \text{ m}^2 \cdot \text{K/W}$ (equivalent to R-10). The standard building was designed for total office use with internal heat gains higher than the 1500 kWhr used in this calculation and thus is not an optimum design for this application. All the values represented are for an effective internal heat generation of 1500 kWhr/month and an indoor temperature of 20°C (68°F).

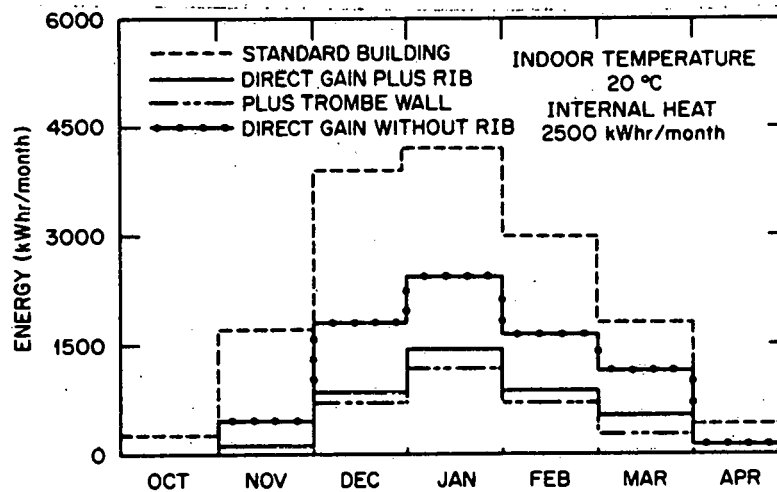


Fig. 10. Auxiliary Heat Required During Winter Months.

The energy savings for the heating season contributed by earth-sheltering and other energy-saving features for a structure similar to JIHIR is demonstrated in Fig. 11.

5.4. Summer Cooling and Shading

An overhang for solar control will be employed on the building. The fixed overhang size is a compromise between the optimum dimensions for winter heating and summer cooling. In addition, a vine-covered arbor for shading the exposed west-facing wall is planned. The RIB unit can be adjusted to reflect the direct solar radiation from the lower portion of the window while the middle and upper portions can be opened for ventilation and natural lighting. The use of natural lighting will save on the direct use of electricity, and it will reduce the summer cooling requirements by reducing internal heat generation.

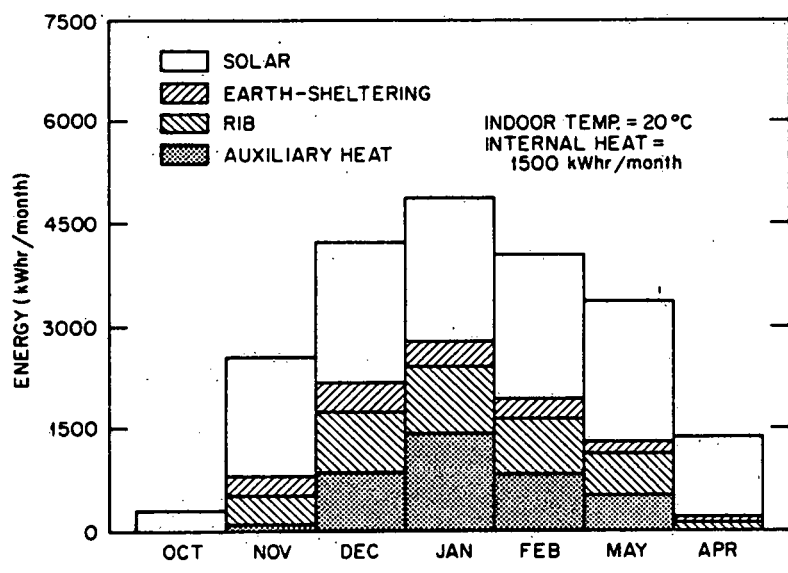


Fig. 11. Energy Savings Due to the Solar Gain, Earth-Sheltering, and Reflective-Insulative Blinds.

An economizer cycle of the heat pump unit will use ambient air to cool the building when the temperature and humidity of the outside air are suitable. Night air flushing of the building will lower the temperature of the structure's mass to a level below the normal set temperature for mechanical cooling. In this way "coolth" can be stored and thus reduce the mechanical cooling requirement for the building during the following day. Outside air will also be used to prevent the building from overheating during periods in the fall when the weather is mild and the solar gain is generally high.

6. Conclusion

The Joint Institute for Heavy Ion Research is designed with innovative features that will greatly reduce its energy consumption for heating, cooling, and lighting.

A figure of merit for commercial buildings is the total annual energy consumption per unit area of floor space. A highly efficient office building in the Oak Ridge area typically uses 120 to 160 kWhr/m². Analysis for JHIR which considers design with natural lighting, earth-sheltering, an annual energy heat pump coefficient of performance (COP) equal to 1.8, RIB and an extendable overhang* uses 71 kWhr/m². The mass storage wall and ambient air cooling will reduce energy consumption still further. The combined savings of the innovative features in JHIR are expected to result in a very energy-efficient design.

* Deleted from final design

The building will be instrumented to monitor its performance, and the measured data will provide means of evaluating the energy savings.

We feel that the inclusion of passive solar and earth-sheltering design will provide a desirable environment for the occupants due to the thorough consideration of potential problems in the design phase. We will verify the efficiency of the design over the next few years.

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Hanna B. Shapira
 Oak Ridge National Laboratory
 P. O. Box X
 Building 3001
 Oak Ridge, TN 37830
 Phone: FTS 624-5817
 (615) 574-5817

THE AESTHETICS OF THE UNDERGROUND BUILDING

by

Don Metz, A.I.A.

Architecture is the most omnivorous, pervasive and enduring of the arts. We are consumed by Architecture. Not only is it around every corner, it defines the corner itself. We go to look at historic paintings at the National Gallery and the building steals the show. Architecture is a barometer of cultural change and a receptacle of all forms of human enterprise. It is at once the most utilitarian and spiritually ennobling of all the arts. From the sophisticated technologies of the high rise tower to the awe-inspiring ambiance of the gothic cathedral, Architecture provides the vital context within which history's important ideas and events have grown and flourished. Architecture combines engineering and aesthetics in a way that is unique among the arts.

Engineering aside, the Architect's creative powers are, as with any artist, mysterious, personal and elusive. The origin of artistic ability is difficult to identify and even more difficult to duplicate. We can teach physics to just about anyone, but only a few can write good poetry, and even they don't really know how they do it.

The issue of aesthetics is a difficult subject to explore without becoming tediously subjective (or just plain tedious). It's a subject full of verbal booby traps and definitions of definitions which all spiral back to the only question worth asking: "Do you like it or don't you?"

I'll try to avoid being tedious or overly simplistic and propose a method of looking at the elements of underground buildings that have architecturally expressive potential. The underground movement has come a long way in the last decade, but the least exploited of its many virtues is its potential for aesthetic expression.

There are surprisingly few cognitive forms in Architecture. These forms have evolved and survived because they make sense to our hearts and in our minds.

And because they have survived and become identified with particular functions, they have become infused with symbolic meaning. The column, the colonnade, the lintel, the arch, the dome, the gable, the step and the tower-- these forms signify certain experiences which we learn to expect from them. The medieval fortress, the Renaissance stairway, the Moorish atrium and the Madison Avenue skyscraper express themselves through architectural devices which symbolize strength, ceremony, sensuousness and industry. A mere building provides shelter and security, but in order for that building to become Architecture it must "signify" something in a familiar, visual language.

Earth-sheltered buildings represent an infinite variety of programmatic functions--commercial, industrial, institutional and residential--and each one must signify its purely functional characteristics in whatever way possible within the earth-sheltered context. What we're looking for is an architectural vocabulary of "earth-shelteredness" that signifies the unique dynamics of building underground.

Much has been made of the rounded, maternal, female forms of the subterranean Minoan structures. The evocation of "Mother Earth" is too tempting to resist, and the womb-like forms of these "primitive" buildings capture the essence of what we seek underground: warmth, security and strength. If these ingredients do indeed characterize the impulse to "dig in" (and I believe they do), then how does the Architect express them? How do we signify warmth or strength, for instance, with masonry, wood and glass? The answers are familiar and intuitive, part calculated and part inspiration. Mostly, they need only to be recognized and applied.

Earth-sheltered buildings are safely engineered to support tremendous loads of earth. We may know this rationally, but subliminally, we need to see how it's done; we want to be reassured that the building is safe and sound. Evidence of a muscular structural system is the only means of signifying this dynamic challenge to gravity. The underside of a flat concrete slab suggests nothing about its thickness or how it was made, and gives no impression of the function it performs. On the other hand, massive timbers, ribbed or vaulted arches, open trusses or articulated concrete planks establish credibility and a convincing sense of security. The exposed

structural components not only demonstrate their heroic function, but we see them as "beautiful" because they are arranged in a way that makes sense and comforts us.

While the arch is the strongest shape for resisting vertical loads, a curved wall (an arch on its side) is equally superior for resisting lateral loads. (Again we return to the Minoan womb, where curved walls both structurally and symbolically signify strength and security.) A further sense of mass and solidity is perceived through window and door openings where the thickness of the walls indicates strength and security.

The entrance to an earth-sheltered building should convey the nature of what's inside, and how the inside might be expected to relate to the outside. The point of entry must extend an invitation to a special environment, with hints of what's to follow. If we can see the earth on the roof, or earth leading up to the earth, we're primed for the ensuing experience. If we're provided with a glimpse of the structural system, we're prepared for the excitement of seeing how it's done, how all that earth is held in place. And if, from the entry, we can see inside to another source of daylight, once again we're intrigued and drawn into the building to find out how it works. The point of entry must invite and excite, a preview of things to follow, not just a door in a wall like any other door in any other wall.

Materials figure importantly in our perception of any environment. Stone and brick connote a solidarity that formica and wallpaper don't. Carpet disguises, quarry tile convinces, gypsum wall board is anonymous, plaster suggests integrity and wood conveys warmth. Any material that shows us how it's put together and what it's made of enriches our participation in our environment. In the underground environment, where structure is so fundamental to every design decision, a celebration of the process of building is a critical aesthetic priority.

Form, space and light are basic to all Architecture. Underground, these elements must be manipulated in such a way as to recognize and capitalize upon the "undergroundness" of the structure. The forms of underground structures will first reflect the loading from above, and secondly, anticipate the structural openings towards outside sight light and sight. Space within the forms

invites variation--narrow, wide, low, high, contiguous and compartmentalized. A row of identical boxes inside a structure misses the opportunity for the enrichment provided by the differentiation of spaces performing different functions.

Natural light is ever changing and important to our psychological sense of well being. Generous quantities of natural light in the underground building is a must. It keeps us in contact with changes in the natural world above and reinforces our sense of womb-like security in a way that artificial light can never do. Lighting from natural sources should be thought of as an important design tool, both practical and dramatic, and essential to the exploitation of space and form.

In brief, the underground aesthetic will find a way to symbolize the warmth, strength and security of underground living. The expression of structure will be central to the thesis, while space, form and material will compliment the structural principle. The issue is intriguing and the solutions are developing. With courage and talent, we'll soon see beauty--below ground--where we've never seen it before.

A 100% PASSIVE SOLAR-HEATED UNDERGROUND STRUCTURE

Jonathan M. Allen

INTRODUCTION

"Each year the sun literally bathes the earth in more than 25 times the energy that is stored in all the planet's known oil, gas and coal reserves. Which means in less than three weeks, the earth receives more solar energy than exists in all the recoverable oil, gas and coal." (1).

During the first oil embargo, in 1974, I began to look to the sun as an alternative source of energy. Twenty years earlier we had built our house with our living rooms facing south, enclosed with 6' high double-glazed plate glass windows with a roof overhang designed to allow December's sun to fill the rooms with sunlight while shutting out most of the rays of summer's sun. This simple design resulted in daytime solar-heated rooms when most needed. And so I accepted the challenge of further utilizing the sun's energy, trapping it and storing it.

I designed a structure based on the premise that the earth could be used as a primary heat-storage reservoir, and that a multilayered translucent panel, positioned for maximum collection of the winter sun's energy, and constructed to allow for maximum transmission of light into the greenhouse and a minimum amount of heat transmitted out would provide adequate solar energy to maintain temperatures for growing plants.

During the summer of 1975, I constructed my first test model: a 12' x 6' x 3' pit-type, completely buried, reinforced concrete-walled, free-standing greenhouse, facing geologic south with a multilayered translucent panel directed approximately perpendicular to the rays of the winter's noon-time sun. This functioned through the subsequent unusually severe winters of 1975 and 1976 (20 miles from the Canadian border) with a brief dip to 38° following ten days of cloudy skies in January. Clear skies for several days following this caused the base temperature to return to the mid-forties in February. Many cold-tolerant plants grew well. The total cost was under \$200.00. These results were impressive, and I felt that if this could be accomplished with such a modest design, much more could be done with improvements in design and materials.

I took temperature readings in various wells in the area during the coldest period (around March 1st) and found them to be in the 43-45° range, which is somewhat constant throughout the year. Our forefathers applied this knowledge by using "spring cellars" and "root cellars" to keep food cool and from freezing. Thermo-stasis was what they sought and used. Caves, if not ventilated, maintain a constant temperature year round. It has been determined that earth and rock can hold approximately one-half the heat that water can; and it is common knowledge that underground rooms lose considerably less heat than above-ground rooms do.

Thus it seemed more and more obvious to me that the answer to solar-heating would lie in the combination of a solar panel and an underground structure placed so that the solar energy (trapped as heat) would be distributed automatically to all parts of the chamber and stored in its walls and the surrounding earth reservoir.

The problem then becomes two-fold: (1) to design a solar glazing using the best combination of materials for the transmission of solar energy into the structure, and for blocking the loss of the resulting heat back through the panel by radiation, conduction and convection; (2) to design a system with a balance between a high-capacity heat-storage medium and automatic distribution of the heat to all parts of the chamber.

In our part of the country (Northern New York) a sparsity of clear days from November through January and the very low average outside temperature in December and January, rate it among the 25% worst solar energy areas in the United States (2). The only answer seems to depend on finding a way to store the summer's solar heat for winter's use.

Basically, my improved design involved using a south-facing hill, constructing a much larger solar panel positioned at an optimal winter angle (3) parallel to concrete steps built into the hillside 7' below it. The upper part of this led to a large underground chamber where heat concentrated at the top could be used to attain a higher mean temperature area to accommodate a wider range of plants, to provide a greater heat-storage mass and produce tolerable temperatures for living quarters above the greenhouse.

DESCRIPTION OF THE STRUCTURE

A. The Solar Panel

The ultimate goal for a solar panel is the transmission of the maximum amount of the sun's energy into the structure where most of this energy is transformed into heat; and to prevent the loss of this heat back through the panel. The first is accomplished by positioning of the panel at an optimal winter angle (2), and by selecting materials with a high light-transmittance value. The second, preventing loss of heat back through the panel, is accomplished by selecting materials which, in addition to the above, have a low infrared transmittance value to minimize the escape of heat by radiation. To prevent further heat loss by conduction and convection, four layers were used with a 2" dead air space between the layers; wood frames were used instead of metal; and air-tight construction was attempted.

The 25' x 24' solar panel was constructed using 2" x 6" spruce for frames and supports placed 4½' apart. Fiberglass (Kalwall Sunlite), selected for its low infrared transmittance value, was mounted on both sides of the 2x6's, and 2 layers of 6 mil polyethylene in-between. Each layer was separated by a 2" dead air space. (See inset of Figure No. 1.)

This entire solar panel was mounted facing geologic south at an angle of 57°. This angle is determined by a compromise of these considerations: 1) Maximum transmission of November through January sunlight for this area; 2) the critical angle of the piled earth with the panel used as a retaining wall and 3) an angle sufficient to shuck the winter snow.

The 24' panel extended 6' beyond the ceiling of the upper room, serving to collect solar energy and store it directly in the earth-store above the ceiling. In addition it served to insulate the heat-store reservoir, preventing further loss of heat by water and air infiltration, and serving as a retaining wall for the earth fill as well. After observing the results of this extension, 6' wide panels were added to each side of the main solar panel increasing by 85% the area of the solar collector over that covering the inside structure.

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B. The Heat-storage and Distribution System (See Figure 1)

In order to make maximum use of the light transmitted through the solar panel, increase heat absorption surface area, and promote air circulation, concrete steps were constructed parallel to the panel and 7' below it and dug into the slope of the hill. These 24' wide steps continued parallel to the panel for an elevation of 10'. At the top of the steps, a room 7' high, 24' wide and 16½' deep was built. Three-inch boiler pipe on reinforced concrete floor was used to support the steel beams and overlapping corrugated steel plates used as ceiling, plus the 5' of earth covering it. Walls of the enclosed shell, made of reinforced concrete and painted black on the inside to increase absorption, conduct heat into the massive heat-store provided by banking the walls with 15-20' of earth.

To minimize heat loss from the earth-store, three inches of styrofoam were placed on top of the earth cover and extended 6' beyond the side walls followed by multi-layers of 6 mil polyethylene extending 10' beyond the side walls to act as a water shield and to direct drainage away from the heat-store. The concept is to insulate where the distance through the dry earth cover is not great enough to check heat loss. Dry sand has insulating qualities if used in 10-12' thickness. To secure the polyethylene, crushed stone, rocks, carpet and earth were placed on top.

A hinged portion of the lower panel was used for access and ventilation. A 30" pipe was placed through the upper wall in the rear of the upper room, leading laterally to the outside for ventilation. However, this was plugged in 3 places and never used.

A water system was designed and built, consisting of a well, force-pump and a 275-gallon storage tank placed outside of the cement wall of the upper room, slightly above it, and buried in the earth-store. This feeds by gravity the hot and cold water systems. A hot water storage tank was placed on the upper level and a radiator was placed inferior to this in the middle of the panel area on the upper steps--"the hot spot". Circulation to the hot water storage-tank was accomplished by gravity flow, hot water being lighter than cold.

FUNCTION

Due to the exceptionally rainy period in the Fall of 1978, the basic structure was not completely closed until December 9, at which time a base temperature* of 40° had already been reached. This was followed by a prolonged period of cloudiness in December and January, and the base temperature remained constant as there had been no heat stored prior to its closing. Even though outside temperatures continued in the zero range, in February the longer sunny sub-zero period caused the base temperature to begin to rise; and this continued at approximately 10° per month to a peak of 84° in August.

It was observed that condensation was regularly more marked deep in the upper room on the ceilings and walls, while the ceiling under the extension of the solar panel was dry. This led to the concept of using an extension of the solar panel over the side heat storage areas as well. Therefore, during the 1979 summer, 6' extensions of the solar panel were added on each side, increasing the effective panel area.

In August, when heat-store temperatures reached 84°, but before the roof area was adequately insulated and water-shielded, a heavy rain caused the base temperature to drop to 74° abruptly. The need for a good water shield for the heat-storage area was obvious. In September, the base temperature had returned to 80° and the 3" styrofoam insulation and multiple layers of 6 mil polyethylene were in place over the earth cover and heat-storage area, when a second heavy rain caused no drop in base temperature.

Instead of our usual sunny October, however, we had a long period of overcast skies which continued into December. The base temperature fell approximately 10° per month. This has been followed by more clear days, so even though the outside temperature has repeatedly dropped to zero and below, the base temperature has stabilized at approximately 52-54° in the upper room.

*Base temperature as used in this paper will refer to the minimum night-time temperature recorded in the upper chamber which is also the storage temperature.

(27)

Temperatures in various parts of the chamber and heat-store have been closely monitored during the past few months. Inside-outside thermometers compared the temperature in the heat-store outside of the wall with the temperature inside of the upper chamber in two different areas. Two thermographs recorded round-the-clock temperature readings for several weeks, and two high-low thermometers gave the maximum and minimum temperatures for the period.

In the greenhouse area, (See Figure 1), the variation in temperature during the 24 hours of a clear day is considerable. During a cold, clear day in February, temperatures may reach 85-90° in the warmest area at mid-day and then reach a low of 52° at night, regardless of the outside low temperatures. However, temperatures in the upper chamber are tempered by the surrounding heat-store and remain in the more comfortable range. On a very hot day last May after a hike we actually went into the upper room to cool off. It was very comfortable at the back of the upper room. Daylight temperatures during the past month have ranged from 58-80° in the upper room depending upon the clearness of the day, while the night time temperatures have returned to the 52-54° heat-store temperature.

As pointed out several times, the zero and below temperatures of our North Country are not the problem in solar-heating, but rather the prolonged periods of cloudiness in December and January. During a week of 15-20° below zero temperatures in February, 1977, in which we had clear skies, the base temperature actually rose 6°. Others have reported similar findings (4)

DISCUSSION

My goal from the beginning has been to develop a 100% passive solar greenhouse; and it was then extended to include a dwelling. The night-time dips to 52° can be tolerated by most plants, and many thrive.

In this design, air circulation is accomplished without need for fans as the warm air rises to the upper room, cools, and settles back to the lower levels. This also has a self-insulating effect in that during prolonged periods of cloudiness, cooler air accumulates

at the lower part of the panel, reducing the temperature gradient and thus decreasing heat loss through the panel.

Remote sensor temperature readings and ceiling condensation have substantiated the values of the south-facing solar panel extension 6' above the ceiling and 6' beyond the side walls of the compartment in increasing heat storage directly to the earth-store, in insulating it from air and water infiltration, in addition to its use as an earth bank retainer.

The placement of the ceiling insulation and water-shield on the top of the earth cover and the extension of the insulation and water shield 6-10' beyond the chamber walls maximizes and conserves the thermal mass in the storage area. This was dramatically demonstrated when a heavy rain in August before the insulation and water shield were not in place resulted in a 10° drop in base temperature, but a similar rain in September after the water shield and insulation were added produced no change in base temperature.

The biggest surprise is that this unit does indicate that I can have a fly-wheel effect of storing summer's heat for winter's use as evidenced by the slow lag of temperature change in the store area both during the heating phase and the cooling phase; and if utilized on a better proportioned relationship, it could be employed as a primary heating unit. It is projected that an increase in heat storage capacity would produce less temperature swing and provide more constant temperature at a usable range.

CONCLUSIONS

Through the use of a solar panel placed mostly inferior to an underground chamber, by using the earth as heat storage mass and gravity flow of air for circulation and distribution of heat, the base temperature of that earth heat-store has been maintained at 52° and above during the coldest part of the year for solar-heated structures (the last two weeks of January).

Although the night-time temperatures in the upper chamber drop to a low of 52-54°, day-time temperatures range in the 60's and 70's during the winter months.

(29)

Most plants tolerate, and many even thrive under these conditions. Humans would probably desire a more comfortable range. Of course, with the use of a very small amount of supplementary heat (preferably electric) this could be accomplished.

However, my goal remains the attainment of a 100% passive solar-heated structure; and it is obvious to me that the answer lies in designing the proper balance between a high-capacity heat-storage medium and the collection and automatic distribution of solar heat to all parts of the chamber. My present test unit has two obvious weaknesses: 1) The heat storage capacity is insufficient. 2) The solar panel, the source of the heat energy in the system, is still the chief heat leak.

The heat-storage capacity can easily be increased by: 1) expanding the size of the upper underground chamber; 2) adding water storage tanks for additional heat-storage; 3) employing the salts (Glauber, etc.) with a melting point in the desired temperature range; and 4) extension of the insulation and water shield of the heat store area.

To decrease heat loss through the panel during night-time and cloudy periods, the construction of a better panel is possible. Over the past several years I have tested various combinations of available materials in an attempt to evaluate these characteristics. New materials have been produced and panels of various combinations continue to be tested. David Allen reported the use of 3 layers of fiberglass (Lascolite) in his successful solar-heated greenhouse (4). A balance between light transmittance and infrared blockage must be found for particular needs.

If the upper chamber were used as a dwelling, the entire solar panel could be placed inferior to it, allowing the heat concentrated at the top of the panel area to be vented into the living areas. Also thermal insulating curtains could be lowered over the panel at night or during very overcast days when the most heat is lost through the panel.

My present model with improved design and materials has succeeded in raising the minimum base temperature from 38° (in my first test model) to 52° and has proved to be adequate for a winter greenhouse. I am convinced that the additional 10° needed for comfortable human shelter can be attained with improved design and materials, and certainly can be done easily in a less demanding climate. (Patent Pending)

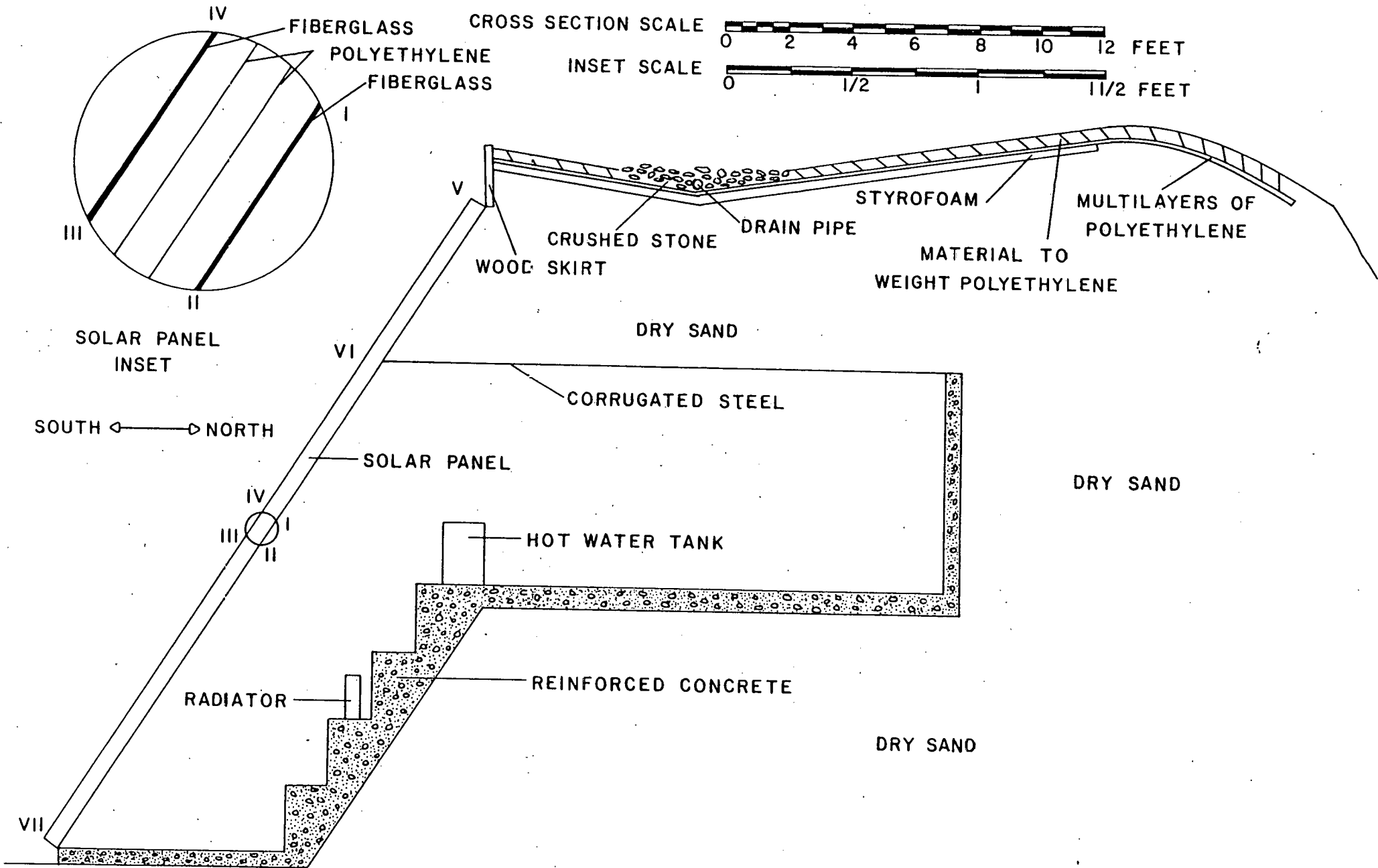
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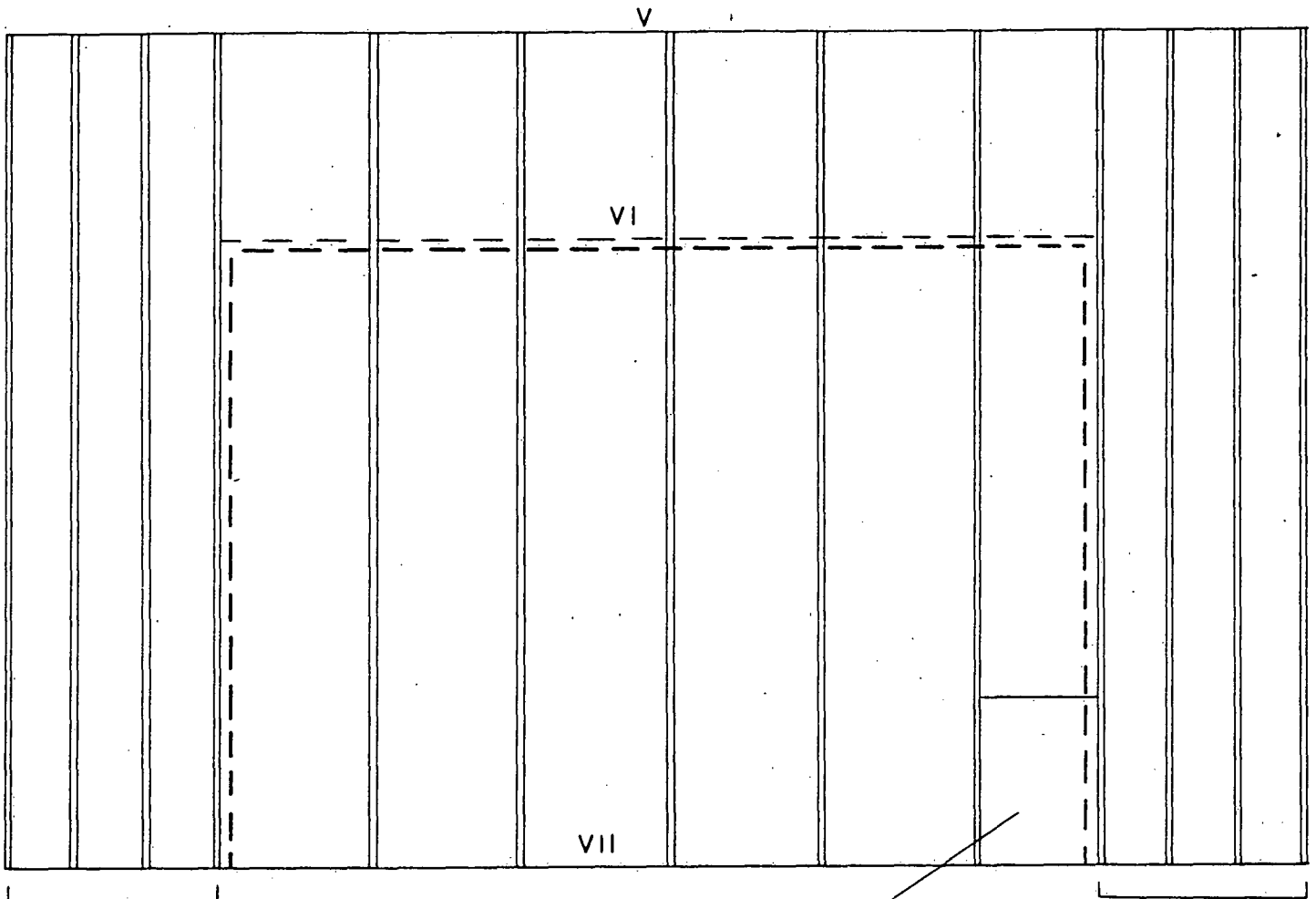
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100% SOLAR-HEATED BUILDING

FIGURE I CROSS SECTION

31





PANEL EXTENSION

HINGED PANEL ENTRANCE

PANEL EXTENSION

--- LIMITS OF INTERIOR CHAMBER

==== WOOD BEAM

WEST ← → EAST

SCALE 0 2 4 6 8 FEET

100% SOLAR-HEATED BUILDING
FIGURE 2 FRONT VIEW OF PANEL

ENERGY PERFORMANCE CHARACTERISTICS OF SELECTED
EARTH SHELTERED RESIDENCES

Thomas N. Bice
Dr. Lester L. Boyer, P.E.
Prof. Walter T. Grondzik

School of Architecture
Oklahoma State University, Stillwater

ABSTRACT

The factor identified as the major reason for building underground is energy conservation. This mode of living has become a viable answer for energy conservation in all climatic regions with an extensive number of earth covered projects completed, underway, and proposed in the Midwest and Southern regions of the nation as well as the numerous projects in the Northern states. The energy performance characteristics of underground residences differ in each of these regions. This paper discusses the energy aspects of six earth covered residences located in Oklahoma.

The discussion contains three parts. The first includes a description of the houses and an overview of certain design considerations for typical Oklahoma earth sheltered dwellings. The next portion presents the actual metered energy usage of each sample residence for a full year on a monthly basis. The last section compares the actual metered consumption to a currently accepted energy conservation standard.

INTRODUCTION

Although it is generally accepted that structures built underground use only a fraction of the energy required of the same structure if it were above grade, there still remains a conspicuous lack of data to support this opinion. Some of the reasons for this lack might be attributed to the developing nature of the earth shelter movement, the vernacular character of most earth covered residences, and the complex heat transfer analysis methods for earth sheltered dwellings which are now available.

Efforts are underway at Oklahoma State University to develop better predictive energy techniques by adapting standard methodologies in order to calculate design peak heating and cooling loads, as well as seasonal energy consumption for earth covered dwellings. (1) In addition, research programs at the Oklahoma State University School of Architecture are currently gathering information on existing earth sheltered installations located in Oklahoma and surrounding states as well as initiating limited on-site monitoring activities.

OBJECTIVES

While discussions of predictive energy usage of earth sheltered residences are of great importance and interest, due to time constraints, this paper will only address the topic of metered energy performance characteristics of six Oklahoma earth sheltered dwellings. A brief comparison of actual metered usage with accepted energy conservation standards is also included in order to illustrate the benefits of earth integrated construction.

House Descriptions

The schematic floor plans of the dwellings to be examined, identified as Sites A through F, are shown in Figures 1 through 6. All of the sites, except one, are located in the South Central area of Oklahoma, and all are of typical Oklahoma earth sheltered construction. In general, the earth backed walls are not insulated, and two sites indicate no roof insulation. All samples can be considered to have substantial earth cover on the roof construction, except for Site C which has a conventional roof with no earth cover.

Reasons for "going underground" in Oklahoma do not differ from those cited as reasons for earth sheltering in northern states. The main concern is energy conservation. (2,3) For Oklahoma locations, the cooling season energy demands are of equal importance to winter heating requirements, which is certainly not the case of northern states where positive effects in summer are considered only in a limited way. Prospective owners and builders in Oklahoma are building earth covered dwellings not only for the energy savings in winter, but more importantly, to reduce required mechanical cooling needed to maintain thermal comfort in the spring, summer, and early fall months.

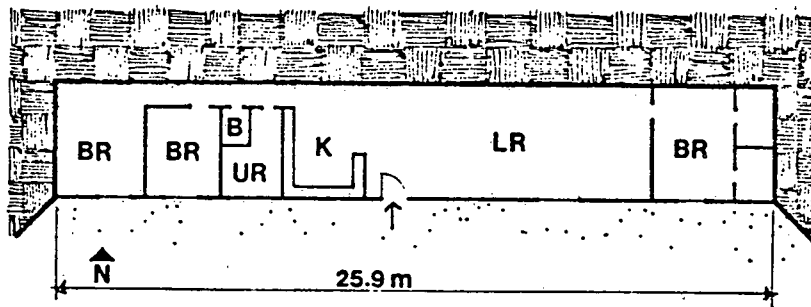


Fig. 1 Site A is a relatively small, narrow insulated concrete structure with the exposed wall facing south.

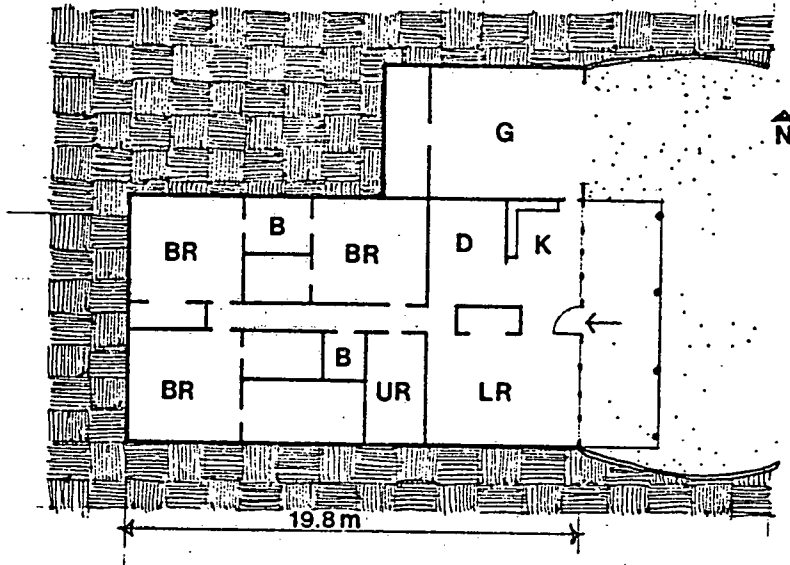


Fig. 2 Site B is a large concrete block structure with no external insulation except at the east facing exposure.

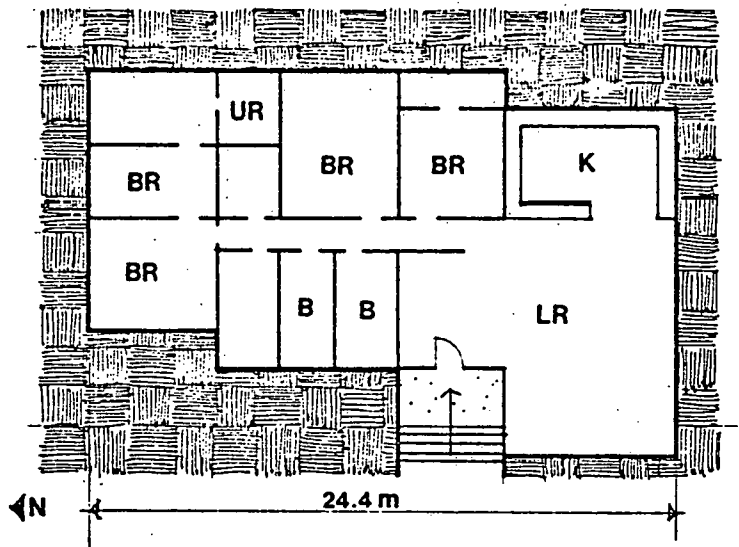


Fig. 3 Site C is a large concrete block structure with an insulated conventional flat roof and underground walls insulated 3 feet down from the roof.

Importance of Earth Heat Sink

The free cooling effect of earth backed walls, floor, and ceiling can improve the overall thermal environment when higher air temperatures and humidity levels are permitted. (4) The average temperature of these surrounding surfaces is known as the mean radiant temperature (MRT). Normal air conditioning design assumes that the MRT equals the interior air temperature, but such is not the case with uninsulated earth backed walls and ceilings. Significant improvements in comfort can occur when these surfaces are installed without furred paneling or suspended ceilings which act as insulation.

By using earth cover, benefits are realized due to the thermal flywheel phenomenon of the earth heat sink. Since soil transfers heat slowly, the heat from the summer sun does not reach below grade structures until fall, and the cooler temperatures of winter are delayed until early spring. With earth sheltered dwellings, which typically have an exposed wall facing south, this free cooling effect can be nullified unless effective solar shading is provided at the facade. In addition, evaporative cooling effects enhanced by frequent watering of the grass cover over the roof can contribute to the earth heat sink effect. (4,5)

In winter conditions, the earth re-radiates the energy stored from the summer season which allows for lower air temperatures while still maintaining thermal comfort. The positive effect of the MRT can be increased with the designed implementation of passive solar gain into the structure.

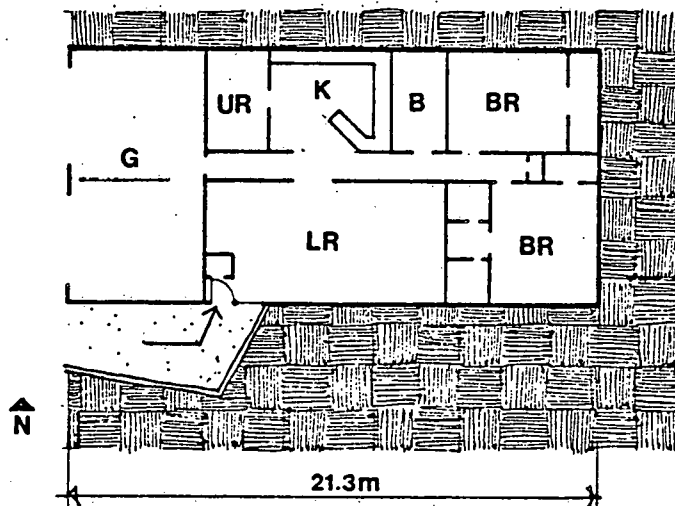


Fig. 4 Site D is a bermed and windowless concrete structure having a bar joist roof assembly. The garage and entry face to the southwest.

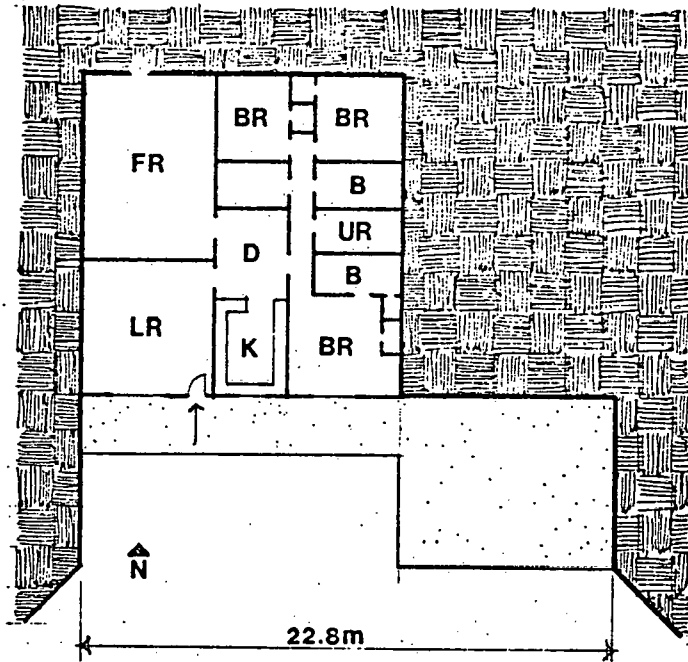


Fig. 5 Site E is a concrete structure with an insulated roof, and an insulated facade facing south.

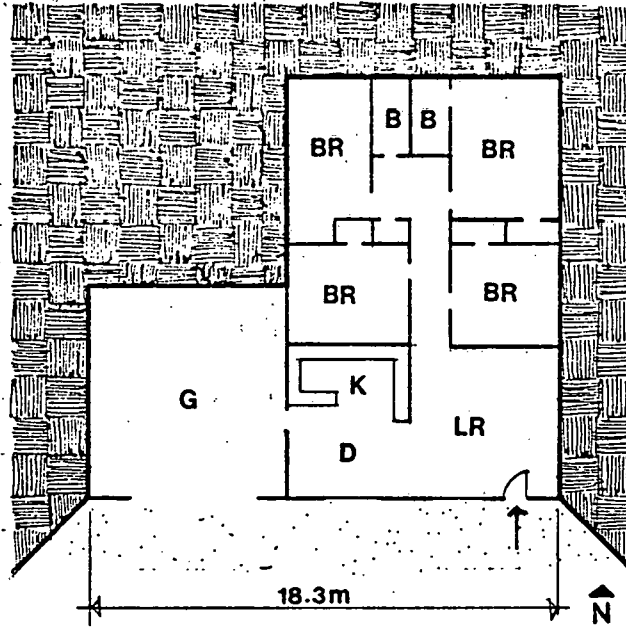


Fig. 6 Site F is a non-insulated concrete structure, but has a suspended ceiling and interior furred wall construction.

Metered Energy Usage

Actual metered energy consumption for each residence examined was obtained from questionnaires assembled for a Presidential Challenge Grant Project conducted by the School of Architecture and the Department of Housing Design and Consumer Resources at OSU. All six of the sample residences are total electric. Monthly consumption for each site is presented in Table I. Although the data indicate that the annual cycle for all sites is not coincident, the winter-spring seasons of 1977 and 1978 were found to be extremely similar from examinations of current weather records. (6) Therefore, any apparent inconsistency between the tabulated values would be attributed to other factors and not weather conditions. All of the buildings are located on rural sites.

The total energy usage for each site includes the energy usage required for space conditioning, hot water heating, and appliances. This total is broken down into these components by estimating the energy required by domestic hot water needs and appliance usage. (7,8) In responding to the questionnaire, occupants indicated the degree of appliance usage as being low, medium, or high. The estimated energy allocation for the appliance load was adjusted corresponding to this subjective assessment for each case.

Energy Design Standards

The proposed Department of Energy Building Energy Performance Standards (BEPS) provides an annual cycle energy usage goal for typical above grade construction. (9) Thus, the annual heating and cooling requirements of earth sheltered residences can be evaluated against a national energy conservation standard.

BEPS requires identification of site locale, building type, and fuel type in order to find the allowable annual cooling and heating energy consumption. Tulsa and Oklahoma City are the only locations in Oklahoma for which budget figures are available. The BEPS annual site energy budgets for space conditioning are as follows:

Sites A, B, C, D, F:	108.13 KW/m ² /Year
Site E:	100.56 KW/m ² /Year

with a hot water energy budget of 172 126 KW/Year for all single family dwellings.

Table I
ANNUAL CYCLE SITE ENERGY CONSUMPTION

Site	Metered Electrical Consumption (Jx10 ⁶)												Time Period Covered
	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	
A	4068	6156	9936	6588	1944	1188	1728	4968	3888	3780	2484	3240	12/77-11/78
B	6419	30017	41411	17028	9122	9724	12132	13950	12308	12179	8539	8647	12/77-11/78
C	9900	12600	18036	18000	13320	7200	9000	12024	12420	12420	9180	9000	12/77-11/78
D	5119	6959	7999	8755	9324	3737	4158	6142	4844	5342	4554	2635	6/78-5/79
E	8546	8953	10264	9565	7852	6487	7452	8330	10080	10130	9544	7132	7/78-7/79
F	8363	9256	8431	6253	5839	4532	7913	8179	6548	6800	3344	6325	6/78-5/79

Energy Use Compared to Standards

In figure 7, the annual metered energy consumption, identified by its components, is compared to the BEPS energy budget determined for each sample. The BEPS budget is broken into its space conditioning and hot water components. The benefits of earth sheltered design are clearly seen. In all cases, except site B (where mid-winter meter readings are suspect), the total metered site energy consumption including appliances is less than the proposed BEPS energy budget for space conditioning and hot water alone.

Popular opinion and calculations indicate that design loads for these earth sheltered residences for both summer and winter are typically on the order of 50% lower than the expected design loads of an identical residence located above ground which conforms to good energy conservation design criteria. (1, 10) Comparisons with the BEPS energy budget can give misleading impressions of expected energy savings as the proportions for space conditioning and hot water heating do not appear to be an appropriate allocation. Primarily, the energy usage allowed for hot water heating is too high for single family dwellings. Thus it is expected that the BEPS energy usage for heating and cooling would be increased to a point where it exceeds actual metered usage by as much as 40% to 50% in some cases.

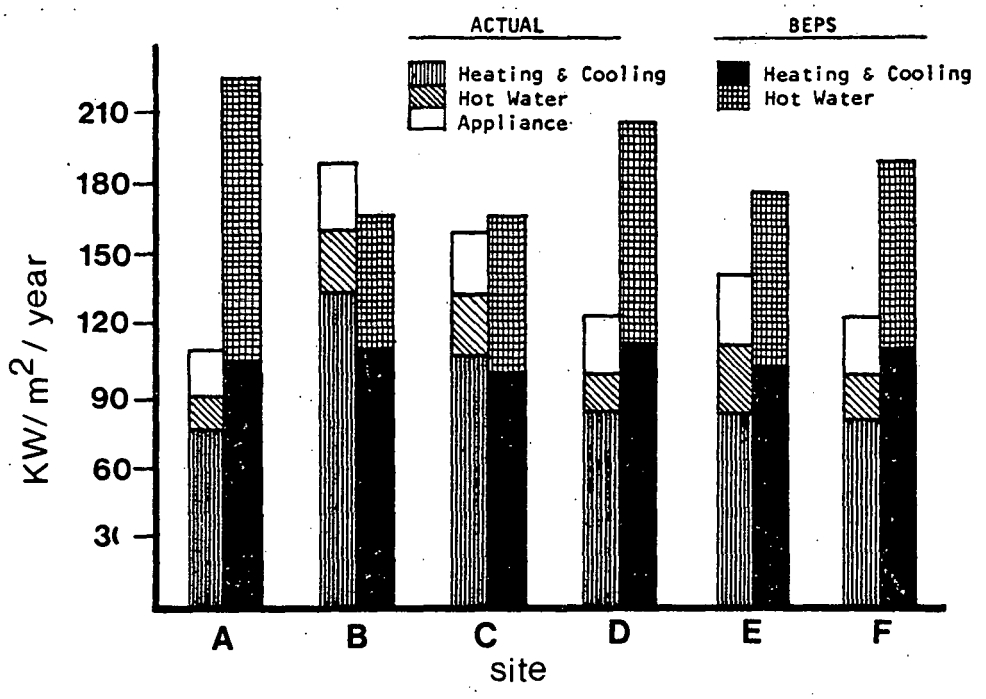


Fig. 7 Comparison of Annual Energy Consumption.

Although, at this time, it is not possible to indicate where all the energy "goes" in earth sheltered dwellings, the energy conservation potential is clearly demonstrated. Proper design of passive solar energy used in conjunction with earth sheltering could make improved comparisons to energy standards due to increased energy conservation. But earth covered residences, such as the contemporary ones examined, still use less energy than good above grade residences, without sacrifice of thermal comfort or occupant lifestyle. Even though methods being developed might prove to give accurate expected energy usage, more detailed on-site monitoring is required to more fully develop an understanding of the energy aspects of earth sheltered design.

ACKNOWLEDGMENTS

The work reported herein is an extension of efforts initiated as a Presidential Challenge Grant project funded in June of 1979 by the Office of the President, Oklahoma State University. The assistance of Jackie L. Bell, Daniel K. Fitzgerald, Carolyn A. Peck and Donald G. Self who served as graduate research assistants on that project is gratefully acknowledged.

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OKLAHOMA EARTH SHELTERS: A STATE-OF-THE-ART REVIEW

Prof. Walter T. Grondzik
Dr. Lester L. Boyer, P.E.

School of Architecture
Oklahoma State University, Stillwater

ABSTRACT

In the course of an on-going research project, over 80 earth-sheltered residences in Oklahoma were identified and investigated via a detailed questionnaire procedure. The questionnaire and subsequent analyses focused upon three major concerns: building construction parameters, occupant attitudes and evaluations, and energy utilization. The current status of research efforts affords an opportunity for a review of the state-of-the-art with an emphasis on these three issues.

Analysis of information assembled to date indicates that earth sheltered housing in Oklahoma is generally successful, although still somewhat experimental in nature. Occupant responses regarding the subterranean environment are overwhelmingly positive. Energy consumption in the structures sampled is representative of a high degree of overall conservation, but does not enter the realm of alternative energy advocacy or optimization.

INTRODUCTION

Background

The Office of Architectural Extension and the School of Architecture of the Oklahoma State University have been involved in continuing education activities with an emphasis on earth sheltered structures for over three years. (1) In order to generate materials for the Architectural Extension seminar offerings, faculty from the School of Architecture have maintained fairly close contacts with many earth sheltered owners, designers and contractors over an extended period of time. These contacts have provided a good overview of Oklahoma earth sheltered trends and activities.

A Presidential Challenge Grant awarded to the School of Architecture and the Department of Housing Design and Consumer Resources in July of 1979 provided funding for a detailed research effort focused on earth sheltered residences in Oklahoma. The primary objectives of the Challenge Grant project were to quantify the art of earth sheltered construction as practiced in the state; and further, to expand

the quantification process into the realm of qualification in order to improve the quality of earth sheltered design. Information gathered in the course of the research project coupled with data obtained through extension efforts has provided an excellent picture of how, why and where earth sheltering occurs in Oklahoma.

Information Assembly

In the summer of 1979 a detailed questionnaire was mailed to identified owners of earth sheltered residences. This questionnaire has provided a wealth of information regarding many facets of earth sheltering in the state. In-depth on-site interviews were performed at several selected sites to reinforce and expand upon data obtained via the questionnaire process. The on-site field interview technique was also employed as a primary information gathering technique prior to the initiation of the Challenge Grant project.

Scope and Objectives of Paper

At this time, data gathered from the questionnaires have been visually reviewed and screened. In addition, virtually all information gathered as of December, 1979, has been subjected to limited statistical analysis through utilization of selected frequency and trend indicator routines contained within the SPSS applications package. (2) This paper will present an overview of Oklahoma earth sheltered residential structures extracted from these extensive, but preliminary, analysis efforts. Emphasis will be placed upon the presentation of information regarding building construction parameters, occupant attitudes and evaluations, and energy utilization characteristics of these dwellings.

Over one hundred earth sheltered residences had been confirmed as of December, 1979, and are shown in Figure 1. Two dozen subterranean schools in the state are also located in this figure. Approximately 80 questionnaires have been mailed out to date with 48 responses being received in time to be included in this report. Long term habitability data and energy records were available from roughly half of this responding group.

Expanded discussions of the habitability and energy aspects of Oklahoma earth shelters have been presented in various forums and are cited in the references. (3, 4, 5, 6) Activities to expand the sample size and to correlate questionnaire data with field instrumentation findings are currently underway at OSU. In addition, a detailed reduction, correlation and indexing project utilizing data currently in hand was recently initiated by the School of Architecture.

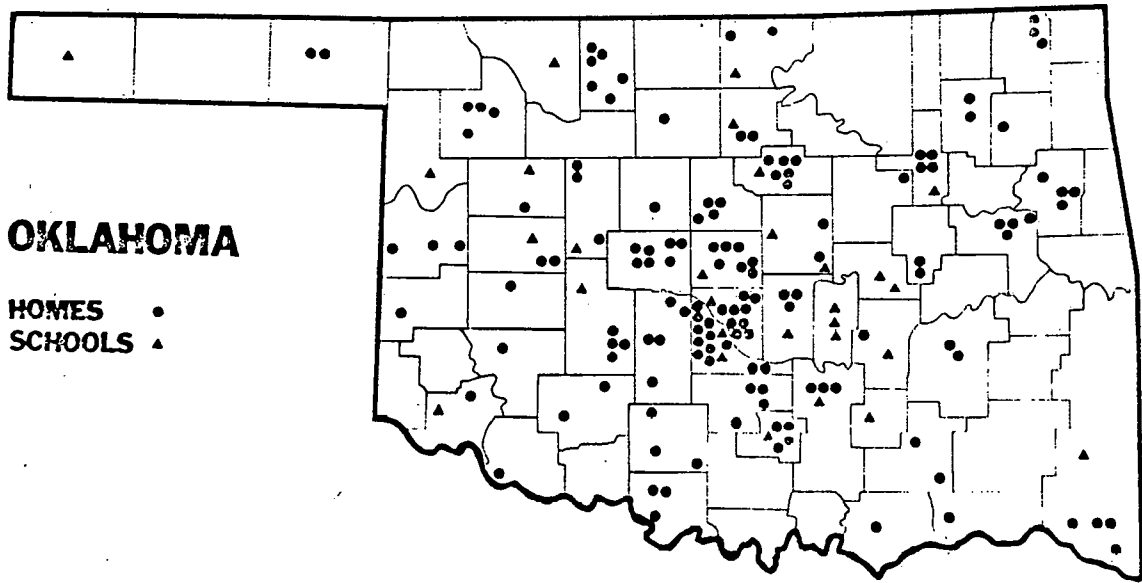


Fig. 1 Identified Earth Sheltered Residences and Schools

CONSTRUCTION PARAMETERS

The Oklahoma Context

Earth sheltered housing in Oklahoma is predominantly a rural phenomenon. All respondents to date report their locale as open or rural country. The mean lot size associated with the samples analyzed to date is 138 403 square metres. However, the median lot size of 48 967 square metres is more indicative of lot size trends with 20 230, 40 460 and 80 920 square metre lots being quite popular. The absence of urban examples is probably as much a result of the nature of those currently building with earth shelter and the character of the state as any other factor. Oklahomans are not being forced into subterranean living, but rather find it to be a viable housing alternative. Those pioneering types currently opting to go underground tend to have a greater affinity for the land than the population as a whole.

The owner of a current generation earth shelter in the state is also apt to be the designer and builder as well. A grassroots approach to design and construction is very much in evidence in Oklahoma. Architects were involved in the design process on only 13% of the dwellings sampled, while engineers were involved on 28% of the projects; 38% of the houses were designed with input solely from the owner or a contractor. With specific reference to the structural

design of dwellings, 36% of the respondents report professional services were solicited; more importantly, 64% of the dwellings were designed without professional structural advice. This is one area in which a grassroots approach to earth sheltered design may be associated with a substantial degree of risk.

In 31% of the cases the owner was primarily responsible for construction work associated with his or her residence. Houses built solely by contractors account for 27% of the existing housing stock. In the remaining 26% of the cases the owners report a substantial input into the construction process. A strong design/build industry for earth sheltered housing does not currently exist in the State of Oklahoma.

It is somewhat difficult to draw a cohesive portrait of the "typical" earth sheltered home owner. The mean age of respondents was 45 years, with a median age of 46.5 years. In general owners are neither first time purchasers nor retirees. A high school education or some college background is the norm. While a rural setting may predominate, only 8% of the respondents are employed in farm related activities. Of the owners questioned, 40% are employed in professional, managerial or clerical capacities and 15% classify themselves as craftsmen. Median family income is roughly \$21,000 with 24% of the families reporting incomes of \$15,000 - \$20,000 and 24% reporting annual income in excess of \$35,000.

The majority of Oklahoma's earth sheltered residences are of recent vintage. Of those currently occupied houses identified thus far, 5 were completed prior to 1977 and the remaining 30 were completed subsequent to that time. In addition, 12 houses were nearing substantial completion as of late fall, 1979. Figure 2 traces the progress of earth sheltered residential construction in the state.

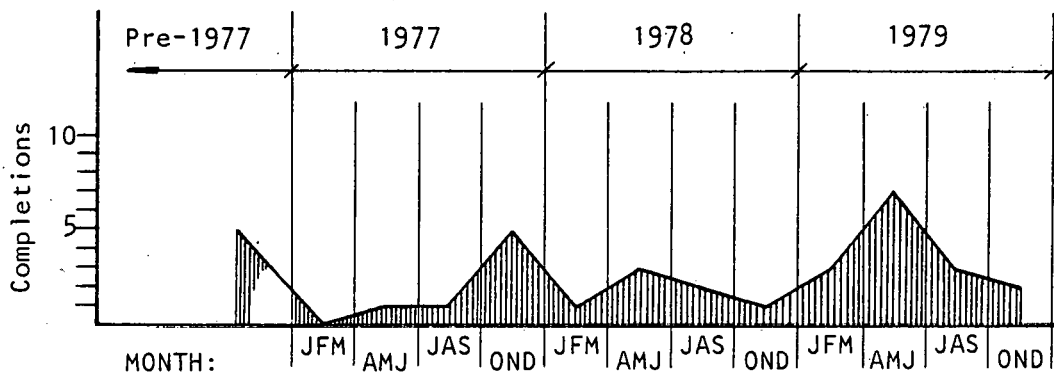


Fig. 2. Chronological Progression of Residential Completions

The Typical House

The typical earth sheltered house has a gross floor area (less garage) of 210 square metres. This is substantially larger than the typical above ground house currently being constructed in the state. The smallest house reported contained roughly 40% of the typical floor area, the largest was twice the typical size. The reason or reasons for the relatively large scale of the underground homes has not been identified although several possible explanations have been proposed.

The mean and median cost figures for identified samples are \$60 100 and \$54 000 respectively. Normalizing for house size, but not for inflation, yields a square metre cost of \$285 for a mean and \$270 for a median. Both figures are quite comparable to what would be expected of equivalent above grade construction practices. That earth sheltered construction can compete dollar for first cost dollar with standard construction has been verified, if not documented, by numerous field interviews. Roughly 70% of the Oklahoma owners obtained financing for their houses. Although the mortgage climate in the state is promising, the financing picture is not at all as clear cut as might be indicated by the 70% figure noted above.

The hillside or elevational type of structure is most typical of Oklahoma samples. This type of design accounts for 80% of the identified structures. Tables A and B provide a good insight into the type of earth sheltered formats popular with Oklahomans. The classification terms utilized in Tables A and B are drawn from contemporary sources. (7,8)

Table A

TYPE of CONSTRUCTION: PLAN

<u>Plan</u>	<u>Frequency</u>	<u>Percent</u>
Totally Underground	3	8
Open Atrium	2	4
1 Side Open	36	80
2 Sides Open	2	4
3 Sides Open	2	4

Table B

TYPE of CONSTRUCTION: SECTION

<u>Section</u>	<u>Chamber</u>		<u>Berm</u>	
	<u>Frequency</u>	<u>Percent</u>	<u>Frequency</u>	<u>Percent</u>
Underground	0	0	0	0
Atrium	2	5	2	5
Elevational	19	46	10	25
Penetrational	1	3	1	3
Conventional Roof	4	10	2	5

Construction Materials

Poured concrete is by far the most popular construction material being used for Oklahoma earth shelters. Earth contact walls constructed of poured in place concrete were utilized in 67% of the residences sampled. Concrete block construction is also quite popular and was reported in 31% of the houses. Precast panels or members have been encountered on only 2% of the structures thus far identified.

The popularity of poured concrete continues as roof systems are examined; 69% of the residences utilize a poured-in-place concrete roof system. Although flat slab systems predominate; barrel vault, waffle slab, inverted beam and post-tensioned slab techniques have been utilized. It appears that bar joist and metal deck roof systems are increasing in popularity with 17% of the respondents reporting this type of construction. Wood roof systems are found on 11% of the houses. This typically implies an exposed roof or second story although one or two earth covered roofs with wood or timber framing have been noted. Precast concrete roof panels have seldom been selected and were reported on only 3% of the currently documented residences. Lack of an effective precast plank supply and distribution network within the state probably is the cause for the surprising scarcity of precast earth sheltered buildings in Oklahoma.

The average depth of earth cover on roofs is 0.52 metres. The most prevalent depths of cover and the respective frequencies of occurrence are:

- 0.00 Metres (13%)
- 0.45 Metres (14%)
- 0.61 Metres (32%)
- 0.91 Metres (11%)

A maximum earth cover of 1.22 metres was reported by 2 owners. In the aggregate, 67% of the wall area in an Oklahoma earth shelter is likely to be below grade or protected by soil. This typically translates to an elevational design in which the primary or exposed facade faces to the South, Southeast or East.

Selection of a waterproofing system is an important consideration in the design process. Current generation structures have in general been waterproofed with relatively basic materials including tars (38%) and dampproofing compounds (17%). Use of specialized materials such as Bentonite or multi-ply membranes has been rather limited. The popularity of tars and dampproofing compounds can be attributed to their ready availability and reasonable cost. No widespread problems with building leakage have been noticed; however, several individual problems of major proportions have been reported.

OCCUPANT ATTITUDES AND EVALUATIONS

An Overview

One question often asked of earth sheltered home owners relates to the decision to build below ground. The Challenge Grant questionnaire included a multi-part query related to this specific issue. Table C summarizes, in index form, occupant responses to twelve suggested factors which might influence the earth sheltering decision process. The index value is the sum of the number of responses for a given factor multiplied by the rating (1-10) of each response. A rating of 1 implies that the factor was not of importance in the decision process, while 10 implies a very important factor.

Table C

<u>Decision Factor</u>	<u>Rank</u>	<u>Index</u>
Storm Protection	1	415
Reduced Heating Load	2	414
Reduced Cooling Load	3	408
Maintenance Reduction	4	381
Enhanced Alternative Energy Potential	5	335
Insurance Reduction	6	293
Security From Vandalism/Crime	7	274
Environmental Noise Reduction	8	255
Personal Privacy	9	246
Improved Lifestyle	10	218
Concept Demonstration/Experimentation	11	208
Land Preservation	12	139

Storm protection and modified energy consumption coupled with reduced maintenance requirements are the motivating forces behind the Oklahoma earth shelter movement.

Although improvement in lifestyle was not reported to be a specific major goal of those opting to go subterranean, it certainly appears to be a resultant of the earth sheltering process. Over 61% of the respondents report that they are very happy with their housing environment. In comparing the habitability of their earth sheltered residence to their previous residence, 61% of the occupants report better to much better habitability in the below ground houses. Another 29% of the respondents report they find the habitability of their earth shelters to be equivalent to that experienced in their previous dwellings.

Specific Benefits

If Oklahomans are building earth sheltered residences to achieve storm protection, energy, and maintenance benefits, are the structures providing such benefits? Questionnaire respondents seem to believe so.

Occupants were asked to evaluate the storm protection design of their dwellings on a scale from 1 (low rating) to 5 (high rating). The mean rating was 4.8, indicating a high regard for the storm protection capabilities of the residences. Reduced maintenance appears to be a potential, if not a guaranteed, benefit of Oklahoma earth shelters. Maintenance requirements lower than or equal to what was expected were encountered by 80% of the owners. Problems typically experienced include wrap-up items which are part of the construction process and erosion situations occurring with steep grades.

Energy utilization and conservation aspects of current generation dwellings were evaluated by residents. Energy consumption commensurate with expectations was reported in 40% of the houses. Energy requirements somewhat higher than expected were noted by 28% of the owners; lower than expected by 25%, and 7% were undecided. When the owners compared current energy requirements to what they experienced in their previous homes, the mean response indicates that the earth sheltered (and generally larger) homes average 32% lower energy consumption. A more detailed discussion of energy and habitability aspects of the homes investigated to date may be found in references (3) and (4).

Unrealized Potential

Insurance reduction expectations and alternative energy enhancement opportunities were two factors which influenced the earth sheltered decision process for many respondents. Typically both of these factors represent currently unrealized potential benefits.

Roughly 46% of the owners indicate that insurance costs for their earth sheltered residence are the same, or only nominally lower, as what they would expect to find is required for a comparable conventional dwelling. The remaining 54% of the owners are not realizing sizable policy savings, but rather may carry no insurance whatsoever. As a matter of fact, 45% of the respondents have no homeowner's insurance.

Although enhanced alternative energy potential ranks as the fifth most influential factor in the decision process, it is an option which has been little exercised. Fewer than 8% of the respondents have installed solar domestic water heaters. No active solar heating or cooling system installations have been reported, and only 8% of the owners believe they have viable passive solar heating installations.

If conservation rather than energy advocacy is evaluated, however, the picture appears somewhat more upbeat. In the aggregate, the typical house is perceived to require mechanical systems input to offset 68% of its heat loss, with the remaining 32% input being obtained from alternative or renewable resources. Similarly, respondents feel 57% of their cooling requirements are met by mechanical systems, the remaining 43% of capacity is attributed to earth cooling and natural ventilation effects.

ENERGY UTILIZATION

Construction Practices

Several factors, including weather, type of construction, and occupant patterns, exert a forceful influence on residential energy consumption. Occupant practices and patterns are perhaps the most difficult factor to quantify, construction practices the easiest. Both of these items will be addressed below. Consideration of metered and calculated energy requirements is beyond the scope of this paper; these issues are presented in references (5) and (9).

Design practices to optimize energy parameters in Oklahoma earth sheltered residences are typically not fully considered. The majority of sites now identified could best be viewed as prototypes. Review of insulation techniques, for example, yields a full spectrum

of conflicting practices. Fully 45% of the respondents indicate their structures have no roof insulation. On the other hand, the mean R-value for roofs with insulation is 130.4 metre^o Kelvin per watt, a rather substantial value. The same relationship is typical of earth contact walls; they are normally uninsulated or well insulated. Insulation, or its lack, must be viewed in the Oklahoma context. A "good" winter design may penalize summer operation and vice versa. One of the primary goals of the Challenge Grant project is to sort out these various concerns in order to provide rational design guidelines for the state and surrounding areas.

Interior wall finishing techniques can have a dramatic influence on the performance of an earth sheltered structure. Finish materials such as furred paneling or drywall tend to decouple the occupied building spaces from the mass of construction as well as the earth. As with insulation, the dwellings in the survey split roughly 50%/50% with regard to decoupling vs. non-decoupling interior wall finish treatments. Again, climate sensitive design guidelines must be developed.

Occupant Comfort

To paraphrase J. R. R. Tolkien: It was an earth shelter, and that means comfort. According to owner responses to the questionnaire, Oklahoma earth shelters are quite comfortable. As thermal comfort most strongly relates to energy consumption, it will be considered herein.

One general impression conveyed by most respondents is that it is not necessary to push an earth sheltered dwelling to or beyond the bounds of thermal comfort in order to achieve energy savings. The mean winter thermostat setting in the residences sampled was reported to be 20.9^o C; the summer setting 24.1^o C. Figure 3 presents the range of responses received to questions requesting data on thermostat settings.

As a result of the temperature stability inherent in most earth shelters, thermostat setback can have only limited effectiveness. Only 40% of responding owners indicate they make setback or setup adjustments a part of their normal routine. Quite candidly, one-half of the owners report no efforts to modify habits or work patterns to save energy in the house.

There is a slight trend for owners to lower summer thermostat settings when moving from an above ground dwelling to an earth sheltered house. No perceptible shift in winter space temperatures has been reported. As previously noted, Oklahoma subterranean designs can and do reduce energy consumption while allowing occupants to maintain or even improve their life style.

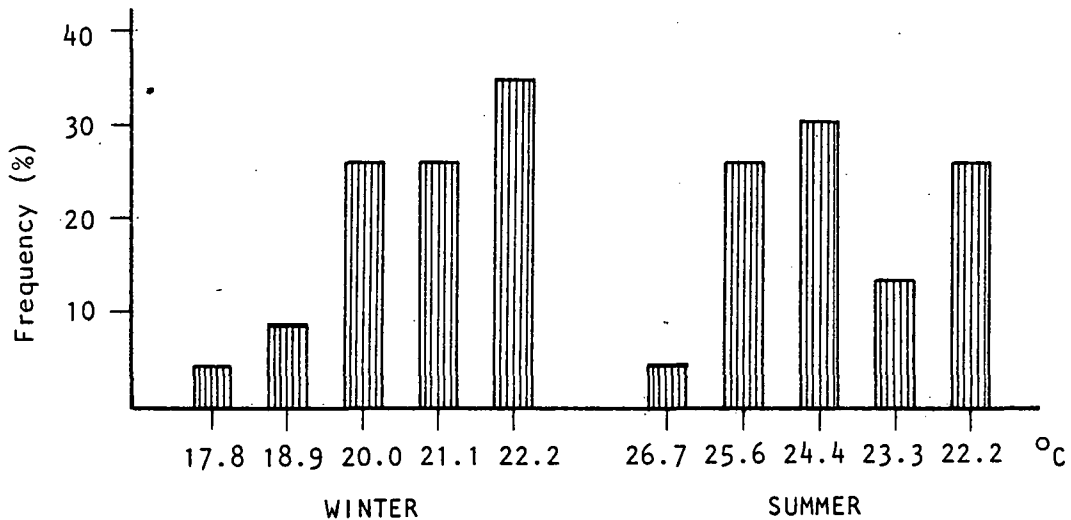


Fig. 3 Summer and Winter Thermostat Settings

CONCLUSIONS

Earth sheltered residences in Oklahoma are, on the whole, providing a quite acceptable and energy conservative habitat for more than one hundred families. As a result of the experimental or prototype nature of most existing designs, the present-day practice of subterranean architecture appears to be more of an art than a science.

The majority of Oklahoma's earth sheltered owners are pleased with their living environment. The primary benefits reported by current generation owners include storm protection, energy conserving performance and enhanced thermal comfort and general habitability.

ACKNOWLEDGMENTS

The work reported herein was initially funded by a Presidential Challenge Grant issued by the Office of the President, Oklahoma State University. Current support from Control Data Corporation is also acknowledged. The efforts of Jackie L. Bell, Carolyn A. Peck and Donald G. Self and the substantial assistance of Dr. Margaret J. Weber and Daniel K. Fitzgerald are appreciated.

Walter T. Grondzik
 Dr. Lester L. Boyer
 School of Architecture
 Oklahoma State University
 Stillwater, OK 74074
 (405) 624-6043

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INTEGRATING SITE LOCATIONAL CRITERIA FOR
UNDERGROUND HOUSING

John Karl Hannula
School of Environmental Design
University of Georgia
Athens, Georgia 30601

ABSTRACT. The rationale and potential for underground structures has been clearly articulated^{1,2} by a wide cross section of professionals in the past few years, but at this time the approach is still piecemeal. The project-by-project basis by which underground housing has been built has revived this ancient solution for shelter and has provided opportunity for research and evaluation; however, a more concerted regional approach is necessary to meet the needs of an increasingly energy-conscious society. This paper will thus discuss site-location criteria and mapping processes for underground housing on a large-scale basis.

As underground housing projects become increasingly large and more numerous, there is a greater need to locate suitable sites for their particular requirements. Any tract of land won't do. Adverse land characteristics such as high water tables and shallow bed rock depth increase both construction problems and costs³. As well, there are large variances of subterranean temperatures⁴ inherent with each site; a lower temperature is quite obviously less desirable in colder climates where heavy heating costs are concerned.

Other issues concern the site planner as well. One is the search for land amenities which make sites more desirable such as good views and adjacency to public transit, shopping and recreation areas.⁵ One must also be concerned with a complexity of site-development factors, such as erosion-sedimentation, sewage disposal, utility lay-out, and visual impacts. Site location criteria can be complex; therefore a logical, step-by-step analytical approach is necessary.

Much research on underground structures exists, but much of it is not available or usable to the very people mostly responsible for underground housing development: design-build professionals, contractors, and individual home builders.

THE PROCESS. Geographic information, to be readily usable to the site planner, must meet certain criteria. It must be:

- a. simple and understandable
- b. presented geographically (or be easily mappable) at the same scale
- c. readily available
- d. modifiable and easy to interpret
- e. organized for easy combination

Fortunately, data which meets the above criteria exists in most areas of North America. The task is to facilitate its combination and analysis so that site location decisions may be derived.

The identification and organization of data for site location can first be done conceptually or "modeled". This process was first described by Steinitz et al., (1976)⁶. The initial identification of specific data items eliminates costly and time-consuming mapping of unnecessary data. Once the data has been identified, collected and mapped (at the same scale) it may be combined or "overlayed" for the spatial location of specific sites. The assumption here is that the modeler has a basic knowledge of site-determining characteristics such as soils, ground water level and topography. The process is summarized in Figure 1. This overlay process has been most recently described by McHarg⁷ and Steinitz, (1976).

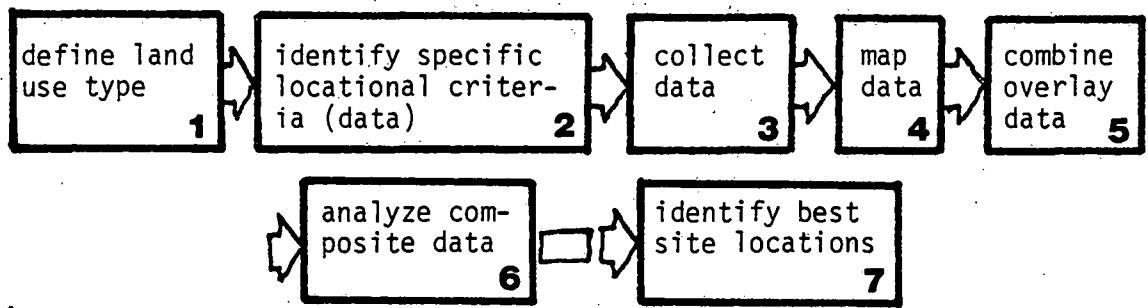


FIGURE 1

The Hand-Drawn Data File System (Steinitz et al.) is used here in the modeling and mapping of the specific locational criteria. This technique was selected because of its simplicity and usefulness in a "first-look" search for appropriate sites. The mapping is done in clear transparencies, usually green in color to symbolize sites good or "attractive" for specified land uses.* Mapped data are then overlayed as conceptually diagrammed in Figure 2. The importance of the data is weighted by making the maps darker (darker is better).

* Red transparencies are used to denote sites which are "vulnerable" to environmental impacts such as erosion-sedimentation, ground and water degradation, or visual disruption. The terms "attractiveness and vulnerability modeling" were thus derived.

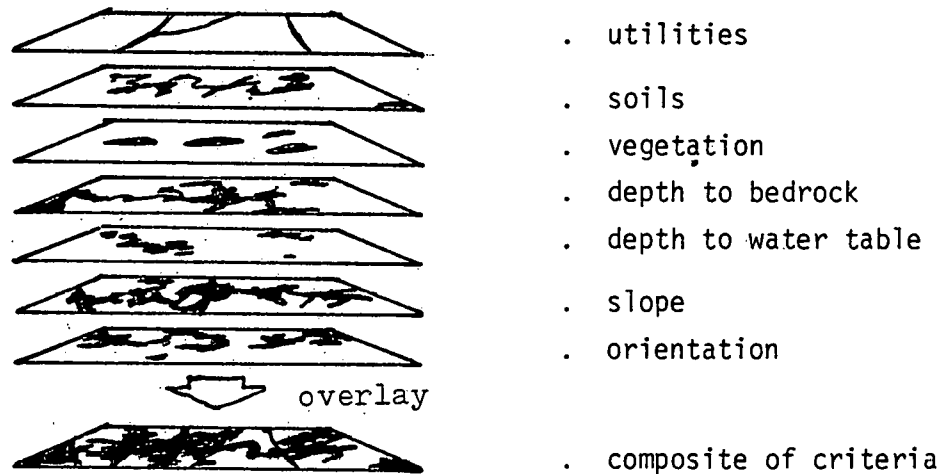


FIGURE 2

SITE LOCATION MODEL (CRITERIA) FOR UNDERGROUND STRUCTURES. The following criteria for underground structure site location has been adopted primarily for its geothermal influences and construction properties. Soil climate is defined by Ufimtseva⁸ as "The multi-annual thermal water and areal regime of soil which is closely related to climate, vegetation, relief, character of soil forming rocks and other components of landscape." All of the data is readily available for use by development professions, and the sources are listed as follows:

- .slope: USGS Map
- .slope orientation: interpreted from the USGS map
- .vegetation: aerial photography or recent USGS Map
- .soils: SCS soil survey (available by county)
- .depth to bedrock: SCS soil survey and "Blue Sheets"
- .depth to water table: SCS soil survey and "Blue Sheets"
- .utilities (sewage, water): planning, engineering offices

CRITERIA JUSTIFICATION.

Slope:

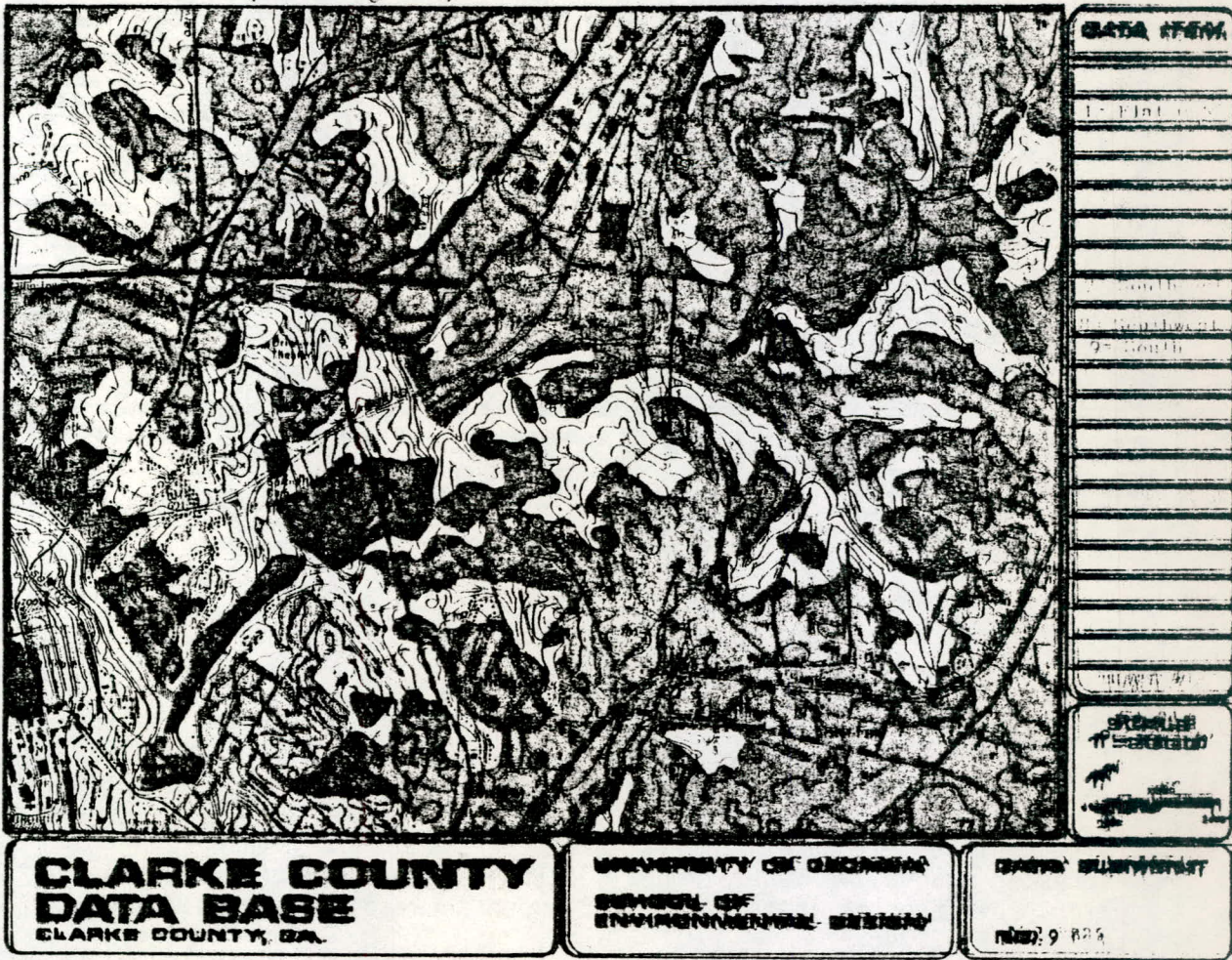
Insolation of south-facing slopes increases with tilt to a maximum year-round btu/sq. ft. absorption occurring at an angle of tilt equal to the site latitude in the midlatitudes of the U.S.^{9,10}. As applied to the example site, located in Athens, Georgia, it would be 33° or 60% slope; however significantly large slopes at this angle are non-existent in this area. The steepest slope mapped is 25%.

It should be noted that steep slopes have high associated construction costs and are susceptible to erosion¹¹, and appropriate slope retention solutions¹²would be necessary with this steepness. However, construction on steeper slopes may offer significant views which may justify the additional construction cost.

Assuming that appropriate solutions will be used for slope retention and soil erosion control, the slopes were sub-divided into three categories for insolation and were mapped, darkest being best. (Only south, southeast, southwest slopes and flat areas were mapped).

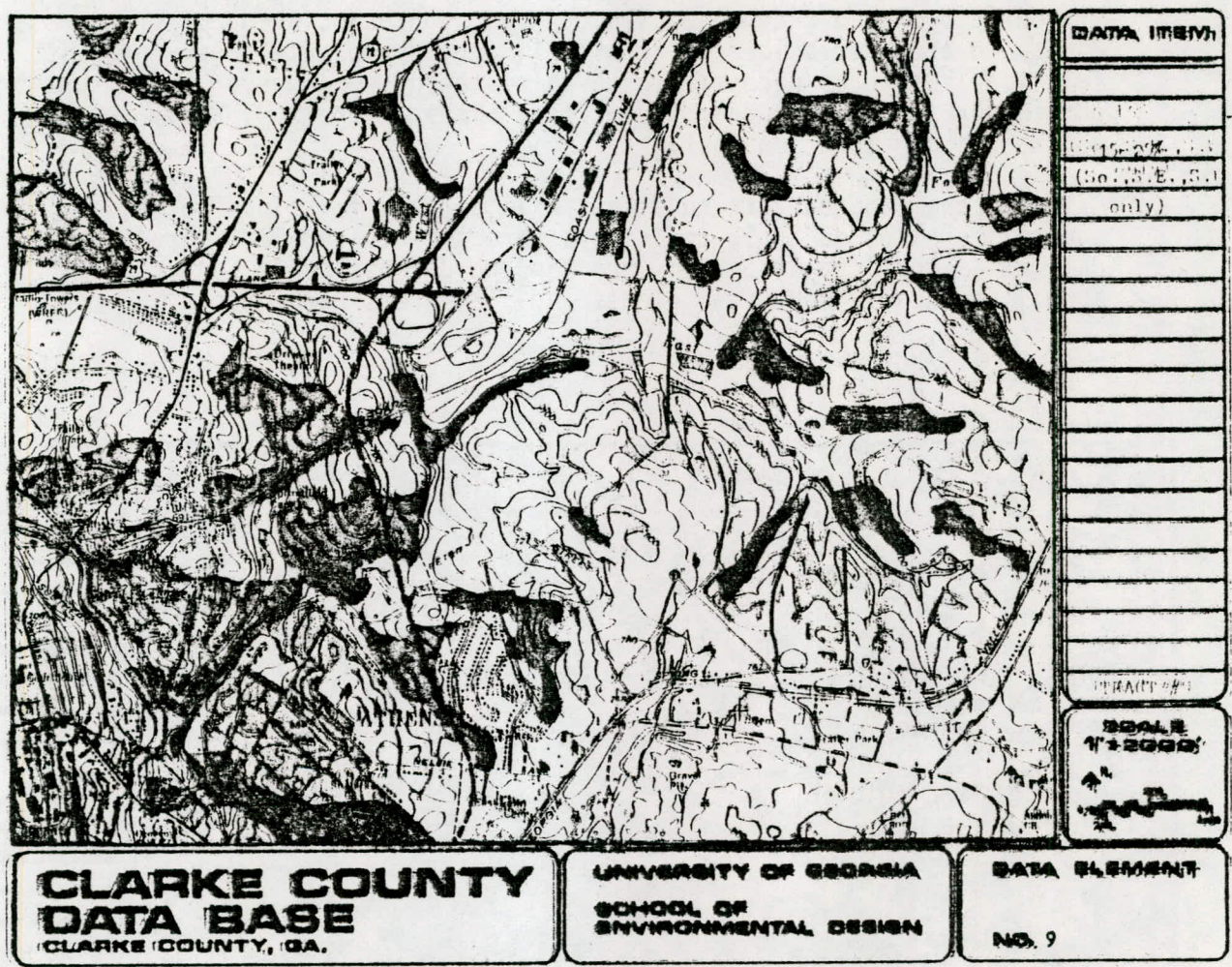
5-15 GOOD (medium green)

15-25 BEST (darker green)



ORIENTATION. The main source of heat entering the soil is from solar radiation¹³ which correlates directly with slope orientation. Temperature differences between grass covered north and south exposures may vary as much as 3.2-7.4^oc.¹⁴ Soil with a horizontal surface heats up more readily than soil on slopes, except for southern slopes.¹⁵

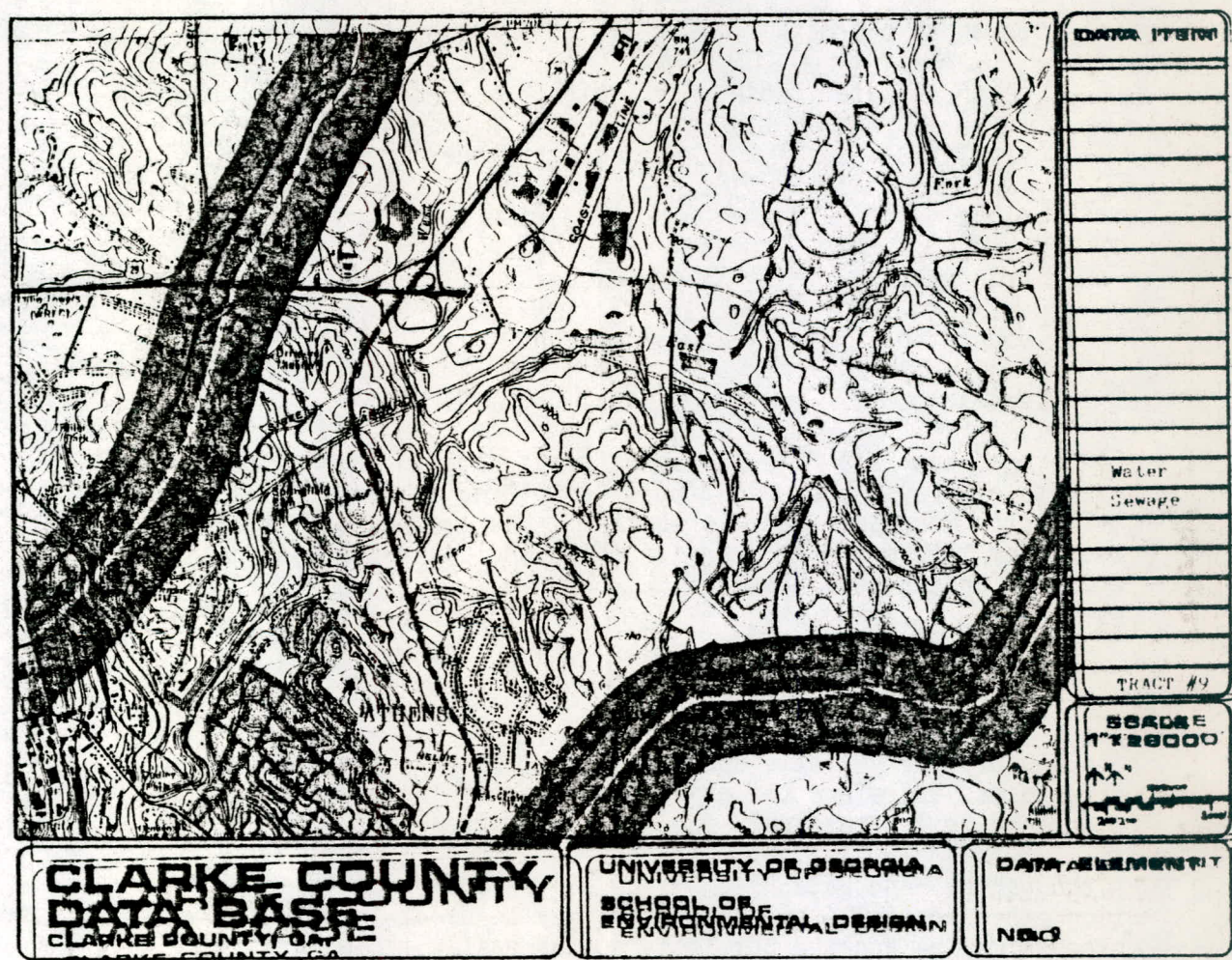
Accordingly, the south slope was mapped as best; south east and southwest slopes as second best, and flat slopes as third most desirable.



Map 2: Topography - Slope Orientation

VEGETATION. Plant cover effects soil temperature by shading the surface in the day and by preventing radiation at night.¹⁶ Bare soil is warmer in the summer but colder in the winter with a net heat loss. A shallow grass cover is often warmer than bare soil by 12°C.¹⁷ Likewise, soil temperatures in grass are often much warmer than under forested stands.¹⁸ Vegetation also traps snow which acts as an insulator. Differences in temperature between snow-covered and bare soil may reach 12.30°C.¹⁹

of the high costs of constructing wells and septic systems.



Map 7: Utilities

CRITERIA COMBINATION AND WEIGHTING. The weighting of the individual criteria is dependant upon planning goals and politics, community values, legal constraints, individual site characteristics, and professional judgement. There can be no set formula. In some cases a potentially good view (which sells houses) may override a 20c advantage in slope aspect. Accessibility and utilities likewise influence site selection. The important thing is that the mapped data is relevant and that the criteria and process is defensible and changable (Steinitz).²³

For the purpose of this demonstration, I have weighted the criteria in the following manner:

- .depth to bedrock high
- .depth to water table high
- .utilities slight-moderate
- .slope moderate
- .orientation moderate
- .vegetation slight
- .soils slight-moderate

Since the Hand Data File System displays data in colored transparent acetate overlays, the weighting is displayed in tones: the darker green, the more important, or better. Each mapped criteria is then overlaid to produce a composite which indicates the most desirable sites for underground housing.

Conceivably, very little space will be allocated for underground structures, therefore the criteria presented in the model may be tightened to indicate only the very best sites.

Although the Hand Data File System was selected for this demonstration other spatial analysis systems may be used. McHarg's²⁴ overlay process may be adopted but it is not as easily manipulatable as data maps. Numerical manipulation and combinations of the data is possible with the IMGRID (Sinton, et al.)²⁵ computer programming system. Its output is displayed spatially with graphic symbols. IMGRID has a high degree of numerical combinant capabilities and is now being widely used in America; however, special training and facilities put its use out of the reach of most developers and builders.

CONCLUSION. Site selection for underground housing on a sub-regional basis can be easily achieved by a wide variety of professionals provided a systematic and logical process is followed. Even though much research is necessary for a fine tuning of the system, existing data and inexpensive technologies permit immediate application. It is hoped that the process, criteria and demonstration in this paper assists the proper siting of underground structures in the future.

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John K. Hannula
School of Environmental Design
University of Georgia
Athens, Georgia 30601

Phone: (404) 542-1816

THE OWNER-BUILDER AND THE UNDERGROUND:
BUILDING A LOW-COST HOME

Robert L. Roy

Author, UNDERGROUND HOUSES (Sterling, 1979)
President, WOOD, WIND, & EARTH, Inc., West Chazy, NY 12992

"The mass of men lead lives of quiet desperation."
- Henry David Thoreau -

In Walden, Thoreau says that Food, Fuel, Shelter, and Clothing are the four "necessaries of life," the human requirements for keeping the body temperature up to the point where one might reasonably be assumed to be alive. Speaking from experience, and paying particular attention to the new reality of energy costs, I can say that Shelter and Fuel are two of the three "biggies" on Henry's list, Food being the other.

Now here's the rub: To a much greater degree today than in Thoreau's time, the American economy thrives on the fact that the mass of men have become quietly convinced that they really aren't capable of supplying the "necessaries of life" directly for themselves; that, in fact, it is necessary to pay all kinds of middle men - "specialists," "experts," whatever - to supply the means of survival. The individual's part in all this is that he, too, becomes a specialist, and the purpose of his speciality had better be that it earns him enough money to pay all the other specialists.

The problems resulting from such a system are complex. Firstly, the dollar cost of the system to the individual (never mind society as a whole) is greatly increased. John buys a tomato at Piggy Mart for a dollar. Jim grows a tomato in his garden or earth-sheltered greenhouse. John's tomato was planted by someone driving an automatic seeder, watered and fertilized by systems that shake the foundations of the ecology, harvested by field workers, plastic-wrapped by someone else using more machinery and petro-chemical products, hauled to a central shipper, shipped across country in a huge refrigerated tractor trailer, distributed to Piggy Mart by another carrier, laid up on the shelves by a stockboy, and rung up on the register by a clerk. I'm sure that my unfamiliarity with the system has caused me to overlook one or two other intermediaries. In the meantime, poor John, to have the buck to spend, has had to earn two. State and federal taxes take their cut. Transportation costs (including car payments) to get to work and to Piggy Mart come out of it. A dollar saved is worth a whole lot more than a dollar earned. because we have to earn so darned many to save so precious few.

Jim's investment in his homegrown tomato is measured in

time and a share of whatever his greenhouse or garden has cost him to establish. "But his time is worth something!" I hear my critics shouting. Yes it is. But what it is worth should be measured in terms of real production, not some artificial dollar value based on some nebulous wage which has little to do with production and real worth, but a lot to do with creditors, profiteers, bankers, labor unions, and tax collectors.

Secondly, the energy cost of the tomato which has traveled up to 2500 miles and has been fertilized with energy-expensive chemicals is unacceptable. An obscene number of energy units are required to deliver one equivalent food-energy unit from San Diego to Albany. This is usually the case with housing, too. Plywood, finished lumber, cement, insulation ... in fact, almost all of the materials which go into the construction of a conventional home are transported over vast distances, increasing both the dollar and energy costs of building. Owner-builders have long known the advantage of that most basic premise of folk architecture as practiced all over the planet: Use indigenous materials. So owner-builders start with a big advantage, especially if they build an earth-sheltered house (ESH), which uses a high percentage of locally available materials.

Thirdly, John's persistence in buying tomatoes (or fuel oil, or electricity, or a contractor's services) continues to reinforce his dependence not on himself, but on the economic system that has brought us the Piggy Mart, Exxon, ConEd and the Uniform Building Code. Jim has learned to grow his food (or cut firewood, or maintain his windplant, or build or repair his own home.) When we are unable to justify or defend six percent of the world's people consuming 30% of the non-renewable resources, which will be better placed to meet the crunch?

Finally, there is a wide qualitative gap between the two tomatoes.

Let us turn the discussion to that "necessary of life" called Shelter, especially the ESH. Modern American Man is in very real danger of allowing himself to be convinced that he is unable to provide his own shelter ... that it is necessary to hire an "expert." The problem is so serious that he is in great danger of sacrificing even his right to provide his own shelter. I refer to the ever more punitive building and planning codes in force around the country. The heating cost of any house, not just an ESH, can vary by up to 30% solely as a function of the orientation of the house. One town near where I live has a planning ordinance that requires that all houses be built "parallel to the road," caring not at all whether the road runs east-and-west, north-and-south, or something in between. A neighborhood with this ordinance may be

requiring 30% more energy for heating - or cooling - than a neighborhood of similar houses orientated to take advantage of siting principles known to the Greeks 3000 years ago. In Massachusetts, state of my youth, codes and inspections have made building one's home so expensive and so difficult that it's really hardly worth the bother. Granted, if one sells a house or contracts a house for a customer, the buyer should be protected from an unsafe home. This was the original intent of the codes and I believe that the intent was just. The owner-builder, on the other hand, is simply trying to provide his own shelter, surely one of the most basic of rights, though not listed specifically in the Bill of Rights. It may have been considered so basic, like breathing, or providing one's own food, that it was not considered necessary to include. These are rights that man has had long before the Bill of Rights came into existence, rights taken for granted by bees, beavers, and bandicoots. I fear it is only a matter of time before a Commonwealth of Massachusetts building inspector slaps a condemnation notice on a beaver lodge for lack of sufficient glazing. A man, like a beaver, should have the right to build his own shelter, even if that shelter should fail. The alternative is too dear by tenfold.

With respect to earth-sheltered housing, it is the responsibility of those architects, engineers, and experimental builders among us to share our knowledge and to make known the structural and waterproofing data to help ensure that owner-builders construct sound houses.

Owner-builders are independent types. That's why they're owner-builders. And, usually, they are aware of the alternatives in housing long before the information percolates up to the general population, probably because they deliberately seek out the kind of literature where these advances are first noted. Owner-builders can readily see that an ESH not only addresses Shelter, but also Fuel (by the conservation thereof) and even Food, if an attached solar greenhouse is included as a part of the design.

The problem is that most owner-builders are inexperienced. When it comes time to build, they are less scared of "traditional" building methods, such as balloon framing, because this is what they are used to seeing. The more adventurous might even tackle a log house. Again, the technology involved seems well within their grasp. Unfortunately, earth-sheltered housing tends to scare a lot of people away, even though they perceive clearly the tremendous advantages of an underground home.

The reasons for this fear are twofold. Firstly, most owner-builders are under the impression that a very advanced technology is required to build a successful ESH. Start

talking about poured concrete walls, pre-stressed concrete beams, expansion jointing, exotic waterproofing techniques ... whoa, he's off to the woods with his axe and HOW TO BUILD A LOG CABIN manual. So we shouldn't talk about those things. They're not really necessary in most cases anyway.

The second myth which must be dispelled is that ESH's are expensive. It may be that contractor-built models are that wee bit more expensive than comparably-sized structures on the surface. A lot of this probably stems from the contractor over-building somewhat to protect himself in this relatively new field. This will change, as engineering and waterproofing knowledge becomes more readily accessible. Anyway, the seeds of doubt are planted in the owner-builder's mind, even though the literature which has planted the seeds has been in reference to contractor-built homes. The reality is that owner-built ESH's compare favorably with owner-built frame houses, log cabins, even log-end structures. Evidence of this is given in the accompanying article to this paper. There is no reason why a good, long-lasting owner-built ESH can't be built in a non-coded area for \$10 per square foot. (In a coded area, this figure might run as high as \$15, because of all the "extras" that have to be incorporated into the design to satisfy the building inspector. This is unfortunate. Good background reading for owner-builders in a coded area is THE OWNER-BUILDER AND THE CODE, by Ken Kern and Co.)

This discussion of cost per square foot brings us around to the matter of size of a home. Here are a few basic rules that hold true for almost all types of construction:

- 1. A large house costs less per square foot than a small house.
- 2. A small house costs less than a large house.
- 3. A small house is cheaper to heat and maintain.

I might add the following particular rule which applies specifically to ESH's:

- 4. Earth-sheltered houses are not easy to add on to.

The exception to Rule Four is when the house is deliberately designed to add on to in the future, the builder knowing that this must eventually happen. Such a strategy might be appropriate for those on very restricted means. One couple recently told me that they absolutely had to have 1600 square feet of living space. The trouble was that they could barely afford half of that. I suggested that they build an 800 square foot home, leaving the east wall not backfilled. In two or three years, they could afford to

build another 800 square foot module east of the first. The common wall of 12" concrete blocks would serve very well as a heat sink and noise buffer when the addition is completed.

Choosing the size of house to build is not as easy as it first appears. Many considerations come into this choice, except where ridiculous planning regulations require a minimum of 2000 square feet. Owner-builders on a low budget instinctively avoid buying a lot in such a neighborhood. Here are some of the considerations (pitfalls?):

The over-reaction syndrome. Jack and Jill have been cooped up in their little apartment or house trailer for so long that all they can think of is, "When we build our house, there's gonna be plenty of space!" They've got lots of time to plan; paper and pencils are cheap. They finally get started on their 3000 square foot masterpiece. The possibilities from there, in descending order of probability, are: (1) There is a great enthusiasm to begin with. After about six months, money, energy, and patience run low ... run out. Jack and Jill split up. (2) After a while, Jack and Jill perceive that they've really bitten off too much. They move into a third of the place. "Someday we'll finish the rest," they say. (3) They pull it off, as planned. I have heard rumor of this, but have yet to witness it through personal contact.

Big bedrooms, lots of bedrooms. The functions of a bedroom are to supply a peaceful venue for horizontal resting of the body and as a storage area, generally for clothes. The bedrooms in most American homes could be divided in two and each would still serve the purpose. Sure, lots of other considerations come into the planning: building codes again; an adjustment, perhaps, of the individual value system; planning a small bedroom to accommodate furniture, etc. One thing is certain: the larger the bedroom (or house, for that matter), the more unnecessary stuff one accumulates. As for number of bedrooms, this is largely a function of individual thinking. Americans seem particularly hung up on a privacy thing. Every kid has got to have his bedroom and then there should be one extra bedroom thrown in for the pot: the ubiquitous "guest room." In the reality of most family situations, the guest rooms are used less than 10% of the time. The living room of our ESH has a convertible sofa, so the room functions nicely as a guest room, too.

I realise that the above paragraph is a personal view, but I want to point out that there are many trade-offs when it comes to building a house which is affordable. To me, affordable means that I will own it, not the bank.

With regard to room size and ESH's utilizing the post and

beam technique, it should be kept in mind that there are definite rafter span limits which should be considered. See attached article.

"I only want to do it once, so I'm going to do it right!" By "right," they usually mean "of high quality," which is fine, but often "big" goes along for the ride. This is similar to the over-reaction syndrome, except that it stems from a different set of premises. The results are usually the same. Most inexperienced owner-builders find that my late father's favorite comment on owner-involved building is the more accurate. "You've got to build two houses to get one right," he said.

On that note, the time seems ripe to share with the reader a plan which addresses the problem of inexperience ... and several others at the same time. It is the Temporary Shelter.

The Temporary Shelter is a small, simple, low-cost structure which the owner-builder lives in while building the permanent dwelling. This plan affords the following advantages: (1) The builder gains actual building experience. This gives him the confidence that, yes indeed, he really can build his own Shelter. Big step. (2) Moving on site saves interim shelter and traveling costs while the main place is built. (3) Actually living on the land familiarizes the owner-builder with the various local factors to consider in siting and orientating his house: sun and wind direction, view, special land features, natural traffic flow, etc. (4) When the house is finished, the Temporary Shelter will be a useful outbuilding: workshop, garden shed, woodshed, whatever. Some consideration should be given to this advantage before building the shelter.

There's no reason why the Temporary Shelter can't be earth-sheltered. This would supply the most practical experience for later construction of a permanent ESH. This also gives a chance to make a less costly mistake, which needn't be repeated on the main building.

Too small. A less common mistake is the building of a house too small. It's a mistake I made myself, because I stretched my small-is-beautiful approach beyond reasonable limits. Our first house, a cordwood cottage, lacked a private place where one could tuck oneself away for a while. Still, the 700 square feet was plenty for my wife and me. One tiny baby changed all that. We were thinking about how we could add on, but I caught the underground bug and we decided to build another house. The two houses together, including septic system, an excellent wind generator, all fixtures, furnishings and appliances cost us less than \$20,000. The underground house has about 1000 square feet, but is much better planned and, unlike

the cottage, has no stairway. Our family of three (plus two large dogs) is very comfortable in this size and we could find room for another little one, if such an event should transpire.

To wrap up this dissertation on house size, then, my advice to a new owner-builder considering an ESH would be: Small is beautiful. It is also less expensive than big, initially and so on down the line. But give a margin, a small spare room, perhaps, for some yet-unknown purpose. Or plan the house with specific expansion potential.

Usually it's not the money that puts people off attempting their own home. After all, the alternative (which, unfortunately, most people will wind up choosing) will cost several times as much. And most people can be convinced that if so-called "primitive" man using few tools and only indigenous materials can build beautiful houses that last hundreds of years, well, the? yes, I guess maybe I could do it. The biggest but - or butt: the spellings are virtually interchangeable in this case - that has to be moved is the one that says, "But I don't have the time. Time is money, you know." I think not. Time, as nebulous as it is, is still something real. Money is credit for something real. We can survive without money, but we're in big trouble when we run out of time.

But, yes, of course, it takes some money to build a good quality ESH. The last page of this paper gives a costing analysis of my home, Log End Cave. The materials and contracting cost of the house, including landscaping and drainage, was \$6750. We've spent another \$250 or so since the article appeared, or about \$7000 for the basic house plus landscaping. Inflation would boost this to about \$8500 in 1980. We also spent about 1800 man-hours on the project, mostly our own, some of it paid (\$660 worth). That's a lot of time. But a couple working together can log that time easily in six months, even with bad weather. There are other time combinations possible to meet different circumstances.

One-third of the "average" American's after-tax income is devoted to Shelter, usually rent or mortgage payments. If a man works from the age of 20 to the age of 65, it could be legitimately argued that he has put in fifteen years just to keep a roof over his head. With six months' work (and \$8500), he and his family could have built their own house.

"All that is fine and dandy for writers, golf pros, and other layabouts," people tell me. "But I'm a working man. I can't afford to take six months off to build my own house."

I reply that to save fourteen and a half years of work, they can't afford not to build, even if it means losing a job. Granted, the \$8500 has to come from somewhere, but this is no more - and probably a whole lot less - than the down payment on a contractor-built home, and less than half the cost of a new mobile or modular home of similar living space. And, like the tomatoes, you can't compare the end product.

The part of this argument that most often throws people is the business of giving up one's job. This is not always necessary and should be treated as a last resort solution. Someone who is really good at their work will not take long obtaining a similar position, or regaining the first. Others look upon this plan as just what they need to get them out of a dreaded job. These are the ones leading the "lives of quiet desperation."

The next four pages, reprinted from Alternative Sources of Energy #39 with kind permission from the editor, discuss the two specific building techniques which I have found to be the most useful in opening up the underground for the low-budget owner-builder.

Robert L. Roy
RR1, Box 40C
West Chazy, NY 12992
(518) 493-7744

How to Build an Underground Home

by Robert L. Roy

Interest in underground and earth-sheltered building has increased dramatically in the past year or two. In this time of constant energy crises, people of all lifestyles are beginning to perceive the tremendous energy advantages of earth-sheltered construction. Of course, there are several other less well-known advantages to building underground, such as freedom from noise pollution, low fire risk, visual amenity, low maintenance, long structural life, and — surprisingly — low cost. Most of the publicity given to subterranean structures would have the public believe that they are practical, beautiful, and expensive. In this article, I hope to show that underground housing is as viable for the low-budget owner-builder as log cabins or stick framed houses. And just as easy to do.

I will use our own Log-End Cave as my primary evidence. Our basic 1000 square foot house, including landscaping (an integral part of earth-sheltered housing), cost us \$7410.57, \$660 of which was for labor. These figures do not include well or septic system, which we already had on site. I will make no wild unsubstantiated claims, but I think it is fair to say that the house will be around for a long, long time. Experienced contractors and builders who have seen the house agree. The actual itemized costing of our Cave is interesting and — I hope — useful as a guide; it appears at the end of this article.

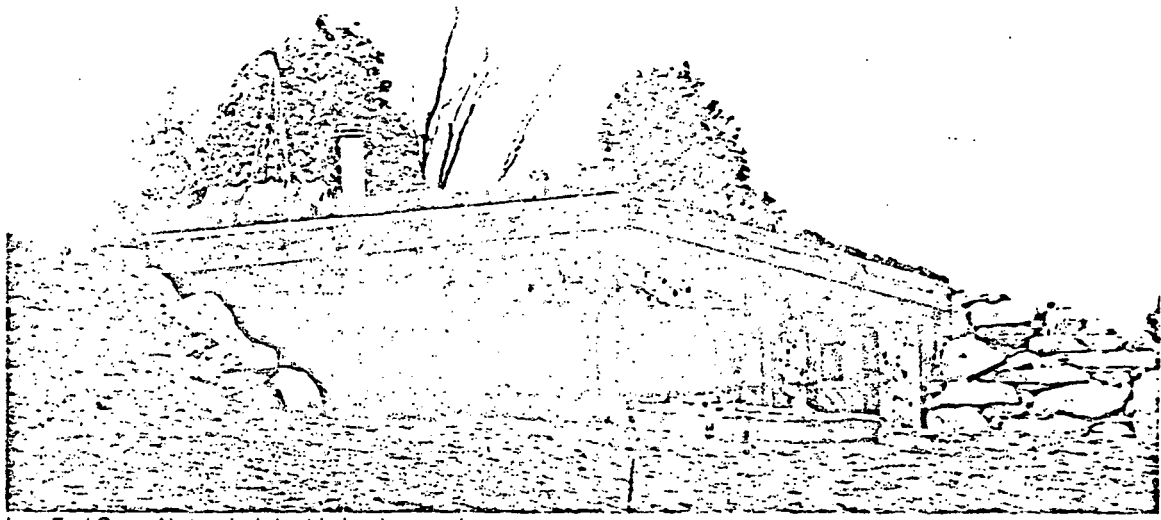
Surface Bonding

Lots of people who are ready to go out and chop down trees and stack them up as a log cabin hesitate when it comes to trusting their ability to construct a sound masonry foundation. There has always been an aura of mystique about masonry (partly attributable to the secrecy of the old mason's societies) which often frightens the owner-builder. It frightened my wife and I when we built our first house, a log-end structure over a full cellar. We hired an experienced friend to lay the concrete block foundation. And I would still leave the pouring of a solid concrete wall to the experts, and carefully chosen experts at that! But there is an alternative to laying up blocks with mortar or having a solid foundation

wall poured, an alternative which is extremely strong, not expensive, and easy to deal with by inexperienced builders if care and attention to detail are exercised. I am, of course, referring to the surface bonding technique of laying up a wall. Not normally a believer in wonder products, get-rich-quick schemes, and free lunches, I really have to say that surface bonding of a block wall is one too-good-to-be-true deal that really works. It is one of the two keys that unlock the underground world for the ordinary man. The other key, plank and beam roof framing, I will discuss later in this article.

"My initial skepticism of surface bonding was dispelled as I used it and began to get a true sense of what I was actually doing to the wall."

Surface bonding is the application of a special cement-based material to both the exterior and interior surfaces of a wall of concrete blocks laid up without mortar after the first course. The first course is laid in a bed of mortar solely for the purpose of establishing a level base course for the further stacking of the blocks. No mortar is ever placed at the ends of blocks, even on the first course. The secret of surface bonding is the thousands of tiny glass fibers which permeate the mix. When applied correctly to a thickness of 1/8" to both surfaces of a dry-stacked wall, surface bonding has been said to be six times stronger against wall flexure than a conventionally mortared wall. (*Construction with Surface Bonding*, see Bibliography.) My initial skepticism of surface bonding was dispelled as I used it and began to get a true sense of what I was actually doing to the wall. The only way that the wall can fall in would be if the 1/8" membrane were to rupture along the whole length of the wall. But you know that isn't going to happen when you see tens of thousands of short glass fibers bridging the tiny spaces between adjacent blocks. This method of construction has something in common with screwing and gluing plywood to both sides of a two-by-four framework: the resulting panel has incredible strength



Log End Cave. Note windplant in background.

which seems to go beyond the inherent properties of the components themselves.

Most people — I used to be one of them — think that mortar “glues” blocks together. This is not strictly so. Mortar’s primary purpose is as a leveling agent. When a block wall fails, the cracks in the wall invariably follow mortar joints. Rarely do the blocks themselves break. People sometimes say to me, “It would seem that the strongest possible block wall would be a mortared and surface bonded wall.” I think not. The mortar will still be the weak link in the chain, and the surface bonding will be of little help because the mortar gap will greatly cut down the probability of the individual glass fibers spanning from one block to its neighbor.

Another advantage of surface bonding is that it is excellent as a waterproofing agent, though any cement-based waterproofing will fail if a foundation crack develops due to settling. For this reason, I gain peace of mind by compacting the earth beneath the footing and by applying a layer of plastic roofing cement to the outside of the bonded wall and pressing a sheet of six mil black polyethylene into the roofing cement.

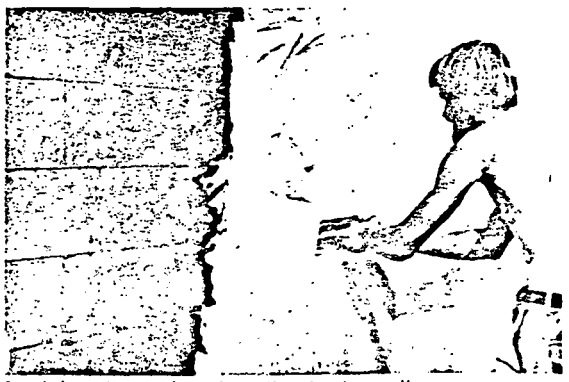
Building a surface bonded wall is not difficult, if the builder pays attention to detail and proceeds carefully. The footing should be as near to level as possible. We shuttered and poured our own footing, able assisted by a good friend in the contracting business. Frequent use of a surveyor’s level will assure that the footing is level to within a quarter inch, but the first course of blocks must be even closer than that for dry stacking, thus the need for leveling the entire first course in a bed of strong mortar. Again, a surveyor’s level and a measuring rod are the right tools for the job. Borrow or rent them. And don’t forget to use a two-foot level width-wise on the block, too, or the wall will soon be

out of plumb.

Stacking the blocks is not difficult. Be warned, though: if you use 12” concrete blocks as we did (and recommend), you will sleep well at night after a day’s stacking. A friend and I stacked 900 blocks in five days, being extremely careful to keep our courses plumb and level. Minor leveling of blocks can be accomplished with wall ties or aluminum printing plates. Do not use wooden shims. It is important, too, to keep the ends of each block butted against one another.

The actual surface bonding takes a little practice to get the knack. Wet the wall ahead of time and apply the mixed surface bonding with a flat trowel. Mix it as wet as it will stick to the wall, but be sure to apply an 1/8” layer. Follow the mixing instructions off the bag, and be sure to work the lumps out of the mix. We used rubber masonry gloves for this purpose.

I have tried to give the reader a basic familiarity with surface bonding as well as to assure him that it is a tried and proven method. It is beyond the scope of this article to give a detailed step-by-step discussion of the processes and to list the various special considerations, but



Applying the surface bonding to the wall.

the information is readily available through the U.S. Government Printing Office. (See Bibliography.)

I also discuss the technique thoroughly in my book, also listed in the Bibliography.

Plank & Beam Roofing

The other major area of underground construction that sends a shudder right down the owner-builder's back — until it hits his wallet — is the roof. So many of the well-known underground architects and designers talk about pre-stressed concrete beams (installed with a crane) or a shuttered and poured concrete roof. Difficult for the inexperienced. Expensive. Again, though, there is a very viable alternative, which is more in keeping with the average owner-builder's skills, confidence, and bankroll. The old construction technique to which I refer — plank and beam roofing — has been used very effectively by Malcolm Wells in his well-known Solaria house, by Don Metz in his two beautiful earth-covered houses in Lyme, New Hampshire, and at our own Log End Cave.

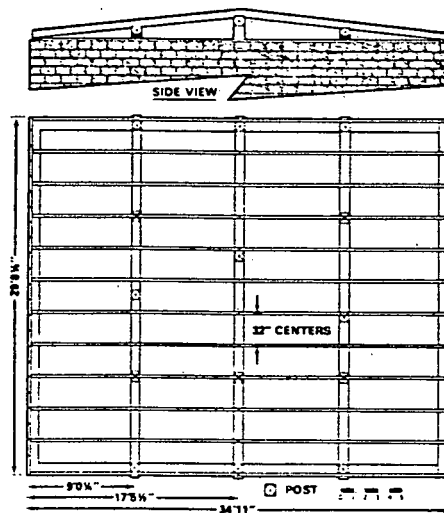
Is it strong? Well, one of Don's houses supports a twelve to fifteen inch earth roof in an area of very high snowloads. Solaria, in New Jersey, supports 24" of earth cover. Although both of these houses are built with heavier timbers than our own house, Don Metz admits that his first house might be a little over-built, but there's a great comfort in seeing those massive five-by-ten beams overhead on sixteen inch centers. Our own house is designed to accommodate the 120 pounds per square foot roof load resulting from four feet of soggy spring snow on six inches of earth and sod. The key to the strength of our house, however, is that we keep our spans down to eight feet by the use of a heavy post and beam framework below. The accompanying illustrations

show the locations of the primary posts and beams as well as the rafter system. "X" marks the spot of the barn beam posts which support the three main beams, hand hewn spruce ten-by-tens, thirty feet long and eighty years old, but in excellent condition. The eighteen-foot four-by-eight hemlock rafters are supported, then, by a twelve inch concrete block wall at their outer ends, and well-posted spruce ten-by-tens at their mid-points and at the "peak" of the house. As stated, the rafters (the "beams" of plank and beam construction) never have to span an actual distance greater than eight feet. Increasing their strength is the fact that each rafter is supported in the middle, preventing sag and eventual fatigue. (See diagram.)

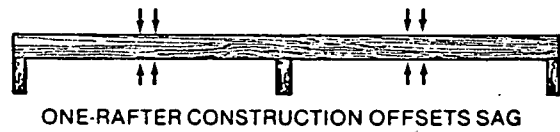
The "planks" of the plank and beam roof are hemlock two-by-sixes of varying lengths. I try to stagger the courses for extra strength. Some of the underground builders, such as Don Metz, use tongue and grooved pine finished to 1-1/2". It looks great, and on the close centers of his beams it is super strong, but it is expensive. I believe that my hemlock two-by-sixes (planed uniformly to 1-3/4") are just as strong, they look pretty good, and I was able to get them from trees I picked out myself at about half the cost of the finished pine.

The load carrying strength of a plank and beam roof is a function of four variables: span, frequency of beams, dimension of beams, and the type of wood used. Examples: A greater span requires larger timber dimensions; the stronger the planking, the fewer the beams required; pine must be of greater dimension to equal spruce for strength. Most houses in the north are built to handle a forty pound per square foot roof load. An underground house with a six-inch earth cover must be built about three times that strong. If in doubt, consult an engineer.

On top of the hemlock planking is a blanket of styrofoam, 3-1/4" thick and shiplapped in both directions to minimize heat loss. The styrofoam is important. There is a popular misconception that earth alone makes for good insulation. This is not true. The advantage of the earth cover is that it provides an ambient of higher temperature than the outside air in winter and cool surround in summer. Without insulation, the transfer of heat to the earth is rapid. For this reason, all underground houses being built today have insulation on the outside of the concrete walls themselves. This allows the concrete to stay warm and act as a heat sink, providing the steady temperatures that subterra-



BLOCK, RAFTER, POST AND BEAM PLAN



near houses are famous for, while protecting the walls against frost damage.

Above the styrofoam, we have a layer of 5/8" particle board. The purpose of this layer is to protect the styrofoam during further roof work while providing a surface for the application of waterproof membrane.

We chose the black plastic method of waterproofing. First we stapled a layer of fifteen pound roofing paper to the particle board, as an expansion and contraction buffer. Then we applied a layer of black plastic roofing cement to the paper, while rolling a huge sheet of six mil black poly. (Note: clear poly will deteriorate.) We repeated the black plastic and six mil layers.

Using a half-inch screen, we sifted a 3/4" layer of topsoil over the six mil, to protect the membrane from stones. Then we added about three more inches of topsoil. As it was November, we did not risk putting the sod up for the winter, fearing that it would not survive such late transplanting. A small test patch proved us right. We covered the roof with hay, pine boughs, and sticks for the winter, and applied the three-inch thick timothy-based sod the following spring. Within a month, the new sod had knitted in beautifully. If I were to do the job again, I would be more careful about using a soil with better drainage, perhaps even to the extent of laying down a three-inch layer of sand right on the membrane. Good drainage takes a lot of pressure off the waterproofing system.

Obviously, I cannot deal comprehensively with the vast subject of underground housing in this short article, but I hope I have shown the way for would-be owner-builders to consider the problem as one which is within the range of both their ability and affordability.

LOG END CAVE — COSTING ANALYSIS

Heavy equipment contracting	.....	\$892.00
Concrete	.....	873.68
Surface bonding	.....	349.32
Concrete blocks	.....	514.26
Cement	.....	47.79
Hemlock	.....	345.00
Milling and planing	.....	240.26

Barn beams	.....	123.00
Other wood	.....	167.56
Sheetrock	.....	72.00
Particle board	.....	182.20
Nails	.....	62.88
Sand and crushed stone	.....	148.21
Topsoil	.....	295.00
Hay, grass seed, fertilizer	.....	43.50
Plumbing parts	.....	124.95
Drain pipes	.....	166.23
Water pipe	.....	61.59
Metalbestos stovepipe	.....	184.45
Styrofoam insulation (used)	.....	254.93
Roofing cement	.....	293.83
Six mil black polyethylene	.....	64.20
Flashing	.....	27.56
Skylights	.....	361.13
Thermopane windows	.....	322.50
Interior doors and hardware	.....	162.80
Tools and tool rental	.....	159.43
Miscellaneous	.....	210.31

Materials and contracting cost of house, landscaping and drainage	.....	\$6750.57
Labor	.....	660.00
Cost of basic house	.....	\$7410.57
Floor covering (carpets, vinyl, etc.)	309.89
Fixtures and appliances	507.00
Total spending at Log End Cave	\$8227.46

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The Underground House: How to Build a Low Cost Home, Sterling, March 1979. Large paperback. How to do it, step by step. Full of drawings and photographs. Available from the publisher or the author (Robert L. Roy, RR 1, Box 40C, West Chazy, N.Y. 12992) at \$5.95! plus a dollar postage.

Rob Roy homesteads in West Chazy, NY., and is the author of How to Build Log End Houses and also: Underground Houses: How to Build a Low Cost Home. Both are available from Sterling Publishing Co., Two Park Ave., New York, NY 10016. Photos and drawings by the author. This article originally appeared in Farmstead Magazine.

INVESTIGATIONS INTO GROUND CLIMATE AS AN
ALTERNATIVE THERMAL BUILDING ENVIRONMENT

Kenneth Labs #C)
Undercurrent Design Research,
New Haven, Connecticut

Keith Harrington
ARGA Associates
New Haven, Connecticut

ABSTRACT

In comparison to the week-to-week irregularities of weather experienced above ground, the climate of the soil is relatively predictable and varies little from year to year. This paper describes a mathematical model for estimating the temperature of a selected vertical profile in the soil, under undisturbed thermal conditions. The profile can be selected to correspond to the depth of placement of various sub-grade walls. Synthesized profile temperatures for several different geographic regions are presented.

Although this model cannot be used to predict heat loss in the form given, it is believed that it provides an expedient method for comparing the elements of above and below ground climates in the overall assessment of design alternatives. Some suggested uses of the model are presented, with particular reference to earth pipes and determining degree day assignments to different soil profiles.

INTRODUCTION

Heat exchange between underground structures and the earth has received little attention until the past few years. Even less attention has been directed toward assessing the heating and cooling advantages of earth sheltered construction and earth pipes in relation to other more conventional design practices. One way to compare the amenities of the subsurface climate with that of the surface is to directly juxtapose normals of air and ground temperature.

Soil temperatures within the field of influence of an underground structure are altered by heat losses (and gains) from the building. Although this can be modeled, the theory is very complex [1], and the problem does not lend itself to an impartial climatic analysis, since certain assumptions about the building itself must be made. Temperatures of undisturbed soil, on the other hand, are fairly easily predicted; these can be modeled at individual depths and can also be averaged over a range of depths to yield a temperature that is representative of the profile as a whole. Undisturbed soil temperatures in themselves do not create the actual driving force for heat transfer, since the overall system is dynamically interactive.

Undisturbed ground temperatures do represent ultimate bounds for the driving potential, however, so they can be used to determine the limitations of the ability of the earth to aid in the heating and cooling of structures. Because of the ease and repetitiveness of calculating temperatures at different depths, the model readily lends itself to electronic computational techniques. By varying the input parameters, a regional analysis of ambient ground temperatures can be conducted. This paper explains the procedure and presents computer-synthesized ground temperature data for six different climatic regions in the contiguous United States.

GROUND TEMPERATURE AT DEPTH x

In most parts of the continental United States, the temperature of the ground can be estimated acceptably by the expression,

$$T(x, t) = T_m - A_s e^{-x \sqrt{\frac{\pi}{365K}}} \cos \left[\frac{2\pi}{365} \left(t - t_0 - \frac{x}{2} \sqrt{\frac{365}{\pi K}} \right) \right] \quad (1)$$

where

- $T(x, t)$ = temperature of soil at depth x and time t
- T_m = mean annual earth temperature
- A_s = amplitude of surface temperature wave
- x = depth below surface
- K = thermal diffusivity of soil (ft^2/day)
- t = time of year (days)
- t_0 = phase constant (days)

The accuracy of this model is in large part determined by how closely the variables T_m , A_s , and K can be approximated. Despite the simplification of the problem, most researchers have found that the model provides agreement within about 2F of field conditions, when the variables themselves are determined from field observations [2]. Field data is not available from more than a few locations, most of which are far removed from urbanizing areas. These input values must therefore, be estimated. For the most part, this may be accomplished satisfactorily by approximation from published air temperature normals [3]; "plug-in" values are discussed in reference [4].

Among the most unknowable of the parameters in the model is the thermal diffusivity of the soil. Analysis by researchers at the National Bureau of Standards indicates that an average value can usually be used with acceptable accuracy, and that even large errors in the value assigned to K will generally result in an error of only $\pm 1F$ or $2F$ for the average profile temperature [3]. It was felt adequate for the present analysis to assume a constant K for all locations of $0.6 ft^2/day$. This value represents a time lag of the temperature wave in the soil of approximately one week per foot. The other values assumed for each region presented here are given with the synthesized ground temperatures in Tables 1-6. The significance of variations in, and influences affecting, the parameters of the model are discussed in detail in reference [2].

AVERAGE TEMPERATURES OF PROFILE H

The average temperature of any selected soil profile H is found by integrating Equation (1) with respect to depth, and dividing this by the height of the profile:

$$T_{(a-b),t} = T_m + \frac{A_s}{(a-b)r\sqrt{2}} e^{-xr} \cos \left[\frac{2\pi}{365}(t-t_0-46) - xr \right] \Big|_b^a \quad (2)$$

where

a = upper bounds of profile H

b = lower bounds of profile H

$$r = \sqrt{\frac{\pi}{365K}}$$

The procedure for determining the integrated average temperature of a soil profile was first introduced by Kusuda and Achenbach, in a paper examining the profile extending from the surface to a depth of 10 feet [3]. Summary data obtained by this method are given for reference in ASHRAE Applications, and seasonal data for over 400 stations have been synthesized for use in estimating heat losses from underground heat distribution systems [5].

A degree day value can be assigned to any selected profile by subtracting the average profile temperature from a chosen base reference temperature. Summation of the daily profile degree days yields monthly and annual degree days. This may be computed by mathematical or numerical integration of Equation (2) with respect to time. Base 65F has been selected here for consistency with published 65F heating degree day normals.

LIMITATIONS

At a glance at any of Tables 1-6, it is possible to immediately ascertain a) the upper limit of the temperature differential established by the earth for basement (0-6 feet) and fully subgrade (2-12 feet) profiles, b) if a useful cooling potential exists in the ground during summer months, and c) at what depths this potential is the greatest, as for the most advantageous placement of earth pipes. Since the tables present temperatures that are lower than those which would exist immediately adjacent to a heated underground structure, their use for calculating heat loss would ultimately result in oversizing of mechanical equipment. As a measure of reductions in heating load, the driving force presented by the undisturbed profile temperature is a conservative indicator of possible energy savings. The degree day reductions, therefore, represent a least amount of energy savings, and not the actual savings that might be anticipated.

Underground degree days and their above surface counterparts are necessarily different because of their unlike thermal media, so the relationship between these should not be taken too literally. Conventional heating degree days (HDD) based on a 65F reference air temperature provide simply a measure of the number of degrees below 65F that the average air temperature falls on a given day, or as accumulated over some time period. Degree days do not account for the effects of solar radiation, infiltration, thermal mass, or other features that vary from building to building. In the past, with poorly insulated and leaky houses, a linear relationship was assumed between base 65F HDD (roughly corresponding to the lower limit of the comfort zone, plus some "free" heating supplied by solar energy and internal gains) and heating demand. With more solar and conservation efficient designs, however, this relationship has been struck down; each house has its own "balance point," or degree day reference base to which a linear rate of fuel consumption can be related [6]. This can be 53F or possibly lower for even a just well-insulated builder house. Identical houses in different climatic regions can be expected to assume different balance points, and the habits of occupants will also affect fuel consumption as a result of determining internal

heat gains. This will be especially true of the new superinsulated houses which depend largely on miscellaneous internal heat production for space heating.

Degree day values generated by summing the temperatures of a soil profile under a 65F base similarly provide an abstract index of "ambient" temperature climate. The relationship between underground degree days and fuel consumption for heating and cooling will also depend on physical design of the structure, including window area and orientation, relationship between roof and wall area, exposed versus earth sheltered perimeter, and location and thickness of insulation. Underground heating degree days (UGHDD) are presented here not as a fuel consumption index, but as a means of comparing accumulated above and below surface temperatures. The fact that unstable air has a significantly higher conductive capacity, or thermal admittance (the square root of the product of conductivity and heat capacity), than soil suggests that an air degree day is "bigger" than an earth degree day [2]. This would account in part for the heat storage effect of the ground in retarding heat loss, but the numerical relationship between these is unknown.

Because a heated underground structure will have a warming effect on its surrounding soil, the cooling potential of the earth in contact with subgrade walls will not be as great as indicated by the tables. The temperature of an undisturbed 2-12 foot soil profile in Atlanta falls marginally below the comfort zone in late summer; earth in contact with subgrade walls will be somewhat warmer, so earth here will not serve as a very useful heat sink. Such considerations must be kept in mind when interpreting the synthesized data.

ASSUMPTIONS

For the purpose of registering the phase of the sinusoidal earth temperature wave within the calendar year, it has been assumed that surface temperature maxima and minima follow 1/8 cycle behind the respective maxima and minima of solar heat flux, in accord

with periodic heat conduction theory. Examination of least squares analyses of observed ground temperature data reported by Kusuda [3] generally supports this theory; in any event, the range of error (7-10 days) is so slight that it would not affect the tabulated results by more than 1/2F. The respective dates taken for surface temperature maximum and minimum are February 4 and August 6.

Values for T_m and A_s have been estimated from air temperature data or obtained from ground temperature records for those regions for which these exist (Minneapolis, Phoenix, Lexington). T_m and A_s are dependent on a number of locally variable factors, including aspect and surface cover type. Each region, therefore, has a range of ground microclimates, so the values selected for use here are intended to typify average conditions. They may not conform exactly to actual observations at any station within a region, but the margin of disagreement is not expected to exceed two or three degrees. Sod cover is assumed.

PRESENTATION OF RESULTS

Synthesized earth temperatures for six different climatic regions are presented in Tables 1-6. Temperatures at seven different depths, plus average temperatures by month and computed annual degree days for 0-6 and 2-12 foot profiles are given. Also contained in the tables are design (air) temperatures reported in ASHRAE Fundamentals [7], and mean daily maximum, average, and minimum air temperatures for the 21st day of each month, as reported in Climatology of the United States [8]. This juxtaposition of above and subsurface temperatures allows one to quickly assess the merit of various earth tempering techniques. A graphic interpretation of the tabular data is offered in Figures 1 and 2, for New York City.

Air has very little heat capacity, so its temperature is closely related to heat exchange at the ground surface. Normally, air temperature at heights just above the ground closely mirrors that of the ground surface. A snow cover, however, acts as an insulative layer that

effectively disconnects much of this exchange. Deprived of ground heating, air temperatures in northern states fall far below surface temperatures beneath the snow blanket. This explains the wide disparity between winter (air) design temperatures and the comparatively stable, warmer temperatures of the ground, even at the shallow 2 foot level.

It should be noted that the average temperature of the soil profile varies considerably throughout the course of a year. In Minnesota, which possesses the greatest surface temperature amplitude of the six cities, the annual range over the 2-12 foot depth is a full 20F--hardly stable, as is often supposed. The temperature range of the 0-6 foot profile is even greater, at 34F. Because the same thermal diffusivity and phase constant have been assumed for all cities, the maximum and minimum temperatures of the 2-12 foot profile are predicted to occur in each case on September 17 and March 18, respectively. The corresponding extrema for the 0-6 foot profile are August 24 and February 23. These represent lag times of only 42 and 19 days, again, considerably less than the three months or so associated with the 12 foot depth.

SUMMARY AND CONCLUSION

A method has been presented whereby ground temperatures can be synthesized at individual depths and averaged over designated soil profiles at any time of year. Synthesized data for six different regions are presented in juxtaposition with simultaneous air temperatures. It is believed that this juxtaposition provides useful insights into some aspects of exploiting the earth as an alternative thermal environment. Detailed analysis and interpretation of the data is not offered because such interpretation would depend largely on the specific interest of the inquirer; a designer of earth pipes, for instance, would interpret the climatic data differently than might a builder considering the underground placement of an inhabited structure.

More importantly, the evaluation of the suitability of the underground as an alternative building environment

requires comprehensive analysis of the above ground, to which it is being considered as an option. This is an area which in itself has not been fully examined by architects and engineers. A comparative analysis of various climate control strategies and a host of physical implementation devices is currently being prepared for the National Association of Home Builders Research Foundation [9]. A paper describing this program, and the range of passive control strategies available to the designer, is found in reference [10]. The latter places particular emphasis on issues related to earth tempering practices.

The broadest conclusion to be drawn from these studies is that earth tempering alone is seldom sufficient in itself to promote comfort conditions. Heating and cooling are usually still necessary, although the magnitude and nature of demand is significantly altered in comparison with above ground demands. Earth tempering can make a significant contribution toward reducing energy demands in new construction but, taken as a whole, attention must primarily be given to the integration of earth tempering with other passive design practices. The most successful exploitation of subsurface climatic amenities will always be a matter of effective design.

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Kenneth Labs
 Undercurrent Design Research
 147 Livingston Street
 New Haven, CT 06511
 203/865-9098

Keith Harrington
 ARG Associates
 938 Chapel Street
 New Haven, CT 06510
 203/789-0555

TABLE 3

CITY: MIAMI, FL

T _m = 75 A _s = 13		TEMPERATURE ON 21ST DAY OF											
		J	F	M	A	M	J	J	A	S	O	N	D
AIR	DAILY MAX	75	77	80	83	86	88	89	90	88	84	79	76
	DAILY AVG	67	68	72	76	78	81	82	83	81	77	71	68
	DAILY MIN	59	59	64	68	71	74	76	76	75	70	63	59
GROUND	2	66	65	66	70	75	80	84	85	84	80	75	70
	4	69	67	67	70	73	77	81	83	83	81	77	73
	6	71	69	69	70	72	75	78	81	81	80	78	75
	8	73	71	70	70	72	74	77	79	80	80	78	76
	10	74	73	71	71	72	73	75	77	78	79	78	77
	12	75	74	72	72	72	73	74	76	77	78	78	77
	15	76	75	74	73	73	73	74	75	76	77	77	77
PROFILE AVG 0-6		68	66	67	70	74	79	82	84	83	80	76	72
PROFILE AVG 2-12		72	70	70	71	73	75	78	79	80	79	77	75

PROFILE TEMPERATURE, MAXIMUM	0-6 (DAY 236):	84
	2-12 (DAY 260):	80
PROFILE TEMPERATURE, MINIMUM	0-6 (DAY 54):	66
	2-12 (DAY 77):	70

ANNUAL HEATING DEGREE DAYS (BASE 65)	AIR:	285
	0-6:	0
	2-12:	0

WINTER DESIGN TEMPERATURE (DBT), AIR	99%:	44
	97½%:	47

SUMMER DESIGN TEMPERATURE (DBT), AIR (W/ COINCIDENT WBT)	5%:	89 / 77
	2½%:	90 / 77
	1%:	91 / 77

SUMMER DESIGN TEMPERATURE (WBT), AIR	5%:	78
	2½%:	79
	1%:	79

TABLE 5

CITY: NEW YORK, NY

T _m = 53 A _s = 22		TEMPERATURE ON 21ST DAY OF											
		J	F	M	A	M	J	J	A	S	O	N	D
AIR	DAILY MAX	37	40	49	62	71	81	85	81	74	63	51	39
	DAILY AVG	32	34	42	54	63	73	77	74	67	56	45	34
	DAILY MIN	26	28	36	46	55	65	70	67	59	49	39	28
GROUND	2	38	36	38	45	53	62	68	70	68	62	53	45
	4	43	40	40	44	50	57	63	66	66	63	57	50
	6	47	43	42	44	48	54	59	62	64	62	58	53
	8	50	47	45	45	47	51	56	59	61	61	59	55
	10	52	49	47	46	48	50	54	57	59	60	58	56
	12	54	51	49	48	48	50	52	55	57	58	58	56
	15	55	53	51	50	49	50	51	53	55	56	57	56
PROFILE AVG 0-6		40	38	40	45	52	59	65	68	67	62	55	47
PROFILE AVG 2-12		48	45	44	46	49	53	58	61	62	61	57	53

PROFILE TEMPERATURE, MAXIMUM	0-6 (DAY 236):	68
	2-12 (DAY 260):	62
PROFILE TEMPERATURE, MINIMUM	0-6 (DAY 54):	38
	2-12 (DAY 77):	44

ANNUAL HEATING DEGREE DAYS (BASE 65)	AIR:	5162
	0-6:	4522
	2-12:	4380

WINTER DESIGN TEMPERATURE (DBT), AIR	99%:	11
	97½%:	15

SUMMER DESIGN TEMPERATURE (DBT), AIR (W/ COINCIDENT WBT)	5%:	87 / 72
	2½%:	89 / 73
	1%:	92 / 74

SUMMER DESIGN TEMPERATURE (WBT), AIR	5%:	74
	2½%:	75
	1%:	76

TABLE 6

CITY: PHOENIX, AZ

$T_m = 70$		TEMPERATURE ON 21ST DAY OF											
$A_s = 20$		J	F	M	A	M	J	J	A	S	O	N	D
AIR	DAILY MAX	65	70	75	85	94	103	105	102	97	86	72	65
	DAILY AVG	51	56	61	69	78	86	92	88	83	70	58	52
	DAILY MIN	38	42	46	53	61	69	76	75	68	55	43	38
GROUND	2	56	54	57	62	70	78	84	86	84	78	70	63
	4	61	58	58	62	67	74	79	82	82	79	73	67
	6	64	61	60	62	66	71	75	79	80	78	75	70
	8	67	64	62	63	65	69	72	76	77	77	75	72
	10	69	66	64	64	65	68	71	73	75	76	75	73
	12	70	68	66	65	66	67	69	72	74	75	74	73
	15	71	70	68	67	67	67	68	70	72	73	73	73
PROFILE AVG 0-6		59	56	58	63	69	76	81	83	82	78	71	65
PROFILE AVG 2-12		65	63	62	63	66	70	74	77	78	77	74	70

PROFILE TEMPERATURE, MAXIMUM	0-6 (DAY 236):	<u>83</u>
	2-12 (DAY 260):	<u>78</u>
PROFILE TEMPERATURE, MINIMUM	0-6 (DAY 54):	<u>57</u>
	2-12 (DAY 77):	<u>62</u>

ANNUAL HEATING DEGREE DAYS (BASE 65)	AIR:	<u>1864</u>
	0-6:	<u>763</u>
	2-12:	<u>212</u>

WINTER DESIGN TEMPERATURE (DBT), AIR	99%:	<u>31</u>
	97½%:	<u>34</u>

SUMMER DESIGN TEMPERATURE (DBT), AIR	5%:	<u>105 / 71</u>
(W/ COINCIDENT WBT)	2½%:	<u>107 / 71</u>
	1%:	<u>109 / 71</u>

SUMMER DESIGN TEMPERATURE (WBT), AIR	5%:	<u>75</u>
	2½%:	<u>75</u>
	1%:	<u>76</u>

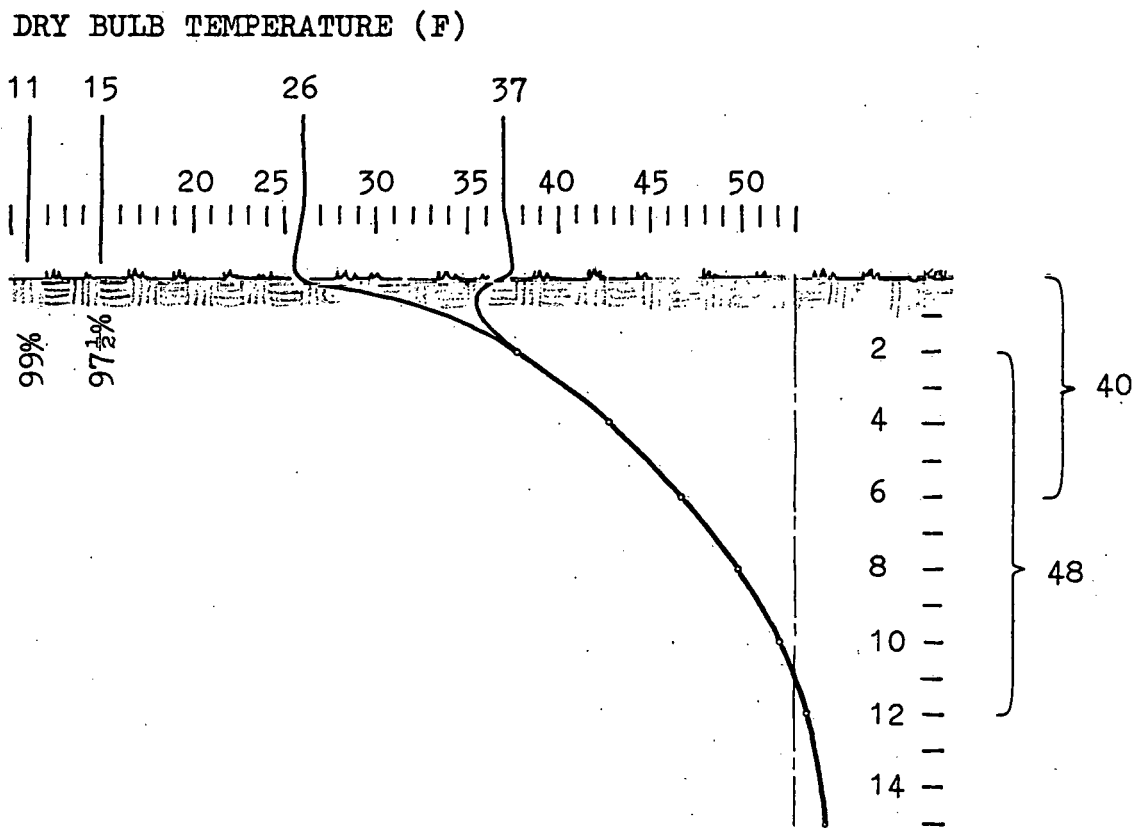


FIGURE 1. Idealized distribution of temperatures in undisturbed ground, New York, January 21. Shown also are winter design temperatures and range of daily average air temperatures.

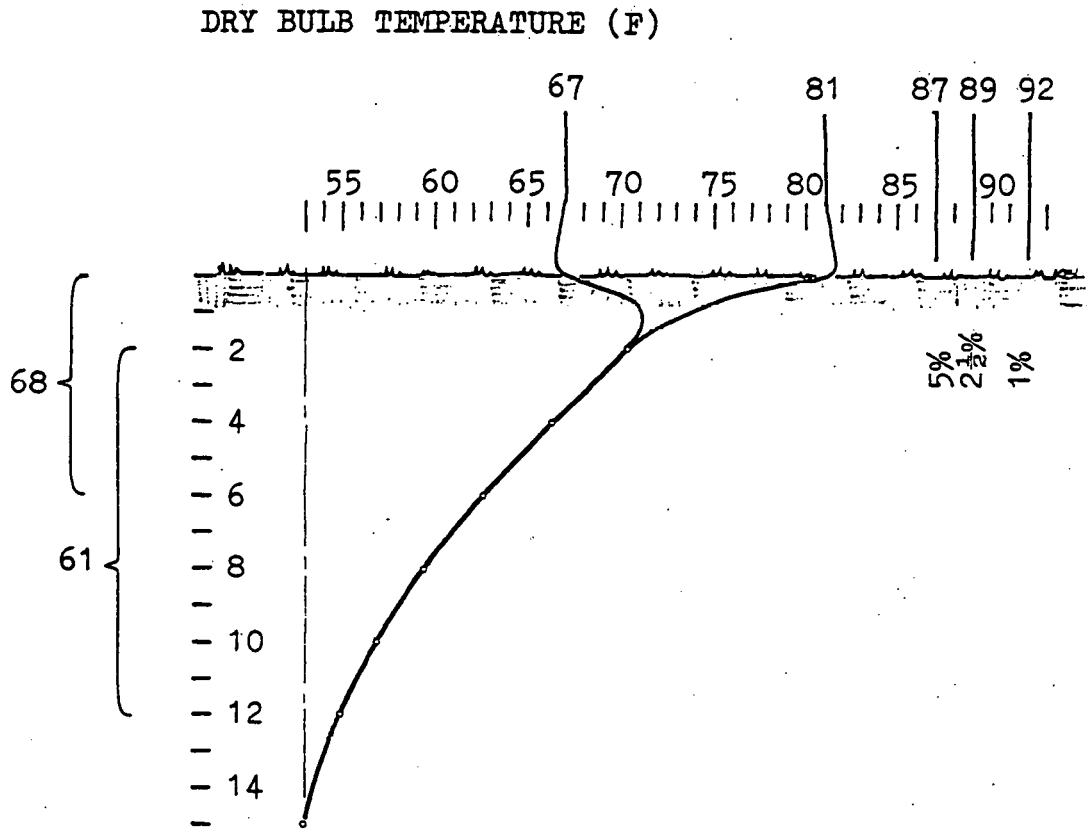


FIGURE 2. Idealized distribution of temperatures in undisturbed ground, New York, August 21. Shown also are summer design temperatures, and range of daily average air temperatures.

THE EXPRESSION OF EARTH SHELTERED ARCHITECTURE

Mark Stephen Wampler
Fifth Year Architecture Student
University of Arkansas
Fayetteville, Arkansas

ABSTRACT

Throughout history the architecture of a certain culture has given us a lot of information concerning the people of that culture, their concerns of that time period, their customs, their fears, and needs. Comparing historical examples we find that Earth Sheltered Structures can make a strong and powerful statement, be aesthetically pleasing, and ecologically gentle with nature. These factors are important to public acceptance, loosening up financing, and creating a stimulating environment for the people of our time.

ROOTS OF ARCHITECTURAL EXPRESSION IN GENERAL

The shape, form, and character of the Architecture of a culture combine to make up the expression of their architecture. These elements grow out of that people's physical needs (needs of expressing esteem and ego, power and nobility) and, of course, the convenience and availability of building materials and their technical base at their particular location as well as the climatic and geographic variables at the site.

In cultures that were proud and aggressive such as was found in Rome during the height of the empire's power the architecture was grand and heroic in scale.

Where ceremonial procession of triumph and power was important to a culture the architects responded with a path of celebration and paying homage. This can be illustrated by the entrance of the great Egyptian Temples.

The architecture could be delicate and gentle if called for as found in the Temple Athena Nike; to Athena, the goddess of love, or strong, heavy, and powerful as in the expression to the powerful god of the sea, Poseidon. Both found in the Greek periods.

It could respond to an overpowering need for protection as the Medieval castles did in a highly barbaric and war prone era.

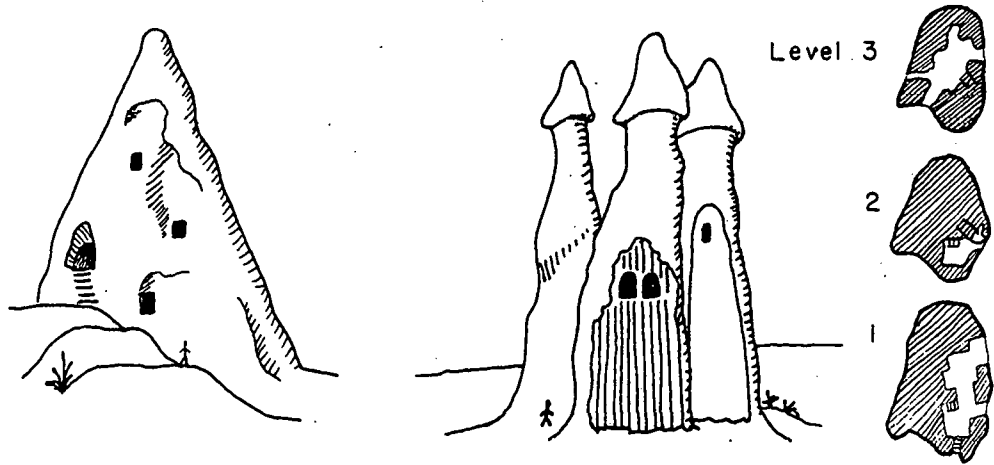
The architecture of the Aegean culture, such as Minos' Palace reflects a gentle and meek people who believed in socializing.

Heavy rainfall and the available building materials did much to shape the villages of Southern Italy. Just as heavy snow caused a response of steep roofs in Northern Europe.

Architectural expression can say many things about a culture.

HISTORICAL ILLUSTRATIONS OF EARTH SHELTERED ARCHITECTURE

Let us look now at some Earth Sheltered examples and at what they can tell us about those who either lived there or now live there.



TYPICAL CAPPADOCIAN HOUSE EXAMPLES

In the region known as Cappadocia, Turkey around 800 A.D. a migration of some of the refugees from the crumbling Roman Empire took settlement in this unusual terrain formed by volcanic activity and wind erosion. They found these spines of soft rock were easily carved and hollowed out. This was the easiest method of attaining shelter in an area where good timber, or mortar was at a minimum.

This peace loving people built their homes, churches, and even monasteries in this manner. In the case of the churches and monasteries they tried to imitate the architecture and art of the existing churches found in areas such as Rome, Constantinople, etc., because this was the accepted style of building and construction. The quality and delicacy attained in existing above grade structures could not be duplicated in this rock-cut method by their craftsmen and perhaps, the blend of accepted style and it's integration with the rock form seemed awkward to those outside the

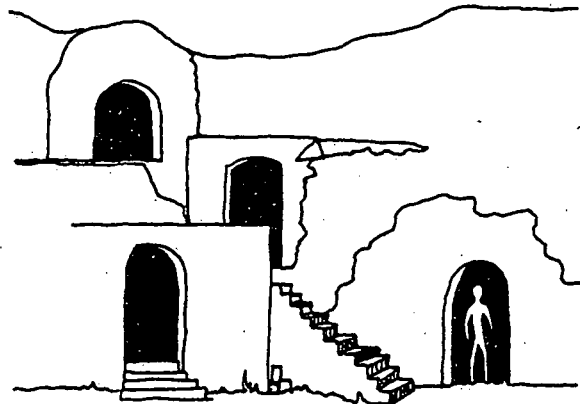
area. But, whatever the reason these people began to be looked upon as crude, and uncultured. Their art work and decorations were considered inferior to the existing work in the world. Perhaps, because of the inability of the soft stone to maintain it's coloration.

Even Bishops and Archbishops sought to avoid being assigned to the area, and were the object of merriment among their peers.

They were abandoned around the time of the invention of gun powder, perhaps, because of fear of being buried alive.

Perhaps, the most elegant example of an Earth Sheltered response is found in Ajanta, India and dates back to the 5th and 6th century A.D.

The elegant decoration is remarkably well preserved in most of the rooms, and is about the only clue to any knowledge of the people who lived there. Inscriptions tell us they were a peaceful people and deeply religious. Their work reveals excellent craftsmanship, engineering and creativity. There is no clue to reasons for their abandonment.



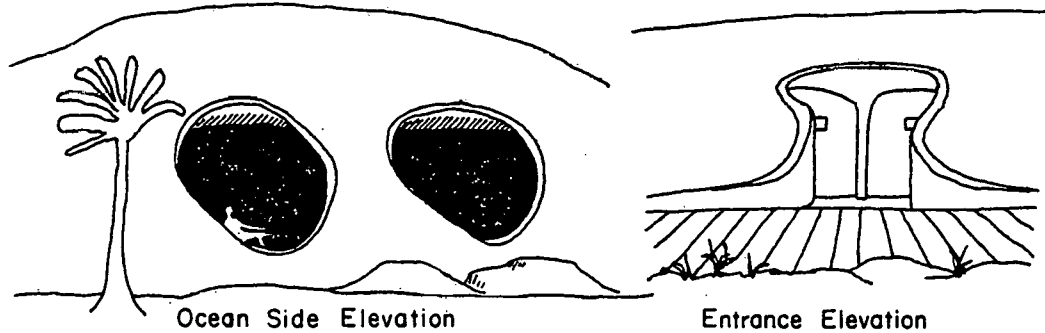
TUNISIAN ATRIUM HOUSE

The Tunisian Atrium houses have lasted through the centuries as an excellent response to the extreme heat of the day and the cold desert nights.

The soil is easily carved to shape the 15 feet high vaulted ceilings that are only vulnerable to collapse in heavy rains, but are usually clean, dry, and can possess all the conveniences that modern technology offers.

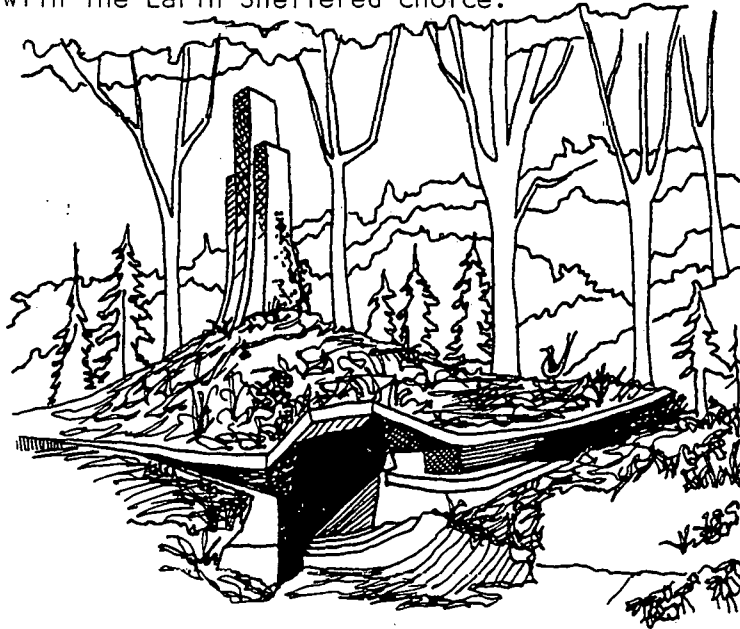
EXAMPLES OF STRONG EXPRESSION IN THE MODERN MOVEMENT

The present Earth Sheltered Movement is a response to the desire for conservation of energy and to reduce environmental impact upon our environment. A good design will respond to these needs, both technically and visually. We'll now look at some examples of this movement and how the Architect responded to the environment of the site.



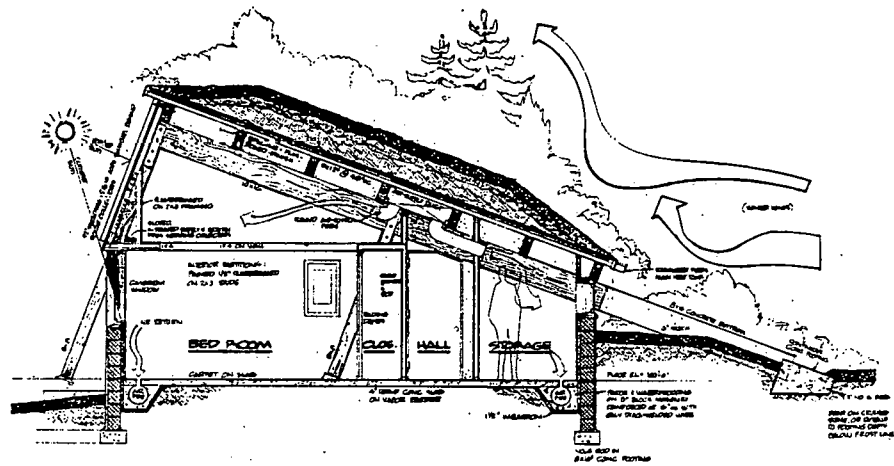
DUNE HOUSE

A practicing Architect from Jacksonville, Florida, William Morgan, placed his Dune House below grade to reduce impact upon the ocean view, and to distract from that view as little as possible. The structure that is exposed at the entrance is softened by curves which imitate the shape often found in sand mounds and dunes. Likewise, the treatment of the side facing the ocean responds in the same manner. The conservation of energy comes automatically with the Earth Sheltered choice.



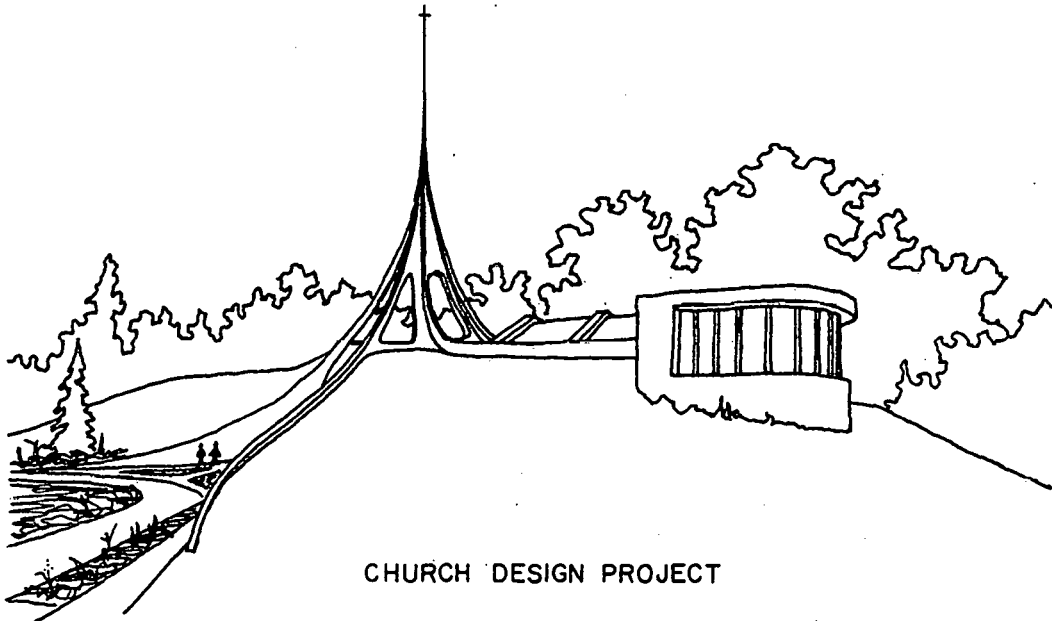
**HOUSE FOR WOODS
IN
NEW JERSEY**

The first house design (though unbuilt) of architect, theorist, and author, Malcolm Wells, from Brewster, Massachusetts, designed in 1964 for a natural woody setting in New Jersey, responds by an external expression of upthrust line and form found in almost any tree of a densely wooded situation, thus it would blend well with it's environment. The lines and overhangs shaping the entrance would remind us of natural outcroppings native to the area. These factors would give the house the ability to give a very subtle impact on the habitats of the native flora and fauna of that area.



SOLARIA

Solaria, also by Malcolm Wells, incorporates the same criteria of minimum visual and environmental impact but came at a later time when self-sufficiency was becoming vogue, as it still is today, thus it took on a desire to go even farther and to capture natural ventilation for air circulation and the sun's rays. It's form was nearly carved by these forces alone as is illustrated by the diagram.



CHURCH DESIGN PROJECT

In a design project for a Presbyterian Church at a busy intersection in Fort Smith, Arkansas, a major factor became exterior sound control. The small membership body wanted a design that would minimize the upkeep and heating and cooling expenses so that more of the small amount of income from donations could be put to use in outreach programs, and the needs of the congregation.

By placing the church within the earth and carefully orienting the entrance to the chapel away from the intersection, exterior sound would be controlled within the chapel and inner spaces. The location of the court yard focusing away from the streets and intersection combined with the use of the rest of the structure's mass as a buffer, control the sound in that area. The landscaping along with the creation of the small lake or pond would develop a peaceful natural setting for the transitional walk between the parking lot and chapel itself. Also by placing the mass of the structure below grade utility and upkeep expenses are kept to a minimum, plus cherished urban green space and ecosystems would be kept to a maximum.

SUMMARY

These examples have all illustrated responses in keeping with the Earth Sheltered Movement. That is to: 1. Reduce energy consumption. 2. Preserve the natural environment and ecosystems or to restore rather than contrast with or upset the balance of them. 3. The lines and expression of the structure complimented

and duplicated lines and forms found in nature rather than contrast with it or rather than to imitate existing forms and place them within a forced and awkward integration with the earth. The expressions that resulted were pleasing to the eye and appealing to the sense of experience. Integration of earth, space, environment, and experience was accomplished smoothly and without an awkward or forced feeling within the viewer or user of the form and environment. 4. Finally by reducing costs of maintenance and upkeep to the owner.

Through good design and by accomplishing these attributes, an Earth Sheltered structure can become an efficient structure to it's owner, it's environment, and to people, flora, and fauna who must experience it.

Mark Stephen Wampler
612 Storer Avenue
Fayetteville, Arkansas

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THE SHELTERRA EARTH HOMES
STRUCTURAL SHELL
AND
OTHER
GENERAL OBSERVATIONS
by

Richard Ohanian
Director of Design
for Shelterra Earth Homes
2930 W. National Road
Springfield, Ohio
45504
(513) 845-3873

Good afternoon, ladies and gentlemen, my name is Richard Ohanian, Director of Design for Shelterra Earth Homes. I hope you are all as excited about this conference and the future of the earth sheltered home industry as I am. This handsome gentlemen on my right is, Mr. David Hamilton, President of Centruy II Concrete and Excavating and represents the construction half and indeed, the better half of our design/build team. The details we have worked out together may prove to be a standard in the industry someday. David is on hand this afternoon to respond to any of your hard core construction technology questions and/or any other details which I am unable to adequately explain for you. We are attempting to address major construction questions for the emerging earth sheltered homebuilder, but would be happy to relate any of our experiences over the past two years in a general fashion to any potential earth sheltered homeowners in the audience.

From the looks of this program, we are to address the question of precaste concrete as a roof system which we have used quite frequently, but I wish for you to know at the outset, that by no means do we consider this to be the only way to construct an underground home. We have both poured roof systems as well as do-it-yourselfer type sod roof systems available. In fact, one home which you will see went with a regular type earthen berm with a regular, but superinsulated shingle roof. The "berm" concept has gained a great deal of popularity lately and we hope to compare the disadvantages and advantages of all systems a little later on in our program.

Now then, if I may have the lights please I would just like to briefly show you a few finished homes, before we get into a discussion, so that you will have a feel for who we are and what we do.

- A. The Gilliam Home is roughly 2200 square feet, 1600 in the living area and 600 in the garage area is made of 10" poured wall and a 12" precaste concrete "Flexicore" roof. The reason for the 12" is that we have spaned 30 feet in the great room area which is slightly above the 22 foot maximum we use for the more economical 8" panel. There is 18" of soil on the roof.
- B. The Tweheus Home is roughly 3300 square feet, 2100 in underground living area, another 300 in the solar atrium which extends from the underground level to the above grade garage in back and another 800 or so in the garage area. The structure is composed of 10" walls and an 8" precaste concrete "Flexicore". Maximum span in this instance is 20'.
- C. The Schroeder Home is roughly 2400 square feet, 1500 in earth sheltered living area, 200 in the solar atrium and another 700 or so in the above grade garage. The structure is composed of 8" poured in place walls and a regular 2 in 12 sloped truss. There is an R of 40 in the roof and it will be interesting to compare the performance of this home with the prior one which is roughly the same type floor plan.
- D. The Jenkins Home is roughly 2200 square feet in the same approximate distribution as the Gilliam home with an additional 150 square foot "skywell" on the backside. This is still a construction shot, but the home is poured in-place-totally with 10" walls and a 12" roof. This home unlike the other three faces West instead of South due to site considerations.
- E. The Bruno Home which as we say in the business, was designed and built by another network, leaks like a sieve. We are redoing the roof for Mr. Bruno and will discuss how the details are at variance with the proper Shelterra details a little later on.

Now then, if I may again have the lights, and before I address the specifics of our precaste roof and poured wall systems and we get into some construction shots, I should like to make a few brief general observations that we have collected over the 1st two years out there in the trenches dealing with the day to day questions of specific clients and putting the darn things in the ground.

ON ENERGY IN GENERAL:

Ladies and Gentlement, I don't really know what to tell you about this so called "Energy Crisis", I don't think anybody does for that matter. I feel personally that it is not a real crisis so much as a constant rollercoaster of traditional forces of economic supply and

demand.

I do recognize two major truths:

A. We live on a round sphere suspended in time and space, "Spaceship Earth" as Buckminster Fuller has called her, and are party to only a limited quantity of natural resources.

B. World energy demand is outpacing world energy supply at an alarming rate, and by the year 2000 we will have a real crisis on our hands.

These are two things that I am sure of, and really the only two things I am sure of. I also recognize, however, that these two facts have been exploited to the point of scare tactics by the powers that be in the fossil fuel industry and I mean oil and gas and coal and electricity. Why should I discriminate, they all suck raw eggs!!

I feel that big business in cooperation with the government and, in part the media in this country would have us believe that at least in the short term there is no solution and we are forced into a nightmarish world of business as usual at a \$1.20 per gallon for gasoline and a rise in the rate home heating oil on the order of 52% this year alone. 52% in one year; a quintupling in price since the 1973 Oil Embargo and with no end in site.

Well we in the Earth Sheltered Home Industry know different!

On the board is a graph that we calculated last year that compares the energy consumption of an aboveground home with that of an underground home and relates both figures to the % of your annual take home pay that you will spend on either this year and in 15 years from now. The results are quite impressive. (See Diagram A).

If we assume the following variables:

- a. an average figure of \$30,000 for total combined family income.
- b. energy inflation at 16%, (using 1978 figures, quite frankly I am scared to death to draw this over at 52%).
- c. increase in annual income of 4%, (taken right of the ABC Nightly News at the time this chart was calculated.)
- d. initial heating and cooling costs for above ground at \$1500/yr.
- e. initial heating and cooling costs for under ground at \$150/yr.

It doesn't take Albert Einstein's mother to see that in year one there is a factor of 10 difference between heating and cooling above ground and underground, but in 15 years from today when your kids are just entering the housing market, which will indeed be high from a cost standpoint, it will take 25.7% or fully 1/4 of their take home pay, to heat and cool their home. The underground home on the other hand will actually result in a decrease in % of take home pay spent on energy because the energy costs are relatively fixed, meaning 1 cord per year and free passive solar as the cost of energy is fixed and your income rises, the percentage of one to the other will decrease.

The professors in the audience I am sure will point out there are two invalid assumptions made for comparison here:

- A. The first is that the cost of 1 cord of wood will remain fixed. I don't think it will either, but it will certainly not inflate at the rate of conventional fossil fuels. This would also depend on what access one had to a woods or other sources.
- B. The second is the two types of energy in comparison are not identical, which would invalidate any comparison of two different structures.

I acknowledge both of the deficiencies, but in the real world mathematical models and theory have no meaning whatsoever. Why? They do not take into account the all important human factor: likes, dislikes, resistance to change, ignorance, stupidity, preserving the status quo.

You see I have made a valid comparison: the difference between what is and what will be compared to and what could be and what should be. (Include note at bottom of page 6 here.)

One wonders, if this difference is so drastic, then why isn't suburbia ripped apart by the threads and replaced with all underground homes or why aren't the builders in the country beating down a path to your door Mr. Ohanian for plans and information?

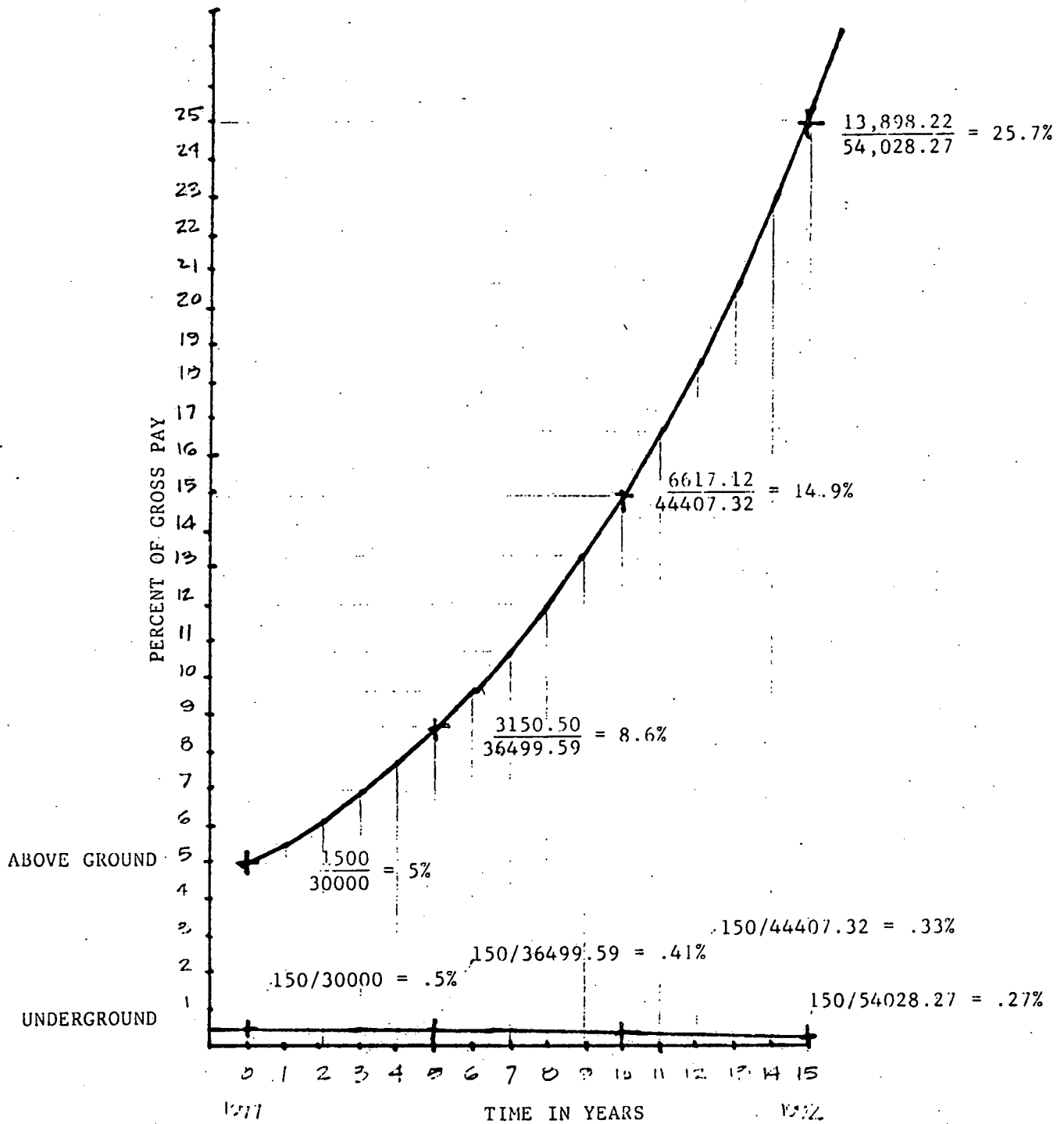


DIAGRAM A: COMPARISON OF TAKE HOME PAY SPENT ON FUEL COSTS FOR ABOVE GROUND VS. UNDERGROUND OVER FIFTEEN YEAR PERIOD.

PERCENT OF GROSS PAY SPENT ON ENERGY FOR HOME:

1. Assuming conventional non renewable energy escalation, oil, gas, electricity @ 16% rate of inflation.
2. Assuming combined family income of \$30,000 and annual increase in income of 4%.
3. Assuming heating and cooling costs initially for above ground to be \$1,500 and underground to be \$150.
4. Assuming wood to be a renewable energy source.
5. Graduated income taxes not figured in.

YEAR	CONVENTIONAL NON RENEWABLE ENERGY SUPPLY	RENEWABLE WOOD 1 CORD	INCREASE IN ANNUAL INCOME	% ABOVE GROUND	% UNDER GROUND
0	\$ 1,500.00	\$ 150.00	\$ 30,000.00	5.0 %	.050 %
1	1,740.00	150.00	31,200.00	5.5	.048
2	2,018.40	150.00	32,448.00	6.2	.046
3	2,341.34	150.00	33,745.92	6.9	.044
4	2,715.95	150.00	35,095.76	7.7	.042
5	3,150.50	150.00	36,499.59	8.6	.041
6	3,654.58	150.00	37,959.57	9.6	.039
7	4,239.31	150.00	39,477.95	10.7	.037
8	4,917.60	150.00	41,057.07	11.9	.036
9	5,704.42	150.00	42,699.35	13.3	.035
10	6,617.12	150.00	44,407.32	14.9	.033
11	7,675.86	150.00	46,183.61	16.6	.032
12	8,904.00	150.00	48,030.95	18.5	.031
13	10,328.64	150.00	49,952.18	20.6	.030
14	11,981.22	150.00	51,950.26	23.1	.028
15	13,898.22	150.00	54,028.27	25.7	.027
16	16,121.93	150.00	56,189.40	28.6	.026
17	18,701.44	150.00	58,436.97	32.0	.025
18	21,643.67	150.00	60,774.44	35.6	.024
19	25,164.61	150.00	63,205.42	39.8	.023
20	29,190.94	150.00	65,733.64	44.7	.022

★ By comparing the figures in the 15th year for % above ground (25.7) VS. the % underground (.027) spent on heating and cooling costs for the home, one can readily determine that 15 years from now, in 1994, at present rates of inflation one will be paying approximately 100 times the energy costs for above ground living as opposed to underground.

It is the old case of "Lord, you give them eyes, but they must be able to kick the tires."

Thus, in our model homes we try to deal with and illustrate beyond any shadow of a doubt or in concrete terms, if you will pardon the expression, the following concerns on the part of all builders and homeowners who have visited with us to date:

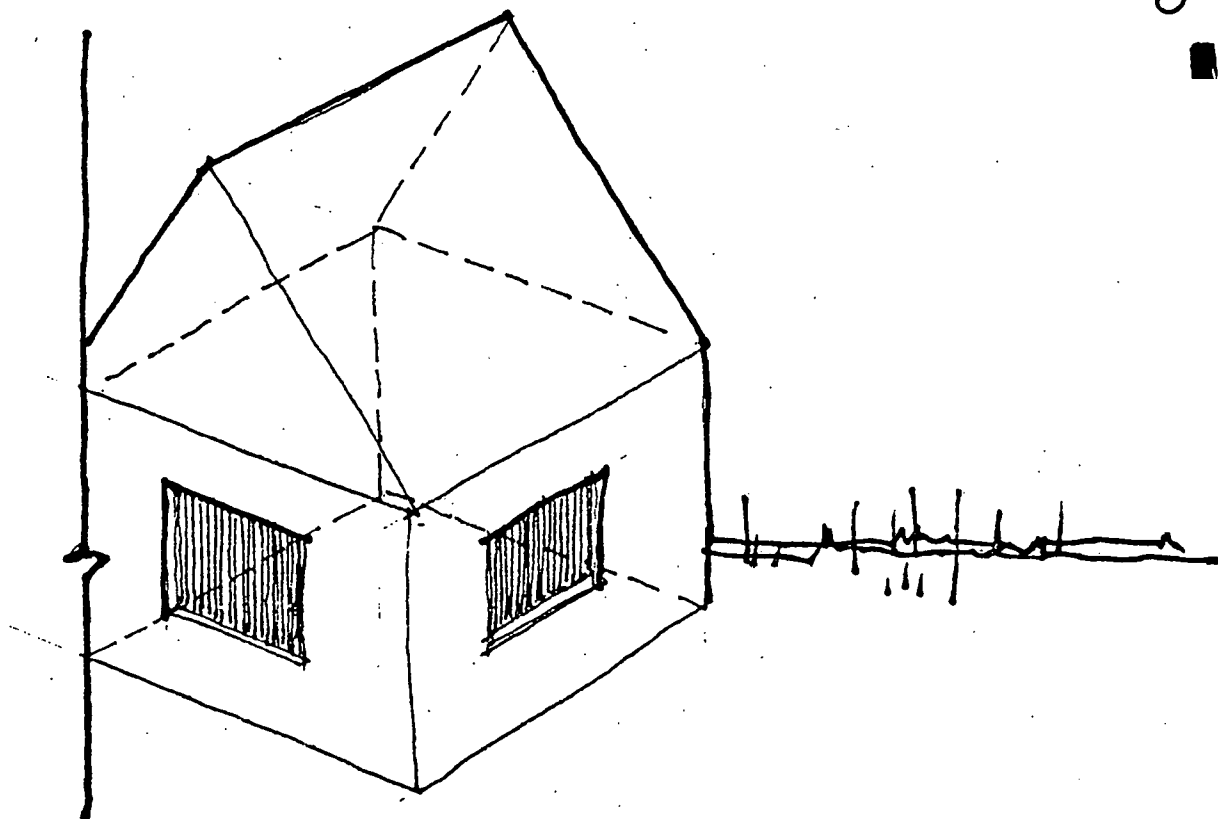
- A. The "why would I want to live in a cave" syndrome?
- B. The lighting quality of the interior.
- C. Conformance with building codes.
- D. The simplicity of mechanical systems.
- E. Humidity and waterproofing problems.
- F. and the basic workings of the structural shell.

A. THE "WHY WOULD I WANT TO LIVE IN A CAVE" SYNDROME.

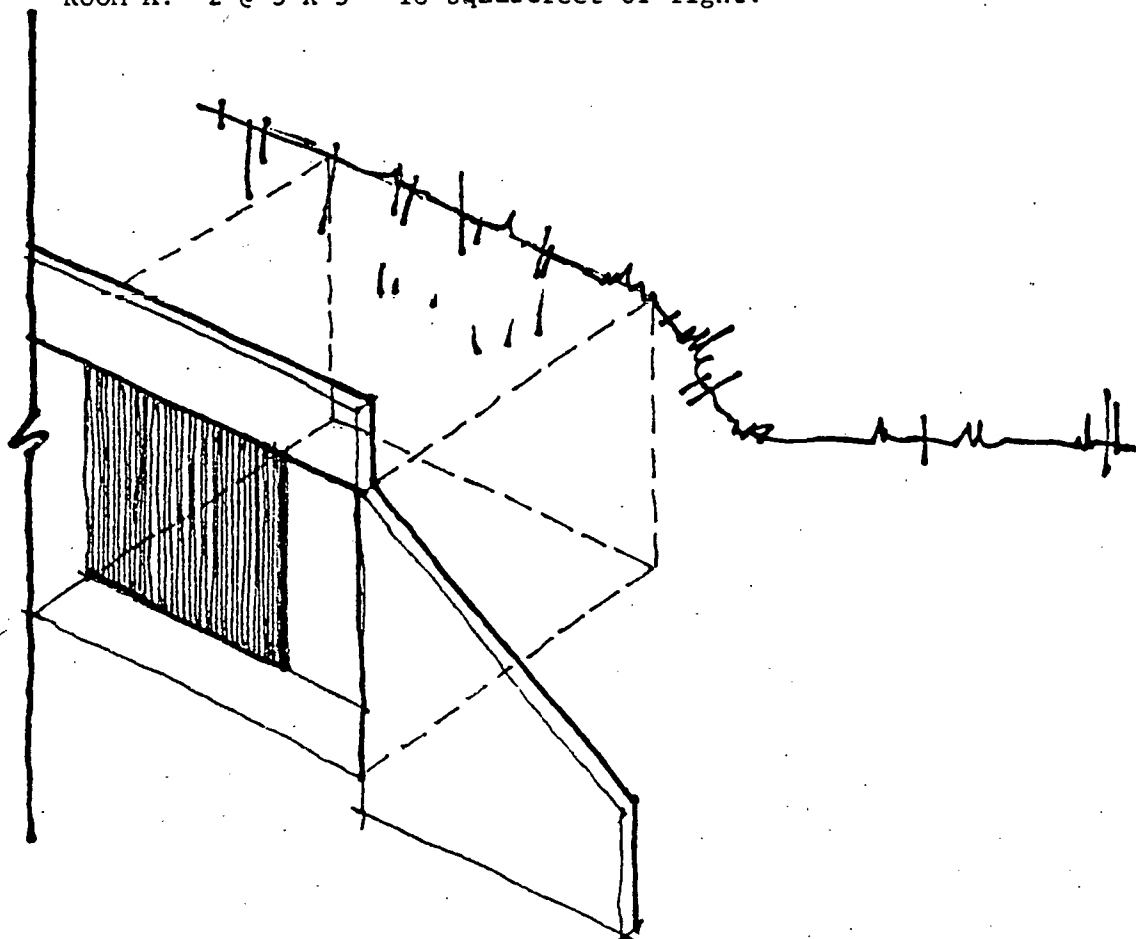
There is no basic conceptual difference between the new underground or earth sheltered home and a traditional type of brick slab-on-grade home. An earth sheltered home is really one of these slab homes that has been sunk into the ground 12' - 0" and its shingles replaced with earth and grass. My favorite question to ask of any client or especially at one of these conferences traditionally held in a meeting room with no windows is : "How may people at this point in time can actually tell if we are underground or not?" Look up. . . Look to the side. . . We can not tell if there is earth or air on the other side of the structure. So much for the "cavelike" psychology of the underground home, but unfortunately this is the single most prevalent reason why many homeowners do not even consider the concept.

B. ON LIGHTING QUALITY.

A major corollary to this cave syndrome is the general feeling that there would be less light entering the underground home than all above ground homes. That is unfortunate, because in many of the earlier and



ROOM A: 2 @ 3 X 3 = 18 squarefeet of light.



ROOM B: 1 @ 6 X 7 = 42 square feet of light.

DIAGRAM B: Light Quality on a sample Corner Bedroom.

well designed underground homes, there is actually MORE light streaming into them, than many traditional abovegrade custom type builder's homes.

This is also a simple arguement, conceptually.

As we look at Diagram B, take for instance two rooms, Room A and Room B. Rooms of the same size and cubic volume, but different glazing treatments.

Room A has a small and may I say typical, Anderson type window, lets say 3 X 3 on the South side and an identical window on the East side, not an untypical situation for an above grade corner bedroom. Room B has an Anderson 6 X 7 windowwall or sliding glass door for the non-builders in the room on its South side and earthen cover on its east side, not an untypical situation for an underground home corner bedroom. One can readily see that there is actually more light entering Room B than Room A even though Room B is underground.

Again, the professors are squirming in their chairs because this is a technically invalid comparison, but with the price of the two windows vs. the price of the well-zoned windowwall, I am sure I am comparing what has been and will be to what is happening in underground and what should be.

One might also argue that all we have to do is to increase the window area of Room A and there could be an equivalent amount of light falling into the room. This is acknowledged, but let me say that this is firstly, not done in the homebuilding industry as a rule, due to costs, and secondly, if we did do this we would be increasing the energy loss by transmission through the enlarged window area and also increasing the amount of heat loss through infiltration along its edges.

It is evident that careful zoning of the glazing which has to occur from any earth sheltered designer worth his or her salt, just by the overiding nature of the design dictates, results in not only an increased

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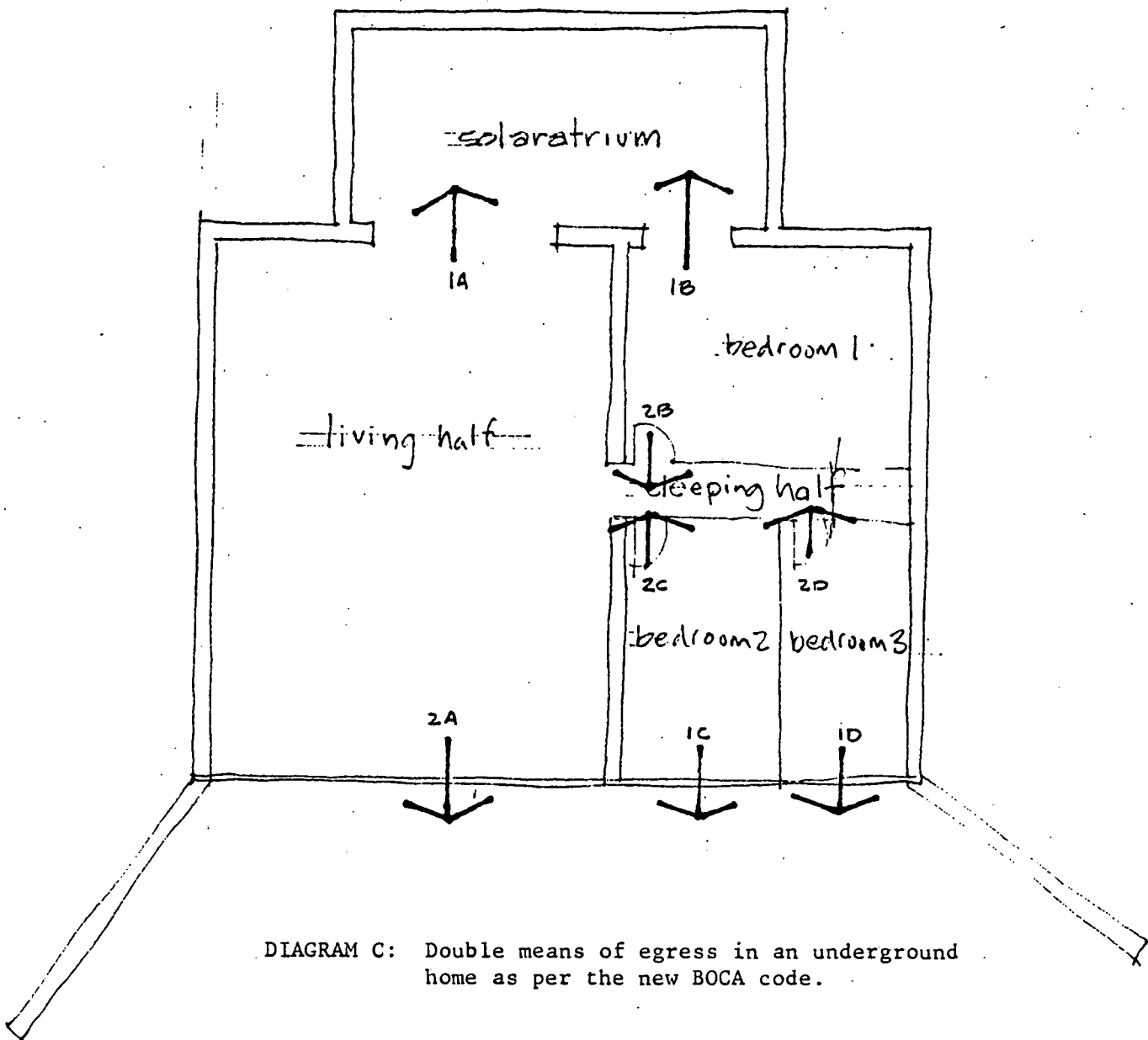


DIAGRAM C: Double means of egress in an underground home as per the new BOCA code.

lighting quality within the structure, but an increase in thermal efficiency as well.

Furthermore, many of our plans contain backside solar atriums, skylights or skywells, as I like to call them, which virtually flood the backside of the home with an equal amount of natural light at minimal expense and loss in thermal efficiency.

The bottom line to all this is that there is more light per square foot coming into an underground by sheer nature of its necessary form than many present or future custom designed homes.

C. CONFORMANCE WITH THE CODES.

Not only does the backside solar atrium or skywell aid in capturing a bit of passive solar energy and improve lighting quality, but it is also the answer to the egress problem posed by certain backside belowgrade habitable spaces.

Formerly, each and every habitable space in the home had to have at least one direct means of access to the outside. Recently there has been a change in the BOCA code, which is the building code for most Northern states which states that instead of one means of direct access to the outside world, there may be two well separated means of access to a room that then exits directly to the outside. This condition happens typically on all of our backside bedrooms. The first exit, (as we look at Diagram C), is out the door into the hallway and then to the outside; the second exit is out the backside sliding door into the solaratrium and then up a set of stairs to the outside.

A second method of handling the code is the open planing "great room" concept evident in the left half or living half of Diagram C. The Great Room allows up to four areas, kitchen, dining, living and family rooms to be considered as one. If there were no backside door into the atrium

in Diagram C the left half of the scheme would NOT be a code violation as the entire great room has egress to the exterior from the sliding door on the front side. In this particular instance, however, there is an extra door into the atrium for lighting purposes, which is just added safety in this case.

D. SIMPLICITY OF MECHANICAL SYSTEMS:

Once again, there is no difference in the mechanical system of an underground home, conceptually, with that of an above grade structure, especially the proverbial slab home, except that the heat loss/gain calculations are drastically reduced.

The heat loss and gain is so low that one may very well find oneself heating the interior in the summer and cooling the interior in the winter such as with the Tweheus Home we saw earlier.

The cheapest system to purchase and the simplest system to install is a woodburning stove as a heat source which is more than adequate to heat the open plan concept by radiation and can be ducted to the colder bedroom wing. We found that heat coming from the stove at about the ceiling level at 110° can be collected and ducted down the hallway to the remote bedrooms and the heat would come out at about 70° relative to the duct run of 20' or so to the furthest bedroom. Backup in this case were local electric resistance floor heaters which was an unnecessary expense of roughly \$800 as they were never turned on once.

We have modified the system into a slightly more expensive and more difficult to install, but more comprehensive system that achieves a maximum of flexibility between natural heating/cooling and ventilation and mechanical supplementation for the desired comfort level.

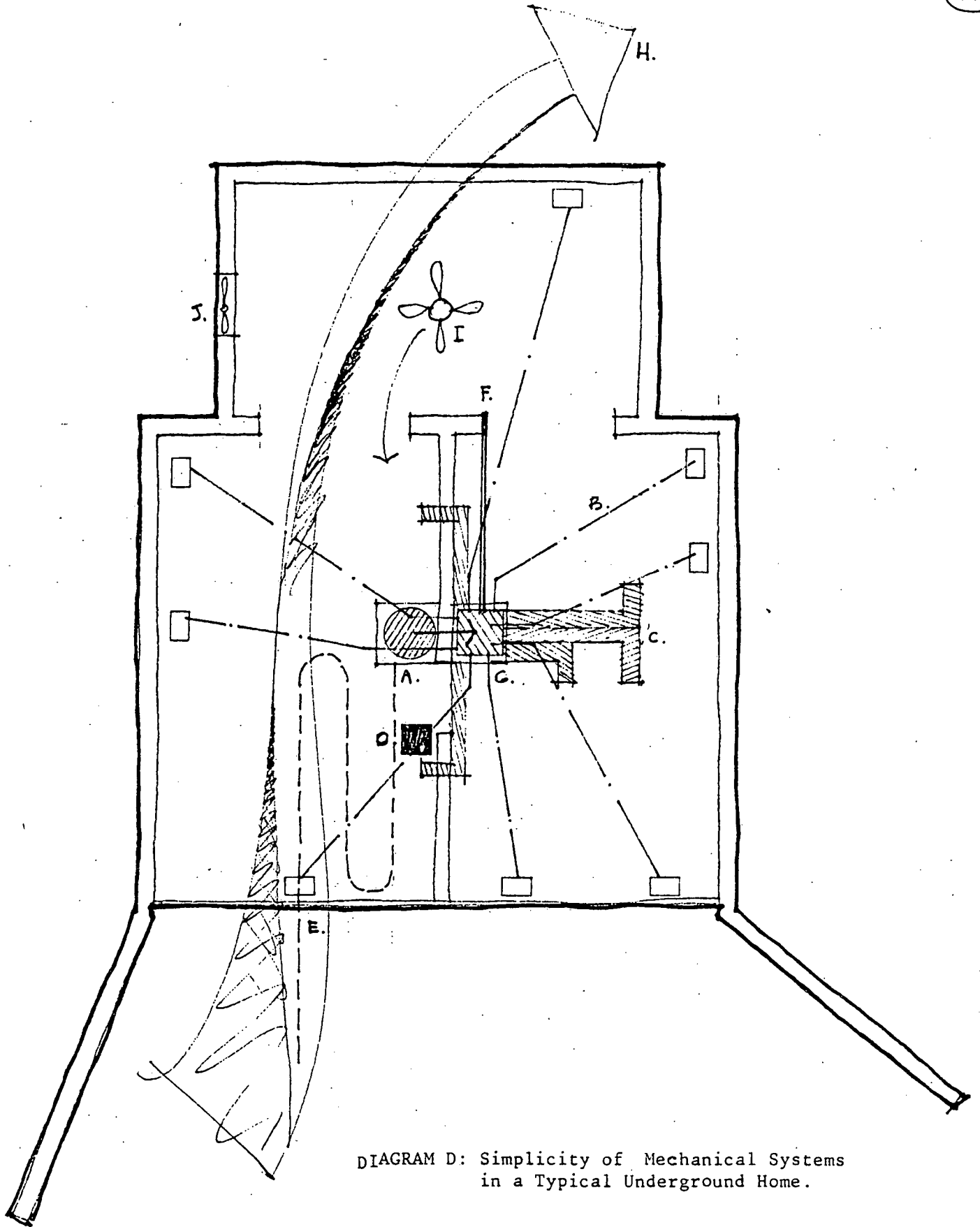


DIAGRAM D: Simplicity of Mechanical Systems in a Typical Underground Home.

The system includes the following elements: (see Diagram D).

- A. A woodburning stove as a primary heat source, but in this case it can be ducted into the return or topside duct of a counterflow furnace before being ducted to the remote bedrooms.
- B. A subslab perimeter "spider arm" supply duct system that takes heat from the stove "through" the counterflow furnace from the stove when the stove is in operation and the furnace is in the fan mode to the furthest side of all remote rooms usually under a window.
- C. A return duct system in soffits in the ceilings and hallways which are concentrated on the opposite side of the room away from the supply registers. This allows for a maximum of cross ventilating drafts when the system is in operation.
- D. A de-humidifier placed centrally in the home which runs intermittently on a humidistat which can be, if floor planning allows, be ducted into the air return system in the utility area.
- E. An underground "earthcoil" system which consists of a 4 to 6 inch "laced" PVC pipe that allows make up air to be prechilled in summertime and preheated in the wintertime.
- F. A duct from the atrium to the return air plenum to the counterflow furnace collects excess passive solar energy in the house in the same fashion as the excess heat off the stove is collected and distributed.
- G. An oil, gas or electric fired counterflow furnace, a Lennox Q11R is a typically specific model in our homes, will supply backup heat as required.
- H. A natural "venturi cooling effect" from opening jointly the windows on the south side and the atrium doorway.
- I. A downdraft ceiling fan that can blow heat gently into the main living space when needed, (usually in summer).
- J. An atrium exhaust fan that draws out unnecessary heat in times where a build up occurs, (usually in summer).

E. HUMIDITY AND WATERPROOFING PROBLEMS.

These two demons are probably the main concerns of each and every homebuilder or homeowner that has visited us and the concerns of everyone in the industry as well.

Firstly, high levels of humidity and the resultant condensation problems are aided by the "tight" nature of the underground home; the walls are not allowed to "breathe", as are traditional frame and brick walls, through porosity, nailholes and cracks and looseness of construction, which allows for an equalization of pressure and moisture content between interior and exterior. Thus we must deal with the problem through detailing and mechanically.

Central to the theme of course is the dehumidifier, very important, especially with poured concrete walls which will not totally cure for one and a half to two years.

Secondly is this most important concept of airflow. A light wash of air through the room will aid in the evaporation of moisture on surfaces which can then be carried out through the return duct system. A light wash of air under a window can virtually eliminate most of the condensation along the glass, so you can image what it can do against the denser concrete wall. Air flow is the reason for installing this more complicated of subslab supply systems, because if the duct system is already in place for heating purposes, then it can also be used for ventilation. This is impossible with a pure woodburning stove system.

Thirdly, architectural detailing can act as a safety valve in case of any condensation that is not eliminated, although in all our schemes these initial fears of heavy condensation have failed to materialize.

The following are added precautions that can be taken:

A. drip strips along the bottom of any large window area above drywall areas such as the solaratrium windows, where condensation if not captured can cause unsightly blemishes along the drywall.

B. proper floor material in the skywell or atrium such as brick, flagstone or indoor/outdoor carpet that will withstand any water drips from glass skylights or domes above.

C. keeping the drywall off of the floor, as in Diagram E, so that if any condensation occurs on the cooler concrete wall, the most that will be damaged is a molding strip. Diagram E was devised so that one might use 8' drywall on an extended 8'-6" ceiling height.

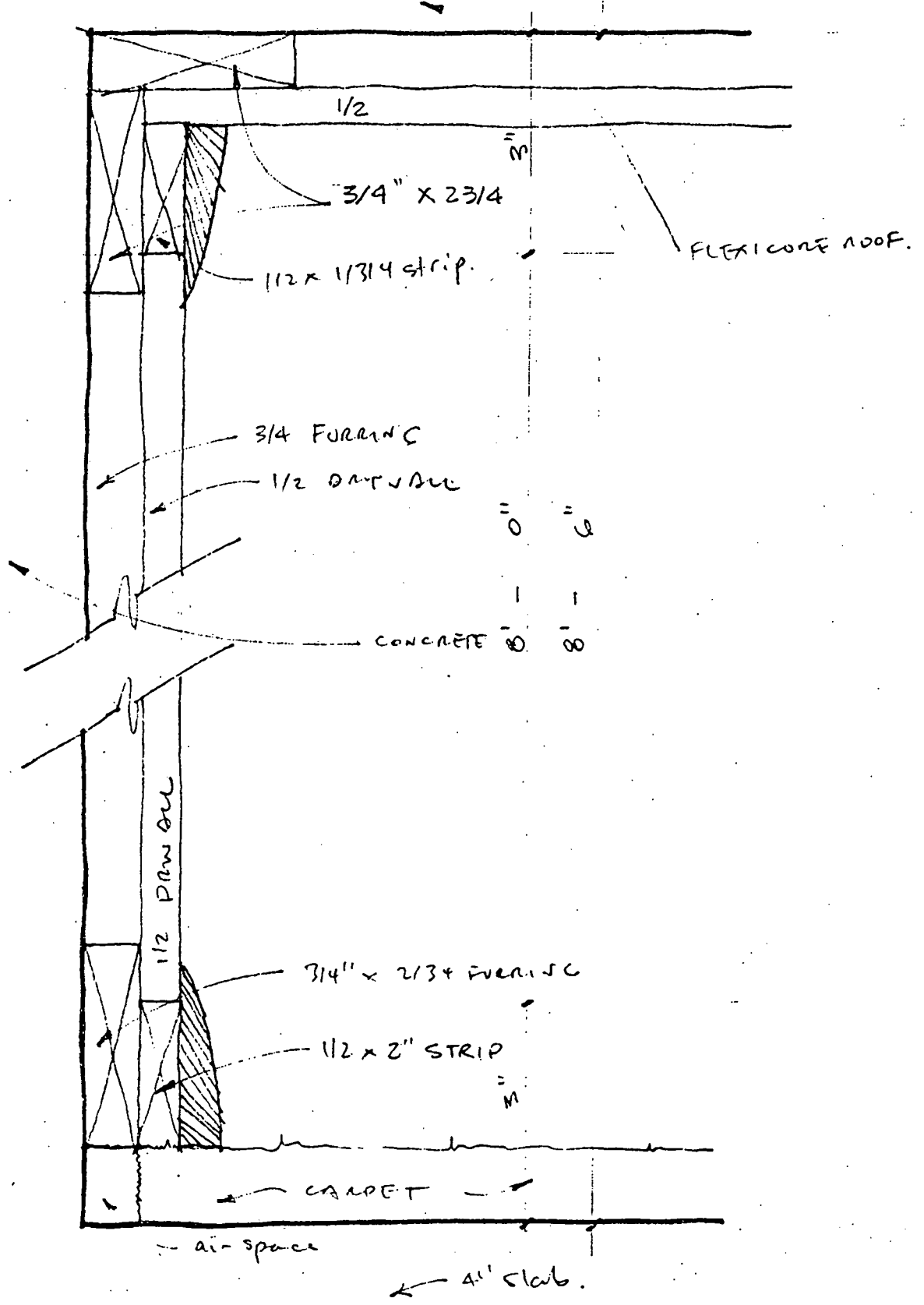


DIAGRAM E: 8' drywall on 8'-6" wall detail.

This solves both the condensation problem and the irregular sizing/cost problem.

D. Usually we furr out the concrete walls with 3/4" furring strips and 1/2" drywall. Even though this may deter a portion of the passive solar energy from passing into the concrete and being stored there for night use, we thusly make sure that there will be no condensation problem. The space behind the furring also provides an ideal chase for plumbing and electrical work. The furring strips are simply ramset to the wall, one at the top and one at the bottom and then vertically 2" on center.

E. An epoxy based paint on the ceiling finish under the precast members. This is a tricky situation which is not totally proven as of yet, but what happens is that warm moisture laden air will find its way up through the grouting and condense against the cooler waterproofing membrane if there is no capping slab on the precast members. This will cause a "rain" back into the room which appears as if there is a "roof" leak when there real is not. This is one of the phenomenon that is unfortunately occurring in the Bruno Home. This would seem, if there was an epoxy vapor barrier along the ceiling, to keep all the condensation in the house where it can be taken out mechanically.

But as I say all of these elements may be a slight case of "over-design" as we have not yet experienced, except for the Bruno Home these anticipated condensation problems.

Waterproofing is even more of a concern in the initial planning stages such as site selection and building design, because if we make a mistake here, as well as with the structural shell, there is a point of no return. To clean up these kinds of mistakes may be more expensive than redoing the entire structure, because of the tremendous amount of demolition of integral units involved. Waterproofing and detailing the structural shell in a totally 'underground' home are one in the same which leads us to the uniqueness of the ShelterraHomes Structural Shell.

REFER TO TYPICAL FOUNDATION/FRAMING PLAN AND WALL SECTIONS INCLUDED HEREIN AS DIAGRAM F AND DIAGRAM G.

Let me first go through the system from a waterproofing standpoint only:

The first and foremost deterrent to waterproofing problems, of course is a well drained site. A rule of thumb which we use at Shelterra is that the centroid of the house shall be the highest point on the site. I keep seeing this diagram with the hill behind the house, even in the book "Earth Sheltered Housing, Guidelines, References and Examples," which is totally incorrect and will cause waterproofing problems later unless a deep swale is cut behind the home in the hill.

There are three new products and 2 key details, as well as an increased sensitivity to site selection and overall design planning that make this system work.

A. The first product is called a Waterstop. (Hold up and pass around).

The waterstop is a 6" X 1/8" ribbed vinyl strip that comes in roles up to 100 feet long. The waterstop is placed along the top of the poured wall as it begins to cure toward the outer 4 or 5 inches of the wall in a three inch keyway. The precast panels are then placed on the inner 4 or 5 inches bearing area of the wall. The capping slab, which is in itself a waterseal over the horizontal grout joints of the precast members, comes down around the plugged end of the panel and flows down over both sides of the waterstop into the keyway. This effectively seals the joint as the waterstop is now integral with the concrete on both sides and not "applied" after the fact. The waterstop has a bead in its middle which allows it to flex somewhat. Should this rupture at this point, then there were more serious problems than waterproofing to consider before one started.

The waterstop is also placed in the footer and after the entire shell cures what we have is really an upside down boat with NO JOINTS!!

This is what irks me sometimes about the "block" people in underground; every joint and there is one every 8" vertically and 16" horizontally, and each and every linear inch of joint is a potential waterproblem as well as a structural crack, a deeper and more damaging crack than the common surface cracks of poured concrete.

B. The second product is called the Laurencio Membrane. (Hold up and pass around).

The Laurengo Membrane is composed of the Laurengo Sheet and the Laurengo Adhesive in varying combinations.

The Laurengo Sheet is a Chlorprene Membrane with a glass fiber mesh reinforcing. The sheet has expansion and contraction capabilities of up to 1/4" which is more than adequate to control any cracks in the concrete.

The specifications of the Adhesive are a trade secret but it is primarily an asphalt based material.

The reason we like this so much over any other product is that aside from any other material this adhesive acts as a glue in which we can cement the first layer of styrofoam rigid board to the structure.

Properly designed concrete cracks for two reasons:

A. Shrinkage.

B. Freeze/Thaw Action.

We cannot control the first easily, as a matter of fact, we call the ready-mix plant on the day of the pour and they guarantee us that there will be at least 3 cracks per yard in this particular delivery.

The second shall prove to be less of a problem in underground homes because of the moderating effect of the earthen mass. You just won't have the type of freeze/thaw action that will obliterate an above grade slab or foundation wall. The membrane, also will have a longer life as it is under earth and sheltered from the deteriorating effects of the sun's ultraviolet rays.

I wish to emphasize for the novices, here today, that these cracks are only "surface" hairline cracks and not structural or anything to worry about.

We recommend that the 1 ply system shown today be used for the walls and the two ply system be applied on the roof without the protection board. The 4" of insulation on the roof and the 2" insulation on the walls will serve as adequate protection of the membrane. A two ply system is also recommended around any vertical thermal breaks.

The price of this system runs about 43.00 per square which is material only. The material comes in rolls 36" wide by 30 some feet long and the adhesive comes in gallon pails.

C. the third product and perhaps the newest is called "Enkadrain". (hold up and pass around).

Enkadrain is a coated wire mesh about 1/2" thick with a nylon filter on one side. The nylon filters out loose soil and allows water to flow freely and immediately to the drain tile. This relieves a major portion

of any hydrostatic pressure build up and keeps the drain tile from being clogged. It is recommended for foundation work where heavy clays and silts are present, but I would recommend it for any underground home regardless of the soil conditions.

It comes in 38" roles with a 3" overlap in whatever size is needed up to 100 feet and is very easy to install. The cost for an entire home is very expensive at \$1.00 over an above all the other precautions exercised.

The two details that i refered two, pictured here as Diagram F and Diagram G are the key to the workings of the Shelterra Earth Homes Structural Shell described as follows:

- A. We employ a 4000 psi, 6% air-entrained mix in all of our walls whether they be 8" or 10". This mix is much denser than the normal foundation wall, which is requisite with this type of home.

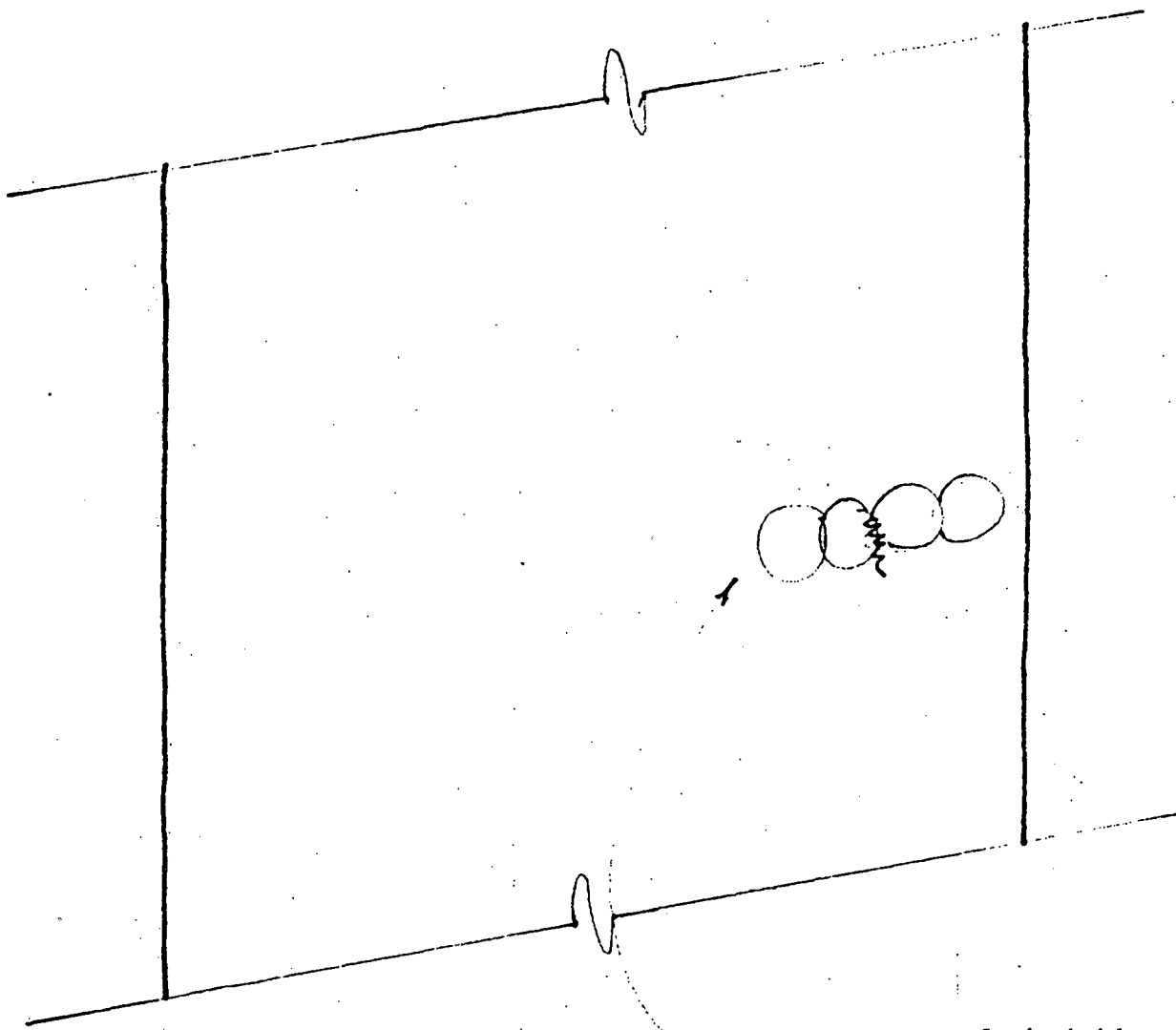
The air entrainment, which we call "fizzies" in the business, is both a moisture deterrent and strengthens the wall by relieving any pressure that may be built up. Just imagine, (as we look at Diagram H), a million little tiny "airbags", just like in modern automobiles, each one bursting against one another relieving the pressure of any cracks that begin to develop or any capillary action that occurs. These forces are stopped in their tracks by the air-entraining agent.

- B. The precast members are placed always from East to West which allows a maximum of clearspan for open planning and a 2 X 6 stud wall "tilt-up" construction on the South side. There must be at 3" minimum bearing area on the wall, ours are usually 4 to 5".

This panel is good for a design load of #355 pounds per square foot which works out as follows for 24 to 30 inches of soil:

Earth @ 110 per cubic foot	220 #
Dead load of capping slab	36 #
Dead load of precast panel	57 #
Live and Snow Load Combined	42 #
TOTAL	355 # per SF

However, these numbers are supposedly based on a safety factor of 2, so for the gamblers in the audience, one might add an additional 24 to 30 inches of soil to the structure for a safety factor of just over 1, but we do not recommend it.



rupture of air bubbles
against each other relieve
pressure and stops capillary
action.

DIAGRAM I: Exaggerated Blow-up of Wall Section showing
Air Entrainment Action.

C. In addition, we tie in each and every panel to the supporting walls with 4 X 4 X 3/16 inch weld plates that are cast into the panel at the plant which are then welded to 2 X 2 X 3/16 inch "L" channels jin-rigged to some leftover anchor ties.

This ties the whole structure in laterally and in order to fall in the earth must now press on 3 to 5 walls instead of just one. The slab supports the wall laterally on the bottom side, so the wall now becomes a strongly supported beam.

DO NOT, I repeat DO NOT backfill until the roof has been tied in, because the wall then acts like a beam in cantiliver, which it has not been designed for and will fail.

D. A 3500 psi crowned capping slab goes over the precaste members to effectively seal the grouted joints. It is usually crowned from east to west, except for linear designs, which will be crowned from North to South.

E. Over the slab and the exterior of the walls goes the waterproofing membrane as described earlier.

F. Over the membrane goes the insulation, which is shiplapped by 1' increments, comes in 2 X 8 sheets and is tongue and grooved. We use closed cell polystyrene by Dow Chemical or blue rigid board as it is more commonly called, 4" on the roof and 2" on the walls down to the footer.

I have also seen this drawing where the insulation extends out horizontally to best get the cooling effects of the earth in summer while breaking the frost line in the horizontal plane.

This is incorrect as the settling that occurs after backfilling will surely break this barrier.

G. Over the insulation we usually put a 6 mil visqueen vapor barrier. This is a must because the density of water VAPOR as compared to WATER is 1/200000 as much at 32° F and will penetrate most building materials. This is a dampproofing coat, not a water-proofing measure.

H. Over this visqueen is either the Enkadrain or a rounded river gravel as darinage material and then backfill.

I. We recommend sodding the home IMMEDIATLY after all major settling has been corrected for the mound has much potential for erosion and washing away.

J. The frontside parapet is waterproofed with all the "traditional" techniques described above and include a 6" steel "C" chanel as a horizontal waterstop.

The "C" channel is welded to the topside weldplates that also hold the parapet rebar. One appendage of the channel is integral with the pour of the parapet and the other appendage is integral with the pour of the capping slab. Any water now has to run up and over these appendages to get into the home.

The parapet is wrapped with insulating material to serve as a thermal break.

Longer parapets for linear designs will require lateral "kickers" every 12 or 15 feet due to possible frost action against the wall. This detail will be the same for atrium and skylight parapet walls also.

Our costs presently are running about \$18.50 to \$23.50 for the shell with finishing costs for the total homes running between \$16.50 to \$20.50 bringing the total costs to about \$40 per square foot as an average. The quoted shell costs include the following:

- A. Excavation
- B. Footers and Steel
- C. Set Walls, Steel, Pour and Strip Forms
- D. Set Retaining Walls, Steel, Pour and Strip Forms.
- E. Waterstops
- F. Precast Members
- G. Capping Slab
- H. Floor Slab
- I. Waterproofing Membrane
- J. Insulation
- K. Damproofing
- L. Drainage Materials and Tiles
- M. Backfilling
- N. All required blockouts for electrical, mechanical, plumbing, windows, doors and nailers.

I should like to open this discussion up for questions from the audience as we go through the list of slides on construction. Thank-you very much.

The following addresses should prove invaluable to you if you intend to build as we do:

A. The Precaste Concrete Institute
20 North Wacker Drive
Chicago, Illinois 60606

-ask for the "Hollow-core Producers Directory to find your nearest precast plant.

B. The Laurent Corporation
P.O. Box 244
Twinsburg, Ohio 44087

-ask for their technical manual on the Laurenco System.

C. The American Enka Company
Enka, North Carolina 28728

-ask for their brochure and product sample of the "Enkadrain".

D. The Sonneborne Corporation
7711 Computer Avenue
Minneapolis, Minnesota 55435

-ask about their brochure and product sample for the "Hydrocide Vinylstop".

E. The Dow Chemical Corporation
Home Office
Midland, Michigan 48640

-ask about their brochure on "Styrofoam" brand insulation.

AND TELL THEM ALL RICK OHANIAN FROM SHELTERRA EARTH HOMES SENT YOU!!

Thank-you again!!

HIGH BANK INSTEAD OF HIGH RISE?

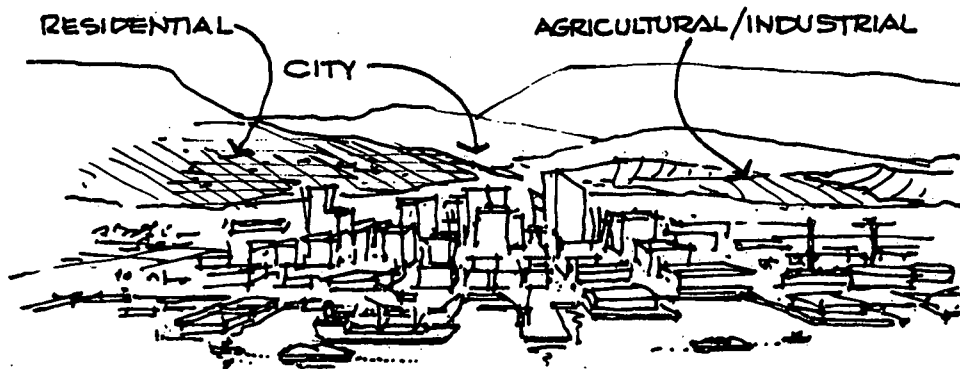
AN EARTH SHELTERED APPROACH TO MEDIUM DENSITY HOUSING

Gerald W. Thorsen, AIPG, Washington State

Roger L. Rue, Rue and Butler, Architects, AIA, ps

Introduction

There are tens of thousands of kilometers of steep banks and bluffs in the U.S., ranging from 30 to 70 degrees; with much of it in or near population centers. These bluffs commonly are as much as 100 meters or more in height and most are stable in their natural state or can be made so by relatively straightforward engineering techniques. Yet, because of their relief and slope, they make access and residential development by traditional methods difficult, expensive, and sometimes hazardous. The result is that slope surfaces commonly remain unused while wall-to-wall houses line the bluff tops and sprawl across the flood plains. Thus, the best agricultural land often goes first and industrial sites and natural resources such as gravel or quarry rock are zoned out of existence through residential crowding.

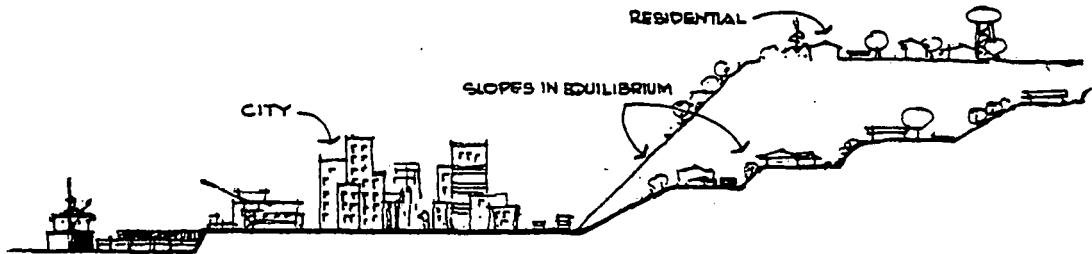


Upon close analysis, "residential" use is probably one of the least critical land uses of all. Industry, waste disposal, raw materials extraction (to name a few) all have unique requirements - residential use has very few. Human ingenuity has coped with the elevation and slopes of Tibet and Bolivia, the foundation conditions of Mexico City and Pisa, and the climate of Bangladesh and Siberia. As long as man recognizes the more violent natural processes of his particular local setting and designs accordingly, or stays out of the way, he can live

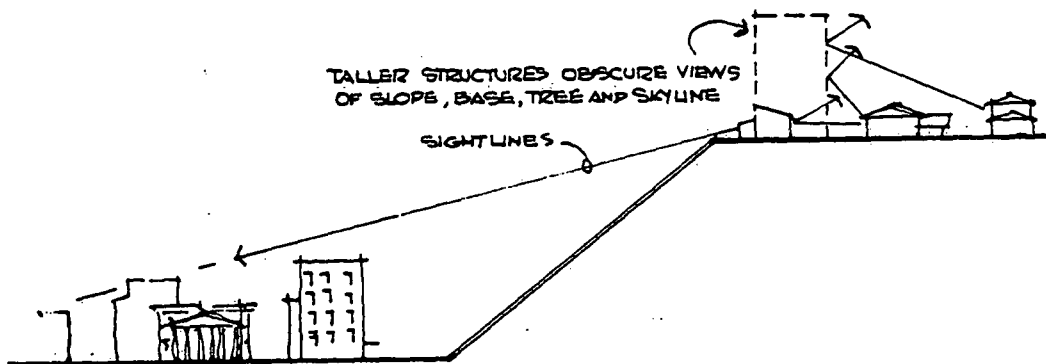
safely practically anywhere on the planet. Modern materials and techniques can even make this existence comfortable and productive. We propose a closer look at steep slopes.

Traditional Slope Development

Medium and High Density - The conventional form of residential development of slopes in or near population centers is by a rectangular pattern of contour and slope streets. These street grids, and standard building design, permit flatland population densities but often provide a challenge for transportation systems on slopes approaching 15 degrees. San Francisco's cable cars represent one areas solution for one period in history. One can find little evidence of a stampede in this direction in 1980, however. The automobile and bus have limitations in this kind of terrain, especially in areas of severe climate. A few inches of snow or icy conditions can paralyze traffic. Thus, on steeper slopes the grid is apt to be replaced by contour streets serving different levels of the same building. The architect must make his building "thinner" or be content with a considerable volume of the lower floors without daylight.



Low Density - Here also we commonly find the street grid, but lined with houses instead of buildings and confined to relatively low slope angles. The cut-and-fill construction sites, often with little or no engineering, present a wide range of foundation and erosion problems. In addition, the percentage of surface area in impermeable materials (roofs, driveways, and streets) creates peak runoff flows that many suburban storm drains are not designed to handle. For really steep slopes (those exceeding 30 degrees) the cut-and-fill approach becomes impractical or even dangerous, so we find pole or cantilever supported structures served by contour, or steep switch-back, roads. In addition to the higher construction costs and difficulties of providing and maintaining transportation and utilities to such structures there are additional energy losses from another exposed surface (the floor).



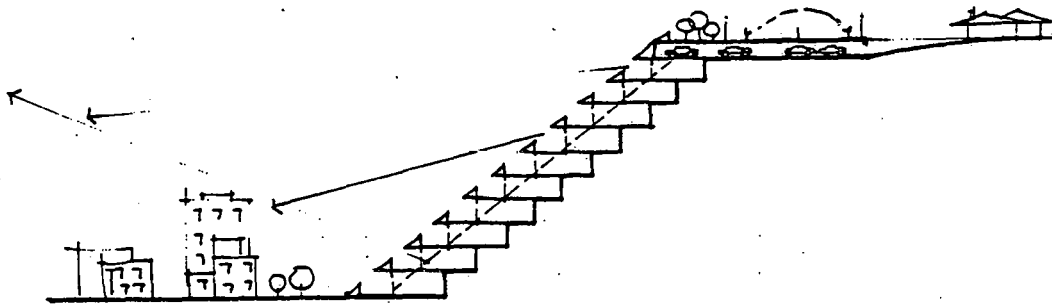
An Alternative

We propose that the steep slopes so common in and near many population centers could be most efficiently and responsibly used with dwelling units stacked stairfashion in a slot cut into the hillside. Such a complex would be accessible from either the top, bottom, or both, without roads on the slope face. Native vegetation would be left undisturbed to either side of the complex. Each unit would be earth sheltered but at the same time have a view; and there would be no intrusion on the natural skyline at the bluff top.

The essential points of the High Bank Residential Complex are:

- utilization of steep (greater than 35⁰) slopes
- continuous (unbroken) use of the full length of the slope
- earth sheltering of the structure
- standardization of the units and complexes

Some of these characteristics are, at least in part, present in existing custom designed complexes. In some instances, because a more desirable site was not available, the architect had to "design around" what he may have considered a difficult site. We propose seeking out such sites and using their physical characteristics as advantages rather than as obstacles to be overcome. While the following discussion is aimed largely at angle-of-repose slopes in soils (generally 35 to 45 degrees) there is no reason that, with relatively minor modifications, such complexes could not be built into considerably steeper slopes, especially in bedrock.



AN UN-INTERRUPTED VIEW WITHOUT DISTURBING OTHERS

Economics - Land costs for the High Bank Complex, other things being equal, should be less per residential unit than they would for most alternatives. As mentioned earlier, steep slopes even in population centers commonly remain unused (except as unauthorized refuse dumps). Thus, the development of an efficient use for these areas would, in effect, amount to the creation of new land. The stacked aspect of construction means that considerably less land would be used per dwelling unit than would be occupied even by densely packed single family residences. Flat land, potentially more valuable for other uses, would be conserved.

In regard to structural costs; on a typical angle-of-repose slope, about a third of each "floor" of the High Bank Complex would be supported on its own foundation by virtue of the stair step method of construction. The extra strength that is needed in the typical high rise to compensate for wind or seismic loading, would be unnecessary. Thus, structural strengths could be minimized at no compromise in safety and units could be made light and strong enough to be prefabricated and lowered one-by-one into place by gravity. Additional structural integrity could be provided for the complex as a whole, by pinning each unit to the walls of the excavation during construction.

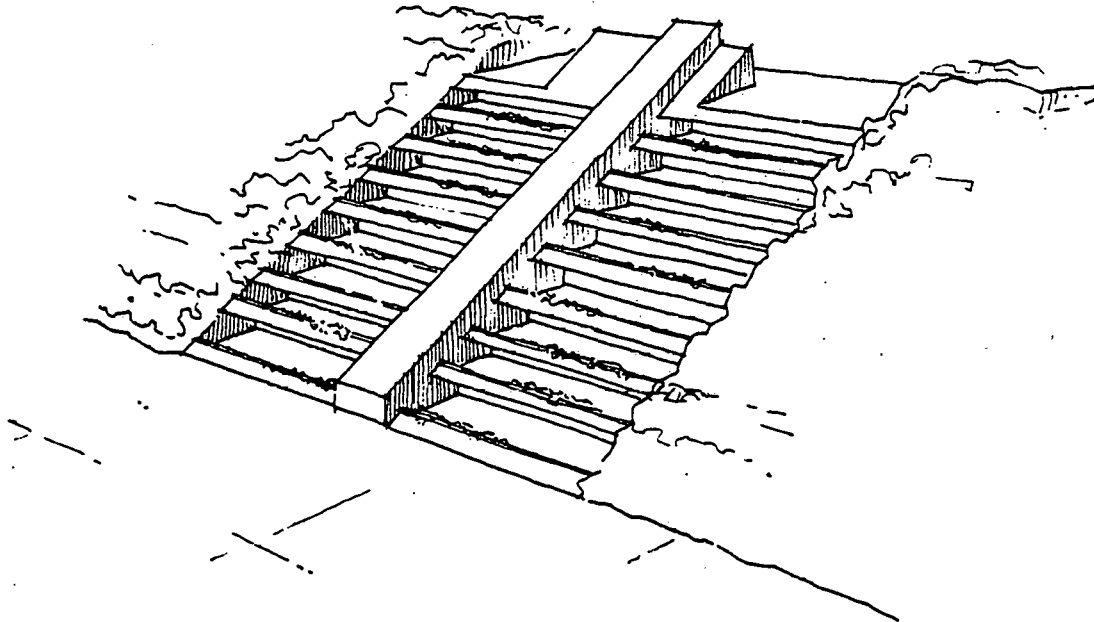
Energy - As energy is no longer merely a question of economics it seems to warrant separate consideration. The High Bank Complex lends itself to a variety of energy-related economies, not only in conservation but relating to collection as well. For example, at the latitude of the United States the slopes discussed provide more surface exposure to solar radiation than either horizontal or vertical surfaces. Complexes with any but a north orientation could, in almost any climate, get a boost from the sun. Heating-cooling costs would get the usual benefits

of earth shelter, as little more than one edge of each dwelling unit would be exposed to the weather. The inclined shafts of counter balanced elevators could be used for natural draft ventilation. The potential applications of gravity to other utilities are too numerous to discuss here. In addition, the proximity of the units to job centers would minimize energy consumption for transportation.

Safety - Safety should be nowhere near the concern it is in a conventional high rise building and, in some respects, less than in a free standing single family residence. At no point could a person fall more than one floor. Escape from fire within structures built on angle-of-repose slopes would be by simply stepping onto the natural slopes flanking each unit. Hazard from brush fires would be considerably less than for above ground units and could be even further reduced in susceptible areas by the use of appropriate shutters. Flood hazard, by the very design and location, would be nonexistent. As with all earth sheltered housing, hazard from wind, except a direct hit by tornado, would be negligible. Challenges to the structural engineer in coping with seismic hazards should be minimal in comparison with those related to free standing multistory structures.

Esthetics - One of the greatest advantages of the High Bank Residential Complex over the more conventional type of development would be in the preservation of the natural terrain. From the lowland view, instead of a scalped skyline trimmed with wall-to-wall houses one would see an unbroken skyline with natural vegetation. From the upland, residences set back from the edge of the bank would not have their views blocked. The scars of mid-slope access roads, with their cutbanks and sidecast slopes, would be totally avoided. Because the complexes would be designed to blend with the terrain and vegetation rather than fight them, concerns about the proposed standardization producing an "institutional" appearance would be largely irrelevant. Such complexes, except for their solar panels, could be practically invisible from a few kilometers distance.

Livability - Residential complexes such as described should be as pleasant to live in as to look at. The carefully designed terrace of each unit would not only ensure an unobstructed view but the privacy of the neighbors below. The panoramic view could make the transition to earth sheltered housing pass unnoticed, even by those with a tendency toward claustrophobia. Such amenities for residents as recreational facilities, covered parking, or even small shops, could be accommodated at the top or bottom of the complex with no compromises in the attributes discussed.



A SIXTEEN UNIT COMPLEX

Other Applications - While this conference is aimed specifically at earth sheltered residential applications it seems appropriate to point out that the concept presented could be adapted to commercial, certain industrial, or even a mix of these applications with residential in the same or an adjacent complex. Industries handling heavy bulk materials could benefit as much in energy and equipment savings from the thoughtful applications of gravity as from the insulation aspects of the High Bank Complex. Metallic ore mills for example, have always had to cope with high energy costs; not so much because of the earlier costs of energy but because of the sheer weight of the rock and volume of process water that had to be handled. Thus, mill designers have long been masters at the applications of gravity to materials handling and would be horrified at the energy waste in the modern "flat land" plant where everything that moves requires new energy input.

Site Analysis - Any development of steep terrain requires a careful analysis of local site conditions, and the degree of detail required will, of course, vary from area to area. The average site in the Puget Lowland of Washington State, for example, may require attention to factors such as highly erratic soil strength, perched ground water (in places under artesian pressure), overconsolidated glacial clays, prolonged seasonal rains, and moderate-to-strong seismic activity. The costs of such analyses, as well as site preparation techniques such as dewatering, can be much better supported by a multi-unit

structure such as the High Bank Complex than they can be individual residences perched in midbluff. Thus, there are many areas where the practical advantages and energy savings of this concept warrant careful consideration.

Gerald W. Thorsen, Geologist
Department of Natural Resources
Div. of Geology and Earth Resources
Olympia, Washington 98504

(206) 753-4031

Roger L. Rue, Architect
Rue and Butler, Architects, AIA ps
4115 Bridgeport Way West
Tacoma, Washington 98466

(206) 565-1011

POTENTIAL PROBLEMS OF LEGAL LIABILITY IN THE DESIGN,
CONSTRUCTION AND OWNERSHIP OF AN EARTH SHELTER

Allan M. Ziebarth
President
EARTH SHELTERS, INC.
Omaha, Nebraska

Earth sheltering strategies present design and construction considerations that can be significantly different in comparison to those considerations in more traditional housing; and the benefits of the earth sheltering option are made possible by successfully dealing with these differences.

To date, the discussion regarding the design and construction of earth sheltered housing has focused primarily on the technical aspects of the earth sheltering strategies. However, the differences of the earth sheltering approach also suggest new considerations, and pose new questions regarding potential legal liability and the practical effect of that potential liability on the design, construction, and ownership of an earth shelter.

Thus, any discussion of or decision about the earth sheltering option is incomplete and short-sighted until it also includes an examination of these legal issues and their impact. This paper will identify some of the potential problems of legal liability and their practical effect regarding the design, construction, and ownership of an earth sheltered residence.

The reader is alerted to the fact that an examination of potential legal liability problems necessarily involves a prediction of everything that could ever possibly go wrong -- no court cases involving these legal issues as they pertain to earth sheltering have as yet been reported.

This discussion is not intended to discourage planners, builders, and others from the earth sheltering concept, rather it is intended to do just the opposite -- to encourage the design and building of earth shelters that are safe and sound and will be a credit to the earth sheltering movement.

Landscaping

The seemingly insignificant choices in landscaping and planting above and around an earth shelter may best illustrate the problems of potential legal liability. The main requirement of any vegetation planted above an earth

sheltered structure is that it prevent the soil from washing away. Suggested possibilities range from garden crops to conventional lawn grasses, which appear to be the most common choice. Choosing to maintain a lawn above the structure translates into making the roof look like a lawn that would blend in with its surroundings. If it looks like a lawn, people will be inclined to treat it as a lawn and engage in those activities that take place on a lawn. Accidents will invariably happen, and any fall from the roof will probably result in serious injury. The likelihood or possibility of such an occurrence increases when a novel earth shelter is located in a more traditional neighborhood and attracts the attention of children. Arguably, the novelty of the earth shelter with a lawn above could be the basis for an attractive nuisance suit.

Ultimate liability may be determined by whether the owner relied on the services of a professional landscape architect who either recommended or planned the lawn treatment, as reliance on the expertise of a professional usually has the effect of shifting all or part of the liability away from the homeowner.¹

The entire situation could probably be avoided by landscaping and planting with the express intention of discouraging rather than encouraging anyone from being on the roof. Thus, some type of ground cover would be superior to a lawn grass; a fence around the property and/or near the front edge of the structure may also be advisable. The railing or fence at the front of the structure may not be aesthetically desirable, but it could be concealed by shrubbery -- preferably of a thorn bush variety.

Structural Engineering

The most critical of the technical considerations of earth sheltering are the structural concerns -- an improperly engineered earth sheltered structure presents great potential for serious harm to the building and those who use it. A structural failure would undoubtedly result in costly repair -- provided, of course, that repair is possible -- as well as the costs incurred due to any personal injury.

The analysis and recommendations provided by a professional structural engineer are the only design assurances that an earth sheltered structure will be sound, and thereby safe. In the unlikely event a structural problem should develop because of improper engineering by a professional engineer, legal recourse would probably be available against the structural engineer whose skills were relied upon.²

The absence of professional engineering -- meaning a layman or the owner engineered the structure -- may present some very real practical consequences. Financing for the project may be more difficult to obtain than it might otherwise be. A building of questionable structural integrity represents considerable risk and any knowledgeable lending institution will be advisedly reluctant to make a loan. Obviously, accepting the building as collateral is unsound. Furthermore, the applicant is competing for funds and the non-engineered structure is less desirable for investment strategy than an equivalent structure with reasonable assurance of soundness.

A building permit, where required, may also be difficult to obtain. Building codes "provide for safety, health and public welfare through structural strength and stability,...to life and property from...hazards incident to the design, [and] construction of buildings and structures."³

The issuance of a building permit implies, at the very least, that the structure will be sound and safe. In addition, inspections are made during the construction period to ensure that the project is built according to the approved plans. A code official, unfamiliar with earth sheltered structures, should be hesitant to give approval regarding the structural integrity of an earth sheltered building, if he does not have the proper training as such action may be the basis for imposing liability. This is particularly important in view of the trend to impose liability for negligent governmental safety inspections.⁴

With time, the general public will become more knowledgeable about earth sheltering, thus potential buyers will be concerned about the engineering of a structure. Regardless of the number of years the structure has stood, there may still be a question as to its structural integrity, particularly if it has not been professionally engineered. Resale of a non-professionally engineered earth shelter will likely be difficult.

An informed purchaser, or a purchaser represented by an informed attorney may require a warrantee (guarantee) of structural safety and/or a reduction in the asking price, assuming, of course, a sale is made at all. Realtors should be reluctant to become involved in the sale of a structure that may be difficult to sell due to what may be a serious design defect, and it is inconceivable to think that a knowledgeable realtor would handle such on a guaranteed purchase basis.

If a structural problem does develop, new problems may arise. Undoubtedly, the owner of a structure where a professional engineer was not used would be forced to bear the loss. And as insurance policies do not presently cover structural failure in traditional housing, it is unlikely structural failure in earth shelters would be insured against. If the structure has been sold to another, the original owner may be liable⁵ -- obviously if a guarantee was given; most likely, any disclaimers regarding structural integrity would be invalid. Finally, adverse publicity resulting from a structural problem would be very detrimental to the widespread acceptance and application of earth sheltering.

The decision to not employ the services of a structural engineer (whose services can be viewed as a type of "insurance" policy) can be a most unfortunate and potentially costly one -- far in excess of the cost of utilizing those services. Further, the decision cannot be justified, as sound and safe structures are in the best interests of all who are presently involved in earth sheltering or may be involved in the future.

Waterproofing and Insulation

Structural engineering may be the most important technical concern, but attention must be given to other details and specifications -- most notably those pertaining to waterproofing and insulation. Recovery for damages caused by the use of improper, substandard, or experimental products or methods will depend on who assumed responsibility in making those recommendations and/or decisions. Reliance upon an architect may again be relatively inexpensive, "insurance" protection for the prospective homeowner.⁶

The Builder

The builder of an earth sheltered structure is in a particularly vulnerable position with regard to potential liability. First, failure to build according to plans is an obvious invitation to problems. More often, the builder may be faced with a situation where he must assume responsibility for making critical decisions regarding details or specifications such as waterproofing, insulation, and structural engineering. An uninformed builder or one familiar only with traditional residential building may make inappropriate choices and incur liability for any damage that may occur as a result.

In light of at least one recent court decision, liability may also include damages for mental anguish as a result of improperly performed work that causes severe defects in the home.⁷ Furthermore, liability may extend to purchasers beyond the original buyer under an implied warranty theory.⁸

Home Tours

Finally, the homeowner conducting tours of his earth shelter should make certain that insurance coverage is provided at least for slip and fall accidents which might occur. Conducting regular tours of an earth sheltered home (particularly where there is an admission price) would probably be considered an activity which falls outside the scope of a traditional homeowners policy, and in some instances may be considered a business activity. Therefore, adequate insurance coverage is imperative.

Conclusion

As discussed previously, identifying these potential problems and their possible consequences are in no way meant to discourage earth sheltering. Rather, it is hoped that everyone -- particularly those offering products, services, and information that others may be relying upon -- will have a greater understanding and awareness of what may be involved. And most importantly, the participation of the prospective owner in the design and construction of the earth sheltered home should be undertaken with full knowledge of what is involved and hopefully will be limited to what the participant is informed about, qualified to handle and interested in doing.

Allan M. Ziebarth
President
EARTH SHELTERS, INC.
P.O. Box 52
Omaha, NE 68101
402/556-5252

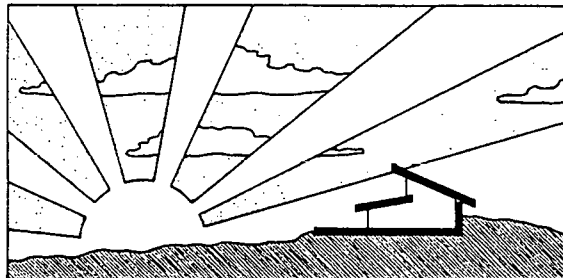
Footnotes

1. See, e.g., Walker, Walker, Rohdenburg, Legal Pitfalls in Architecture, Engineering and Building, (McGraw-Hill), (1979), at 3-4.
2. Id., at 31.
3. National Building Code, 1976, Recommended by the American Insurance Association, at 1.
4. See cases collected at 23 American Trial Lawyers Association Law Reporter 52 (March, 1980). Of special note, see Runkel v. City of New York, 123 NYS2d 485 (App. Div. 1953) and Smullen v. New York City, 268 N.E.2d 763 (N.Y. 1971).
5. In such case, the owner may be given the status of a builder. See the discussion regarding builders following.
6. Legal Pitfalls in Architecture, Engineering and Building, supra note 1, at 49.
7. B & M Homes Inc. v. Hogan, 376 So.2d 667 (Ala. 1979).
8. "Court Rules: They Can Sue You - Even If They Didn't Buy From You", Housing magazine, February 1980, at 14.

michael t. levy associates

February 28, 1980

Mary Rollwagen
TLH Associates, Inc.
4th & Cedar Streets
St. Paul, Minnesota 55101



Dear Mary,

Enclosed you will find my paper for the Earth Sheltered Housing Conference. I have conformed with all your requests and specifications (I even met the deadline!) with the exception of one. I have not used metric units for measurements included in the text.

This request crosses my principles or "better judgment". Although I appreciate the desire for "standardization" as a fine rational idea, I feel that it is a very poor intuitive idea.

The practice of architecture and building construction in this country has been functioning consistently on the standard of measurement of the English system for years. I use body measurements such as the foot and yard for estimating measure in the field when I am without tape on frequent occasions.

Personally, I have the feeling that metrication is being foisted upon us by Big Brother (multinational corporations) for their own selfish reasons and greed. It is specifically to do something positive about the problems created by this attitude toward "Spaceship Earth" that I have dedicated my practice in environmental design to passive solar and earth sheltered architecture.

I have enclosed an article by my colleague, Steve Baer, addressing this issue and articulating our viewpoint. I would like to suggest that if you insist on converting my primary measurements to the Metric system, you give "equal space" to the opposing viewpoint by printing this letter and/or Steve's article. I have no objection to your listing metric measurements in subtitles or parentheses after my primary units as shown in the English system.

Sincerely,

Michael T. Levy

Handwritten signature of Michael T. Levy

A DESIGNER'S FIRST EXPERIENCE
WITH TROGLODYTE SUBCULTURE
(An earth sheltered atrium plan residence with active
solar system utilizing unique construction methods)

Michael T. Levy
Associate AIA
Solar Designer
107½ West Berry
Fort Wayne, Indiana

presented for:

Earth Sheltered Housing Conference
April 9-11, 1980

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The Underground Space Center
of the
University of Minnesota

A DESIGNER'S FIRST EXPERIENCE
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(An earth sheltered atrium plan residence with active solar system utilizing unique construction methods)

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Associate AIA
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Fort Wayne, Indiana

1. Abstract

The project consists of a 1900 square foot residence built into a southeast facing slope. The plan configuration features an enclosed atrium courtyard which is open to the sky. Location of the building site is in northeast Indiana (41° North latitude, 6250 DD, 41% possible winter sunshine).

Heating, ventilating, and air conditioning are achieved by means of a solar-assisted water-to-air heat pump with woodburning auxiliary. A unique low-cost solar collector was built on the site by embedding PVC plastic water pipe in an exterior concrete wall with glazing cover. Thermal storage is contained in a 28,000 gallon insulated water tank located beneath the garage.

The building construction system consists of an unconventional thin shell sandwich wall of pneumatically placed concrete (shotcrete) and cavity filled with expanded polystyrene insulation board.

Evaluation is given of methods and processes, costs, performance, and second thoughts. A brief review is given of the designer's other earth sheltered projects in progress and solar and energy conservation products designed for production by local industries.

2. Introduction

The owners of the residence, Watson and Barbara Custer, are a middle-age couple both employed as school teachers. This home is the first one they have built. The design program for the residence was primarily to serve the needs of the couple, as their children are grown

and no longer living with the parents. The project budget was modest and economically minded.

↳ The involvement of the solar consultant on this project occurred by virtue of being the head of the architectural/engineering department for the corporation that developed and was marketing the innovative wall construction system which integrates solar design features. The owners had employed a stick-frame builder interested in solar and energy conservation who had formed a new partnership in order to develop the unique building system used in this project.

The owner became aware of earth sheltered architecture through his employment as the director of the media center at a local high school. A fellow teacher had recently occupied an earth sheltered home and requested assistance in documenting his experience. The owner became intrigued with the earth sheltered idea as its virtues began to sink in. This undercurrent surfaced when the owner returned home from school one evening and posed the weighty question to his spouse, "How would you like to live in an underground house?" This subversive inquiry eventually undermined their building plans and led to their reading Malcolm Wells' Underground Architecture, numerous periodicals, and eventually Earth Sheltered Housing Design.

The site for the house is in a rural setting north of Huntington, Indiana. Their acreage is surrounded by typical Indiana corn and soybean fields, rural homesteads, and more recent ranch houses. The owners chose a site with a moderate sloping hill facing a little east of south. The home itself is oriented with the solar collection wall facing due south.

3. Architectural Design

The plan of the house is basically a square with sides forty-nine feet long. The center of the plan contains an atrium courtyard (21' x 24') which is open to the sky. The atrium is a private outdoor living space and includes a built-in barbecue grill. All of the habitable rooms surrounding the atrium have major window or door areas onto the courtyard for natural light and ventilation. This plan results in about 1900 sq. ft. of living area.

The west wing contains the master bedroom suite and living room. The living room itself features a conversation pit (10' x 10') facing the fireplace. There is a free-standing stove in the master bedroom also.

The north wing contains the dining room (11' x 12'), kitchen (10' x 12'), a half bath and a utility room. The main entrance to the house is through the atrium and into the living room or kitchen. There is a service entrance off the utility room to the attached two car garage. Another door serves as a separate entrance to the guest bedroom from the atrium.

The east wing contains a walk-thru study or extra bedroom (12' x 12'), full bath, and guest bedroom (12' x 15'). The circulation problem that atrium plans generally pose in this harsh winter climate is solved satisfactorily in this program because the walk-thru study only needs to be used as a bedroom for temporary situations.

4. Wall Construction

The unique wall construction of this project utilizes a sandwich wall consisting of 3" of concrete on both sides with 4" of polystyrene beadboard insulation in the center. The concrete used is high density pneumatically placed reinforced concrete (6,000 psi, "shotcrete"). The wall can best be described by outlining the step-by-step construction process.

First, a wall "stud" is assembled on the job site by placing #3 reinforcing bars into 1 1/4" x 7 1/2"-12 ga. steel wall ties located at 2'-0" o.c. and hammering the rolled end of the ties shut to wedge the rebar in place. This is done on a jig table. A wall tie with a base plate is used at the bottom of the "stud".

This wall "stud" is then secured to the concrete slab foundation by shooting a concrete nail thru the base plate and into the foundation with a power driven gun. Two foot wide boards of 4" thick beadboard are then placed between the studs located at two foot centers. The insulation board butts tightly to the wall ties leaving only a .10 inch gap. These insula-

tion boards are held in place by shoving rebar horizontally behind the vertical "studs" and fastening them to the vertical rebars with special metal clips.

At this stage all the solid building walls are standing in place composed of insulation board. Wherever a window or door opening is required, the insulation board is cut out with a keyhole saw and the rebar is clipped out. Window and door frames and headers consist simply of extra horizontal rebars shoved in place eliminating the cost of extra structural framing. In this way, free spanning arches or any shape wall opening may be cut out. Also, since concrete is a plastic material, rounded and curved walls may be constructed for little or no additional cost.

The mechanical systems are strung on the bare wall (electrical, plumbing). The electricians may make the runs up ahead of time and need not be on the job site when masons or carpenters are working. Trades people may easily pierce the wall for mechanical runs by using their pocket knife or a keyhole saw. Mistakes may be corrected by simply replacing the polystyrene bead-board material. After this, a structural wire mesh is stretched over the rebar frame. The wall is then ready to receive the concrete which is sprayed onto the wall by means of a hose from a concrete pump.

This construction method was devised to render improved thermal performance and reduce labor time, skill, and effort thereby resulting in cost savings for above ground construction. The Custer residence is the first use of this system for earth sheltered construction.

Structurally, this construction is extremely strong (allowable load = 20,350 lbs/ft. of 8' high wall) and impervious to fire, moisture, and deterioration. Thermal performance of the mass-insulation-mass sandwich wall is superior to conventional wall systems because it eliminates the stud or concrete block web member penetrating the insulation core which results in considerable conduction heat loss. The monolithic concrete slabs on each side of the insulative core provide thermal damping, totally eliminate infiltration, and provide the desired thermally isolated mass on the interior.

Labor required to construct this system is entirely unskilled. The physical labor expended by the work crews is minimal -- one person can carry about 100 sq. ft. of wall (insulation board) in a single trip. There are no heavy materials to transport or scaffolding or formwork necessary. It does not even require electrically powered tools to successfully erect major building shells. The concrete is sprayed on by the hose operator and is considered the most fun part of the sequence. These labor benefits combined with the increased ease and speed of construction result in substantial savings in construction costs.

5. Roof Construction

The roof structure begins with 12" steel bar joists located at 2'-0" on center. The end bearing is achieved on a 3" x 3" x 1/4" transverse angle iron welded to the vertical reinforcement bars of the walls. On top of this is laid a corrugated galvanized 26 gauge steel roof deck. Four inches of polystyrene beadboard is placed on the metal deck before a 4" concrete topping with wire reinforcing mesh is poured. Next, the waterproofing membrane is applied, a vapor barrier laid down, and 4"-6" of pea gravel put in place. A layer of straw was placed on top of the gravel to prevent the soil from washing into the gravel until settling had occurred. The final operation was to put 18" of topsoil on top of the roof sewn with grass seed. The earth covering was tapered to 15" at the perimeter walls to give positive drainage. Later, 2 1/2" of polyurethane foam insulation was sprayed to the underside of the metal deck before a gypsum board ceiling was applied to the bottom chords of the roof joists.

6. Energy System

The Custer Residence achieves heating and cooling for thermal comfort by means of five components: active solar collection, water thermal storage tank, water-to-air heat pump, woodburning auxiliary, and passive elements. The active solar collection is incorporated into the south facing exterior concrete wall. Before concrete is sprayed onto the wall, 1/2" PVC plumbing pipe is placed vertically at 6" o.c. and connected at

top and bottom with 1 1/4" PVC headers. After the concrete encases the solar plumbing, the wall is painted black, glazing channels attached, and a windscreen (fiberglass reinforced acrylic sheeting or other) applied.

During the heating season, a comparative thermostat activates a pump from the storage tank whenever the temperature in the solar wall exceeds the tank temperature by 5°F. Freezing of water in the solar wall plumbing is prohibited by the thermal lag of the concrete wall and gravity drain down in case of power failure.

The thermal storage tank is located under the floor of the garage. It is 24' x 28' x 5 1/2' deep and is capable of holding 28,000 gallons of water. The side walls of the tank are of the same sandwich wall construction insulated to a value of R-20. The ceiling over the thermal tank (garage floor) consists of a vapor barrier, metal roof deck, 2" of beadboard, and 3" concrete slab supported on concrete columns and lintels. On the inside wall of the tank an additional 2" reinforced concrete wall is added for positive protection against leakage. The floor of the tank is an uninsulated 4" reinforced concrete slab. The storage capacity of the water tank in conjunction with the heat pump allows for a 60°F. temperature differential yielding about 500 BTU's per gallon of water -- or a total capacity of 14 million BTU's when fully charged.

The thermal transfer between living space and water storage tank is accomplished by means of a water-to-air heat pump and complimentary ductwork and plumbing. The unit used has a rated capacity of 26,000 BTUH in the cooling mode and 33,000 BTUH in the heating mode. The energy efficiency ratio (EER) of this unit for cooling is 9.8 and the coefficient of performance (COP) for heating is 3.0. It is coupled with a 900 cfm fan and 5 gpm water pump. Throughout the summer, the heat pump air conditions the living space as required. The heat which is drawn out of the air is transferred to the water tank to charge it to a maximum 110°F. The minimum tank temperature to allow efficient operation is 45°F. During the winter heating season, heat gain stored from the summer is drawn out of the storage tank to heat the living space.

Supplemental auxiliary heat is provided by three wood-burning units. There is a small free-standing stove located in the kitchen. The main fireplace in the living room has a fan activated heat recirculator box and contains a hydro grill which circulates heated water back into the main storage tank. There is also a free-standing fireplace in the master bedroom. The potential for passive solar assistance exists by closing in the interior atrium.

The owners intend to add skylight glazing and a paneled wrought iron gate to the front entrance when their budget permits. This additional 600 sq. ft. of collection area will provide approximately 100 million BTU's of passive solar heat per heating season. Also, the atrium will then become livable space all year long.

7. Waterproofing and Insulation

All of the earth covered walls and the roof are sealed with an experimental waterproofing membrane specifically formulated for concrete application. This product is of the latex silicone rubber elastomer nature. It can be thinned with water prior to curing and is applied by spraying. Common tub and tile caulking is similar in characteristics.

In addition, the entire earth covered portions of the house were wrapped in a double layer of 6 mil polyethylene with the seams tarred. Drainage tile was placed at the perimeter of the atrium parapet, horizontally at the top of the exterior walls, and a second row at the bottom of the wall. Vertical drainage tiles connect these at 8' to 10' on center. The atrium slopes to three built-in planting areas and toward the entrance. Perimeter drainage tile connects these.

Insulation value for the 10" sandwich wall construction is R-20. The roof provides an R-35 insulation rating.

8. Costs and Performance

Use of an innovative building construction system en-

gendered its own risks and costs. Construction time for the house took over a year (August 1978 - September 1979) and it is still only 90% complete. The original new construction partnership foundered. One partner attempted to finish the job and performed inadequately. In a rush to complete the concrete spraying, the solar plumbing wall was entombed in concrete before the pipe joints were tested for leaks. This has resulted in the active solar collector system being inoperable. To complete construction, the original builder has been rehired at an additional cost beyond the building contract price. Costs for the residence to date are about \$80,000 or \$42.11 per sq. ft. of living area. This figure is about 10% more than a comparable quality above ground conventional home for this locale. The owners claimed the maximum tax credit for alternative energy property of \$2,200 off their 1978 Federal tax liability. No incentives exist for alternative energy utilization in the state of Indiana.

The owners exceeded their contract budget allowance for interior furnishings in virtually every room. The insurance rate for the home is based on fire resistive (masonry) construction resulting in a \$44.00 per year savings or a 12% reduction. The insurance agent feels the premium basis is not fair for an underground home. He admits that a total fire loss could not possibly exceed half the value of the house (interior furnishings), yet there is no special allowance by the insurance carrier for earth sheltered homes.

The owners report a public health inspector checked the drainage and sewage provisions, but they have never seen the building inspector (nor do they wish to). They had no trouble obtaining a conventional mortgage from their local bank. This was attributed to their good reputation and rapport with the loan officer, the fact that the bank held the mortgage on their previous residence, and their use of Malcolm Wells' book and other articles to educate the lender.

Total electric energy use for the residence for October 1979 - January 1980 has averaged 2265 kilowatt hours or \$97.71 per month. All of the appliances and water heating are electric which accounts for about \$50.00 per month of the bills. Therefore, for the 2 months the heat pump has been operating

the space, heat cost amounted to \$52.14 for December and \$93.53 for January. This figure is equivalent to about 50% of the energy use of a well insulated conventional house above ground. The owners came to the conclusion that their heat pump is defective when they discovered their storage tank water temperature had dropped to 38°F. Of course, the storage tank was not charged up from summer heat gain, the solar wall was not recharging the storage tank, and the fireplace was not able to keep up with the heating load. To date, they have used about 1 1/2 cords of wood in the fireplaces.

9. Owner Satisfaction and Second Thoughts

The owners are quite satisfied with their earth sheltered home in spite of the difficulties they have encountered. The owner complained of being tired of painting his previous home frequently in the summer. He has traded this for splitting wood in the winter -- which he thoroughly enjoys.

Neighbors and friends who have not visited the home think of the residents as cave dwellers and ask, "isn't it dark?" This gives way to surprise and shock when they visit the Custer residence and experience how nice it is and how much natural light the interiors are blessed with. One overweight lady who imagined trap doors and ladders inquired, "How do you get into it?" The owners' relatives like the house and are fascinated with the idea. They consider their troglodyte relatives to be "brave".

The owners themselves project quiet confidence and commitment in their decision. They exhibit a great deal of pride in ownership of their underground home and graciously entertain the multitude of curious visitors. Their biggest pleasant surprise in occupying the earth sheltered house was the quietness it affords. They never realized how noisy an above ground building is. Even the movements of occupants within the house is less audibly distracting. They mentioned that their daughter played the stereo and they were unaware of it until she informed them the next morning.

The psychological comfort afforded by the security of earth sheltering has positively influenced the owners. Mrs. Custer recalled not even being aware of a severe wind storm until a wind spout of leaves blew into the courtyard. Complaints by the occupants were limited to the wind funnel effect into the atrium entry and the discomfort in attempting to achieve proper control of the heating system.

Problems with the house other than those already mentioned are relatively few. The clothes dryer exhaust tube was causing condensation thru the sealing. This has been remedied by installing a self-venting kit and ducting the exhaust into the return air plenum.

There has been minor moisture spotting following heavy rainfalls on the ceiling below the parapet wall enclosing the atrium which retains the earth on the roof. This detail is to be avoided in future designs. The wind funnel effect in the atrium will be easily solved when the plexiglas covered wrought iron entrance gate is installed.

The energy system is not yet satisfactory as has been pointed out. However, at the time this residence was in the planning stages (1977) everyone involved had only vague notions about the implementation and effectiveness of passive solar design. Fortunately, the hybrid and diversified energy systems available in the design give the owners assurance that performance can only improve considerably with further refinements. The enclosure of the atrium will most certainly be cost effective as well as aesthetically beneficial. The owners are also considering the cost effectiveness of installing active solar collection on the south facing exterior wall as was originally intended.

10. Conclusions

From the designer's viewpoint, the future use of two major components is seriously questioned. The unique sandwich wall construction is of dubious value in comparison with solid poured concrete walls for underground construction. While this system is an excellent solution for above ground buildings,

its cost and performance record for underground is questionable. For approximately the same initial cost, 8" poured concrete walls insulated on the exterior would result in more than double the amount of interior masonry thermal storage mass available to the structure. The heat pump, solar wall, and massive water storage tank could be omitted except where a building program requires absolute temperature and humidity control. Current designs by this author are emphasizing the use of passive solar components and design practices rather than active systems. The wall construction system as built in this project does not provide properly for thermal breaks in the concrete at corners, edges, and extensions.

The unfinished state of the building exterior at this time emphasizes the glaring need for landscaping on earth sheltered buildings. The aesthetic elements of above grade construction such as building mass, form, proportion, color, etc. must be replaced with landscaping for underground architecture. While this designer considers landscaping an integral part of above grade building design, it must be considered a major component of earth sheltered buildings. Landscaping for earth sheltered buildings is the aesthetic component of the classical architectural formula, "firmness, commodity, and delight". If we omit delight, we can not aspire to artistic success.

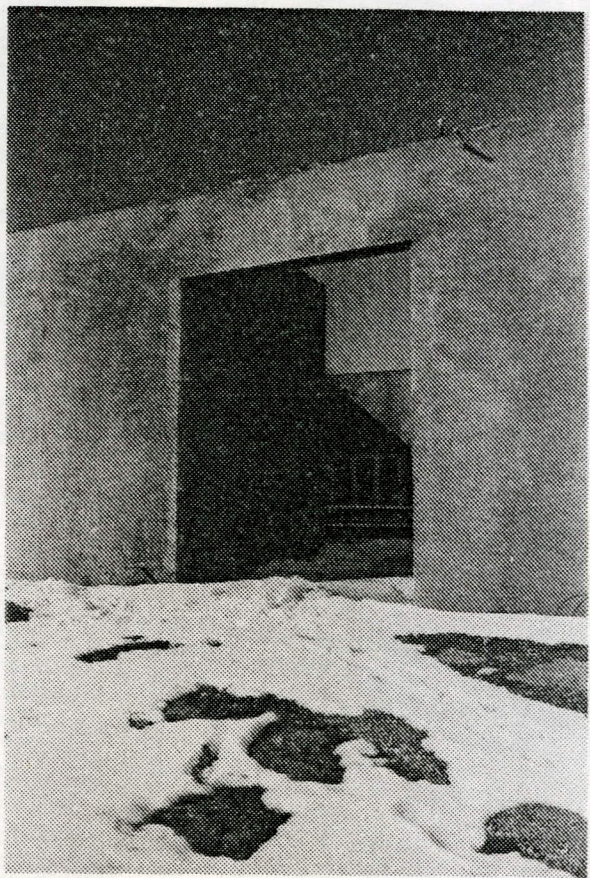
The presentation of this paper at the conference also includes examples of the sandwich wall system used quite successfully in existing above ground buildings. Current projects under development by the designer in earth sheltered passive solar housing will be shown. Also, solar and energy conservation products which have been designed for a local manufacturer will be illustrated including "Suntap" low cost window and wall mount passive solar collectors for existing buildings. "Sunstor" architectural waterwall thermal storage modules for space and water heating, "Heatsoc" heat recirculators for decorative lighting, "Insail" moveable insulation for large windows and sliding doors, "Suntap" solar chimney vent, and "Earthtap" earth/air heat exchanger.

In conclusion, it is perceived by the designer from

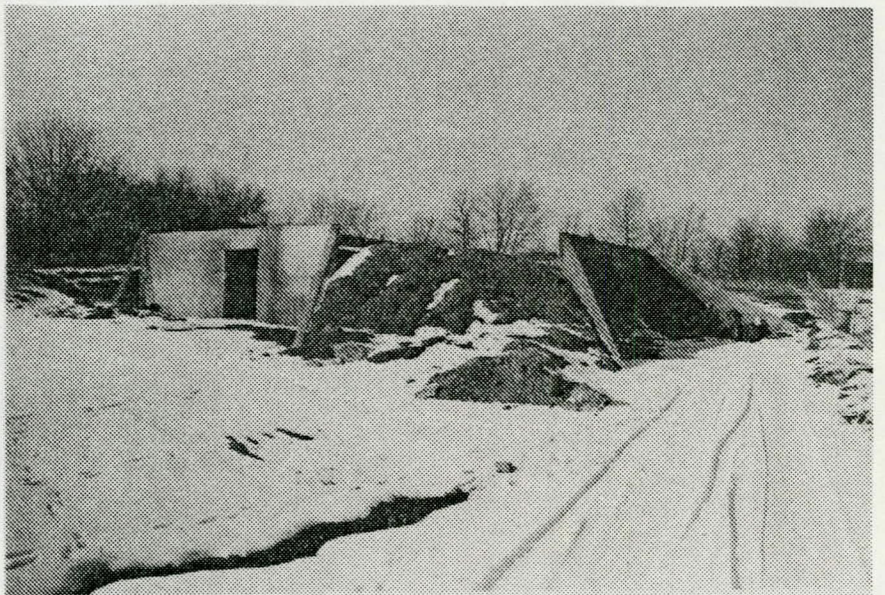
this first experience in the subterranean realm that the acceptance of society for earth sheltered housing will definitely be affected by the successes or failures of technology. However, the major dragon in peoples mental dungeons is lifestyle considerations. Equally, or perhaps more important than technology, will be the attitudes of early underground home owners which reflect the quality of their lives.

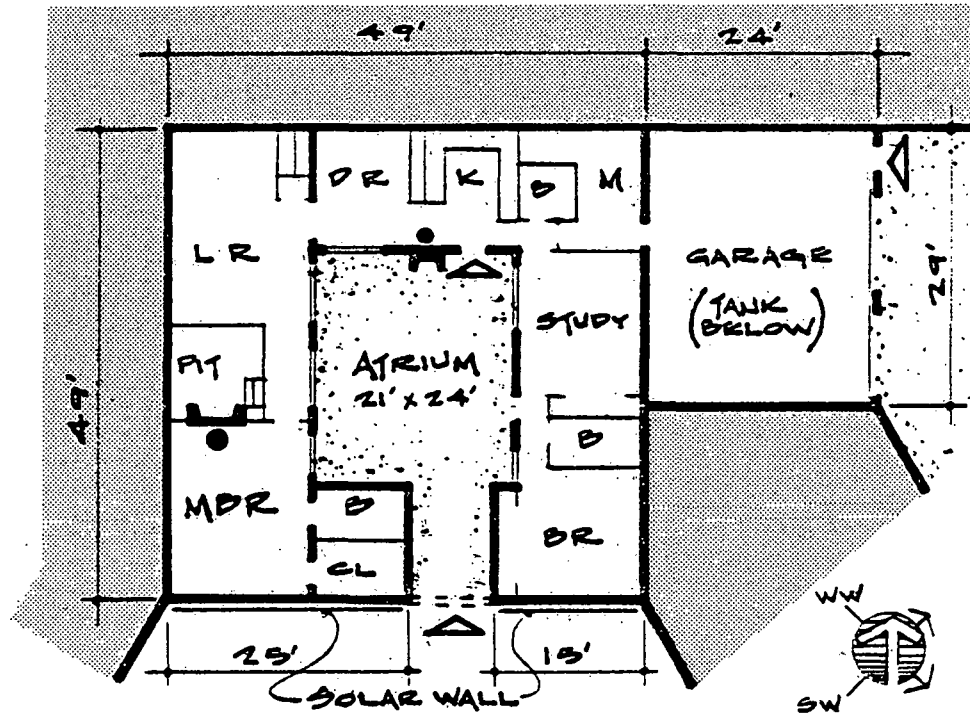
For further information, contact:

Michael T. Levy
Michael T. Levy Associates
107 1/2 West Berry Street
Fort Wayne, Indiana 46802
Telephone: (219) 422-6287



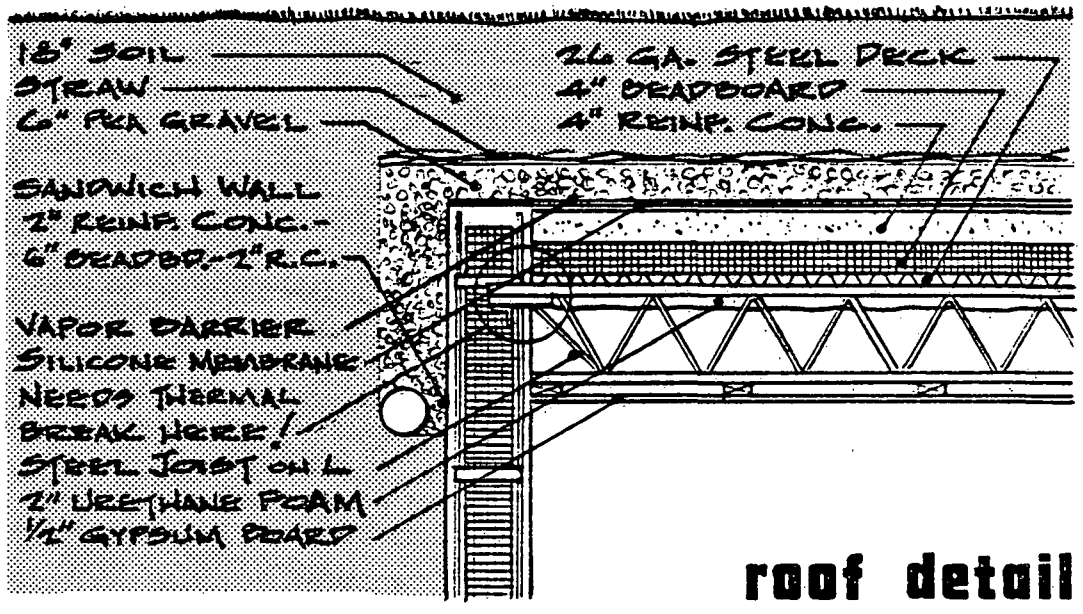
153





floor plan

M.T. LEVY ASSOCIATES
PORT WAYNE, INDIANA



roof detail

RESTRICTIVE COVENANTS: A BARRIER TO EARTH SHELTERING?

ALLAN M. ZIEBARTH
President
EARTH SHELTERS, INC.
Omaha, Nebraska

Most persons interested in earth sheltered housing are aware of and concerned about the impact of such legal concerns as zoning ordinances and building codes on earth sheltering. Although legislative action may be necessary to solve the most difficult problems,¹ the general consensus would seem to be that code and ordinance requirements are at most obstacles -- rather than barriers -- to earth sheltering; it is generally possible to design in conformity to the requirements, obtain a variance, or get those requirements modified or changed.²

Fewer persons interested in earth sheltered housing are aware of, let alone concerned about, the impact of another legal concern -- restrictive covenants -- on earth sheltering. The problems posed by restrictive covenants have not yet been addressed, notwithstanding the fact that our experience indicates that restrictive covenants may and do function as barriers, as certain provisions common to most housing developments may effectively prohibit the building of an earth sheltered structure. Moreover, it is effectively impossible to change or modify those provisions. Therefore, earth sheltering enthusiasts must be concerned about restrictive covenants when they purchase property; waiting until it is time to design and build may be too late.

This paper will examine restrictive covenants and their impact on earth sheltering to help the prospective earth shelter designer and builder avoid the problems with restrictive covenants and to aid developers and others in writing restrictive covenants that will encourage, not discourage, earth sheltering.

RESTRICTIVE COVENANTS IN GENERAL.³ Restrictive covenants are private land use restrictions, in the sense that they are binding between private persons or businesses, as opposed to governmental entities. Generally they restrict the use, the structures, or the activities on a particular piece of property. In this sense, restrictive covenants are not unlike the more familiar

zoning ordinances, which are public land use restrictions. The covenants are written to conform to zoning ordinance restrictions, however covenants usually tend to be more comprehensive and restrictive.

Lots in most, if not all, subdivisions are generally subject to restrictive covenants, which are usually created when a tract of land is first developed and a general building plan is established. The covenants control the character of a neighborhood in order to achieve a desired degree of uniformity. Purchasers of property subject to covenant restrictions become bound by those restrictions by virtue of the purchase, and the deed to the property will recite this fact. For example:

"lots...are and shall be owned and held under and subject to the covenants, conditions and restrictions set forth below."

The deed will also contain each of the covenants or will refer to a separate document recorded in the land records which contains the restrictive covenants which bind the property.

If a property owner finds a particular covenant objectionable, he may seek to change it. Provisions providing for modification of covenants are very often included:

"The covenants are to run with the land and shall be binding upon all parties and all persons claiming under them until January 1, 19__, at which time said covenants shall be automatically extended for successive periods of ten years, unless by vote of a majority of then owners of the lots, it is agreed to change said covenants in whole or in part."

From a practical standpoint, however, changing covenants may prove to be extremely difficult at best.

Failure to change the objectionable covenant leaves the courts as the only recourse to change the restriction. The courts may also become involved in a restrictive covenant dispute in the event a proscribed activity takes place and another land owner in the subdivision seeks redress:

"If the owner of any lot or their heirs, successors or assigns, shall violate or attempt to violate any of the covenants herein, it shall be lawful for any owner of any lot involved herein to bring any legal proceeding against such person violating or attempting to violate such covenants either to prevent him or them from so doing or to recover damages or other compensation due for such violation; but this instrument shall not be construed as placing any liability or obligation for its enforcement upon the undersigned. Invalidation of any one of the covenants by judgment or court order shall in no way affect any of the other provisions, which shall remain in full force and effect."

Subject to limitations -- such as being unconstitutional or contrary to statute -- the court will enforce restrictions to the same extent that it would lend judicial⁴ sanction to any other valid contractual relationship.

Developments in the solar energy field may help to illustrate how restrictive covenants operate and what problems they pose for the utilization of conservation measures and renewable energy resources. A number of cases regarding restrictive covenants preventing the installation of solar energy systems have arisen.⁵ Covenants forbidding the placement of appliances on roofs, or requiring all roofs to be made of cedar shakes have been used to prevent the installation of roof-top collector systems. The results have been varied -- from solar users not contesting the covenants to courts upholding the restrictions. One interesting and positive court holding occurred in California where the Los Angeles Superior Court held restrictive covenants to be "invalid and unenforceable to the extent that they prohibit the roof-top installation of solar collector plates."⁶ The Court based its holding on its finding that the restrictive covenants (and the subsequent action of the Architectural Committee) were "contrary to and violates the public policy of the State of California to encourage the use of solar energy systems."

RESTRICTIVE COVENANTS AND EARTH SHELTERED STRUCTURES.

Research failed to reveal any situations where covenant restrictions affecting earth sheltered structures have been tested in court -- the ultimate determination. In the absence of any of this hard data, we cannot be absolutely certain about their effect.

Knowing how restrictive covenants operate in general, we can, however, make some reasonable assumptions about the difficulties that may be encountered. Among the more obvious is the definitional problem of the term "basement" in the following provisions:

(a) "No trailer, basement, tent, shack, garage, barn or other outbuilding erected in the tract shall at any time be used as a residence, temporarily or permanently, nor shall any structure of a temporary character be used as a residence."

(b) "Dwellings shall be restricted to the following minimum square foot ground floor areas (exclusive of garages, breezeways, porches and basements."

Especially troublesome are those covenant restrictions which delegate broad authority to Architectural Committees as in the following:

(a) "Foundation walls shall be constructed of brick, concrete block or poured concrete. If constructed of concrete block or poured concrete, such walls shall be faced or veneered on all front and side elevations, with brick or stone or any other product approved by the Architectural Committee."

(b) "Any grade change exceeding 18 inches must have the approval of the Architectural Committee."

These two provisions would have particular applicability to earth sheltered structures and approval of the Architectural Committee would probably be necessary in both instances.

The most difficult type of provision to deal with may be the following:

"No building, fence, wall, signboard or other structure shall be erected, altered or placed on any building plot on the aforesaid lots until complete plans, specifications and plot plan showing the location of such building or improvement have been approved in writing by the Architectural Committee of _____ Association as

to use, conformity and harmony of external design with existing structures, topography and finished ground elevation."

As a complete set of engineered plans is expensive, few people would be willing to spend the money if they do not own the property. However, the plans are necessary to get a decision from the Architectural Committee.

RECOMMENDATIONS. In the absence of court decisions or legislative action (both of which are highly unlikely in most states in the near future) prohibiting covenants which unduly restrict earth sheltered residences, the prospective lot buyer must be fully informed about earth sheltering and restrictive covenants. In some instances it may also be necessary to rely on the services of someone with the knowledge and expertise to provide competent legal counsel. It is important to consult an attorney in the purchase of any property, and it may be imperative in the purchase of property subject to restrictive covenants when the intent is to build an earth sheltered home. A determination of the effects and enforceability of the restrictive covenant provisions should be made. Such a determination would have to be specifically requested and, to be of value, it is essential that the person providing the opinion be knowledgeable about earth sheltering in general and fully informed of your plans specifically.

Uncertainty and potential conflict can be eliminated, of course, by seeking property in a development with covenants that specifically allow for earth sheltered structures. In that regard, developers or others planning developments or subdivisions for energy efficient structures should ensure that competent draftpersons prepare the governing covenants. Terms, such as "basements" and "earth sheltered structures" should be defined, and earth sheltered structures should be specifically referred to.

This kind of proper planning could make restrictive covenants a boost to earth sheltering, and eliminate their negative effect on this new and exciting concept for residential construction.

ALLAN M. ZIEBARTH
President
EARTH SHELTERS, INC.
P.O. Box 52
Omaha, NE 68101
402/556-5252

1. Swenson, Gregory S., "Zoning Ordinances as Obstacles to Earth Sheltered Housing: A Minnesota Perspective", Underground Space, Vol. 3, No. 4, January/February, 1979, pp. 165-174.
2. See generally, The Underground Space Center, "Cost and Code Study of Underground Buildings", August, 1978; Earth Shelter Digest and Energy Report, July August, 1979, pp. 4-7; "Code Change Followed Up", Earth Shelter Digest and Energy Report, September/October, 1979, p. 22.
3. The law with regard to restrictive covenants is highly complex and varies somewhat from state to state. It cannot be covered in depth outside of a legal treatise. Thus, our discussuion here will necessarily be oversimplified.
4. Covenants, Conditions and Restrictions, 20 Am. Jur. 2d § 182, note 15.
5. Solar Law Reporter, Vol. 1, No. 1, May/June 1979, pp. 8-10, pp. 20-22.
6. Id., p. 8.

(161)

STEEL REINFORCED CONCRETE SHELL STRUCTURES:
FORMING TECHNIQUES, STRUCTURAL DESIGN, AND
EARTH SHELTERED APPLICATIONS

MICHAEL SULLIVAN, GEOSPHERE INCORPORATED

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INTRODUCTION:

This paper is based on the construction of an experimental earth sheltered structure by Geosphere Inc. (a non-profit research organization) during the summer of 1979. Described herein are the details of the actual construction process as well as some projections of uses for this process in a full scale solar heated dwelling.

The test structure is a 6.1 meter in diameter ellipsoid (eccentricity .75) constructed of steel reinforced concrete. This structure is covered by no less than 20 cm. of earth and sod on top and no more than 1.5 m. on the side.

The primary purpose of constructing this building was as a test of a previously untried (at least by us) construction method. The structure was built with private funds from the members of Geosphere Inc. and no grants or organizationally backed loans were received. The Renaissance Festivals Inc. were extremely helpful by providing a lot, access to earth moving equipment and landscaping materials.

For further information contact:
Geosphere Inc. c/o Michael Sullivan
295 Summit Ave. St. Paul, Minnesota 55102

FORMING TECHNIQUES:

Concrete shell structures have been constructed using a variety of forming techniques with development forming with earth and wooden forms being those most commonly in use. Geosphere Inc. has developed a modular system of fiberglass reinforced plastic concrete pouring forms which have many advantages over other systems.

These forms consist of inner and outer molds which are broken down into grids of individual units fastened together. The forms are very light (they can be erected by hand- no crane is required) and strong as well as being resistant to breakdown by water and the alkaline chemicals in cement.

Because these forms are modular there is great flexibility in placement of penetrations as well as in the overall dimensions and configuration of the completed structure. The forms can be used many times and are easily transported thus facillitating actual mass production of shell structures. Geosphere Inc. has designed a full scale solar heated structure which is believed to be a very efficient configuration although other configurations are possible with the use of these forms.

The actual construction process consists of the following steps:

1. a footing is poured with re-bar dowles protruding
2. inner forms are anchored to footing
3. re-bar is tied over inner forms and to footing
4. outer forms are erected in concentric rings and the space between the inner and outer forms is filled with concrete before the next ring is attached
5. inner form is vibrated periodically to remove voids
6. top of structure is poured and troweled off
7. curing of concrete and eventual removal, cleaning and reuse of forms

STRUCTURAL DESIGN:

The structural design of our prototype structure was done by Dr. Ladislav Cerny, University of Minnesota Department of Civil Engineering. This was done primarily by hand calculation.

The prototype ellipsoid shell is 11.5 cm. thick with two layers of #3 reinforcing rod. The reinforcing rods are laid out in a grid with a maximum spacing of 30.5 cm.. The grid follows a "longitude/latitude" pattern with a 1.9 cm. cover on the inner and outer surfaces and a 3.8 cm. spacing between layers. Additional reinforcing with #4 bars was used around openings. The shell was attached to the footing by pairs of #3 bars spaced every 15.24 cm.. The building is designed for an earth cover of 45 cm. on top plus a 600 kg./sq. m..

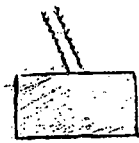
Static load testing of the structure is planned to take place early in the summer of 1980. Concrete samples taken during construction were found to be over or reasonably close to the designed strength of 226 kg./sq. cm..

The full scale structure to be constructed by Geosphere Inc. during the summer of 1980 has also been engineered by Dr. Cerny and is similar to the prototype in the placement of reinforcing rods, concrete strength and designed loading.

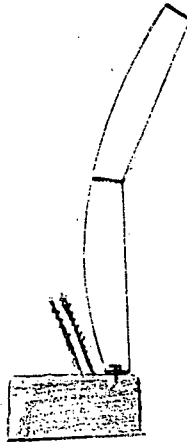
EARTH SHELTERED APPLICATIONS:

Because of the versatility of the forming system designed by Geosphere Inc. a variety of structural configurations are made possible. The full scale structure soon to be constructed consists of two half ellipsoids connected by an elliptical vault with a large penetration in the south facing portion of the vault. Because the forms are modular "capsule" shapes of varying length can be constructed. Structures With a half ellipsoid and a vault section open on the vault end would be ideal for a garage. Because these are shell structures there are no interior bearing walls, thus allowing complete flexibility of interior floor plans. The buildings have curved roofs so a natural looking berm form is possible. Also the curved roof allows for excellent drainage and control of runoff.

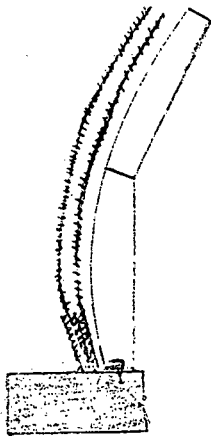
The primary advantage of this structural system is that, with practice, the shells could be constructed in much less time than rectilinear, flat roofed earth sheltered structures. This mass production capability may bring earth sheltered homes within the financial reach of many middle income families that are presently priced out of the market. The ideal application for these forms is in a multi-unit development because transportation of forms is minimized and construction costs could thus be cut significantly. Also the versatility of interior plan allows for a wide range of finishing possibilities including totally owner finished interiors. It is felt by the members of Geosphere Inc. that steel reinforced concrete shell structures could revolutionize the earth sheltered housing industry as well as greatly expand the market for dwellings of this type.



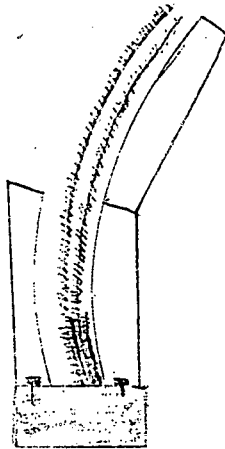
STEP 1



STEP 2



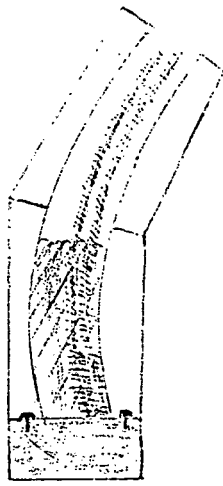
STEP 3



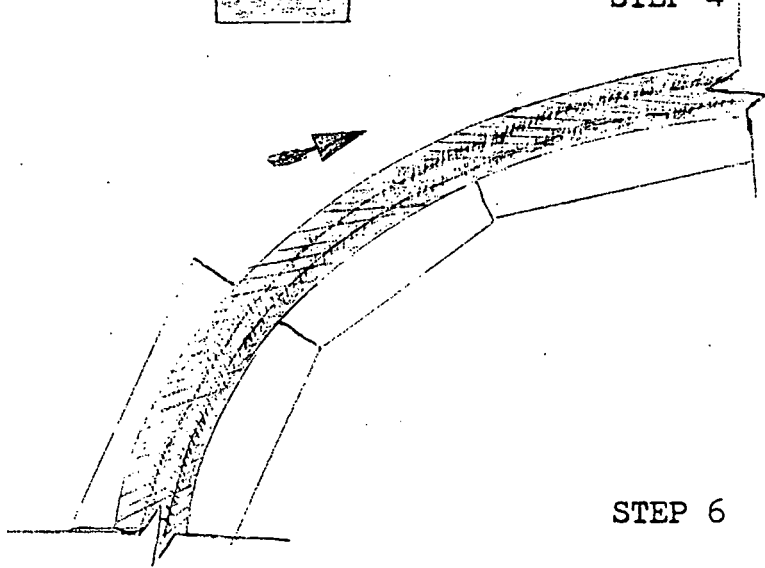
STEP 4

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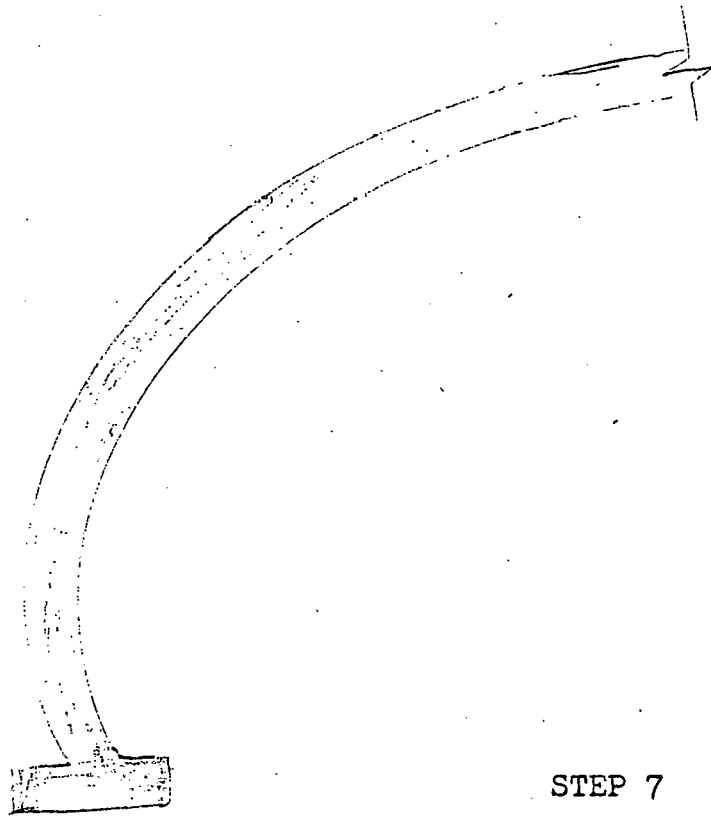
fig. 1 (cont.)



STEP 4

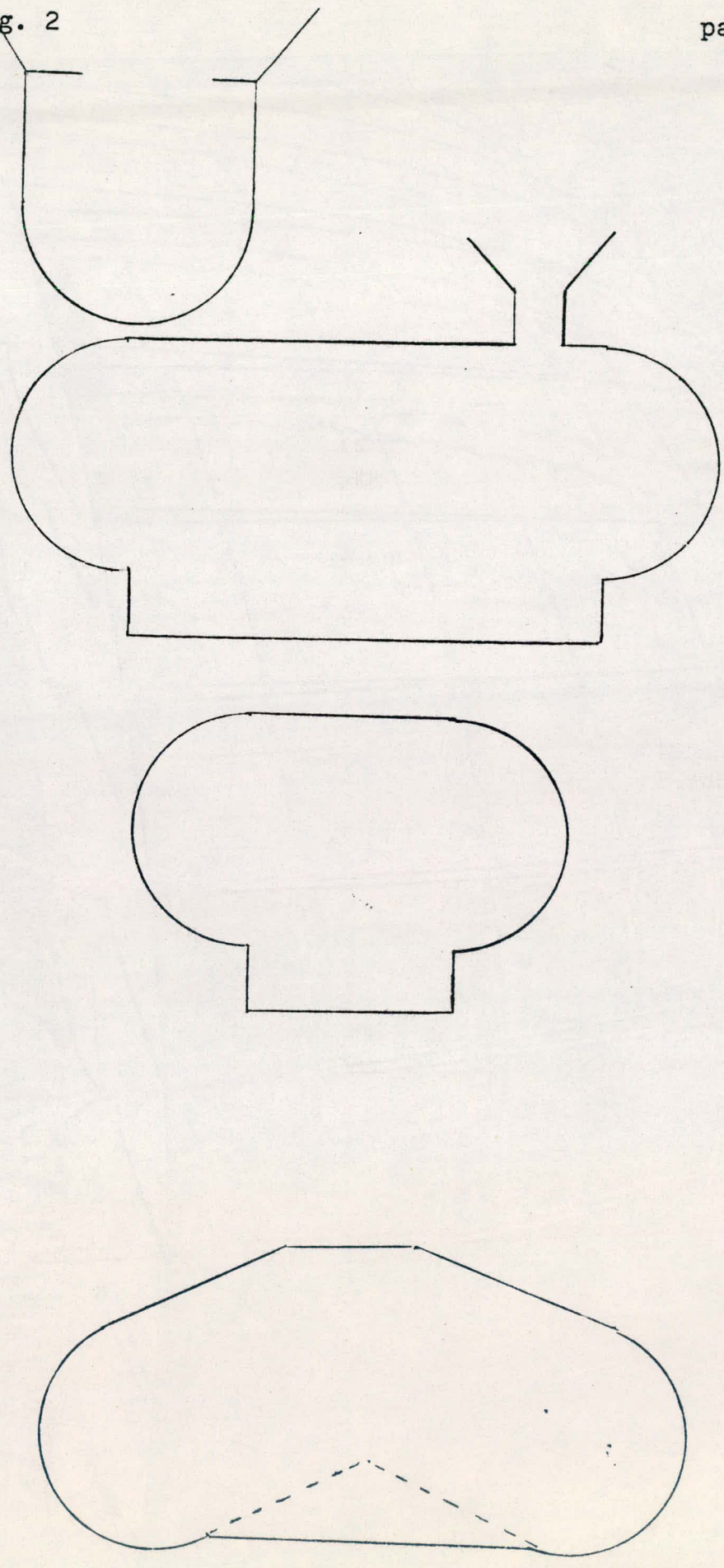


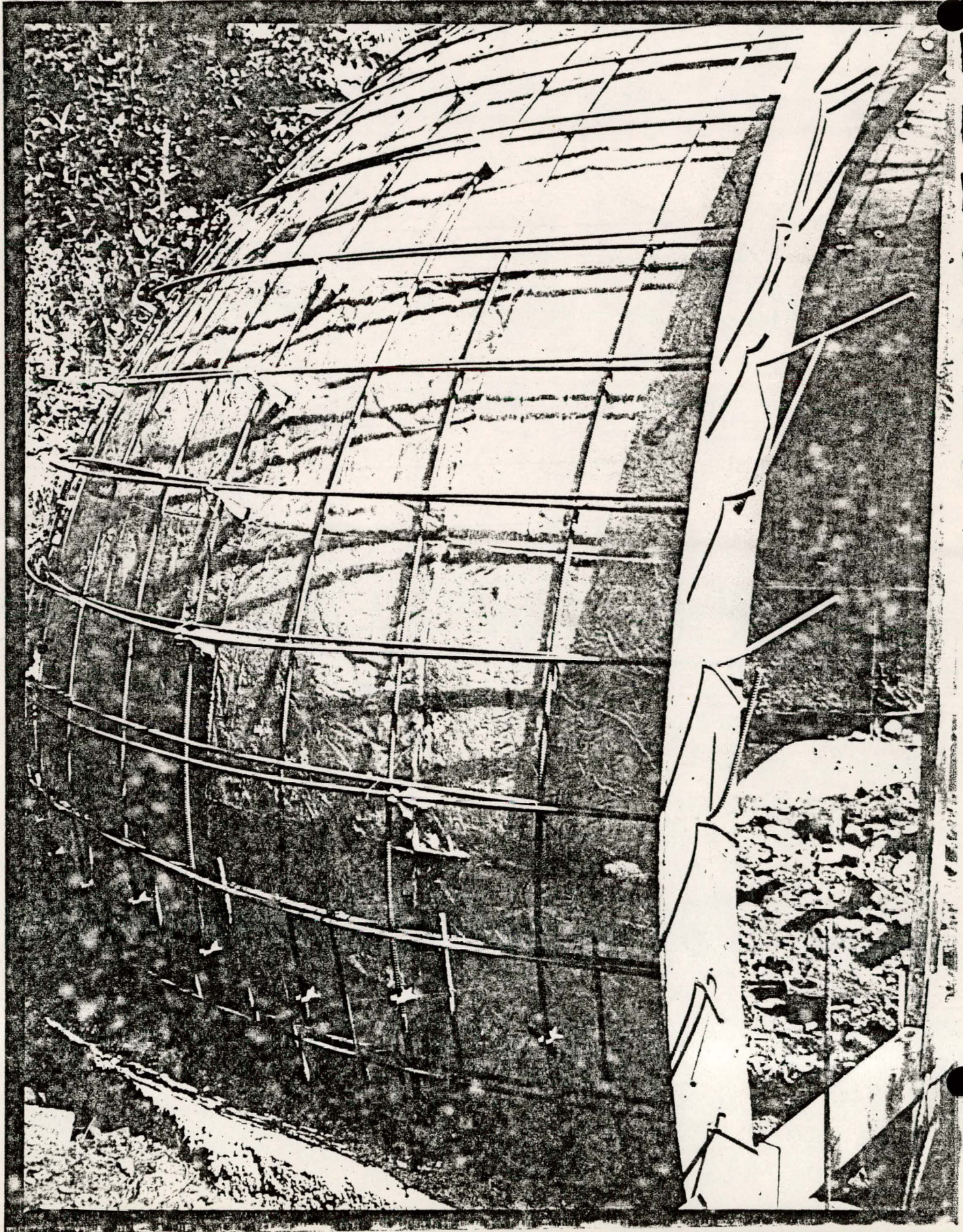
STEP 6

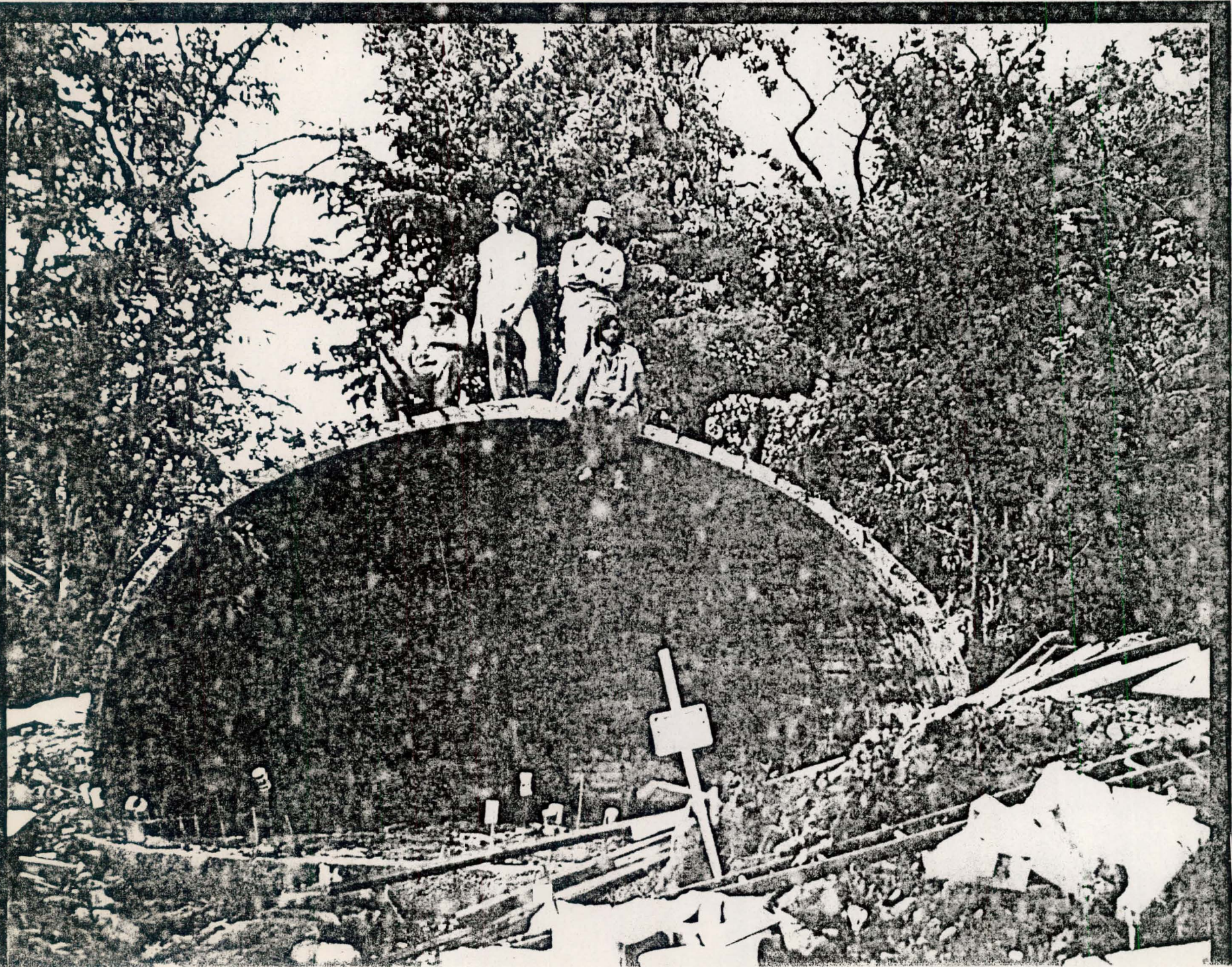


STEP 7

fig. 2



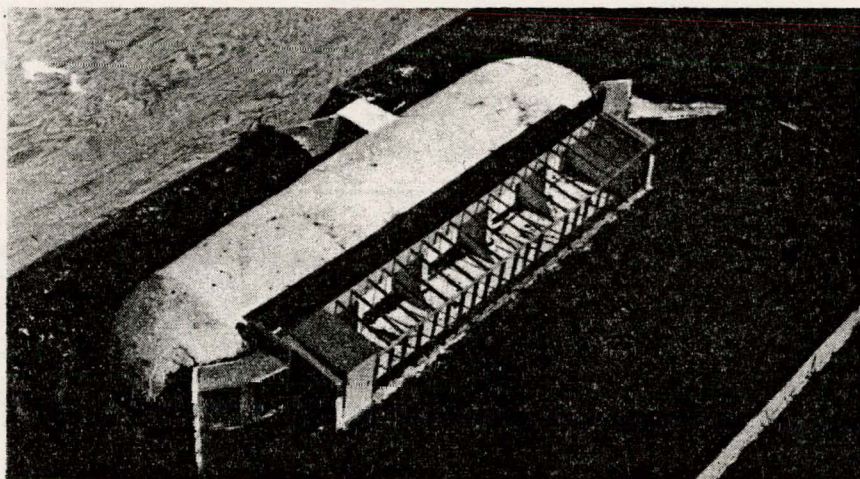




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fig. 5

page 9



EARTH SHELTERS BY INFLATION FORMED THIN SHELL DOMES

By

Mert Hull - Tecton Corporation

This presentation will bear directly upon the utilization of Inflatable Form Moulding of Thin Shell Concrete Domes for earth sheltered construction purposes.

We will allude only briefly to the inherent design strengths of the simple and/or compound curved structures. Our main thrust will be to present a method, which is patented, for constructing a thin shell concrete structure which is both time and material conservative. The advantage of this structural method and the gains to be derived by the Architect/Designer and builder utilizing this procedure will become evident.

Persons involved with the design or the placement of structural concrete are aware of the relatively low strengths of concrete for applications other than straight resistance to compression loads. And even in applications where loads are basically compressive, steel reinforcement is an important concept in concrete design. The simplest concrete design concept for a space enclosing structure is recognized as a dome - a hemisphere. This is especially true when the structure is to be subjected to heavy external loads. Particularly those loads associated with earth sheltered housing. Both vertical and horizontal earth loads are dispersed as compression stresses throughout the entire shell of a concrete dome structure.

The more conventional concrete systems utilized for earth sheltered structures require large masses of concrete and steel to withstand the forces imposed by the earth cover - both side and top cover. Whether these structures be poured in place or assembled of precast sections, most all make use of linear shapes which are then subjected to bending stresses. And bending or beam stresses must be resisted with steel reinforcement. Whether the labor is applied on site or in a manufacturing facility, the costs for time and reinforcement material are substantially higher than they would be for an equivalent dome structure.

A dome structure, however, requires very labor intensive framing procedures or somewhat costly prefabricated forms to receive on site application of reinforcing and concrete. If forms are built on site, they must be removed and physically rebuilt even if another unit of the same size is to be erected. If prefabricated forms are utilized, much erection time is saved. But a relatively expensive form set is required for each structural configuration. Special handling equipment is also required.

The inflatable form solves a number of problems. First it is light weight. A 20 Meter (65 Foot) diameter form can be easily handled by two men. And it can fit into a box of about 1/2 Cubic Meter

(15 Cu. Ft.) and weighs about 265 Kg (120 Lbs). No special handling equipment is required.

Second, the form can be erected very quickly by two men. The inflatable form is first spread out over a conventional footing shaped to the configuration of the building. The bottom edge of the form is secured to the footing. One or two conventional squirrel cage blowers are started and the form is "blown up". This total procedure would take two men less than half a day. Blowing up the form takes only a matter of minutes.

Third, the form is reuseable. Two men and a couple of hours can remove the light weight balloon from a structure and stow it back in its small box and slide it into a pick up truck - ready for use at the next site.

Fourth, the per use cost of the balloon form is quite low as compared to other forming systems. Both as compared to cost of material and or handling equipment and the cost of labor.

Fifth, the inflatable form system is adaptable to a wide range of structure sizes and shapes. Conceptionally, ground level floor plans may be round, elliptical, oblong or special configurations. Elevation shapes can be hemispheric, elliptical, parabolic or a combination of compound curves. They may be half sections such as a hemisphere or truncated sections - 3/8 or 5/8 sphere or ellipse for example. Sizes may range from 7 Meters (Approx. 25 Feet) or less to well over 30 Meters (approximately 100 feet) in nominal diameter. Structures in this range of sizes and formed by this method are currently in use. A maximum size is hard to guess at. Certainly diameters of 90 Meters (approx. 300 feet) could be well within the capability of the system.

The patent referred to earlier in paragraph two applies to the forming system and its method of use. The method of use explained in the following paragraphs is the real key to what we believe is the great advantage to construction of earth sheltered housing using this patented method.

With the form inflated, the first step is to spray on the INSIDE of the form a layer of polyurethane foam. This foam layer can be applied to whatever thickness is required to provide the insulative value desired. The spray application of urethane foam is a well established industrial insulation process now being incorporated into residential construction. Equipment and chemicals are available from a number of sources. Most metropolitan areas have contractors specializing in foam application.

Spraying foam on the inside of the inflated form provides a smooth surface against the form - a surface which will become the base for weather and waterproofing the outside of the structure.

Of even greater importance is the fact that working on the inside, nearly complete weather protection is provided. Rain, snow, cold, ice or whatever is outside the working area. It is evident that if you

need only 2 or 3 hours of weather without high winds to first inflate the form you gain materially from being able to work from then on in your own protected environment.

The next step is to place door and window bucks in required locations. Then electrical conduit and boxes are secured to the inner face of the polyurethane wherever perimeter electrical service and feed lines are planned. All this work is being accomplished inside the insulating polyurethane shell!

Then you Shotcrete a concrete mix containing steel fiber reinforcing against the inside of the polyurethane. In doing so you are applying the concrete structural and thermal mass and the reinforcing all in one operation. The concrete is built up to whatever thickness is required to satisfy the structural and thermal mass requirements. For most residential structures, this thickness is approximately 5 Centimeters (approximately 2 inches). So this is truly a thin shell concrete dome. Very conservation minded in its use of both concrete and steel reinforcement materials. Yet very strong. Tested cores indicate 5,000 to 8,000 psi for the placed concrete! Engineering indicates structure load capability in excess of 1500# per square foot!

Imagine, if you will, the scheduling and time advantages available when your concrete work is done inside a Dome of polyurethane insulating material - especially if the weather turns bad. It is also very comforting to know that your concrete is curing inside an insulated weather excluding structure.

When the concrete shell has cured, the interior surface of the shell may be treated in whatever manner is desired. The concrete itself will normally have a very pleasing textured surface. This textured surface has amazing capability in break up the reflection of sound. However, acoustic materials may be added. But remember that it is not desirable to add any significant amount of insulative material because it would restrict the heat mass and heat leveling characteristics of the concrete. The interior concrete surface is often simply painted. Plaster or stucco like finishes can be applied if desired. Experience to date has indicated that this extra expense is not justified.

At this stage windows and doors may be installed just as they would be in a conventional building. The inflatable form is usually removed at this time, for windows and doors complete the structure's own weather seal.

The exterior of the structure is then ready for the application of whatever materials have been specified for weather, ultraviolet ray and waterproofing protections. The readily available urethane elastomers and other industrial coatings can be sprayed directly on the surfaces which will be exposed. These coatings will be very effective in protecting the polyurethane foam from weather and ultraviolet degradations. They are also excellent waterproofers for exposed surfaces. The bentonite waterproofing processes can be very effectively used on the surfaces which will be earth covered. It is not our intent to prescribe one only method of outside surface protection and waterproofing. But rather to indicate that industry standard materials are readily available for these purposes.

It should be pointed out that the very shape of a compound curvature (Domed) structure which is totally monolithic on its exterior surface goes a long way toward preventing water penetration problems. No flat or depressed basins occur. Therefore, there is no place for water to accumulate. No pooling of water to accelerate the decomposition of protective materials. Hence no need for special control of backfill or covering soils to provide water drainage ways. Water just naturally flows downward along the surface of the shell to ultimately reach the drainage system provided at the footings.

Perhaps the most outstanding advantage of the inflatable form dome structure for earth sheltered housing is its capability to provide completely free span interiors. There are no needs to provide interior structural walls or posts usually required to support both heavy structural and earth cover loads. The total interior space is open to be used by the Architect/Designer to create space utilization in any manner he wishes. The opportunity is also present to combine the vertical and horizontal curvatures of the structure with interior flat plane or curved design elements. Very interesting - certainly not the old time worn rectilinear-design concepts are easily incorporated.

Air tempering considerations for the inflatable form dome structure are no more difficult of execution than in any other structural systems. In fact, the natural-shape induced-circulation significantly aids in effective even temperature distribution. From a practical viewpoint, this shape almost totally eliminates stratification of air. Dome structures as high as 24 feet have demonstrated temperature differentials as low as 4° F. top to bottom. The earth tempering, the concrete heat mass leveling and the insulative layer act just as they would in any other earth shelter design.

The dome structure adapts very well to solar assist heating systems - either passive or active. The structural integrity of the sprayed, steel fiber reinforced, concrete shell has an amazing tolerance for penetrations of the shell for light, ventilation, access or passive solar heating applications. The structural design within this concept can accommodate penetrations either very small or large enough to permit a semitrailer truck to enter. Ground level penetrations of about 19 Meters (60 lineal feet) of periphery have been accomplished! That would allow for a lot of passive solar windows.

You might think that a curved perimeter does not expose any significant surface directly to the south. That is true. However, the specialists in passive solar design have determined that glass facing either 25° east or west of south still receives about 90% of the available solar radiation. (A passive solar design expert might see some real advantage to placing his glass around part of a curved perimeter.)

The incorporation of the mechanical systems, HVAC, plumbing and electrical, into these structures follows the same methods used in conventional construction. The only exception being the need to plan and place the electrical service required on the periphery wall.

There have been other systems for utilizing inflatable forms for constructing buildings incorporating compound curved surfaces. These systems have applied materials to the outside of the balloon

form. One reason that not much has been done with these systems is that the very act of spraying concrete or other materials against the outside under the pressures required at the point of impact tend to indent and deform the inflated form. The end result has been less than desirable for many uses. This is especially true where concrete is desired as the final inner surface material - the location required for this heat mass if it is to be effective.

In the most elemental analysis, the inflatable form dome structure system offers simple solutions to many of the problems related to most earth sheltered housing construction systems. A few of these simple solutions are:

1. Forming is simple, quick and cost effective.
2. Structural materials are applied quickly and with great conservation as relates to quantity of material.
3. Very high structural strengths are obtainable at very moderate cost.
4. Exterior finishes and waterproofing are easily applied and can be expected to have very long life.
5. Internal design can be completely free in intermediate structural elements.
6. System is very adaptable to utilization of solar energy.
7. System is free of most weather limitations during construction period.

Although construction by this Inflatable Form construction method is currently controlled under existing patent, information relative to a license to use the system is available from:

Tecton Corporation
4714 Templeton Gap Road
Colorado Springs, CO 80918

Telephone (303) 599-9535

EARTH SHELTER DESIGN REVIVAL:
WHO'S BUILDING WHAT, WHERE?
KATHLEEN VADNAIS, EDITOR
EARTH SHELTER DIGEST & ENERGY REPORT

There are two ways to look at the earth sheltering phenomenon: one is from the safely cynical viewpoint, that all this underground talk is a lot of nonsense-- a passing fad that will settle down any day now.

The people who say this are most ready to laugh about caves and bats and bug-eyed earth dwellers with little comprehension of reality.

The other way to look at earth sheltering is from the positive, informed viewpoint. This is the perspective of the design form's proponents who have met the enemy and conquered it, so to speak.

That is, they have looked at this little bubble of cheap energy the past couple of generations have experienced and then looked into the future and concluded that energy and environmental conservation alternatives are vital if the species wants to survive.

One of those alternatives for shelter is cooperating with the earth, not conquering it. This can be done by borrowing the security of the earth blanket and pulling it around the house, instead of leaving it huddled against the wind, rain, snow, noise and vandals. By looking the problem in the eye and dealing with it unflinchingly the earth shelter advocate ends up with a realistic approach to the future.

And anyone who would be inclined to mutter, giggle or poke fun would be the only person in the dark. While the earth shelter folks work with nature with their last laugh trailing behind.

I'm approaching the earth shelter phenomenon--and that's the only way I can describe this new interest and awareness--as a journalist. And I have to admit, I've been caught up in the enthusiasm and commitment of the owners, builders, architects, engineers and students. I consider the magazine to be a national forum available to anyone who has an experience to share.

Just who are the readers? And who are the people who are seriously considering earth sheltering? I've already brushed aside that foolish group of people who ignore change and live only for today.

That means the people I meet are involved with earth sheltering and are able to ignore sneers and keep their sights set without wavering.

Without benefit of a formal market study it appears that earth shelter proponents can be categorized somewhat loosely as being very aware of the world around them, and very willing, resourceful and determined to do something about the problems. Sometimes their interest is not only for themselves--meaning their pocketbook and comfort--but as their part in the greater scheme of things.

One study was done in Minneapolis testing the market for a proposed earth shelter townhouse development. The people polled had already responded to the ad for the townhouses. Although the sampling was small (under 30), some conclusions could be drawn. I ran a summary of the study in our first issue.

It points out that the people are actively seeking an energy efficient home with many other advantages. They have a "high awareness of the world around them. Most are professional people who are articulate and have definite preferences. They read for relaxation, listen to public radio and watch educational television. Energy and environmental conservation come across as major reasons for purchasing earth sheltered homes.

"The majority of those questioned would look for conventional financing. About one fourth would work through FHA or VA.

"This group is specifically interested in the townhouse project being built in Minneapolis--a project uniquely blending energy and environment in an urban setting. Over one half hadn't considered anything else they'd looked at.

"Most respondents desire the earth sheltered townhouses because they would put them within five miles of work, near stores, in a diverse neighborhood, on a bus line, near parks and schools--all in a setting of quiet buildings requiring little maintenance."

This was the first, last and only attempt at a formal poll of earth shelter buyers, leaving any questions about the real market and its potential unanswered until our own Earth Shelter Data Bank is computerized, this year we hope.

However, I do have a barometer to go by now, and it's with me every day of the week, and has been for over a year. That's the interest in the magazine which has become a focal point for earth shelter information. The people I talk with come from all walks of life, all ages, and all corners of the map.

Articles are written in a semi-technical style because we try to give something to every type of reader, from the person just discovering earth sheltering right up to the professionals who are earning a living from it. It's a little hard to break down the readership, but I'd say it's about a third people who are looking (including lenders, realtors, appraisers) a third contractors and builders, and a third professional designers and engineers. Somewhere in there is the group who've already built their homes and are sitting in them snugly right now.

The circulation of the magazine may give you another perspective on the market. The first issue got started from my kitchen last January. Issue No. 1 started with a bang; we had 2,400 subscribers on our first mailing. There were three of us handling the inquiries, and I was trying to follow up on the interest we'd tapped. People couldn't seem to get to us fast enough to tell us about their project or research. And I've been in the enviable position of having enough copy for the next issue ever since that initial burst.

Since August 1979 we've been printing over 10,000 copies of each issue and mailing to people in all 50 states, 9 foreign countries and 2 ships at sea. That's no small jump in circulation, clearly demonstrating the strong interest in earth sheltering.



By publishing we seem to have struck a nerve. Our confidence in the continuing interest is demonstrated by the fact that I have been full time since last April (prior to that I'd retained a position with the Minnesota Energy Agency as Press Aide). Our Earth Shelter Data Bank is about to be computerized, and we have a variety of professional help contributing to the magazine, a secretary since January of this year and a university intern. An advertising team is just beginning to tap into the huge and very interested list of potential advertisers with products relating to earth sheltering, including concrete suppliers, building expertise, energy items, and earth shelter plans and franchises.

Those of you who have read our publication have seen the map of earth shelters we've run. That has grown with us, and every time I hear of a new structure I write or call, so I can verify the report, and we can see the extent of earth sheltering and also the distribution across the map.

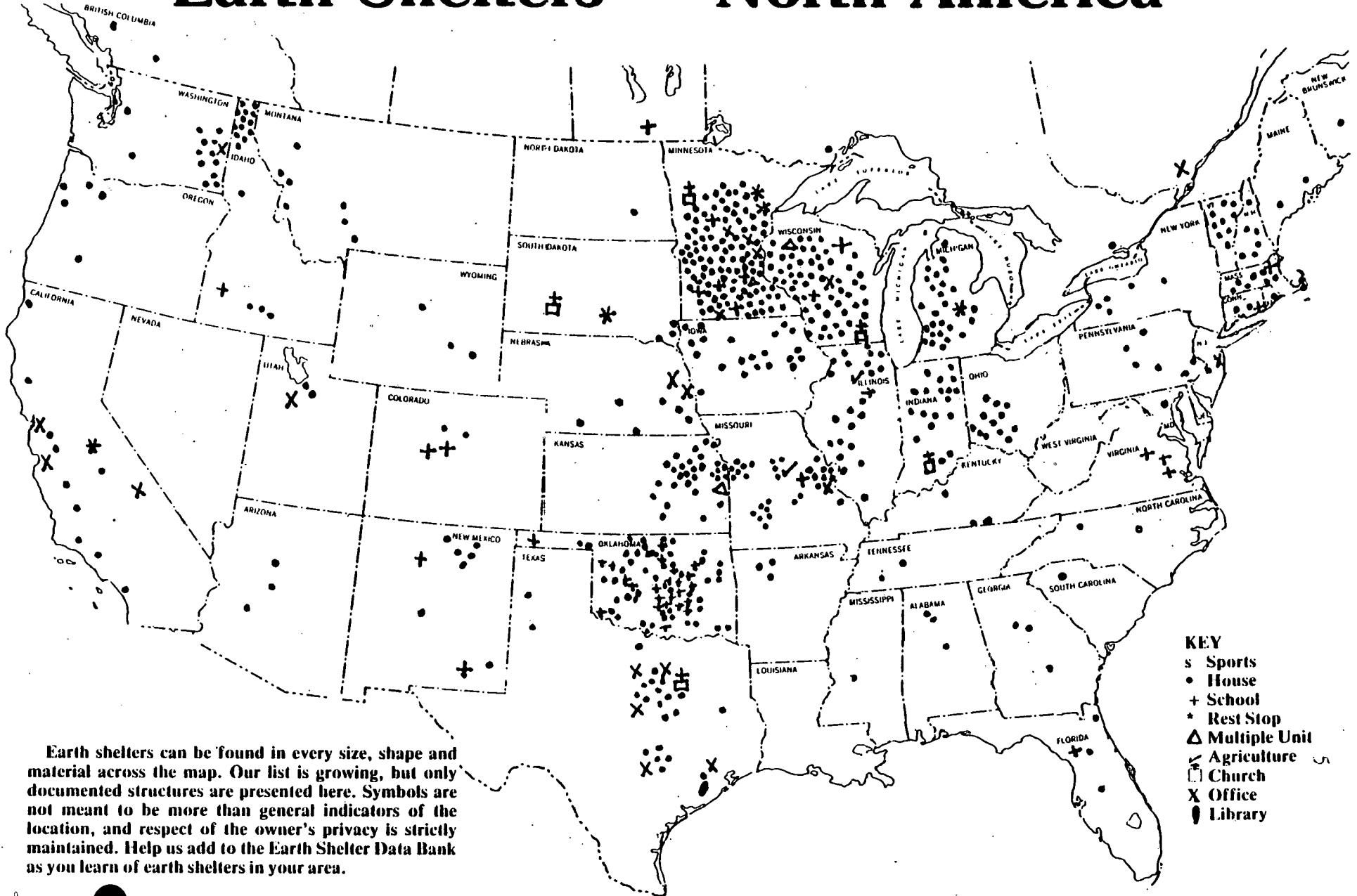
My luck in locating so many has not only been a result of aggressiveness, but also because I guarantee strict confidentiality to all earth shelter owners. I don't waiver in this, even though many reporters, educators and other reputable sorts have asked me for names and addresses of people in earth shelters.

Most of the owners of private homes don't want publicity. Initially, they cheerfully welcomed their local newspapers and then suffered through the subsequent crowds, usually numbering in the hundreds, until they probably wished they could cover the final side of their earth covered home to avoid the tourists.

Our map of earth shelters (even out of date at press time in December 1979) gives you a good idea where the pockets of interest are. And I think the proportion will be fairly constant. The heaviest interest in this design form is not coming from the coasts, as trends often do in this country. Rather there's a distinct concentration from Minnesota right down to Texas. The heartland of the country is where the groundswell of activity is occurring.

I can't account for the big three--Minnesota, Wisconsin and Oklahoma--states leading in earth sheltering in numbers. I do know that Oklahoma has the most earth sheltered schools because of the tornado protection they offer, but the newer schools are being earth sheltered with energy savings as a goal. The extreme temperatures and severity

Earth Shelters – North America



Earth shelters can be found in every size, shape and material across the map. Our list is growing, but only documented structures are presented here. Symbols are not meant to be more than general indicators of the location, and respect of the owner's privacy is strictly maintained. Help us add to the Earth Shelter Data Bank as you learn of earth shelters in your area.

- KEY**
- s Sports
 - House
 - + School
 - * Rest Stop
 - Δ Multiple Unit
 - ⌘ Agriculture
 - ☐ Church
 - X Office
 - Ⓛ Library

of winters in Minnesota and Wisconsin may account for the activity there. It could be the energy considerations both states suffer from, being at the end of the energy pipelines, and conservation is critical.

Earth shelter interest seems to be running high everywhere. I could almost pick up the phone to any state and obtain information on structures already up (or down), contractors getting into it, and professionals with experience.

There is no lack of contacts. There are people building in the states with 100 degree annual temperature swings, and those in arid lands in the south where cooling is the main concern

Not only is there technology beyond our pioneers' sod huts, but interest, and it's blossoming.

Types of earth shelters range from homes (residential is the main application), to schools, libraries, offices, churches, rest stops and multiple units. You'll find established firms have designed earth shelters for crowded college campuses such as the new sports center under the football field at Georgetown University, also the domed underground office plaza for Mutual of Omaha in Nebraska, the shopping mall of underground Montreal, the townhouses, animal barns (with claims that the animals produce better in the stable environment), and others. There are earth sheltered highway rest stops along interstates, a natural for blending into the landscape; and a county maintenance building in Oregon with no need to be above ground.

Construction is being done mainly with reinforced concrete, either poured or sprayed, block, or precast panels (for the roof, and, in some cases, for walls), but also with wood and other techniques. Designs are aesthetically innovative and range from one to two stories with earth cover or conventional roof.

Every day I talk with people who have just discovered earth sheltering. They range from the backyard putterer to the serious engineer who's considered the problems of the universe until he came upon this one viable "answer."

So they go ahead and sketch out their plans, take them to a lender, and watch him as he tries not to laugh out loud. And if their loan application is rejected, they somehow scrape up the resources and courage to build an earth shelter. Then they try not to laugh out loud when the mobs start coming to see the "answer" for themselves.

Sometimes a contractor gets involved, and after he's done he decides this isn't such a stupid idea. Once cooperation is established, the costs, which seem to run around conventional custom construction costs, are a little more under control. Occasionally a partnership is created, and a new earth shelter company is on its way.

I know of about six companies that got started something like that, and now they're in on the ground floor of a growing business, franchising dealerships for earth shelters, complete with plans, consulting help, troubleshooting and model homes. Many more custom homes have been built as a result of early examples, and developers are getting rolling.

So there are people getting into earth sheltering not just as a habitat, but as a business. Those who saw potential early are now the pioneers, and they're in demand for their experience and headstart. Most of them are not only building homes for clients, but they're making sure they have a model open for the throngs who "just want to get inside one." There are many earth shelters on the market being spec'd for sale by builders with faith in the demand. The next step is full development of earth shelters.

Right now I'm aware of several developers who have land and some contracts for the beginning of entire subdivisions of earth shelters. The impact of this will be to lower the building costs because it's less expensive to have crews work on more than one house at a time. The braver developers have already built an earth shelter to spec, and if they were caught since the money tightened, they're using the home as an office and model and charging for tours, with admission between \$1 and \$10. Be ready to stand in line if you attend an open house. We had a tour last fall and ended up with three bus-loads. One owner reports he had 7,500 visitors in three days.

The interest extends to the suppliers who are meeting the demand by offering pertinent product information since they've discovered this new market. Some of them are even cooperating in promotions through home shows, such as in Minneapolis, Chicago, Kansas City and elsewhere, giving attendees a chance to walk through an earth shelter model built right in the auditorium. In Des Moines this season, a bus transported people from the energy show to a nearby earth shelter every 15 minutes for \$1.

Conferences are jam packed with earth shelter enthusiasts. An array of energy groups, educational and commercial organizations are sponsoring programs on earth sheltering for anywhere from an evening to two days and even to several weeks worth in courses. People are paying from \$6 for a day of lectures to \$245 for a program billed for professionals. Our conference listing page is replete with events occurring around the country, and I probably don't have half of them listed.

Lenders, appraisers and contractors are beginning to attend these programs. This is encouraging because these are the people I see as the inhibiting factors to a real surge of earth shelter activities. I constantly get calls from people asking for the name of a sympathetic lender in their area. Sometimes I can help them, but usually I give them the most successful formula for getting a loan--that is to have plans carefully designed and engineered before trying to talk to a skeptical loan officer. That seems to make the difference in getting the nod, presuming the applicant's credit checks out.

The secondary mortgage market has already handled earth shelter loans, so that's not an excuse with well-designed and presented projects. And certain FHA offices have processed loan guarantees. I've written on both these subjects in the magazine, trying to explain what's happening and attempting to take the mystique out of the financing process.

This has been a quick view of earth sheltering from an independent perspective. Maybe it's helped you understand that there is an acute interest in alternative shelter and a better way of life implicit in it.

I sense a strong desire to get away from the traditional construction techniques of raping the landscape and weighing down and obliterating the ecosystem we all depend on.



AN AFFORDABLE, EARTH SHELTERED, PASSIVE SOLAR HOUSE

David S. Marcum
Hobbittat, Inc. *Lexington, KY*

Abstract

The incorporation of earth shelter and passive solar heating techniques can easily result in a range of 80% to 90% efficiency in heating requirements. This can easily be accomplished with the proper considerations of design, material, thermal storage and glazing sizing. These considerations, due to their simplicity, can result in a house being built at 60% to 75% of the current cost of conventional housing. With a 25% to 40% saving in capital investment and 80% annual saving in the fuel bill, over the life of the mortgage a homeowner could save an amount equal to or greater than his investment.

A 2700 sq. ft., 2 story house, using these methods, will be discussed. This house is earth sheltered (18 ft. east and west walls and 22 ft. north wall) and has a conventional roof.

Introduction

This house was constructed from February to November 1978 by the owners, Sam and Dee Swain, and this author acting as general contractors. The excavation, concrete work, wiring, plumbing, and drywall bids were awarded to local subcontractors.

Design and Materials

In the design of this house we wished to accomplish energy efficiency in a method that would be acceptable and affordable to the average home buyer.

Energy conservation being paramount, an earth sheltered house was the most feasible alternative. The Swains choose a two story configuration which necessitated poured-in-place concrete walls. However, with our initial cost objectives in mind, we elected to use a wood roof structure (2 x 6 joist, fiberglass insulation) rather than concrete and earth cover due to the cost of overhead concrete placement and survey reports that indicated that less than 5% of the people shopping for homes in our area would consider purchasing an earth "covered" house.

Heating

Heating is accomplished from a direct gain through 156 sq. ft. of thermopane windows on the south facing, lower level. An additional

27 sq. ft. of skylights gives light to the upper level. The glazing area represents 14.7% of the floor area.

The auxiliary heat is supplied via a Vermont Casting Wood Stove.

The thermal mass storage for this house is 100 cubic yards of concrete in the 10" walls and 4" floor slabs. The entire structure is insulated on the outside with 1" of styrofoam.

The winter of 78-79, the total auxiliary heat was provided in the form of 4000 lbs. of seasoned oak firewood.

Cost

The total cost of this house was \$20.37 per sq. ft. This price reflects a \$7000 cost overrun on the concrete work contract.

Conclusion

At the time the house was built, comparable conventional housing in our area was averaging \$34 per sq. ft. This represents a \$36,700 difference in initial investment.

A check of four homes in our area that ranged from 2600 to 2800 sq. ft., revealed an average annual fuel bill of \$1200. With this as a comparison, it can safely be assumed that an additional \$1000 per annum can be saved.

The presentation will include full illustration and blueprints.

David S. Marcum
Hobbittat, Inc.
1705 Leestown Road #116
Lexington, KY 40505

SELLING EARTH SHELTERED HOMES

(Meeting the public and marketing earth sheltered Townhouses for Seward West Redesign, Minneapolis, Minnesota)

This past year I have worked with Seward West Redesign to help market twelve earth sheltered Townhouses. The Townhouses are located near downtown Minneapolis and border on a busy interstate freeway. This project was completed in September, 1979, and we opened a model to the public at that time.

During the first weeks of open house hours at the model we were literally inundated with people. An average of 500 people a day were coming to see the Townhouses. By the end of December, I estimate that 10,000 or more had come through one of our open houses. Interest in earth shelters is running high because there is concern about rising energy costs. The energy saving features of earth shelters are becoming better known and people want to see what this kind of home looks like.

The people who came to our open houses could be roughly divided into three populations: 1. Those who really knew nothing about earth sheltered concepts but were intrigued with a house that had earth on the roof; 2. Those who were quite knowledgeable about earth sheltering and often were planning a future home of this kind; or 3. Those who have some limited knowledge of earth sheltering from the news media or magazines and thought it sounded like a good idea. This third group was by far the largest population, those who have been attracted to earth sheltering and want to know more about it.

The Townhouses have active solar systems which help to heat the home and also pre-heat water for domestic use. This hybrid design has served to demonstrate just how well earth shelters fit together with active and passive solar design. We have a heating estimate, based upon heat loss calculations, that one of the Townhouses will use approximately \$47 worth of gas a year for back-up heat. People found such energy savings incredible, and thought this figure must be a monthly estimate rather than an annual one.

Being centrally located, the Townhouses are extremely convenient for anyone who wants to live and work in the same area. They are also attractive to people who want to retire and not be bothered by home maintenance. Our location represents a double energy savings: not only is the house itself more efficient but suburban commuting is virtually eliminated with savings in time and gas money.

Our central location has meant that the project is highly visible. Many people watched the project from beginning to end. For most people, this was the first time they had actually been in an earth sheltered home. The most common responses have been: "Oh, it's much lighter than I thought it would be"; "You don't feel like you're underground"; "It looks like an ordinary house inside"; and, "It looks nice, I'm surprised!" Such comments reveal people's assumptions about earth sheltered homes: that they are darker, damper, and feel cave-like. Fortunately, these prejudices are being dispelled as people come through and view a pleasant, light and spacious atmosphere inside the homes. Saving energy does not have to be gloomy or involve sacrificing one's personal well being.

Almost all of the comments we have received on the project have been favorable. Any negative reaction usually has to do with the location of the Townhouses next to a busy freeway. Although the earth dampens the noise of traffic quite effectively, still many would prefer a different location. The most common question asked was, "Are you going to build anything like this somewhere else?" Implicit in the question is the feeling that another location would be more desirable.

Several people who came through were planning to build an earth sheltered home sometime in the future. They wanted to get different ideas and compare design and construction methods. These people were particularly interested in one level vs. two level designs, structural support, waterproofing, etc.

Sales were very good during the months of September and October, and then slowed down in November and December. Rising interest rates and a tighter money supply have had a negative impact on sales. We are selling the Townhouses for \$66,000 and \$76,000 for two and three bedroom units. The two bedrooms have 1054 square feet of space and the three bedrooms have 1387 square feet. Most people find these purchase prices in line with today's construction costs for new housing. Interest rates of 12%, however, make for extremely high monthly payments and many potential buyers are just not qualified. Monthly payments, when taxes and association fees are included, are running \$700 to \$800 for the two and three bedroom units respectively.

As of January, 1980, six out of twelve of the Townhouses have been sold. A year or two ago these homes would have probably all been sold within a matter of months. High interest rates have eliminated many potential buyers and only a choice few can afford today's rates. Builders and developers are beginning to offer energy efficient homes and now fewer people can afford them.

Monty Williams

A TAXONOMY OF UNDERGROUND SPACE

Sydney A. Baggs, F.R.A.I.A., A.A.I.L.A., A.R.I.B.A.

The University of New South Wales

INTRODUCTION

In the 1960s, underground, earth-covered architecture emerged in the United States of America with isolated examples in universities and schools and continued into the 1970s with a handful of private houses. It was not until 1977 that the number of residences began to increase substantially. New houses and projects underway are now numbered in the thousands and a continuation of this trend has been predicted. The literature accompanying this growth has also burgeoned at a similar rate, and some of the new terms have been effusive and anomolous. Most of those adopted for use here were chosen for their obvious clarity of meaning but others required re-definition.

Further there were many types of underground spaces that could be considered generically related while no holistic system of classification existed with which to integrate and order those relationships. Consequently, it became necessary to develop a taxonomy for this purpose, and to facilitate communication between the professional disciplines, the 'private languages' of which sometimes lead to misunderstandings.

Also, because some of the terms that were being used in the literature were non-specific and did not take into account critical factors such as the relationships of underground spaces to the land-surface above, of the morphology, characteristics of air movement and degree to which interior conditions are affected by ambient climatic conditions, the types of space to which they refer have been taxonomically classified.

Terms used in this Taxonomy are defined, and reasons are given why others in the literature will not be used here.

EXPLANATION OF TERMS

Underground: For the purpose of this work, when 'underground' is used, 'ground' will refer to the finished ground surface whether it is predominantly occupied by landscaping or pavement or whether it is natural or manmade (i.e. 'surficial' q.v.). In all cases the ground (or grade) is considered as the interface between between the earth/rock enclosing an underground space and the atmosphere above. When underground is used in connection with housing, it is used in the general sense to include both dugouts and earth-covered dwellings and is synonomous with other terms e.g. subsurface, earth-sheltered, and earth-covered etc.

Space: The term 'space' will be used here in its Aristotelian sense as 'the container of all objects' [1] i.e. "as it is defined in terms of its three dimensional limits and not in any other philosophical sense. These limits are seen as being set by enclosing elements whether natural, manmade, permanent or ephemeral that in turn may effect some degree of change in the climate of the space they

enclose.

Surficial: The definition by Professor Patrick Horsbrugh describing 'topographic geotecture' as 'terranean molding as distinct from subterranean construction' [2, p.153] will not be adopted here, as it conflicts with the taxonomic classification of geotecture as being located in geospace, i.e. enclosed by the earth. (q.v., Figure I,). The use of 'surficial' by Royce LaNier [3,p.21] as describing 'earth-moulding-carving-berming', is more acceptable.

EXPLANATION OF TAXONOMY OF UNDERGROUND SPACE

The Taxonomy of underground space that is suggested here and illustrated diagrammatically in Figure I, comprises a series of seven steps (shown down the centre of the diagram). For convenience the terminology of biology is used to describe the hierarchical structure of this Taxonomy although no biological or botanical connotations are thereby implied and the use of 'family' and 'genus' has been avoided altogether.

In column 1 of Table I following, these Steps Nos. 1-7 are shown to assist in the explanation of Figure I. The corresponding quasi-biological terminology that is used as the basis of the Taxonomy is shown in column 2 while alphabetical/numerical short forms of reference for each step are shown in column 3.

TABLE I

Sequential Steps in the Taxonomic Classification Procedure

Sequential Step Number	Taxonomic Terms (quasi-biological) used to describe each step.	Short Form of Classification
1	Division	G or Ar
2	Class	t or d
3	Sub-Class	T or L
4	Order	A or B, or C or D
5	Type	A1 A2 A3 A4 or B1 B2 B3 B4 or C1 C2 C3 C4 or D1 D2 D3 D4
6	Sub-type	Vp or Va
7	Species	S or T

From Table 1 it is to be noted that the final short form of classification of a particular space will include the cumulative use of each alphabetical/numerical reference symbol indicated in Figure I, e.g. GtT.A2/VpS.

STEP NO. 1

Geospace (G) or Architectural Space (Ar)

Step No. 1 in the Taxonomy is based upon an initial division of

all spaces whether naturally occurring or manmade, on the basis of their occurrence or siting. Two classifications are prescribed. If a space is sited above the surficially altered final interface of the earth surface with the atmosphere, it is classified as Architectural Space ('Ar'). If a space sited below the surficially altered final interface of the earth surface with the atmosphere is soil/rock covered, and is functionally or visually contiguous with the land surface, it is classified as Geospace ('G').

Geospace (G): It is intended to adopt the term 'geospace' in the sense that it includes all space that is earth/rock covered and located beneath the natural or surficially altered final interface of the earth with the atmosphere at both shallow and deep levels beneath the ground surface. It should be noted that Horsbrugh [2, p.131] adopts this sense of the word when he defines 'geotecture' as being the 'concept and practice of subterranean spacial construction of any kind, at any depth, providing services and accommodation for any purpose' [ibid, p.152]. It is also to be noted that Professor Truman Stauffer Jr. [4, p.37] has employed the term 'geospace' in a restricted sense inappropriate to this taxonomy, in referring to manmade or natural caverns that are utilised specifically for the storage of fluids and semi-fluids.

Architectural Space (Ar): All spaces above-ground (above the bed of sea, lake, river, etc., i.e. under and above water) are seen as being outside this field of study and are not further classified here. Usually so-called 'earth-integrated' [5] architecture is included in the literature as belonging to the division 'Geospace' (G). However buildings with this nomenclature often do not have earth-covered roofs, (e.g. the basement type schools of Santa Ana, California [6]) consequently they are not underground buildings within the meaning of the previous definition and are therefore unclassifiable within this Taxonomy beyond the general division (Ar). In the future, this division could also be extended to further cater for 'basement' building types and is also seen as an appropriate one for further taxonomic classification along the lines of the terminology employed by Horsbrugh [2].

STEP NO. 2

Geotecture (t) or Geodoid Space (d)

A further classification into two classes of the Division Geospace is made on the basis of whether the space in question is manmade (Geotecture 't') or predominantly naturally-occurring (Geodoid space 'd').

Geotecture (t): The word 'geotecture' derived from geo: (Gk) 'earth' and tekton: (Gk) 'carpenter or builder' was used by LaNier [3]. Kenneth Labs uses the term in its 'tectonics' sense from the U.S. Funk and Wagnall dictionary as 'the science or art of constructing functionally beautiful buildings or things'. In adopting the term 'geotecture' in its specific sense as 'the design and creation of subterranean accommodation' [8], he accepted LaNier's explanation that 'geotecture is to the subsurface as architecture is to the surface' [3]. For the purpose of this Taxonomy, this will in turn be accepted and elaborated as follows: terratecture and lithotecture are to the subsurface as architecture is to the surface.

Geodoid space (d): Stauffer uses the term 'geoidal' to describe large voids or caverns in geospace, perhaps intending to associate the

idea with the hollow space within a geode, i.e. ('hollow, globular bodies...characteristic of certain limestone') [7, p.204]. However 'geoid' means: 'the earth considered as a mean sea-level surface' [ibid, p.205] and this is obviously an unrelated concept. Possibly Stauffer meant to infer 'geodelike' by his use of this word, in which case, 'geoid' would have been appropriate as the adjectival form. To avoid further proliferation of these descriptive terms, 'geoid' will be adopted to describe naturally-occurring cavities in Geospace such as caverns, chambers and caves. It is not intended that this classification should exclude naturally-occurring caverns that have minor artificial extensions or modifications excavated or built into them, a predominance of naturally-formed space will be the diagnostic basis of classification.

STEP NO. 3

Note: When sub-classifying the class Geoid (d), Step No. 3 is by-passed.

Terratecture (T) or Lithotecture (L)

From the class Geotecture (t), the further sub-classes of Terratecture (T) (in terraspaces) and Lithotecture (L) (in lithospaces) are derived. The Stauffer definitions of 'terraspace' and 'lithospace' will be adopted here [4, p.37] as follows:

Terraspaces (earth type), underground space developed as a basement in the immediate subsurface, not geologically separated from the surface and developed from the surface by excavation.

Lithospaces (rock type), underground space developed in geologic strata and geologically separated from the surface being developed by mining (techniques).

It follows that terratecture is the design and construction of buildings in terraspaces, and lithotecture is the design and construction of habitats and usable volumes in lithospaces. Labs adopts the Stauffer definitions by implication when he refers to 'near-surface or shallow space' as being terraspaces and 'possessing a relatively thin layer of earth cover' [8, p.112]. The use of lithospaces by Stauffer and Labs to describe deep-space cannot be adopted without qualification because it is based upon the 'architectural distinction between these (concepts of terraspaces and lithospaces) as not primarily one of depth, 'but...in the degree of functional relationship between the underground and the surface' [ibid]. Stauffer and Labs adopt 'lithotecture' by linking it with its derivation from lithos: (Gk) 'stone' and tekton: (Gk) 'a carpenter or builder'. This again implies the sense of tectonics and would include those spaces constructed by mining technology in lithospaces (although technically this need not mean 'stone' as gravels and sands, etc., may be mined to create these spaces). Because this use is appropriate for the purpose required here, 'lithotecture' is adopted.

Multiple land-use is considered a major attribute of all underground space. This is often achieved by adopting terratectural as well as lithotectural design procedures. Labs and Stauffer use terratecture in the sense of 'constructed in terraspaces' (to use their phrase) i.e. constructed underground by excavation and backfilling

techniques. They do however include the concept of permanent consonance of surface, and subsurface space because of the connecting openings linking both; but anomalies can arise from this approach, as for example when lithospace is connected by deep light wells to the surface, land-use functional relationships can be disrupted and the relationship of surficial to underground space would be equivalent to the use of terraspace.

Consequently a land-use basis for defining the difference between terraspace and lithospace is not adopted, the distinguishing characteristic between them being the nature of the cover (earth or undisturbed rock strata respectively) and the techniques of construction whether by the use of excavation and backfill procedures (i.e. 'cut and cover') or the employment of mining techniques.

Note: Step No. 4, A and B, and A1, 2, 3, 4 and B1, 2, 3, 4 of Step No. 5 basically comprise a slightly modified version of the Labs amended Taxonomy [8]. In Step No. 4, for consistency where Labs has used 'bermed' and 'subgrade', they have been changed to 'above' and 'below' (grade), respectively to apply specifically to the relative levels of floor and outside ground. In Step No. 5, for clarity the 'Elevational' classification in Labs' 'Bermed' (here referred to as 'Above' or category A3 in Figure I) is also illustrated with a minor change in the sectional ground line. (The basement type constructions (with no earth-cover to the roof are often mistakenly included in the A4 'Penetrational' classification).

STEP NO. 4

Above (A) or Below/grade (B) for Territecture or Above (C) or Below/grade (D) for Lithitecture

This step further divides a space into two orders, the distinction drawn being whether the floor or an underground space is above or below the outside ground or level. This is classified as above grade (A) or below grade (B) for Territecture and above grade (C) or below grade (D) for Lithitecture.

STEP NO. 5

1.Chamber, 2.atrium, 3.elevational, 4.penetrational for (A) and (B) or 1.chamber, 2.sink/atrium, 3.open shelter, 4.air shafts for (C) and (D)

Above (A) or below (B) grade for territecture and above (C) or below (D) grade for lithitecture are further divided into types: 1. chamber, 2. atrium, 3. elevational, and 4. penetrational for (A) and (B); for (C) and (D), types: 1. chamber, 2. sink/atrium, 3. open shelter, 4. air shafts. Both (A) and (B) use the system proposed by Labs, that is adapted in (C) and (D). The stylised architectural sections devised by Labs that accompany his descriptive terms have been adapted to suit the needs of both territecture and lithitecture and the format of Figure I, and appear at the bottom of the boxes numbered 1-4 under the respective orders (A), (B), and (C), (D).

This typology is also applicable to the description of air drainage characteristics of underground spaces, i.e. whether night-cooled air is able to drain viscously into the interior space through entrance portal(s), or via ductwork of some description to provide fresh cooled air either directly into the interior or indirectly into thermal mass storage (solid or liquid) to be utilised in the maintenance of comfort conditions during the heat of the day in summer. Conversely it creates a design problem to be solved to avoid

accumulation of chilled air in winter. This physical property of cold air retention has been called the cold air 'sack' effect when applied to caves [9, 10] and it is from these sources that the term is adopted for use here.

Above (C) or below/grade (D) for lithotecture: Returning to Step No. 2, it becomes possible to describe another sub-class of the class Geotecture that, being constructed using mining technologies, comprises geospatial cavities that are self-supporting, e.g. dugouts for dwellings and mined chambers for storing liquids, solids and gases; these are of the class 'lithotecture'.

Returning to the subclassification of naturally-occurring Geodoid (d) types of space such as natural caves, caverns and chambers, as previously noted, these are seen to bypass Step No. 3 and be classified under Step No. 4 as of the order (C) or (D) according to the level of the chamber, cave or cavern floor(s) in relation to the portal sill(s) that occur at exterior grade level.

STEP NO. 6

Passive (Vp) or Active (Va)

The existence or intended use of Passive (Vp) and Active (Va) ventilation systems becomes the next step in dividing all types of geospace into sub-types. The ventilation system referred to in (Vp) and (Va) is defined as extending from the point(s) of intake of ambient air to the point(s) of supply through registers or ventilators in an interior space, and does not include subsidiary systems for the total or partial re-use of air.

Passive system (Vp): A passive system is one that produces a movement of air by thermal convection, radiation, induction or exchange for the purpose of ventilating an interior space and without the introduction of significant amounts of mechanical energy external to the system.

Active system (Va): An active system implies that energy external to the system is introduced to produce a movement of air for the purpose of ventilating, conditioning, heating or cooling an interior space.

STEP NO. 7

Static (S) or Transit (T) Space

The aerodynamics of the interior spaces are now considered as the basis for the next step comprising species Static (S) and Transit (T) of the subtype (Vp). The distinction to be drawn is whether there is one connection to the outside atmosphere or more than one. For the former case the terms 'static space' (S) is used and 'transit space (T) in the latter.

Static space (S): When the interior air in geospace has only one connection to the atmosphere (usually an entrance portal) an air exchange with the exterior is prevented by the imperfect elastic collision of outside air with the air contained in the enclosed cavity it will be described as Static space (S) [11].

Transit space (T): When manmade or naturally occurring geospace has two or more openings to the outside air (whether window, door, shaft or any other type of opening) it will be described as Transit space (T). Air moves within such a space as the result of the differential air pressures at the various openings.

It should be noted that for both (S) and (T) species even when

there is no wind and the air is still, pressure differences can still occur between the inside and outside with changes in atmospheric pressure, and air movement will result. In an above-ground 'relatively tight space' [12] with all doors and windows shut, approximately two complete changes of the interior air occur per day. However, in Geospace, air diffusion or infiltration from sources other than windows and door closure clearances does not occur because the enclosing earth or rock seals the spaces tightly (apart from a certain tendency in lithotecture with bare walls for the rock itself to effect delayed air exchange through its porous structure).

Examples of Taxonomic Classification

Apply the foregoing step procedure to specific examples, by addressing the questions noted in the centre boxes of Figure I, using a step-by-step process, and noting the 'short form' for each stage of the classification. The final 'short form' of classification then comprises a series of letters and numerals segregated into discrete groups for mnemonic purposes. For example a typical underground earth-covered residence sited into sloping ground (with a door and at least one window facing out and no rear windows, having no major mechanical ventilation or air-conditioning) would be as follows:

Geospace	G
Geotecture	t
Terratecture	T
Above grade	A
Elevational	3
Passive	Vp
Transit	T

= GtT.A3/VpT

<u>Example</u>	<u>Classification</u>
The 'bear-pit' or recessed atrium dwellings of China	GtL.C2/Vp (S or T)
Bulk storage spaces for liquids and gases as in Scandinavia	Gd.D1/(Vp or Va) (S or T)
John Barnard's 'Ecology House', Mass.	GtT.B2/Va
Abo Elementary School, Artesia, N.M.	GtT.B1/Va
University Underground Bookstore, Minneapolis, MN.	GtT.B4/Va

CONCLUSION

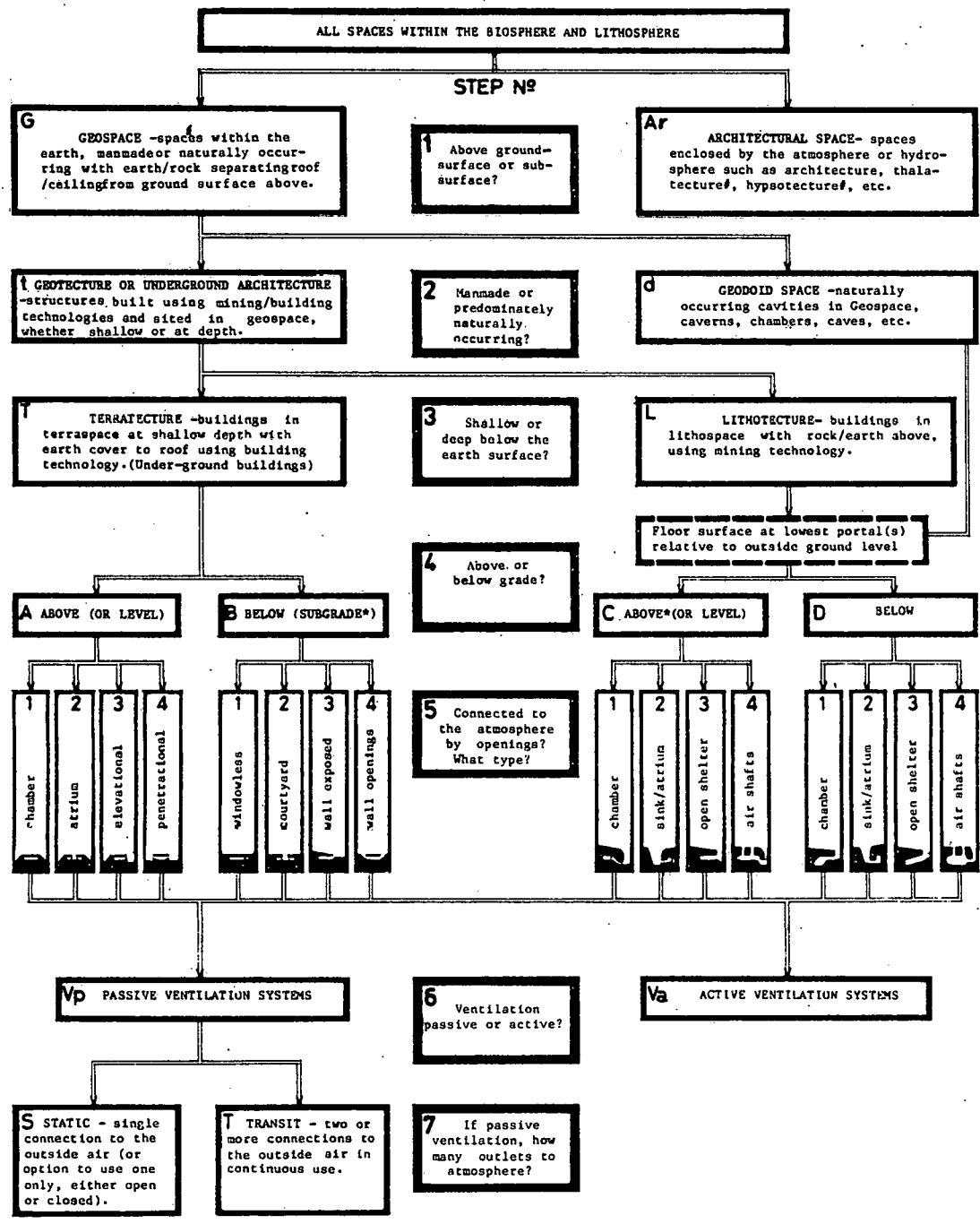
While this procedure was developed for the writer's specific purposes to clarify and order the diverse array of information that, of necessity, has to be dealt with in the relatively new field of underground space, it is suggested that this contribution be considered as part of an ongoing process to facilitate communication between our various disciplines.

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*Adapted from Labs' Taxonomy.

Horsburgh 1975

S.A. Baggs 1980

FIG. 1
A TAXONOMY OF UNDERGROUND SPACE

PRECAST CONCRETE WALLS FOR EARTH SHELTERED CONSTRUCTION

Martin R. Lunde, Principal - Bressler, Armitage and Lunde

During the past several years, the firm of Bressler, Armitage and Lunde has been intimately involved with the design of earth sheltered and earth covered residences. As a result of this involvement, and as a result of the ever increasing cost of residential construction, the author has researched and analyzed several wall structural systems. The result of this analysis points towards the utilization of precast concrete wall panels for residential below-grade wall construction when compared with: reinforced concrete block, wood and cast in place concrete construction techniques.

Historically, the people of Minnesota have favored the utilization of 8" to 12" thick concrete block for the construction of earth retaining (basement) walls in above ground residences. When utilizing block in an underground residence, the designer must significantly increase the amount of steel reinforcement so that the wall may safely resist the high lateral earth pressures inherent in underground construction. In reviewing residential bids received during the 1978 residential construction season by Bressler, Armitage and Lunde, the following masonry prices were noted for earth covered or earth sheltered projects: \$3.60 per square foot, \$4.96 per square foot and \$5.39 per square foot - for an overall average of \$4.65 per square foot for similarly reinforced masonry walls. Because this cost appeared excessive, cast in place concrete, wood and precast concrete were considered as alternates.

Cast in place concrete was eliminated as an effective alternate because:

1. In the Minnesota area its cost is relatively high at \$6 per square foot.
2. It requires forming, pouring, basic curing, and form stripping before the roof deck can be installed. As such, it is time-consuming.
3. During winter construction it requires special measures and temporary heat.

Wood was considered but eliminated because:

1. It had difficulty resisting the high lateral loads involved in underground design.
2. It had difficulty in providing the support necessary for the precast concrete roof deck best utilized in underground design.
3. It lacked mass when compared with the concrete materials.

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However, one should note that the wood wall is an attractive system for earth sheltered (that is, earth bermed, but not covered) structures. Therefore, it is a fully acceptable option for many residences. The lack of mass may be somewhat compensated for by locating foam floor insulation approximately 2 feet below the floor, thereby incorporating such mass within the insulation envelope.

This brings the designer to precast concrete wall panels. A comparison of some of the significant properties of the most utilized residential below-grade wall (block) and a precast below-grade wall is summarized in the following table:

Block*	Precast Concrete+
--Requires 7 to 10 days of field erection.	--Requires 1 day to erect 1,200 square feet of 12 inch precast roof (or floor) panel and 920 square feet of 7 inch precast wall panel.
--Generally utilizes 12 inch <u>reinforced</u> block.	--Can utilize 6 to 7 inch thick precast panel, allowing more interior lining space.
--Strength and appearance highly dependent upon the individual mason.	--Excellent strength and uniform appearance because it is manufactured in precise forms within controlled environments in a manufacturing facility.
--Erection schedule dependent upon favorable weather conditions, difficult to handle during cold conditions.	--Can be erected during most weather conditions including extreme cold.
--Cost approximately \$4.65 per square foot in Minnesota, presently is universally available.	--It appears that such a panel could be manufactured and erected for approximately \$3.50 to \$4 per square foot. Not presently mass manufactured for residential scale projects, although some manufacturers are just now beginning to enter the market.
--Weighs approximately 96 lbs/ft ²	--Weighs approximately 78 lbs/ft ²

*Cost data is 1978 based.

+The erected cost of the precast panel was estimated based upon the following:

--Numerous discussions with precast and ready mix concrete suppliers, during 1978.

--920 square feet of wall panel in 4 feet by 9 feet by 7 inch thick modules as designed by the author to meet existing codes and underground house loading conditions utilizing 3,000 psi concrete and No. 4, grade 60 rebar.

The reader should note that the above table of properties compares reinforced concrete block with present concrete. In general, unreinforced concrete block walls are limited to use in the construction of conventional residential basement walls, where burial depths do not exceed 5 to 6 feet. Beyond this depth, the tension stresses in the mortar joints become quite large, resulting in horizontal tension cracks at the over-stressed joints.

Figure #1 is a partial cross section of a fairly typical earth covered residence with a lateral earth pressure diagram. The reader should note that the horizontal reactions resulting from the lateral earth loadings are carried into the roof deck at the top of the wall and into the floor slab at the base of the wall. Also, on the cross section the author has noted the following critical design points:

1. Point A -- approximate location of maximum bending stresses.
2. Point B -- approximate location of maximum shear stresses.

Utilizing the above, tempered with past structural design experience, the author established a list of assumptions to be utilized in the design process of a precast concrete wall panel. These assumptions included, but were not limited to, the following items:

1. Vertical loads in the range of 3500 lbs/lin. ft. to 5000 lbs/lin. ft. applied to the top of the wall panel.
2. Full lateral restraint of both the top and bottom of the wall panel.
3. No rotational restraint at either the top or bottom of the wall panel.
4. A 40 lb/sq. ft. surcharge load due to normal winter snow conditions in Minnesota.
5. Sandy backfill and existing site soils. The reader should note that the actual lateral earth pressures will vary with: soil type, moisture content, compaction density, etc. Hence, professional soil tests are strongly recommended in order to determine such specific properties.
6. Insulation and waterproofing applied to the outside of the roof deck and wall panels.

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The reader is now referred to Figures #2 and 3: Figure #2 is the cross section of a typical reinforced block wall, while Figure #3 is the cross section of the prototype precast concrete wall - either of which may be used in an earth covered residence. In reviewing both the Uniform Building Code and Figure #2, one should note the following items involved with reinforced block wall construction:

- a. 12 inch concrete block should be used for one story construction; whereas, 16 inch block should be used for the lower floor of the two story construction.
- b. Minimum areas of reinforcement have been established in both the vertical and horizontal directions - total area of reinforcement must be greater than 0.2 percent of the gross cross sectional area of the wall, minimum in either direction is 0.07 percent. However, lateral soil loading generally requires providing a #4, #5 or #6 rebar 16" to 32" on center with each respective core filled with 3000 psi grout.
- c. Maximum spacing of vertical rebar is 48" on center.
- d. Rebar dowels at the top of the wall must be properly designed to safely resist the applied lateral loads.

In reviewing the Uniform Building Code, the American Concrete Institute Codes and Figure #3, one should note the following items involved with the prototype precast concrete wall:

- a. Section 14.2.6 of the A.C.I. Code indicates a minimum thickness of 6" for all load bearing walls, whereas Section 14.2.7 indicates a minimum thickness of 8" for all basement walls, foundation walls, etc.
- b. Minimum vertical steel reinforcement area is .0012 times the cross sectional area of the concrete, with maximum rebar spacing of 18".
- c. Minimum horizontal steel reinforcement area is .0020 times the cross sectional area of the concrete, with maximum rebar spacing of 18".
- d. Rebar diameter must be greater than 3/8" ϕ and less than 5/8" ϕ .
- e. The utilization of reinforcing mats is acceptable if the minimum reinforcement areas are modified.
- f. Rebar ties are used only to tie the precast deck and wall panels together to resist separation; they are not designed to resist lateral loads.

Hence, it is obvious that either a reinforced concrete block wall or a precast concrete wall can be safely designed within code constraints to resist the loads of an earth covered structure: i.e., all critical bending, shear and compressive stresses can be safely handled. However,

if the code constraints induce problems for a particular structure, the code requirement may be modified if calculations prepared by a Registered Professional Engineer are submitted to the code official demonstrating the safety of the design. In general, the design of reinforced concrete block walls is the responsibility of the Architect's Structural Engineer for a given project; whereas, the design of a precast concrete wall panel is handled by a staff Structural Engineer at the precast manufacturer's offices. Hence, utilization of the precast wall panel may well be simpler and more economic for the novice because the design is automatically handled by a professional whose fees are spread over many thousands of square feet of precast material, rather than applied toward a single project.

Figures #4, 5, 6 and 7 show several precast concrete wall panel designs; obviously, thousands of design variations are possible within the constraints listed heretofore. The reader is also asked to again review Figure #3 with particular regard to the suggested connections at the roof, deck and footing, and the details involving the cove base/electrical plug mold.

This latter detail was developed as a cost effective method of eliminating the need to position individual electrical duplex boxes (inter-connected with conduit) within a reinforced concrete block wall. As shown, this detail meets all the code requirements of the National Electric Code while providing the following:

- a. Multiple circuit capability that allows the switching of some circuits while others remain "live" all the time.
- b. Outlet spacings that vary from a minimum of 3 feet to a maximum of 10 feet.
- c. Various methods of finishing the intersection of the floor finish and the precast wall (i.e., wood trim, carpet return, etc.).

Although not shown in specific detail, the waterproofing of the vertical joints in a precast concrete wall panel system can be handled in several ways. Any of the techniques described in Chapter 5 of the Earth Sheltered Housing Design Manual can easily be utilized. In addition, a rope type bitumastic sealer should be installed in the center of each vertical joint. As adjacent panels are set into place, the bitumastic rope will compress to fill the joint. The bitumastic compounds and the techniques involved with such joints, have been in common use for many years in the precast concrete culvert pipe industry; hence, are well known and effective.

As stated in the beginning of this dissertation, it appears that the precast wall panel system is more cost effective than a reinforced concrete block wall system. The reasons for this are several. First, all the precast planks (roof and wall) for a 30' wide by 40' long earth covered residence can be set in place by the precast manufacturer in less than one day; this compares to approximately seven days for a reinforced block wall. Hence, the home is enclosed sooner, and the time

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required for a high interest rate construction loan is reduced. In addition, the more precast concrete sections used on a job from one supplier, the cheaper the cost per square foot of installed plank. If the travel distance to the job is significant, erection teams are usually charged to the job for a full day even though installation time may only be a matter of 2-3 hours. Hence, additional planks can be installed with only an increase in material and transport costs.

Secondly, utilizing a 7" thick precast wall panel yields 40 square feet of additional useable floor area when compared with a 12" concrete block wall for a typical 1200 square foot earth sheltered residence. Hence, when comparing residences of equal interior areas, the home constructed of reinforced block must be slightly larger in overall dimensions than a home constructed of precast concrete.

Thirdly, the prototype precast concrete panels appear to be cheaper than reinforced concrete block on an installed first cost basis and long term basis. It appears that since the original cost estimate in 1978, the price of reinforced block construction has risen approximately 10%, while the cost of precast construction has not noticeably risen. Assuming a 30 year mortgage at 13½% interest with 25% down, the following figures apply.

Reinforced Block Construction:

$\$4.65/\text{ft}^2 \times 1.10 = \$5.12/\text{ft}^2$	(1980 installed cost)
5.12 $\$/\text{ft}^2 \times 920$ sq. ft.	\$ 4,710.00
25% down payment	1,177.00
30 year mortgage	<u>14,537.00</u>
Total 30 year cost	\$15,750.00

Precast Concrete Construction:

Use upper figure of $\$4.00/\text{ft}^2$ for 1980 installed cost	
4.00 $\$/\text{ft}^2 \times 920$ sq. ft.	\$ 3,680.00
25% down payment	920.00
30 year mortgage	<u>11,387.00</u>
Total 30 year cost	\$12,307.00

Hence, the following savings can be realized when utilizing a precast wall system.

$$\begin{aligned} \text{Initial cost savings} &= \$4,710 - \$3,680 = \$1,030 \\ \text{30 year savings} &= \$15,750 - \$12,307 = \$3,443 \end{aligned}$$

However, if one realistically compares houses of equal interior square footage the savings become even larger.

Reinforced Block Construction with Corrected Floor Area:

Wall Cost = 5.12 \$/ft ² x (920 + 16)	\$4,792.00
Additional Roof and Floor Cost	<u>400.00</u>
Total Cost For Corrected Area	\$5,192.00
25% down payment	\$ 1,298.00
30 year mortgage	<u>16,065.00</u>
Total 30 Year Cost	\$17,363.00

Hence, the savings now become:

Initial Cost Savings = \$5,192 - \$3,680 = \$1,512
 30 Year Savings = \$17,363 - \$12,307 = \$5,056

It is the opinion of the author that a significant market exists for precast concrete basement walls and underground housing walls. However, at the present time the author knows of only one manufacturer in the United States that is entering this new market. However, in Canada several manufacturers are presently producing such panels. The reader should further note that the panels shown in the paper are prototype designs; hence, they should not be utilized in any construction projects until they have been fully designed, built and tested.

Martin R. Lunde, P.E.
c/o 1002 Wesley Temple Building
Minneapolis, MN 55403
(612) 870-7011

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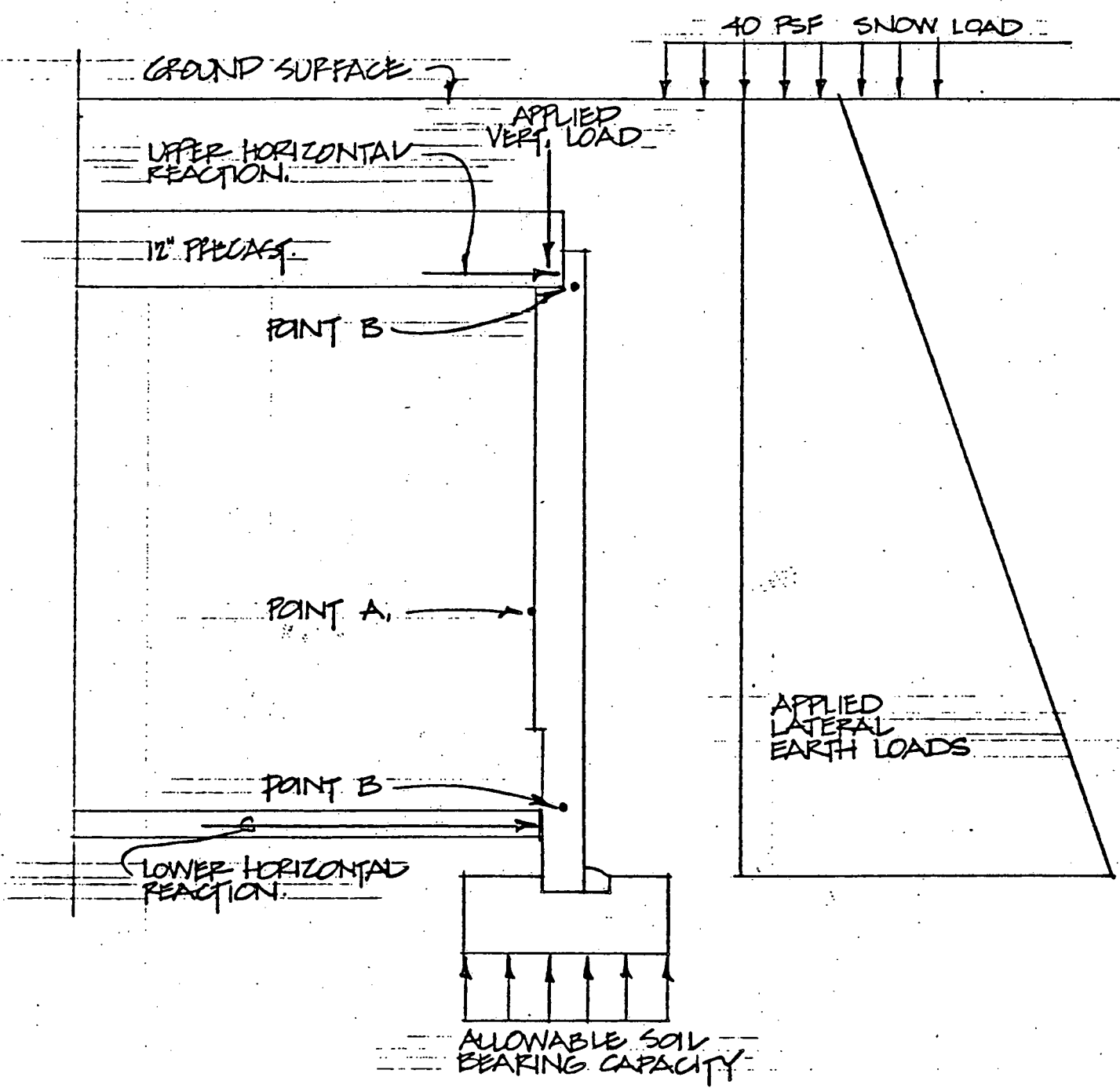


figure 1

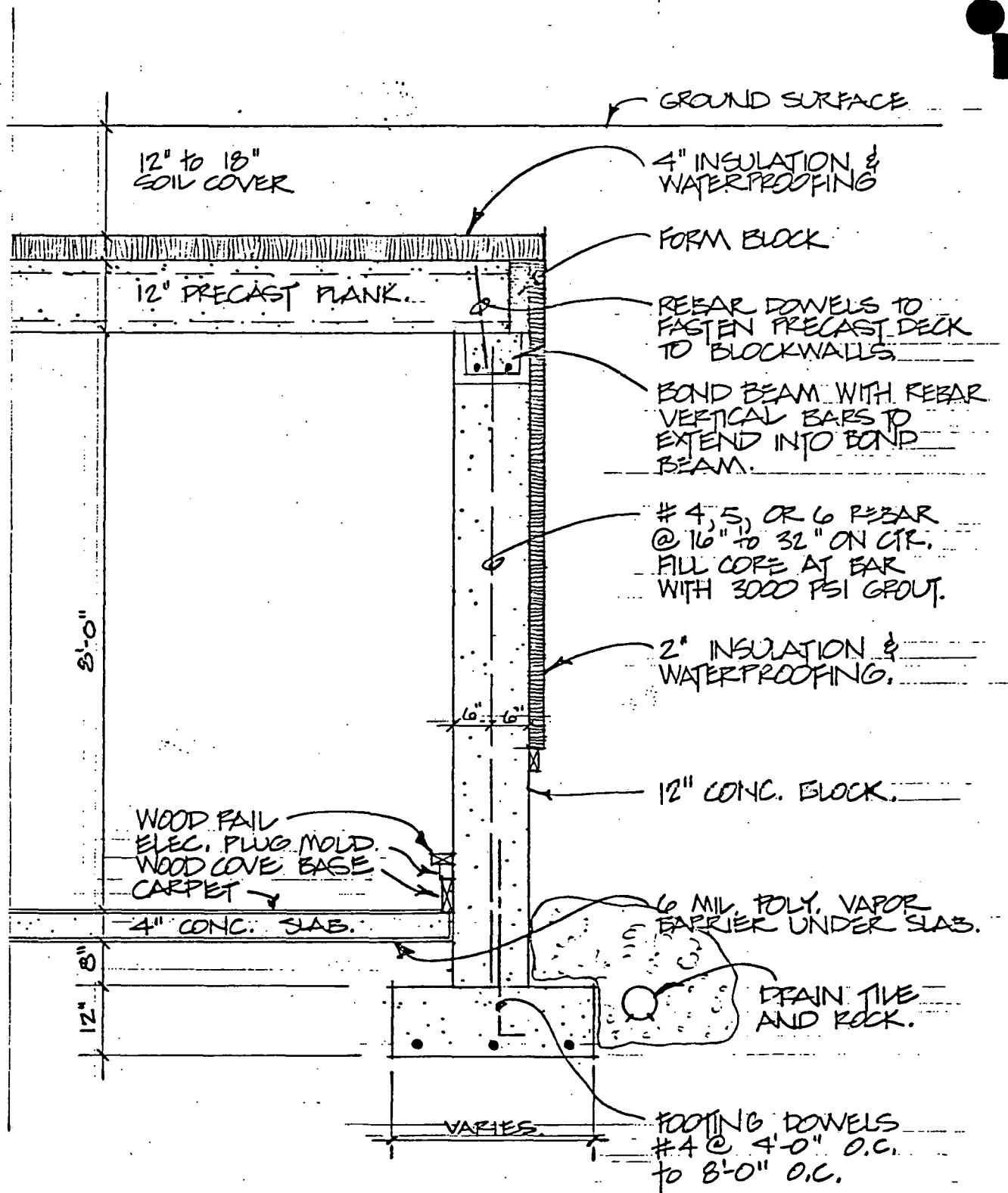


figure 2

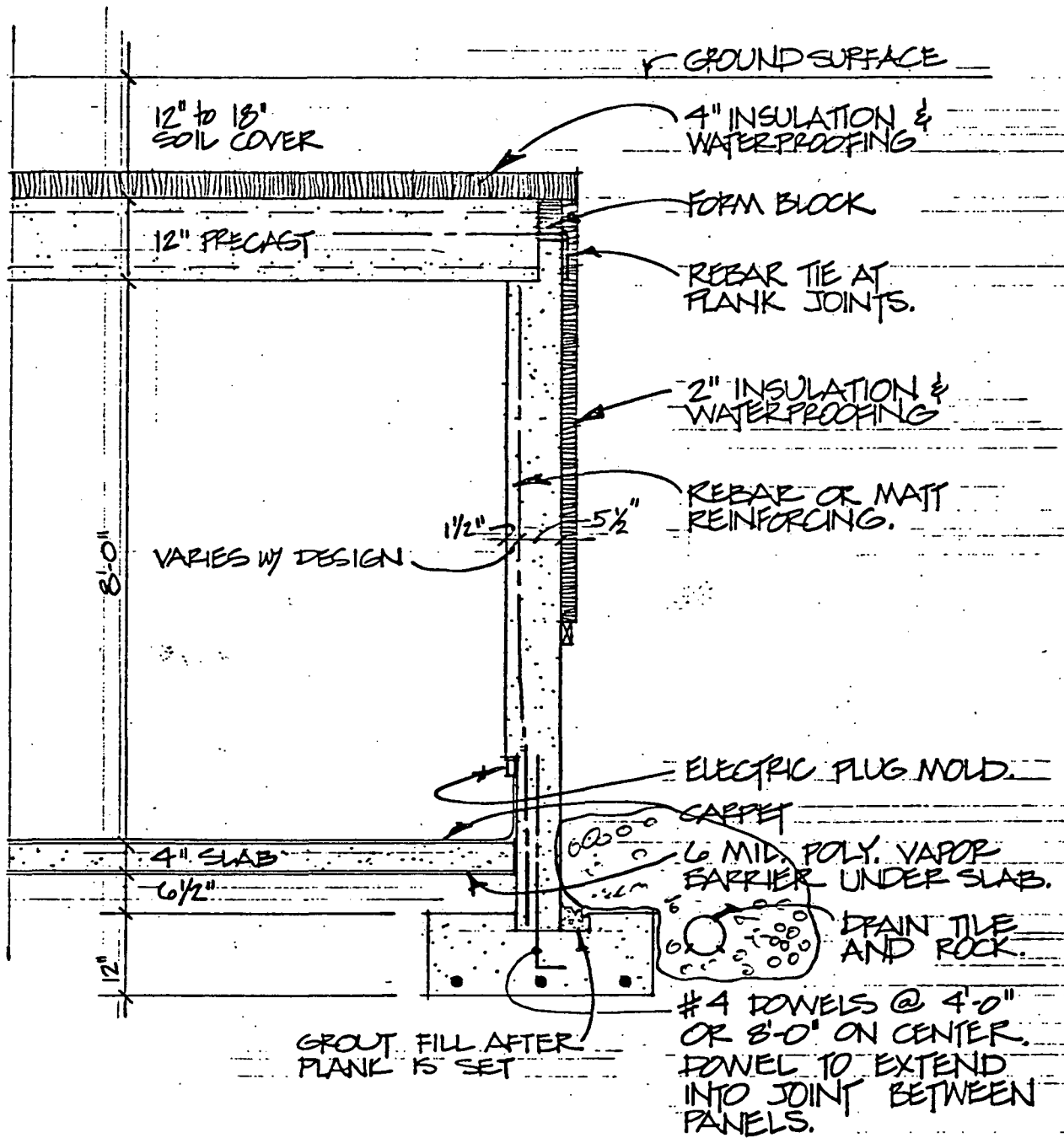
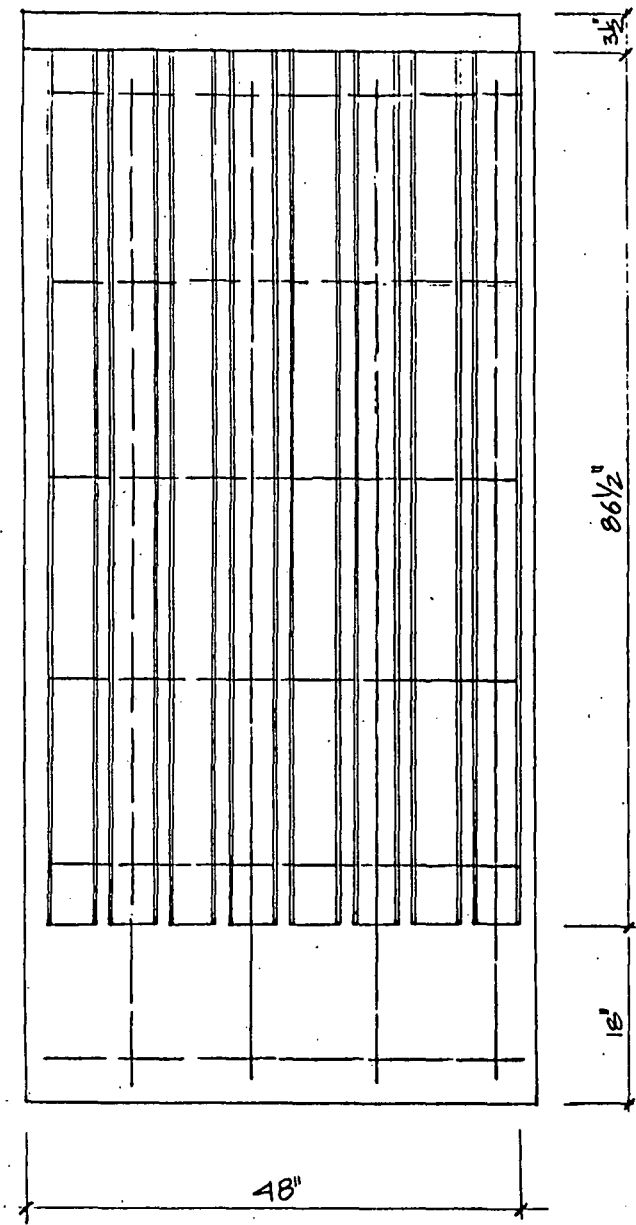
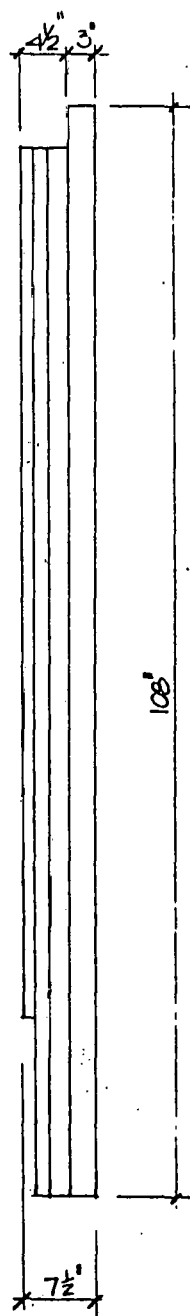


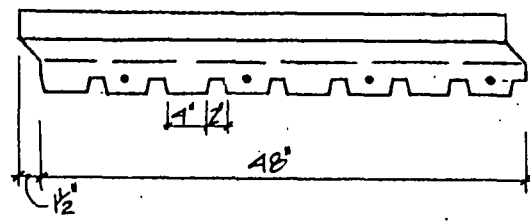
figure 3



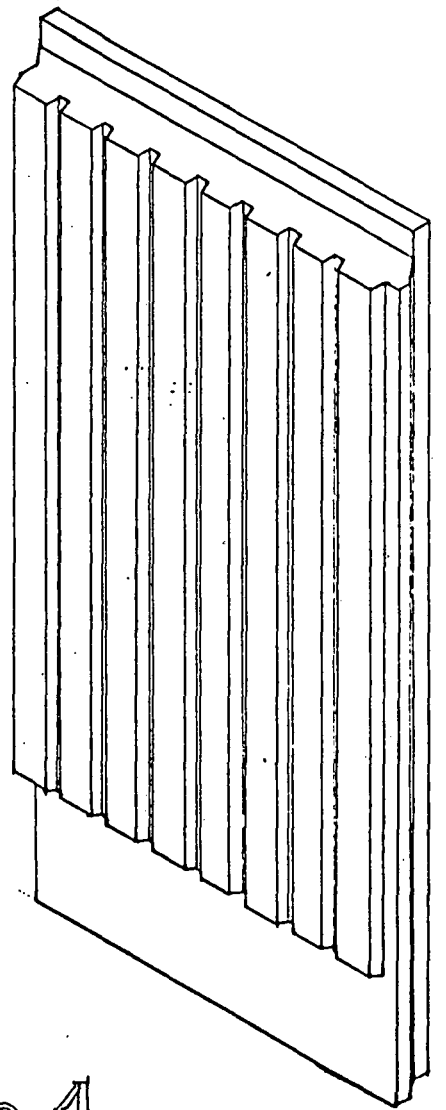
front view



side view



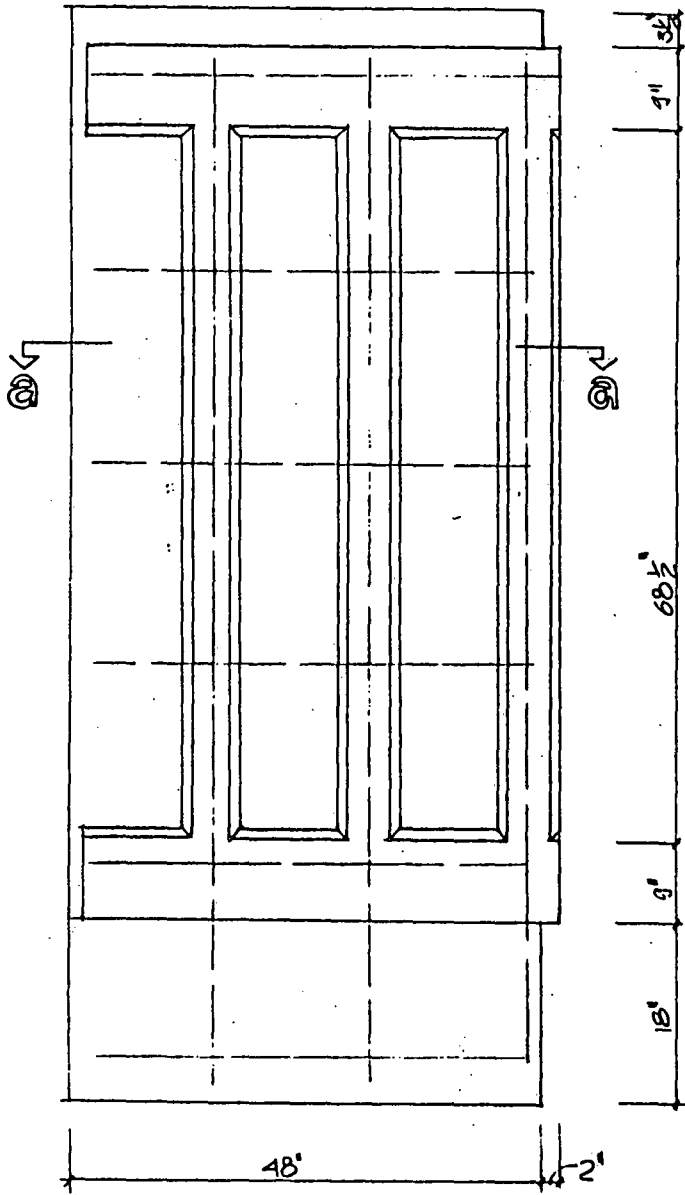
top view



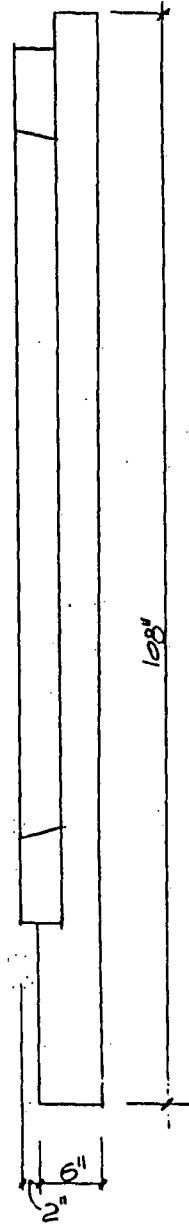
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28 DAYS
REINFORCING - GRADE 60
4#4 VERTICAL
6#4 HORIZONTAL

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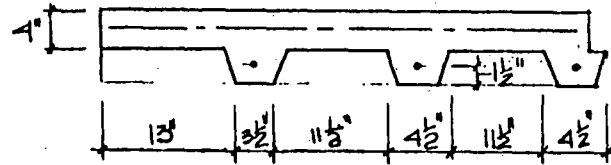
figure 4



front view



side view



section aa

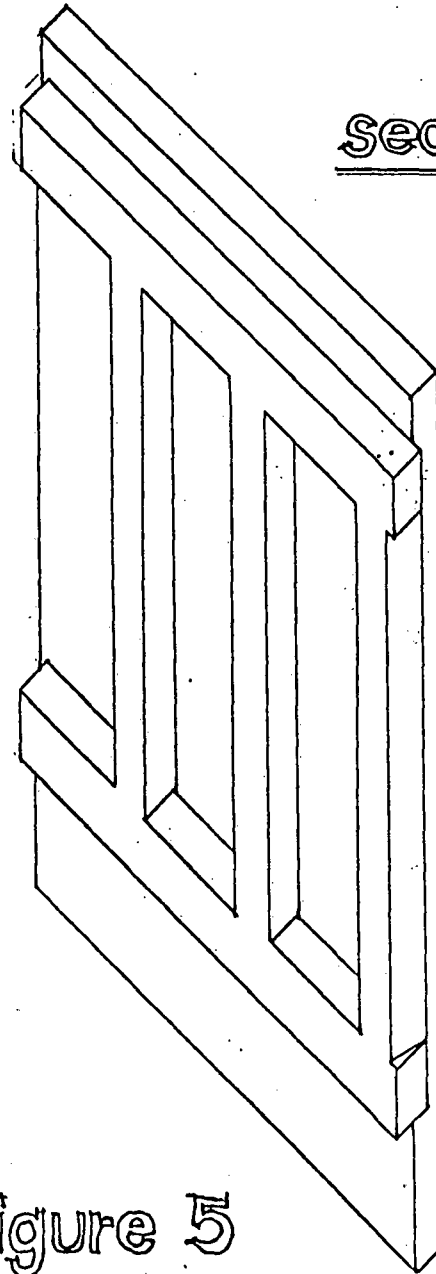
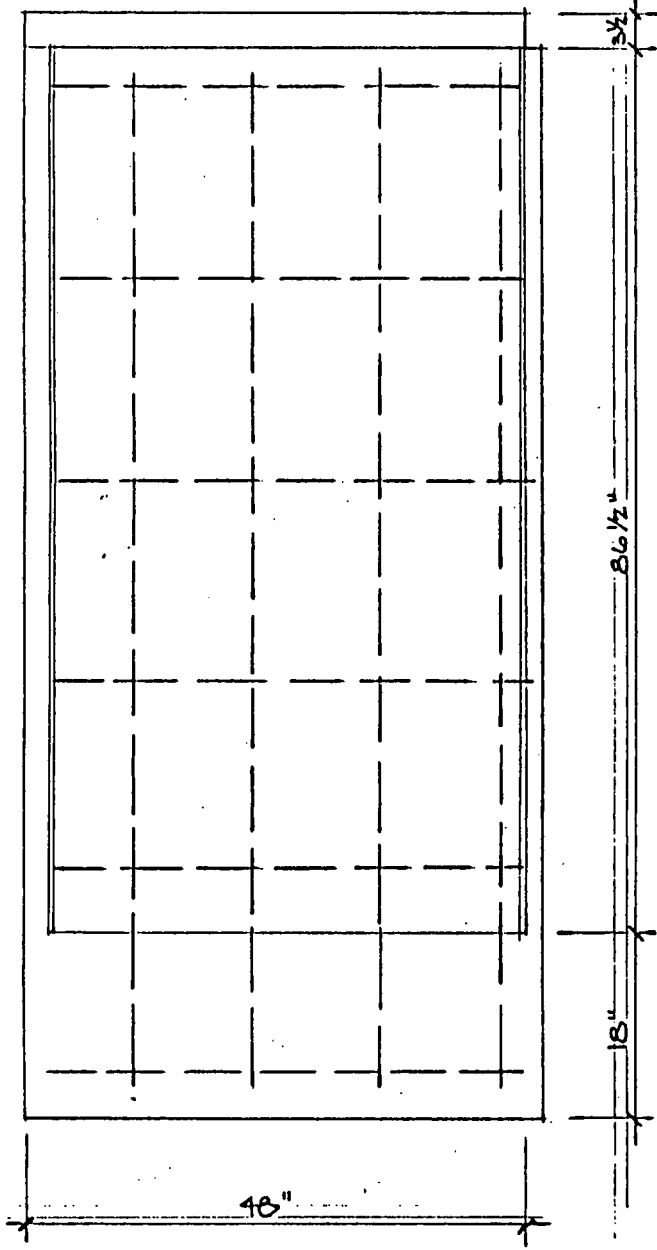
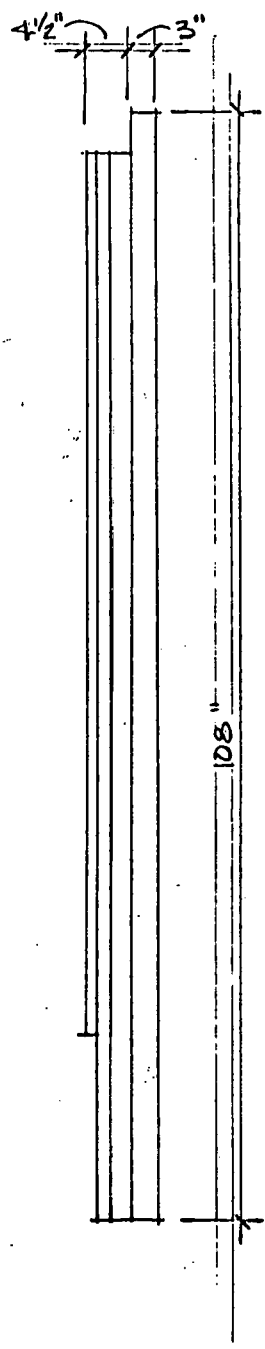


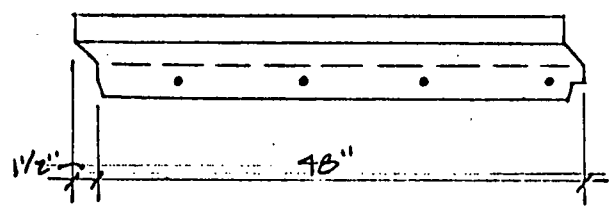
figure 5



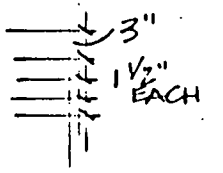
front view



side view



top view



CONCRETE - 3000 PSI @
28 DAYS
REINFORCING - GRADE 60
4 # 4 VERTICAL
6 # 4 HORIZONTAL.

figure 6

(119)

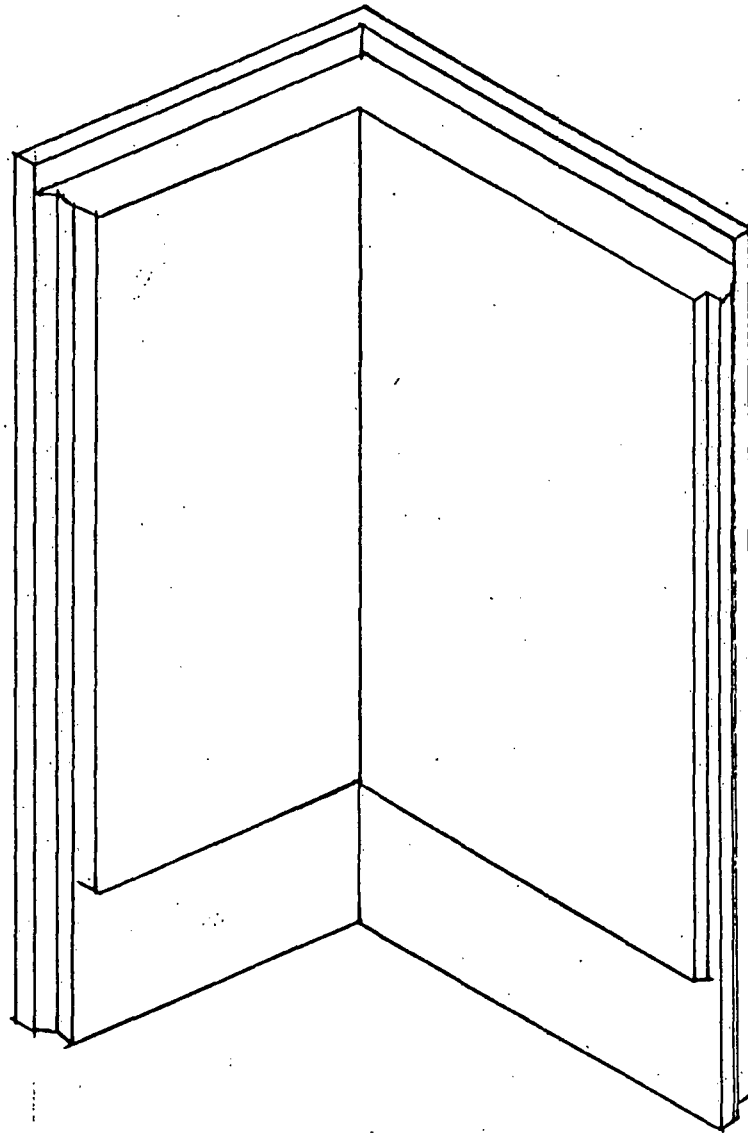


figure 7

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CHAPTER 14 – WALLS

14.0 – Notation

- A_g = gross area of section, sq in.
 f'_c = specified compressive strength of concrete, psi
 h = overall thickness of member, in.
 l_c = vertical distance between supports, in.
 P_{nw} = nominal axial load strength of wall designed by Section 14.2
 ϕ = strength reduction factor. See Section 9.3

14.1 – Structural design

14.1.1 – Walls shall be designed for any lateral or other loads to which they are subjected.

14.1.2 – Proper provisions shall be made for eccentric loads and lateral forces.

14.1.3 – Unless designed in accordance with Section 14.2, walls subject to combined flexure and axial loads shall be designed under the provisions of Section 10.15.

14.2 – Empirical design method

14.2.1 – Walls may be designed by the empirical provisions of Section 14.2 if resultant of the factored axial load is located within the middle-third of the overall thickness of wall and all limits of Section 14.2 are satisfied, except as provided by Section 14.2.2.

14.2.2 – Limits of thickness and quantity of reinforcement required by Section 14.2 may be waived where structural analysis shows adequate strength and stability.

14.2.3 – Design axial load strength ϕP_{nw} of a wall within limitations of Section 14.2.1 shall be computed by

$$\phi P_{nw} = 0.55\phi f'_c A_g \left[1 - \left(\frac{l_c}{40h} \right)^2 \right] \quad (14-1)$$

where $\phi = 0.70$

14.2.4 – Length of wall to be considered as effective for each concentrated load or reaction shall not exceed center-to-center distance between loads, nor width of bearing plus 4 times the wall thickness.

14.2.5 – Overall thickness of bearing walls shall not be less than 1/25 the unsupported height or width, whichever is shorter.

14.2.6 – Bearing walls shall not be less than 6 in. thick for uppermost 15 ft of wall height; and for each successive 25 ft downward (or fraction thereof), minimum thickness shall be increased 1

in. Bearing walls of two-story dwellings may be 6 in. thick for total wall height, provided the factored axial load P_u does not exceed the design axial load strength ϕP_{nw} computed by Eq. (14-1).

14.2.7 – Exterior basement walls, foundation walls, fire walls, and party walls shall not be less than 8 in. thick.

14.2.8 – Overall thickness of panel and enclosure walls shall not be less than 4 in., nor less than 1/30 the distance between supporting or enclosing members.

14.2.9 – Walls shall be anchored to floors, roofs, or to columns, pilasters, buttresses, and intersecting walls.

14.2.10 – Area of horizontal reinforcement shall not be less than 0.0025 times gross area of wall. For reinforcement with specified yield strength of 60,000 psi or greater, and not larger than #5 bar or W31 or D31 welded wire fabric, reinforcement ratio may be reduced to 0.0020.

14.2.11 – Area of vertical reinforcement shall not be less than 0.0015 times gross area of wall. For reinforcement with specified yield strength of 60,000 psi or greater, and not larger than #5 bar or W31 or D31 welded wire fabric, reinforcement ratio may be reduced to 0.0012.

14.2.12 – Walls greater than 10 in. thick, except basement walls, shall have reinforcement for each direction placed in two layers parallel with faces of wall in accordance with the following:

(a) One layer consisting of not less than one-half and not more than two-thirds the total reinforcement required for each direction shall be placed not less than 2 in. nor more than 1/3 the thickness of wall from exterior surface.

(b) The other layer, consisting of the balance of required reinforcement in that direction, shall be placed not less than 3/4 in. nor more than 1/3 the thickness of wall from interior surface.

(c) Bars, if used, shall not be less than #3 and spaced not more than 18 in. on centers. Welded wire fabric, if used, shall be in flat sheet form.

14.2.13 – In addition to the minimum reinforcement required by Sections 14.2.10 and 14.2.11, not less than two #5 bars shall be provided around all (window or door) openings. Such bars shall extend at least 24 in. beyond the corners of openings.

14.2.14 – Where bearing walls consist of studs or ribs tied together by other reinforced concrete members at each floor or roof level, such studs or ribs may be considered as columns.

CHAPTER 16 – PRECAST CONCRETE

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16.1 – Scope

16.1.1 – Provisions of Chapter 16 shall apply only for design of precast concrete members manufactured under plant controlled conditions.

16.1.2 – All provisions of this code shall apply to precast concrete members, except as specifically modified in Chapter 16.

16.2 – Design

16.2.1 – Design of precast members shall consider all loading and restraint conditions from initial fabrication to completion of the structure, including form removal, storage, transportation, and erection.

16.2.2 – In precast construction that does not behave monolithically, effects at all interconnected and adjoining details shall be considered to assure proper performance of the structural system.

16.2.3 – Effects of initial and long-time deflections shall be considered, including effects on interconnected elements.

16.2.4 – Design of joints and bearings shall include effects of all forces to be transmitted, including shrinkage, creep, temperature, elastic deformation, wind, and earthquake.

16.2.5 – All details shall be designed to provide for manufacturing and erection tolerances and temporary erection stresses.

16.3 – Precast wall panels

16.3.1 – Precast bearing and nonbearing walls shall be designed in accordance with provisions of Section 10.15 or Chapter 14.

16.3.2 – Where precast panels are designed to span horizontally to columns or isolated footings, the ratio of height to thickness shall not be limited, provided the effect of deep beam action, lateral buckling, and deflections are provided for in the design. See Section 10.7

16.4 – Details

16.4.1 – All details of reinforcement, connections, bearing seats, inserts, anchors, concrete cover, openings, lifting devices, fabrication, and erection tolerances shall be shown on the shop drawings.

16.4.2 – When approved by the Engineer, embedded items (such as dowels or inserts) that either protrude from concrete or remain exposed for inspection may be embedded while concrete is in a plastic state provided:

(a) Embedded items are not required to be hooked or tied to reinforcement within plastic concrete,

(b) Embedded items are maintained in correct position while concrete remains plastic, and

(c) Embedded items are properly anchored to develop required factored loads.

16.5 – Identification and marking

16.5.1 – Each precast member or element shall be marked to indicate location in the structure, top surface, and date of fabrication.

16.5.2 – Identification marks shall correspond to the placing plans.

10.15 – Special provisions for walls

10.15.1 – Walls may be designed by provisions of Chapter 10 with limitations and exceptions of Section 10.15, or by provisions of Chapter 14.

10.15.2 – Minimum ratio of vertical reinforcement area to gross concrete area shall be:

(a) 0.0012 for deformed bars not larger than #5 with a specified yield strength not less than 60,000 psi, or

(b) 0.0015 for other deformed bars, or

(c) 0.0012 for welded wire fabric (smooth or deformed) not larger than W31 or D31.

10.15.3 – Vertical reinforcement shall not be spaced farther apart than 3 times the wall thickness, nor 18 in.

10.15.4 – Vertical reinforcement need not be enclosed by lateral ties if vertical reinforcement area is not greater than 0.01 times gross concrete area, or where vertical reinforcement is not required as compression reinforcement.

10.15.5 – Minimum ratio of horizontal reinforcement area to gross concrete area shall be:

(a) 0.0020 for deformed bars not larger than #5 with a specified yield strength not less than 60,000 psi, or

(b) 0.0025 for other deformed bars, or

(c) 0.0020 for welded wire fabric (smooth or deformed) not larger than W31 or D31.

10.15.6 – Horizontal reinforcement shall not be spaced farther apart than 3 times the wall thickness, nor 18 in.

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500300

IONIZING RADIATION LEVELS IN ENERGY CONSERVING STRUCTURES*

Harold May, Argonne National Laboratory, Argonne, IL.⁺

Introduction

The potential benefits of "going underground," though obvious to this group and gradually being perceived by more and more of the public, are inevitably accompanied by technical and social problems. There is a growing concern that indoor air pollution may be a significant limitation in structures having low air infiltration.^{1,2} One of the pollutants frequently mentioned is the naturally-occurring radioactive gas - radon. I shall outline this morning, to the extent that time permits, the physical principles governing release of this gas as a result of the decay of the parent element radium, found everywhere in the soil and many building materials. We shall then examine factors contributing to concentration or build-up within a building. Having some understanding of how radon enters will facilitate the design of structures so that the possibility of significant concentration levels may be minimized. Finally, I will examine what health effects may be predicted at the levels which have been observed, or appear to be possible. This information, most of which has appeared in environmental and health physics publications, does not seem to have been previously brought to the attention of builders, architects, and engineers such as this group, except for a brief "spur-of-the-moment" note at the "Alternatives in Habitat" conference in Fort Worth about two years ago.³

There are two major radioactive elements found in the earth's crust, and rather uniformly distributed in rocks, soils and their constituent minerals, namely, thorium and uranium. Thorium is more abundant on earth, but uranium-238, by virtue of its very radioactive descendant radium-226, is responsible for much of the environmental activity, and hence we limit this discussion to the latter. The behaviour of radium-226 and the succeeding daughter elements resulting from its decay are illustrated in Figure 1. When radium, together with the

* This work was supported by the Department of Energy, under contract #W-31-109-ENG-38.

⁺ Present address: 428 Phillippa, Hinsdale, IL. 60521

elements produced by or "born" at its decay are confined, as for example within an impermeable rock, the local concentration of activity or decay rate of each member of the family is equal and constant with time, being determined solely by the 1620 year half-period of radium. The decay products are then said to be in equilibrium with the parent. In the much more common situation in which radon can escape, its half-period of 3.82 days is sufficient to permit transport over appreciable distances, and consequent dispersion of the decay products. The activity concentrations of the family are then different, and normally change with time. The relationships, while readily defined mathematically are seldom easy to visualize, and need not concern us.⁴

Radon, being a noble gas, does not combine chemically with other available elements, but it may escape by diffusion from the mineral or rock where it originates. From a few to twenty percent is released, depending upon the type of mineral, its past geological history and physical condition. A much higher fraction is available from the soil. The gas moves relatively freely by diffusion through the interstitial air spaces within soil, until it reaches the earth-air interface, or possibly some denser barrier. Radon may be rapidly transported into the atmosphere by thermally-driven convection and surface winds, or under conditions of temperature inversions may be concentrated near the ground. A drop in atmospheric pressure is accompanied by increased release from the ground, and there is good evidence that the micropulsations in pressure which are present during windy periods exert an additional "pumping" action. Periods of rain or frozen soil both sharply reduce the rate at which radon is released.

The concentration within buildings, particularly of homes (as opposed to most public buildings with forced ventilation) is usually higher than that outside, by a factor of ten or more. The various ways in which radon may enter an earth-shielded structure are shown in Fig 2. If there are large amounts of brick, stone, or concrete in the structure, these make a contribution, especially if they are directly exposed to the interior. A most important source is infiltration of soil gas via below-grade cracks, unpaved and unvented crawl spaces, and drain tiles which communicate directly with basement or utility room sumps. High concentrations of radon characterize most sources of natural gas, and may not have decayed even after thousands of miles of pipeline transmission. Water supplies, particularly from deep wells which draw water from extensive aquifers sometimes contain radium

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or dissolved radon, and hence may release large amounts when showers are run. Clearly, the rate at which outside air enters must play a major role in the resultant indoor levels.

Having thus briefly outlined the course of this discussion, let me lay the foundation for a more quantitative analysis by defining the units by which radioactivity is measured. The Curie (abbreviated Ci), is defined as 3.7×10^{10} disintegrations per second. It is nominally equal to the decay rate of one gram of radium and for most purposes is an undesirably large unit. For most "real life" calculations, the microcurie (10^{-6} Ci) or picocurie (10^{-12} Ci) are more useful. In 1974 an SI unit of decay rate, the Becquerel (abbreviated Bq) was adopted, namely one disintegration per second. Over the years it has become customary to measure airborne activity concentration in picocuries per liter, and I shall retain that convention.¹

Rocks and Soil

Let us now consider the abundance of radium in some earth materials. The uranium content of the earth's crust is estimated to average around 3 parts per million,⁵ which is equivalent to 1 pCi/gm. The radium content, assuming equilibrium conditions (which is always the case in rock, but may not be completely met in soils), is the same. Basalts, sandstones and many limestones have lower than average activity; granite tends to contain higher levels, and to show greater variability from place to place. Colorado granites average 1.5 pCi/g, while individual samples are as high as 33 pCi/g. Minnesota, Wisconsin and Canadian (pre-Cambrian shield) granites are slightly lower than the above average, while the Conway deposits of New Hampshire underlying roughly one third of the state range from 2.7 to 8.3 pCi/g.⁶

I stress the great variability in the radioactivity of various rocks for two reasons: (1) Rock may be used as aggregate, as building stone, or as a heat storage medium in conjunction with solar-heated air collectors. In each instance there is ample opportunity for direct release of some radon to the living space. I will return to this point in a moment. (2) Radon release from soil immediately surrounding the building is in most cases the single most important source of indoor

¹ The preferred SI unit of Bq/m³ is obtained by multiplying numerical values in pCi/l by 37.

levels. The mineral content of soil is totally derived in some way from rock - the admixture of loess, clay, silt, sand and possibly volcanic material all reflect a geologically complex past. The radium content and emanating properties of soils are thus also highly variable, but to some extent correlated with the materials from which they were derived. Most undisturbed soils are not very uniform, showing several distinct types within a depth of one to two meters. One study showed consistently greater radon release from subsoils, commencing 40 to 50 cm below the surface.⁷ Average radium content of North American soils is believed to be around 0.7 pCi/g.⁸ It may be worthwhile pointing out that a volume of soil one kilometer square by 1 meter in depth thus contains on the average 1 gram of radium. Paradoxically, this "scarce" element which has sold for as much as \$130,000 per gram, and whose entire world production since discovery is only about 1 kilogram, is found all about us.

Transport

The diffusion of radon from its place of origin in the ground takes place via the air spaces within the soil. Consequently, it is dependent upon the water content and degree of compaction. The radon concentration increases with depth below the surface and eventually reaches a constant or equilibrium value. In dry, sandy soils around 50% of the radon escaping to the atmosphere originates within 1 meter from the surface, and true equilibrium is approached at around three meters. When the air spaces are filled with water, equilibrium may exist at a few centimeters below grade. Since clay soils retain moisture and diffusion is retarded, their levels tend to be relatively high and stable with time. At a depth of two meters, concentrations from 500 to over 5000 pCi per liter have been reported,⁹ as compared with an average atmospheric level over the continents of about 0.15 pCi per liter. With concentrations of this magnitude around footings or under the floor slab, it is not surprising that conventional dwellings generally show elevated radon levels in their basements. Thus the sealing and water-proofing precautions which are a part of good earth-shielded construction practice are just as desirable in preventing entry of radon. Any measures designed to improve drainage, such as tiling around walls and use of porous backfill materials, are equally beneficial in providing an alternate route for its escape.

Since concrete is relatively porous, it is also possible for radon to enter a structure by diffusion from the radium present in the wall

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itself. A typical concrete porosity of 10 to 15%¹⁰ results in a diffusion length of 10 cm. If we assume a 20 cm thick wall, and diffusion in only one direction,** then 40% of the available radon escapes from the inside surface. Measurements have demonstrated a release of 240 to 450 pCi per hour per square meter of wall surface.¹¹ This results in a total release of from 270 to 500 nanocuries (10^{-9} Ci) per hour from the walls of a typical 140 square meter (1500 ft²) basement. If the same thickness of an interior wall is assumed, diffusion takes place toward both surfaces, and the total release is approximately 40% greater. An exposed outside wall will clearly contribute less to indoor levels.

How important is this release of radon from the building materials into the living space in an actual structure, where ventilation and uncontrolled infiltration depend upon changing weather and other random factors? If there are no cracks or other paths of direct entry from the soil, then this is the major determinant of indoor radon levels. In Table I I have compiled data from several sources, clearly revealing the trend to higher levels associated with brick and concrete structures.

Table I

Location	Building materials	Estimated ventilation rate (hr ⁻¹)	Radon level (pCi l ⁻¹)	
			mean	max
Sweden (12) (63 homes)	Brick veneer	0.4 - 0.7	1.5	3.8
	Wood frame, with basement _a	0.4 - 0.7	5.4	10.
	Concrete block _a	0.2 - 0.5	7.3	11.1
	Brick veneer _b	0.1 - 0.2	11.1	15.1
<hr/>				
Hungary (13)				
(409)	Fired brick	?	1.6	
(356)	Cinder block	?	5.2	

** This means either a radon-tight barrier on the outside surface, or soil emanating at the same rate, so that no gradient exists at that point.

Table I - continued

Location	Building materials	Estimated ventilation rate (hr ⁻¹)	Radon level (pCi ⁻¹)	
			mean	max
U.S. (14)	Frame, full basement _c	0.1		30.

^a Walls of alum shale based, low density block. Shale radium content approx 5 pCi/g.

^b "natural" ventilation, apparently showing trend to "tighter" construction. See ref. 15. All other buildings with some mechanical exhaust.

^c Special demonstration house by Nat. Association of Home Builders Res. Laboratory.

Table II summarizes extended measurements of nineteen homes in the New York City area,¹⁶ including in most cases readings taken in second floor rooms. The data clearly shows higher levels in basements, but this cannot be the only source of radon, for if so the second floor concentrations should be systematically lower than those on the first floor, which is not the case. The plaster or gypsum board undoubtedly adds to the radon at both levels.

Table II

House no. & type	Mean Radon concentration - pCi per liter		
	2nd floor	1st floor	Basement
1 Frame	-	2.6	3.6
2 Frame	1.3	1.3	4.4
3 Frame	1.5	1.3	2.2
4 Frame	-	-	1.2
5 Frame	-	1.0	1.4
6 Frame	-	1.0	2.1
7 Frame	0.57	0.52	2.3
8 Frame	-	1.1	2.8
9 Frame	1.0	0.6	1.5
10 Frame	0.45	0.52	0.73
11 Frame	-	0.41	0.39

Table II - continued

House no. & type	Mean Radon concentration - pCi per liter		
	2nd floor	1st floor	Basement
12 Frame a	0.83	0.77	-
13 Frame b	-	2.0	4.1
14 Frame b	-	3.1	3.4
	mean	1.25	2.32
15 Brick	-	0.25	0.88
16 Brick	0.9	1.0	2.7
17 Brick	-	0.43	1.1
18 Brick	-	0.5	0.9
19 Brick	0.57	0.39	0.96
	mean	0.51	1.31

^a No basement

^b Raised ranch construction, providing a more open path for air exchange between floors

The mean ratio of basement to first floor concentrations is 2.1 in the frame houses, and 2.6 in the brick, which is probably not a significant difference. Since six of the houses had elevated radon levels in their water supply (ranging from 260 to 1400 pCi per liter), the authors suggest that this might result in somewhat elevated concentrations, but the data fail to confirm such an association. The house having the highest mean (and maximum) reported levels was supplied with water near the lower limit of reported values.

Behaviour in the Atmosphere

The weather is capable of influencing outdoor radon levels by means of several mechanisms. I shall briefly touch on the principal effects in order once again to demonstrate the difficulty of making more than very general predictions in the face of Nature's complexity.

As already mentioned, the diffusion to the surface is determined by soil moisture, while soil temperature and air pressure fluctuations also have a lesser influence. Once in the air, radon may be either

trapped near the surface by an inversion, or carried away by vertical convection and by advection, i.e. horizontal wind currents. When the soil is covered with vegetation there is additional transfer by transpiration from leaf surfaces. This process is also weather-controlled, but in a much less direct manner. While sizeable amounts of radon are believed to be released, the quantitative details are not too well known - hence we shall neglect them. The following figure and results is essentially a case study covering a period of one week, relating to a particular combination of weather variables.¹⁷ Three samples of outside air were collected daily at one meter above ground. Since this process was not automated, samples were collected only during the normal work week, while all meteorological data was accumulated automatically and continuously.

Figure 3 illustrates conditions resulting in maximum radon release; typical fall weather with light winds, the days bright with high temperatures and the nights clear. Notice the stability data - strong inversions four nights in a row and very light winds throughout. Each inversion was accompanied by a buildup of radon which, on the nights of September 10, 11 and 12 were unusually high. Actual peak values were undoubtedly higher than this figure shows, due to the averaging over eight hour intervals. Note that a cold front passed the observing station early on the afternoon of the 13th, followed by cooler and dryer air. The combination of increased advective transport and a weakened inversion resulted in a barely-detectable increase in radon during the daylight hours of the 14th.

The three sections of Figure 4 summarize the results for slightly more than a year of data collection. The maximum, mean and minimum levels are shown, as monthly averages, for each of the eight hour periods during which radon was collected. We see that the highest maximum and average values were observed during the early morning hours, reflecting the strong influence of night-time temperature inversions. The fluctuations were also greatest at this time, for although this great variability occurred mostly during fall months, it persists to a lesser degree all year. Note that for the collection period centered at noon, highest radon levels were found in December; and also that the lowest monthly average minima were in this time period.

Instrumentation

Before presenting some results of the current Argonne studies, I shall briefly describe the instruments we employ. Design of the

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equipment used to date for direct radon measurement¹⁸ is illustrated in Figure 5. ## The active volume within which radon is actually measured is defined by a hemispherical dome wire mesh, covered with black polyurethane foam. The purpose of this open-pore material is to exclude all dust or particulates while permitting unrestricted access of room air. At the center of the hemisphere is a small collecting electrode made of Lucite and covered with a thin layer of aluminized Mylar. When radon within the enclosed space decays, the daughter polonium 218 (RaA) atoms having a net electric charge, are attracted to and deposited upon the electrode. About 40% of the alpha particles subsequently released by decay of this Radium A and its successors penetrate the Mylar and give up their energy to a thin layer of zinc sulfide phosphor underneath. The individual flashes of light which result are directed to a sensitive photomultiplier tube in optical contact with the lower surface of the Lucite; the resultant electrical impulses are fed to a fast electronic amplifier and counting circuitry. At periodic intervals the accumulated total is printed out, and the counter reset to zero, and the cycle repeated. The relationship between observed counting rate and actual radon level is determined by a one-time calibration.

It is desirable to also measure the concentration of radon daughter products in the air, since this is a more direct indicator of possible health effects. At the moment when these products come into existence they are single ions, but they rapidly attach to submicroscopic aerosols which are always available in the atmosphere. These in turn become fixed to walls, draperies, heating system ducts, filters, etc. with the result that the daughter elements are almost never in equilibrium with the parent radon. Their abundance depends upon the relative humidity, concentrations and size distribution of aerosols and large particulates, and other details such as where the radon originated and how it reached the point where measurements were made. Precise knowledge of these variables is seldom available, but may be lumped into what is loosely called the "age" of the air.

In order to measure the individual concentrations, the particulates contained in a known volume of air are collected on a suitable filter of high efficiency. The filter is then counted, preferably with separate detectors for the alpha and beta particles. The results are customarily

Designed at the Institute of Environmental Medicine, New York University, and available commercially

expressed in unit of the Working Level (WL), which is defined as any combination of radon decay product concentrations which will ultimately release 1.3×10^5 Mev of alpha energy per liter of air.¹⁹ In a closed system in which all the daughters are in equilibrium, a concentration of 100 pCi/l of radon results in one WL. In all practical situations, from 200 to 1000 pCi/l are required to produce a 1 WL atmosphere. In fact, the ratio of actual WL to that which would be observed in equilibrium with the radon present, the so-called "working level ratio" is a useful indicator of the "age" of the radon-air mixture. The maximum permissible levels recommended for buildings occupied by the general population, are .03 WL for commercial or public-use buildings, and .01 WL for homes and schools.²⁰

The mechanical portion of an instrument for rapid determination of the WL is shown in Figure 6. A length of filter material on the left roller is fed through the air collection aperture, between two radiation detectors, and onto a take-up reel. The cycle of operation for one determination is as follows (1) a clean portion of filter is moved under the detectors, and a background count taken, (2) an air pump moves approximately 80 liters of air through the filter, (3) the accumulated sample is quickly advanced to the counting position, and counted for three minutes, and (4) from the numbers observed, an internal micro-processor calculates the concentration of each daughter element, the standard errors in the determinations, and the resultant WL. The statistical uncertainty in measurement of a .01 WL sample, which corresponds to about 16 atoms per liter of Radium A, is 8 percent. The total time required to make a measurement is just under six minutes; when programmed to sample once an hour there is sufficient filter to operate for more than a week, or it can be set to shut off automatically at a selected time.

There are other methods of measuring radon concentrations that are better suited to survey work, and yet provide satisfactory accuracy. All WL determinations, however, involve precise timing of the sample collection and counting sequence, so that measurements in the field practically demand automated, hence sophisticated and expensive equipment.

Measurements at A.N.L.

The radon investigations summarized here commenced about two years ago. Our attention was first directed to a split-level frame construction home owned by an Argonne National Laboratory employee.

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The unvented crawl space under the living and dining area (approximately 53 m² area) was unpaved and without a vapor barrier, and was thus subject to relatively unrestricted air exchange with the gravel stratum beneath it. The home totalled about 190 meter² floor area, and was otherwise conventional. Repeated samplings of the bedroom and living areas revealed radon concentrations of from 7 to 30 pCi per liter, seemingly caused by radon emanation from the crawl space. There was no apparent reason why this house was unique, and therefore we began sampling other dwellings in the same area. Seventeen of the 31 houses tested to date had radon levels of at least 3 pCi per liter, as averaged over periods of a few days to a week or more. Most of them belonged to Laboratory employees, were located in the upper middle class western Chicago suburbs and were built within the last twenty years. Hence they probably have less natural air infiltration than that found in the "average" U.S. home. If they are truly representative of millions of suburban homes, we see no reason to doubt that the observed radon levels are also typical.

The upper portion of Table III contains data from three of these homes, the first entries being from the split-level already mentioned. The highest levels measured occurred in the spring (lines two and three versus one), in contradiction to the previous comments about the effects of wet soils. Since the central air conditioning was operating over most of the August sampling period, it might be argued that the moist surfaces of the chill coils were effective in capturing a large portion of the airborne aerosols. Such an argument cannot be applied to the radon itself - and in fact, the figures show a proportionately higher WL in August. A possible explanation for the high spring readings is that radon-rich ground water percolates to the underlying gravel without completely saturating it. If the gravel is sufficiently coarse, release of gas from the wetted surfaces and subsequent transfer to the crawl space may take place. The gravel deposit upon which the entire subdivision is built provides excellent drainage to a nearby small river. The house designated V-2 (fourth line) is basically identical with V-1, and is located only four or five blocks distant, at a slightly lower topographical level and nearer the river. It is tempting to speculate that the soil and gravel beneath it was saturated at the time these readings were taken, hence the low radon observation. We obviously need to make many simultaneous measurements at different locations to clarify the true cause of these differences.

The house designated H-2 is a conventional ranch style structure built upon heavy clay soil. A drain tile system is located at the outside

Table III

Radon and Daughter Concentrations in Selected Houses

Ident.	Type	Season	Radon (pCi/l)		Working Level	
			mean	range	mean	range
V1	SL-F	Aug	11.0	7.1 - 17.6 ^a	.023	.001 - .08 ^a
"	"	Feb	28	23 - 31	.018	.008 - .035
"	"	Mar	29	21 - 54	.024	.01 - .047
V2	"	Mar	1.0	0.9 - 1.5	.001	.0004 - .002
H2	R-F ^b	Oct	11.2	8.1 - 16.1	.016	.0021 - .037
"	"	Jan	6.2	4.5 - 7.1	.0072	.005 - .013
IL1	ES	Jul	6.4	4.4 - 10	Below use. range	
IL2	"	Jul	9.3	3.3 - 16.1	"	"
W1	" ^c	Feb	3.8	1.2 - 7.2	Not avail.	
W2	"	Feb	4.9	3.2 - 8.2	.004	
IN1	"	Mar	4.1	2.6 - 5.5	.0043	.002 - .007
IN2	"	Mar	Not avail.		.001	.0002 - .003

Notes: a. Air conditioning on, except 1 night
 b. Full basement, drain tile on footings to inside sump
 c. Closed in, but under construction

of the footings and connects to a sump within the basement. It is believed that this is equally effective in collecting radon. A few days prior to the readings shown, levels of from 11 to 50 pCi per liter were obtained in the basement. These few examples, showing rather great differences in radon level from houses just a few miles apart, demonstrate the great need for more extensive measurements and analysis.

The remaining portion of the figure gives the results from the six earth-shielded homes which have been sampled. The first four of these, in Illinois and Wisconsin, are located in sandy soil; the remaining ones are in clay. All the observed levels are quite low, and apparently indicate that there are no strong sources of radon present. Two factors are probably most responsible for this fact: (1) Design of footings and walls is conservative, as compared with conventional buildings. Site preparation and actual construction, in some cases under owner supervision, is of superior workmanship. (2) Since all the buildings were constructed recently, the backfill around the walls is still more porous than the undisturbed soil nearby, with consequent reduction in the radon concentration. Choice of site and local grading to insure good drainage may also be a contributing factor.

Health Effects

Breathing radon itself does not result in any significant health hazard. By far the most localized radiation exposure results from the inhalation of the attached fraction of daughter products, which deposit on membranes of the respiratory system. Up to 60% of the daughter ions borne by inhaled aerosols are retained on the bronchial epithelium or within the fine-divided passages of the pulmonary lung. The aerodynamic processes which determine quantitatively where this deposition takes place depend upon aerosol size distribution. The greatest dose is delivered to the basal cells of the bronchial epithelium from the absorption of high energy alpha particles.

Knowledge of these harmful effects is derived for the most part from epidemiological studies of uranium miners. For this purpose, comparisons have been made of the measured or estimated total exposure, expressed as the product of WL and the time actually spent within the mine, to the observed number of lung cancers in excess of the incidence of a control group. There were, of course, uncertainties in the actual radiation exposure and difficulties in properly evaluating the true number

of cancers attributable thereto. In one study of over 4000 miners,²¹ the statistical evidence of malignancy in individuals exposed to less than 120 WL-months (WLM) * was slight, although it is possible that some cases may develop eventually. By way of comparison, an individual living in an average .01 WL atmosphere (i.e. around 2-5 pCi per liter) for fifteen hours each day except for three weeks of annual vacation would accumulate 3 WLM in ten years.** It is uncertain whether this data can ever be used to estimate the risk of low concentrations of radon. Certainly, the aerosol size distribution is completely different. The majority of malignancies observed at all exposure levels were in miners who also smoked tobacco, and much uncertainty exists as to the proper methods for making the necessary corrections. A group of experts in this field reached the conclusion that ". . . composition of the study population indicates that the population at risk in this dose range. . . is now so small as to make it unlikely that even future follow-up will settle the matter."²² The additional risk of incurring cancer from the observed environmental radon levels, should we choose to use presently-available estimates, is of the order of a few cases per million person years. Since the present risk of lung cancer from all causes for males in this country is around 600 times as great, such a small increase would not be detectable.

Conclusions

From this discussion we may conclude, I believe, that there is no reasonable expectation of detectable radiation effects upon individuals living in earth-shielded homes, at least if they continue to be built without infiltration of radon-rich soil gas and are ventilated as well as those reported so far. If there is cause for apprehension, it applies equally to many conventional homes. However, we cannot be sure that all earth-shielded homes will be properly designed and constructed in order to maintain such performance throughout their useful lifetime. A periodic examination may become desirable.

I have not made any attempt to place this discussion in perspective with regard to other known airborne health hazards, such as particulates, sulfur dioxide, lead, and organic chemical vapors. Yet even

* The month in this context is defined as 170 working hours.

** The average length of occupancy of a house by one family in urban U.S. is said to be about seven years.

a casual knowledge of the environment in which we live is a reminder that such a perspective is necessary if a public consensus is to be reached on the sources of energy required for the next generation. I hope this paper has served to stimulate your concern in these matters.

Acknowledgement

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Common name	Scientific name	Half life	Particle	Energy
Radium	Radium-226	1260 year	alpha	-----
Radon	Radon-222	3.82 day	alpha	5.49 Mev.
Radium A	Polonium-218	3.05 min	alpha	6.00 "
Radium B	Lead-214	26.8 min	beta,gamma	-----
Radium C	Bismuth-214	19.7 min	beta,gamma	-----
Radium C'	Polonium-214	10 ⁻⁶ min	alpha	7.68-Mev.
Radium D	Lead-210	22 year	beta	

FIGURE 1

Partial Decay Scheme of Radium-226 Chain

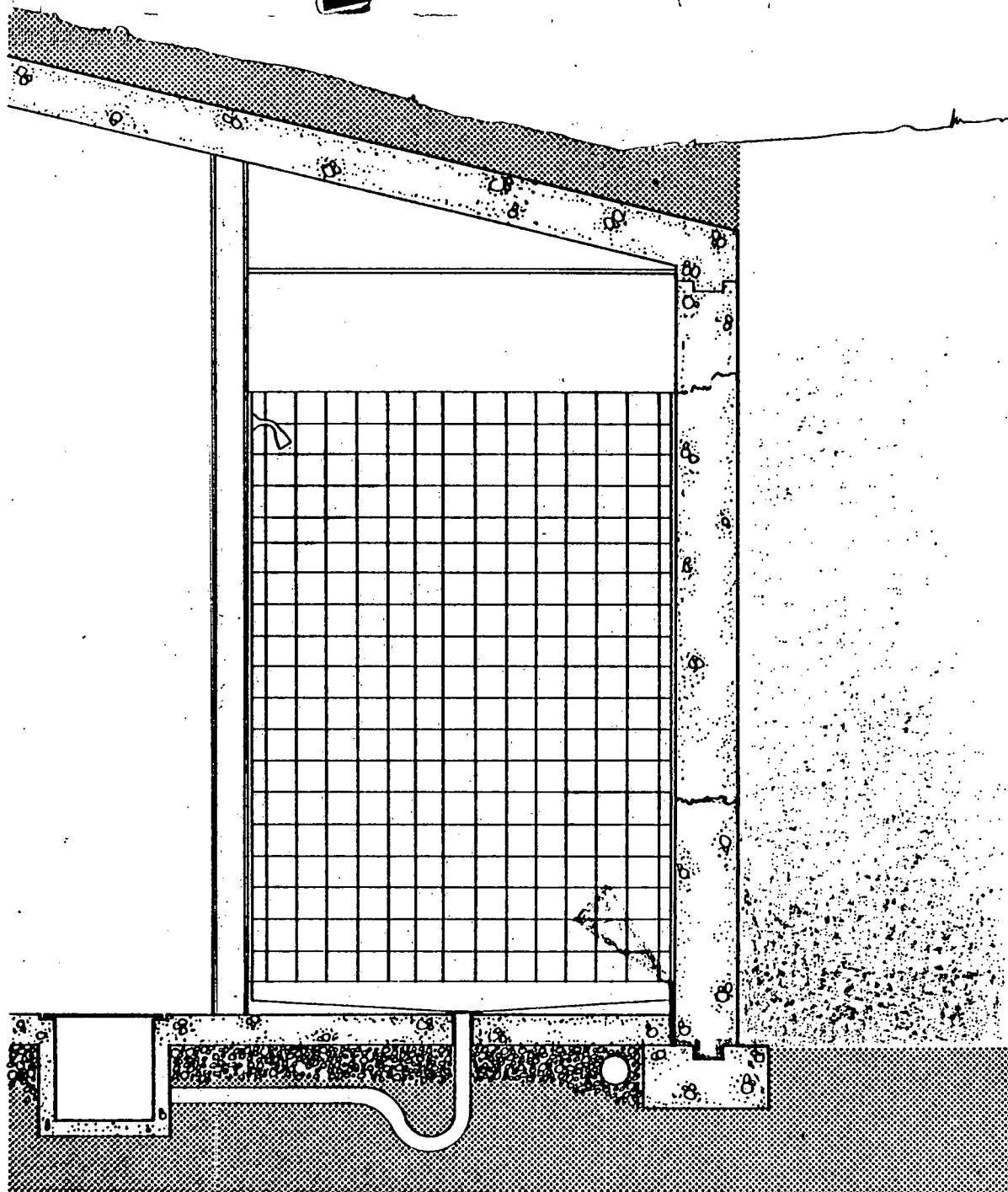


Figure 2

EXTERIOR WALL DETAIL

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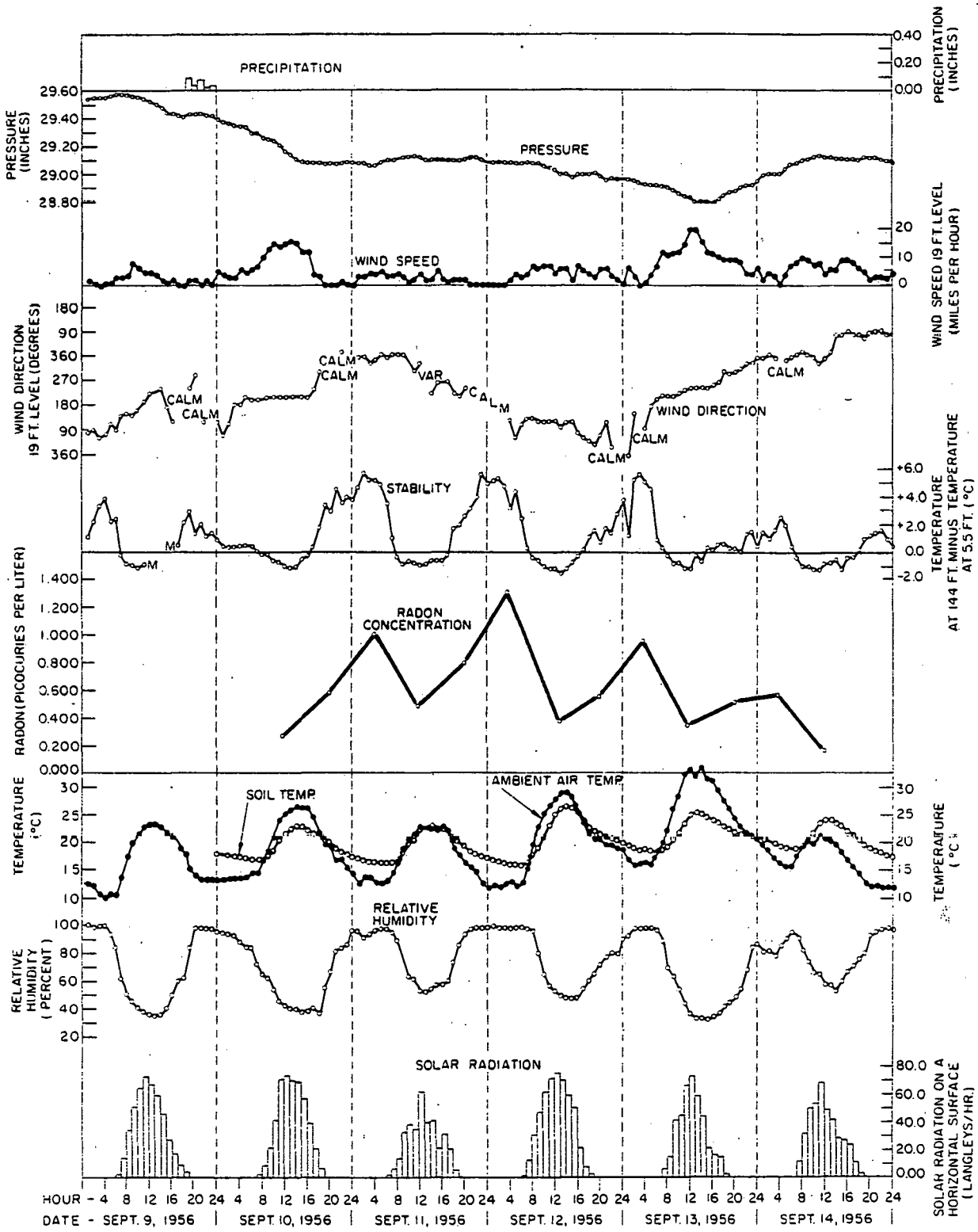


Figure 3

Case study of radon concentrations with intense thermal convection during day and strong nocturnal inversion during night

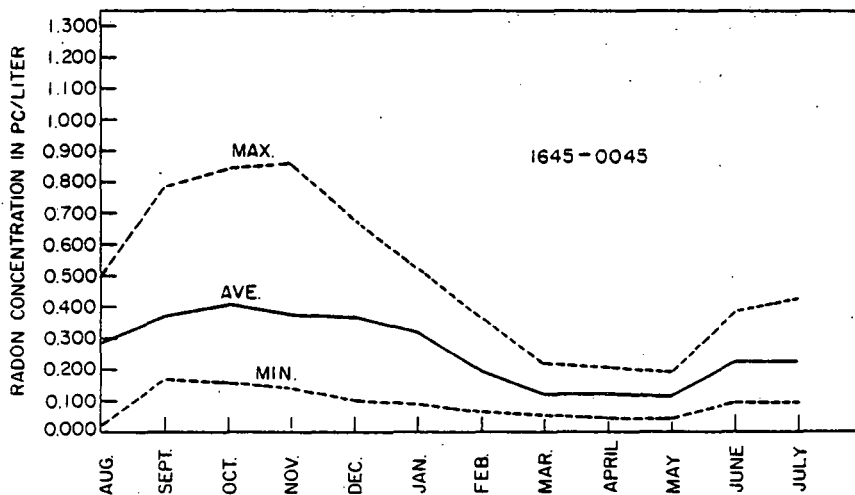
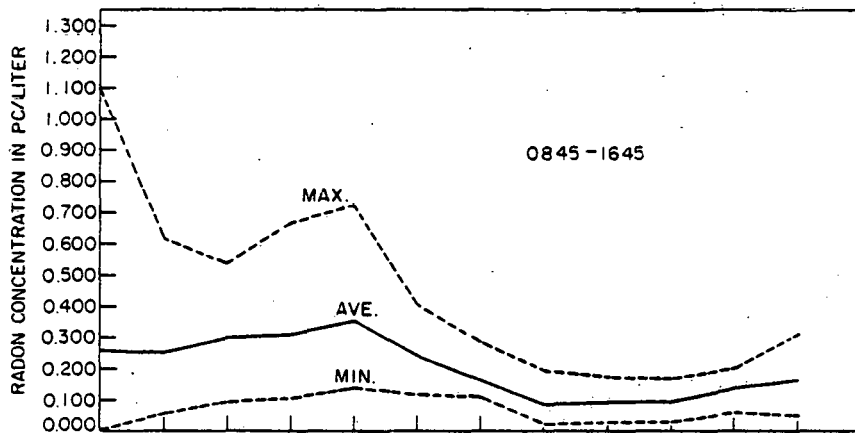
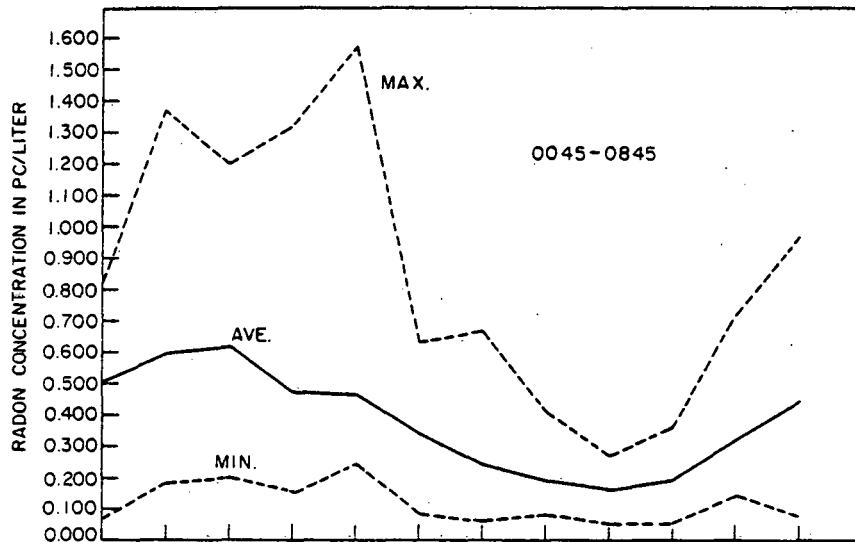
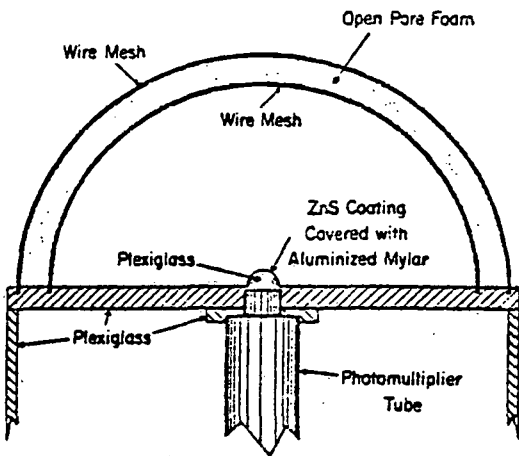


Figure 4

Monthly maximum, average and minimum values of radon concentrations based on indicated eight-hour period.

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DETECTOR CROSS-SECTION
Cross-section of radon
monitor sensitive volume.

Figure 5

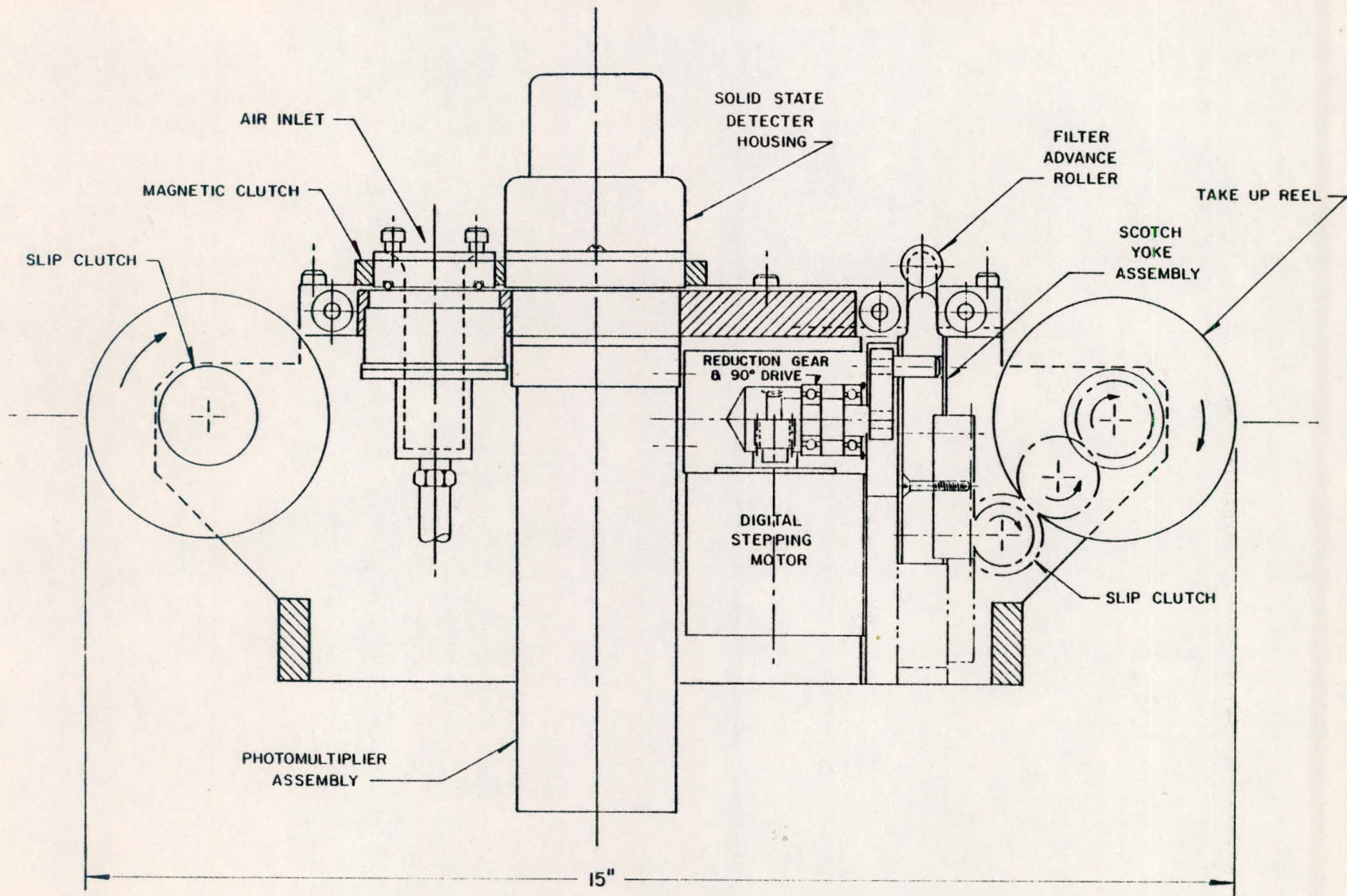


Figure 6
 DETECTOR and FILTER DRIVE

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