The entire area shown in this prototypical housing design covers approximately 25 acres (10 ha). This total includes the area of the two ravines, which are considered unbuildable. By building a total of seventy-five units, an overall density of 3 units per acre can be achieved. Although this is not a particularly high density, it must be evaluated in the context of this rugged and somewhat inaccessible site. Even with the fairly efficient land use associated with the two-level earth sheltered units on the steeper slopes, much of the area below and around these structures must remain open. More conventional methods of development applied to this site would undoubtedly result in far fewer units.

By applying the design concepts and strategies from previous chapters of the book to a real site, it becomes apparent that each site has its own particular opportunities and limitations. Hence, generalizations concerning densities and idealized diagrams of optimal layouts must be viewed with discretion. On the site selected for this prototypical design, the location and spacing of the units was strongly dictated by the land forms and the limited access to the site. With the exception of substituting conventional town houses for the one-level earth sheltered houses on the gentler slopes, there were very few possibilities for increasing the number of units. The topography also dictated the orientation of the housing units on this site. Although the majority of the units have excellent southerly orientation, a few are oriented more toward the east or west than to the south. Careful attention must be paid to the detailed design of these units to compensate for this poorer orientation. For example, the large undesirable heat gain from the east and west in the summer must be screened. On this site the extensive vegetation should accomplish much of the required screening. In addition, south-facing skylights or clerestory windows could be used in these units to increase the passive solar gain in winter.
plan

plan

plan

section—two level units
plan—one level units

section—one level units
Minnesota Housing Design Study

The building concept here is one of clustered terraced housing.

Relationship of Spaces: The upper level has the active spaces (kitchen, living room, dining) and the lower level has the passive spaces. Also, the primary spaces are grouped toward the front for maximum views and sunlight.

Circulation: All parking is located at the top of the hill with an underground circulation spline running down to the lower units.

Structure: Reinforced concrete is utilized and is an appropriate response to earth sheltered construction.

Unique Features: - Terraced housing allows for greater views, increased solar exposure, and use of otherwise unusable land. - Solariums are used in some units for heating. - Energy conscious design

earth sheltered natural ventilation southern exposure passive solar gain - Preservation of the natural environment.

Image Features: - symmetrical and assymmetrical features - low profile, blends with the environment - greenhouses give a "solar" look to units

Influence: This project and the one that follows were the most influential. My project is a mixture of the two with quite a few other ideas of my own. Even though the individual units have a strong fixed order, the combination of them has a wonderful organic structure to it, working well with the topography of the site.
This twenty-one-unit condominium proposal is another excellent example of earth sheltered units used effectively on a marginal, steeply sloping site. The project, located on a south-facing river bluff in the Minneapolis-St. Paul area, was designed for a developer in 1980 by Jay M. Johnson of Miller Hanson Westerbeck Bell Architects of Minneapolis. The rugged 5-acre (2-ha) site would normally be rejected for conventional one- or two-family detached units because it has so little flat, buildable area for conventional housing. It was estimated that no more than six detached houses could be placed on this site. Building attached town-house-type units that step down the slope achieves a density of 4.2 units per acre, however, and much of the site remains in its natural state.

The south-facing slope is ideally suited for maximum solar gain and the two- and three-level units are designed so that sunlight penetrates into every room. A variety of passive solar heating techniques—such as massive concrete floors and solariums—is employed in the units. Passive cooling through natural ventilation is induced by the stack effect in some of the units and by cross-ventilation in others. The multi-story units are almost completely buried on the north side, with only the conventional well-insulated roofs extending above grade.

This project clearly demonstrates a number of energy-efficient strategies and techniques. The housing units are compact and attached in order to reduce heat loss through the exterior. Moreover, they are designed to maximize passive solar gain and earth sheltering. Finally, the siting of the project on marginally developable land represents efficient land use. In addition, this project illustrates some of the major assets associated with building on sloping sites. Although relatively dense, the complex has very little visual impact on the residential neighborhood to the north, and the earth serves to dampen any noise from the road. Each housing unit also has a clear view of the river valley below and a great sense of privacy since no other units are directly visible to the residents of each unit.
solar heating

natural ventilation
River View Condominiums
Minneapolis-St. Paul

The building concept is one of terraced, greenhoused housing.

Relationship of Spaces: There are two rows of units with the garage area between and underground with gardens above it. The top units are organized with the active, or living spaces on the first level and the passive, or sleeping, spaces on the second. The lower units are organized just the opposite. The top units utilize a two story greenhouse in front. The lower units have a greenbuse on the entry level only. Again the servant spaces are located to the rear, giving maximum view and sun to the living areas.

Circulation: A special feature of circulation in the lower units is the stair wells, which "stack" action draws up the warm air and out to aid natural ventilation.

Structure: Reinforced concrete bearing walls and floor slabs are used for the condominiums. Concrete T beams are used over the garage. Wood trusses are used for the roofs of the units.

Unique Features: -Using land unsuitable for typical development due to slopes of hill.
-Underground garage area--keeps automobiles out of sight.
-Solar greenhouses and heating.
-Excellent views of river valley.

Image Features: -Contemporary solar design.
-Good sense of privacy as no other units are directly visible to the residents of each unit.

Influence: As I said earlier, this project was one of the most influential. It probably best correlates to my project than the other examples. The concept of keeping parking centralized, low profile, and segregated from the pedestrian, that this project most successfully uses, was also used in my project. Also the concept of natural ventilation used was also of help. Many of these condominiums also had sunspaces included in each unit to help provide heating. Overall, this particular project is very exciting to me and it really got me going on my own project.
In order to illustrate many of the design considerations which are discussed throughout this study, two earth sheltered designs are presented in this section. The layouts presented and the type of construction used are intended to represent economically feasible, simply constructed houses. They are comparable to well built, well insulated above grade housing, although they should not be considered as overly luxurious. These designs are not intended to represent optimal configurations or prototypes, but simply to be used as a means of illustration. Three major aspects of these designs are discussed. First, the architectural design and site planning considerations are presented for the two designs. Then energy use projections based on methods used in section 3 of the report are shown and discussed. Finally, preliminary construction cost estimates (which were obtained from a local contractor) and various cost considerations are presented. The issue of initial costs and life cycle costs of a house are of primary importance to the development of earth sheltered housing.

This last example is included to show my preliminary energy analysis and cost estimates as the buildings here are similar in many respects to those of my thesis project.
design A

This one level design is a simple elevational plan since all of the windows are located on one exposed wall with earth placed against the remaining three walls. An 18 in. layer of earth is placed on the roof. Since the design was prepared for a hypothetical site, it is assumed that the window wall faces to the south which is the optimal orientation for passive solar collection. Space for a flat plate solar collector is also shown on the south facing elevation of the house. The garage which is linked to the house by an entry is located on the north side so that the public entry area and driveway can be separated from the private outdoor spaces. It should be noted that the house can be placed on a flat site as well as sloping site as shown in the drawings.

Design A represents a minimum program size for most families considering that the 1800 sq ft area includes mechanical and storage spaces normally located in the basement. In this one level elevational design, all of the living and sleeping spaces are placed along the south wall. The only spaces that do not require windows are the bath, mechanical, laundry and storage rooms which are placed along the north wall of the house. This arrangement creates a long narrow plan. Although the length of internal circulation in this house is acceptable, it would be excessive if a larger house were laid out in this manner. The sloping roof over the living, dining and kitchen spaces allows greater light penetration into these areas in the winter while the overhang and planter serve to diminish the unwanted solar radiation in the summer. Ventilation is also enhanced by the sloping roof since the warmer air can escape through the upper windows.

For purposes of energy and cost comparisons a variation of this design, referred to as Design A-2 was developed. In Design A-2 the earth cover remains placed against the exterior walls but is removed from the roof. In either case the garage roof may be earth covered or conventional.
floor plan

section y-y
design by Carmody and Ellison
Similar to Design A, this large two level design is a simple elevational plan with all of the windows located on one exposed exterior wall. For maximum passive solar collection, it is assumed that the exposed elevation is oriented to the south. The remaining exterior walls are covered with earth over their entire two story height and 18 in. of earth is placed on the roof. In addition, the south wall of the lower level is partially earth covered. In this design, the entry occurs in the south elevation and the garage is located adjacent to the house with a separate entrance into the lower level. This arrangement does not provide as clear a separation of public entry and private outdoor spaces as an entry on the north side, as shown in Design A. However, this is overcome by separating the entry from the other outdoor spaces with level changes and landscape elements. A completely earth sheltered two level design such as this, is more suitable on a sloping site although it could be built on a flat site with substantial amount of fill.

The 2700 sq ft area of Design B is considerably larger than that of Design A. This larger program, which includes three bedrooms, a large family room and a workshop area, represents space requirements suitable for a larger family. In this layout the major living spaces are placed on the upper level which allows for a clear view of the outdoors and greater exposure to the sun. The bedrooms, storage and shop spaces are located on the lower level. On both levels the bathrooms, laundry, mechanical and storage spaces are located along the north wall away from the windows. A two level design is more compact than a one level scheme resulting in more efficient internal circulation even though it is much larger. One interesting feature of Design B is the large directional skylights in the living and family rooms. These provide additional light and passive solar radiation to these large spaces and can serve as a means of ventilation in the summer. Overhangs on the upper level windows and balconies over the lower level windows allow winter sun to enter the spaces while the summer sun is screened out.
design B

upper level plan

lower level plan
Based on the methods of calculation used for the comparisons in Section 3, energy use projections were made for the two designs presented in this section. In each case, there are two variations of the basic design. Energy use projections for the single level house (Design A) are presented for designs with and without earth cover on the roof. One variation of the two level house (Design B) has large directional skylights over the living and family rooms, while the other has a completely earth covered roof with no penetrations. Separating the skylights in this manner illustrates their contribution to the overall energy performance of the house. The types of construction on which these calculations are based are presented in the following discussion of costs.

Although these projections are based on monthly temperature averages and are subject to a number of variables, they still represent a reasonable estimate of seasonal energy use after an initial period of three years. The results indicate remarkably low net energy requirements for both summer and winter in all cases. Several points can be illustrated by comparing the various alternatives.

The most striking result is that the two level house (Design B) actually has a lower energy requirement than the one level house (Design A) even though it has 50% more floor area. In fact, the two level house actually shows a net heat gain during the winter months, while the one level house shows relatively low heat losses for the same period. This means that the internal heat gain used in these calculations is greater than the losses due to transmission and ventilation. In addition, the net cooling load in the summer is less for Design B than for Design A even though the internal heat gain is slightly greater. There are two main reasons for the superior performance of Design B. The first is that the two level plan represents a more compact configuration than the one level plan. Although the floor area of Design B is 50% greater than Design A (2700 sq ft vs. 1800 sq ft), the total exterior surface area is only 15% greater (5770 sq ft vs. 4990 sq ft). The second reason for the superior performance of Design B is that the structure is deeper into the earth, and that it has a greater ratio of earth cover to exposed wall than Design A.

A second interesting comparison is the performance of the single level structure with an earth covered and a conventional well insulated roof (Cases A and A-2). The winter heating requirement is only slightly increased (from 1630 kW-hr to
1862 kW-hr) however, the greatest impact is in the summer cooling load. Due to the additional solar radiation reaching the roof, the total summer heat gain is nearly doubled (from 1741 kW-hr to 3315 kW-hr). It should be noted, however, that this is still a reasonably low figure when compared to most above grade structures.

**design A—** one level w/earth covered roof

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**design A-2—** one level without earth cover

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**design B—two story without skylight**

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**design B-2—two story with skylight**

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Finally, the energy use of the two level structure with and without the large directional skylights is worth noting. The effect of this feature is a slight increase in the winter transmission loss as well as the summer heat gain. Although, the skylights do make a noticeable impact on the energy requirements, the totals are still quite low. It should be noted that the directional skylights used in this comparison are far more energy efficient than the more typical flat or bubble units. This is because the south facing directional skylight gains passive solar heat in the winter reflecting it into the space while screening out most of the solar radiation in the summer.
Construction costs for the two designs are presented below. These costs are only preliminary and are based on a number of assumptions about the structure and the manner in which it is finished. Basically both structures are assumed to be 8 in. thick cast-in-place concrete walls with a 4 in. concrete slab floor. The roof structure and the intermediate floor in the two level plan are precast planks spanning the north-south direction thus requiring beams over the window openings to support the roof. The precast planks in Design B span in the east-west direction supported by the concrete bearing walls within the house. In Design B the south wall is a non-bearing 2 x 6 stud wall with 6 in. of fiberglass insulation. It is assumed that the walls and roof of both structures are waterproofed with a bentonite based material and that 4 in. of styrofoam insulation is placed on the roof and the upper five feet of the walls. Both designs have a forced air heating system and include a metal fireplace. All prices for windows, doors and other materials are based on good quality products and installation. The cost of Design B is given both with and without the large directional skylights over the living and family rooms. Although they have considerable aesthetic benefits, they can be considered as optional.

In addition to the two basic designs an estimate was prepared for Design A-2. This alternate design is exactly the same as Design A except that there is no earth cover on the roof. Costs for two conventional roof systems are included. One system consists of 2 x 12 rafters with plywood sheathing and asphalt shingles. This system includes 10 in. of fiberglass insulation and a sheetrock ceiling. The second system consists of laminated beams (8 ft O.C.) with 2 1/2 in. wood decking, 4 in. of styrofoam insulation and pitch and gravel roof. These two systems were selected to represent the range of costs associated with various roof systems.

Although these cost estimates are only preliminary and are subject to a number of variables, it appears that the cost of earth sheltered construction is quite comparable to good quality conventional above grade housing. Generally, construction costs for housing can vary according to location, time of year, and the amount of construction activity in the area. Constantly changing prices for basic materials have recently caused fluctuations in housing costs as well. In addition to these variables there are some unique aspects of earth sheltered construction that will also affect costs.
preliminary cost estimate

design A
1800 sq ft @ $42.27/sq ft $ 76,100

garage
  earth covered $ 7,325
  conventional roof $ 5,325

design A-2
  conventional
  2x12 roof
  1800 sq ft @ $40.77/sq ft $ 73,400

laminated beams (STEEL BAR COSTS SHOULD BE SIMILAR IN $)
  pitch & gravel roof
  1800 sq ft @ $43.94/sq ft $ 79,100

design B
  2700 sq ft @ $40.37/sq ft $109,000

garage (earth covered) $ 6,855

design B-2
  with directional
  skylights
  2700 sq ft @ $41.48/sq ft $112,000

notes:  1. land costs not included.
  2. earth moving and $1,000 for landscaping is included; this figures can vary up to $5,000.
  3. all utilities are included except for a well (if necessary).
  4. reasonable allowances for all finishes (painting, carpeting and light fixtures are included).
  5. appliances are not included.
  6. These costs pertain to the Mpls.-St. Paul area, spring 1978.
  7. costs include 10% contractor's overhead & profit.

Contractors often will require a higher price for any innovative type of construction. This is mainly due to their unfamiliarity with certain materials and techniques. This may initially affect the cost of earth sheltered housing even though it
appears to be relatively simple to construct. Once contractors have gained some experience with this type of construction and can confidently predict their own costs, the price is quite likely to go down. Another related consideration is that many typical wood frame housing contractors may not have the experience or interest to deal with a different type of structure. Many earth sheltered designs, such as the two shown here, may be more familiar to contractors with experience in commercial buildings. Thus, there may be a limited number of contractors who are capable of building this type of structure and are also interested in a relatively small project such as single family residence. This would not be a problem with a multi-unit development. It should be remembered that the construction industry is quite adaptable, and the problems mentioned here are likely to affect costs only before earth sheltered construction becomes a more familiar alternative.

In comparing the cost of earth sheltered housing to conventional above grade construction, it is essential to consider the life cycle costs of the two alternatives. The true cost of housing cannot be limited only to the purchase of land and the initial construction cost. The continuing costs of heating and cooling as well as maintenance must be included. Predicting life cycle costs is somewhat uncertain since prices change over time. However it appears inevitable that energy costs will continue to rise substantially in the future. As energy costs rise, the life cycle cost of an earth sheltered house will become increasingly favorable when compared to a conventional structure. For instance, the energy analysis section indicates that a 6000 kW-hr per year reduction in heating load for an earth sheltered house compared to a well insulated above grade house is a reasonable assumption. Making a further assumption of an energy cost (allowing for short term inflation only) of $0.06/kW-hr, the savings per year in energy costs alone will be of the order of $360 per year. If cooling costs are added this figure will become even larger.

In addition structures with relatively little exposed exterior surface area are virtually maintenance free when compared to an above grade house. The cost of maintenance is often overlooked but can be substantial over a period of years. Even if an earth sheltered home costs slightly more to construct initially, the cost to live in it over a period of time is likely to be significantly less than in a typical above grade house. The concept of long lasting, low maintenance housing with relatively low energy requirements is very appropriate in a time of limited material and energy resources.
Appendix 2  Research Grant
A Research Grant Study for Ball State University
by David D. Conklin
May 10th, 1984

The Development of Sand & Gravel Pits for Energy-Conscious Earth Sheltered Housing
Why reclaim a sand and gravel pit for earth sheltered, recreational housing developments? For the following reasons:

1. Optimum Location
Sand and gravel operations are generally located in close proximity to urban centers where the greatest demand for land exists for recreational sites and activities.

2. Desirable Site Features
The nature of sand and gravel sites and operations are conducive to the production of terminal physical site characteristics considered ideal for recreational activities; namely, topographic relief and water areas.

3. Alternative Use Sequence
In accordance with wise land management and progressive rehabilitation practices, recreational uses can occur on sand and gravel sites prior to, concurrent with, or subsequent to site excavations over the extended periods of operation which are characteristic of the industry.

4. Multiple Benefits
In consideration of conforming with typical zoning regulations and requirements, creating a positive public relations image, and realizing mutually advantageous economic returns, the development of sand and gravel sites for recreational uses should be of significant benefit to both the industry and local public agencies.

5. Effectuation Procedures
The successful transformation of a sand and gravel site into a potentially valuable recreational resource is achieved through the application of a comprehensive and systematic planning process based on a thorough understanding of the characteristics of the area and the requirements of the people, including basic resource inventories and identification of alternative development possibilities.

Why earth sheltered over conventional construction?

1. Low energy costs
2. Quieter than conventional homes
3. More structurally sound
4. Not as affected by tornadoses and severe storms as conventional homes
5. Good environmental sense
6. Blends architecture and landscape together
7. Ability to be placed on steep slopes
The first phase of this research project was to examine reclamation procedures and earth-sheltered building design from books on these subjects. A bibliography is provided at the end of this report.

The second phase was to go see examples of earth-sheltered housing and talk to their inhabitants and their designers. The advice and viewpoints received during these conversations were very helpful and complemented my book knowledge with the field experience. The following are some examples of the developments I visited and learned from.
Some of the Developments Visited
One of the most innovative and unusual earth sheltered housing projects to date, the Seward town house development in Minneapolis, Minnesota, resulted from a cooperative effort involving the community and the architects. The site, located immediately adjacent to a very busy section of freeway and adjoining a major intersection, had become undesirable to most residential developers. It was slated for use by a major restaurant chain when Seward West Redesign, a nonprofit neighborhood corporation concerned about increasing commercialization of the area, proposed an alternative: an earth sheltered residential complex. The project was designed by architect Mike Dunn of Close Associates, Minneapolis.

The town houses, completed in 1980, demonstrate how a thoughtful, well-planned design can turn normally undesirable site characteristics to advantage through the application of earth sheltering and passive solar techniques. For example, the fact that the noisy freeway is located immediately north of the site dictated that the complex face south—the ideal orientation for passive solar gain. By facing the units south and creating a berm of earth on the north side and both ends of the complex, the architects successfully dampened the freeway noise. The limited size and completely flat topography of the site required a very efficient plan in order to fit twelve units on the 100- by 300-foot (30- by 91-m) site, resulting in a density of 15.8 units per acre. The efficiency in site planning results from the compactness of the two-level units and the use of retaining walls at the site edge to reduce the land area required for earth berms.

The twelve-unit (nine two-bedroom, three three-bedroom) development is completely covered by berms on the three sides; the roof is planted with long natural grasses. The north berm, designed as a continuation of the grassy edge predominant along the freeway, is punctuated by entrances to each of the units. On the south are located the primary entrances and the individual unit courtyards where owners may plant gardens or shrubs. To make the town house units as energy efficient as possible, the architects incorporated both an active solar system and passive solar features into the design.
Burnsville House

This suburban Minneapolis home was designed to meet three objectives: conservation of energy by using earth sheltering and insulation in conjunction with passive solar heating, reasonable construction costs, and integration of energy efficiency and cost effectiveness with an aesthetically pleasing design that uses the earth cover as a positive design feature.

A major factor influencing the design of the Burnsville house was the challenge presented by the steeply sloping, heavily wooded site. Working with the slope, the designers placed the house into an east-west ridge that slopes away to the north and south.

By opening the house to both the north and south sides, the architects have separated the more public entry and driveway area (on the north) from the private view of the outdoors, which faces onto the primary living spaces. The original slopes to the site have been maintained so that the house blends in very naturally with the surrounding land forms. Treated timber retaining walls and planters harmonize with the rough cedar siding used on the exterior, which in turn has weathered to reflect the natural colors of the woods.

An outdoor deck—placed at the east end of the house so as not to interfere with the sunlight to the lower level—provides an exit to grade from the living areas, which are located on the upper level. In addition to reducing the area required for the exterior building envelope, the compact two-story configuration of the house minimizes the potential problem of lengthy internal circulation.

The roof of the house is completely covered with earth, as are most of the east, west, and north walls. The designers made significant use of retaining walls to manipulate the earth for the elevational changes that were required to achieve earth sheltering to the roof of the structure.

All the utilities have been consolidated in a shaft that extends up the middle of the south-facing front of the house. By means of this unique design feature, roof penetrations through the waterproofing and concrete roof plank have been avoided.

The sloped roof and rather narrow plan allow greater penetration of sunlight into the living spaces. Additional solar heat gain, as well as substantial natural light, is admitted through the large clerestory windows. The living spaces on the upper floor act as collectors for direct passive solar gain. Solar radiation is absorbed by the dark brown, unglazed ceramic tiles of the intermediate floor, which then release heat into spaces on both levels of the house.

In summer, sunshades over the windows, in combination with the tall deciduous trees on the south side of the house, keep out direct sun. The north entry and operable clerestory windows help provide natural ventilation throughout the house.
LOCATION: Burnsville, Minnesota
ARCHITECT: John Carmody, Tom Ellison
STRUCTURAL ENGINEER: Martin Lunde
MECHANICAL ENGINEER: Terry Tillman
CONTRACTOR: Ellison Design & Construction
CONSTRUCTED: 1979
PHOTOGRAPHY: Tom Ellison

GROSS AREA: 1,850 sq. ft. (175 ca)
STRUCTURE: 12 in. (30 cm) reinforced concrete block and 2 x 6 wood stud walls, precast concrete plank roof, precast and concrete slab-on-grade floors

EARTH COVER: 100% on roof
60% on walls

INSULATION:
Roof—6 in. (15 cm) rigid insulation
Walls—4 in. (10 cm) rigid insulation, tapering to 1 in.
(2.5 cm)

WATERPROOFING: Butyl rubber membrane

HEATING
DEGREE-DAYS: 8,382
HEATING SYSTEM: Electric furnace, forced-air system

COOLING SYSTEM: Natural

CONSTRUCTION COSTS:
Site work $17,010
Concrete masonry 17,430
Waterproofing 7,310
Carpentry 20,715
Heating 1,790
Plumbing 2,890
Electrical 2,630
Interior finishes 7,290
General requirements 3,000
TOTAL $99,925

*These costs reflect special Min-FA Demonstration Project requirements and local construction industry conditions.

Temperature Data

The temperature inside this un-air-conditioned house varied 7°F (3.9°C) on a sunny, 72°F (22.2°C) day. The maximum temperature stratification—taken from sensors located at the ceiling peak and at the lower level of the house—was 5.75°F (3.2°C) during the same day.
UNDERGROUND BUILDINGS ESCAPE THE COLD

When Saint John’s University of Collegeville, Minn., decided to build new student housing, the Benedictine monks looked around for a building system that would save energy, require little maintenance and provide students with a learning experience.

The choice: earth-sheltering, an energy conservation technique that applies equally well to for-sale or rental housing.

Saving energy — specifically heat — was a large concern because the college is located 70 miles north of Minneapolis where winters are among the most severe in the country.

“During an average winter we have 50 to 60 days of below zero temperatures,” said Father Roman Paur, vice president of student affairs.

According to architect Ted Butler, Hammel, Green & Abrahamson, Minneapolis, “The idea is to bury the buildings in the ground to avoid northern exposure while opening up the south side with extensive glazing to capture passive solar heat.

“Solar heat entering through the windows is stored in the massive concrete structure and released later to the living space,” he explained.

Completed last September, the five earth-sheltered buildings Butler designed for Saint John’s are expected to reduce heating bills by an estimated 60 percent a year.

“The earth itself is a good insulator,” Paur said, “but if it reduces the effects of the wind chill factor to nearly zero.”

In addition, the earth below the frost line maintains a fairly constant temperature of about 55 degrees F. year-round. That helps warm the buildings in winter and cool them in summer.

The concrete, wedge-shaped buildings consist of two floors, with the lower level dug out below ground level on the south side.

The 16-inch-thick side walls consist of 4-inch split-faced concrete block on the outside, 3 inches of rigid insulation, a 1-inch air space plus 8-inch painted block on the inside.

Below grade the walls are 16-inch solid concrete block with 4-inch rigid insulation to a depth of four feet plus 2-inch rigid insulation below that to the footings.

In order to fit more buildings onto the site, the side walls were not earth bermed, Paur said, adding, “We were assured that the insulation would do just as well. In any event, the split-faced concrete is quite handsome and complements other buildings on campus.”

The north wall, which is completely buried, and the 4-inch concrete slab floor are uninsulated in order to take full advantage of earth temperatures.

The 12-inch concrete roof slab is covered with a seamless, a waterproof membrane, 6 inches of rigid in-
sulation, 4 inches of gravel and 18 inches of earth.

The roof insulation extends 8 feet behind the back wall to help the earth maintain its 55 degree temperature within 20 inches of the surface. (The frost line is about 8 feet below ground.)

There is still more concrete inside the building which provides both structural support and mass for thermal storage. Walls between the four apartments in each building are 12-inch concrete block reinforced with steel and filled with concrete. And the floor between the levels is 8-inch concrete.

The only windows in the buildings are along the south wall. Yet the apartments are “light and airy,” said Pour, who lives in one of the units.

Each 1,000-square-foot apartment houses four students. The lower level includes two two-person bedrooms along the south window wall and a bath and storage area along the north wall.

The open plan upper level contains a living room-dining area on the south side and a kitchen and closet along the north wall.

Three-foot-wide overhangs and deciduous trees shade the glass during the summer. In addition, some of the windows open, and excess heat is exhausted through vents in the roof. Special insulating drapes, lined with a reflective metallized polyester fabric, also help prevent overheating and winter heat loss.

The drapes, however, were expensive, costing about $1,600 per apartment.

To encourage students to use the drapes and conserve energy generally, the school is planning to determine the average amount of energy the units consume each year and give students a rent rebate if they use less.

Financed primarily with a $1.3 million loan from the U.S. Department of Education’s college housing loan program, the buildings cost approximately $65 a square foot to construct. Costs were high due to the large amounts of mass and structural reinforcement required for the buildings.

Maintenance, however, is minimal. “About all we have to do is mow the roof,” Pour said.

Although this was the architect’s first earth-sheltered project, Butler said there were no design or engineering problems. “The technology is pretty well known,” he said.

It was also a first for the contractor, Bruce Gohman, W. Gohman Construction Company, St. Joseph, Minn.

Primarily a commercial builder, the firm was used to working with concrete, but Gohman said there were some construction differences, for example, the need for heavier waterproofing and landscaping on the roof.
The third phase was to assimilate the found data and derive the guidelines. This phase was the most difficult, but worth it as the guidelines helped me through my thesis design. The following guidelines are a result; they do not intend to be comprehensive for earth sheltered community development, but are to provide guideposts and a way to go about the process. They are to give one a overview of the issues involved and how they may be dealt with.

The Process

Establishing and reclaiming a gravel mine within an urban or suburban setting is a difficult job. As in any development, governmental coordination is necessary, and permit approval must be obtained. Implementation is further complicated by the uncertainty of future projections: although the time lag between initiation of mining and reclamation for a housing development may be decades, concepts and plans are frequently required before the beginning of mining.

Because the project will be protracted over a decade or more, a number of key factors - including surrounding land uses, gravel and housing markets, technology, understanding of the environment, public perceptions, employees, and elected officials - will change. To accommodate these variable components, design decisions - the assumptions on which they were made, and their effects - should be recorded and periodically reevaluated.

Design

Figure 1 presents the proposed design process, beginning with the preliminary design studies. On-site and near-site inventories include geological, hydrological, and ecological surveys, as well as socio-political and economic data-gathering.

![Diagram of design process](image)

Fig. 1. Developed specifically for mining/earth-sheltered housing design this cyclic design process allows for the dynamics of time, and the coordination of mining with eventual housing development.

A repeating cycle of analysis and concept development follows. As the on-site and near-site inventories are completed, they are analyzed to identify major constraints relating to mining, earth-sheltered housing, and the possible uses of mine wastes to improve the site. A design concept is then developed, taking into consideration the site constraints. Once this design concept has been shown to be feasible for the site, a plan is developed for implementing
it. This operational plan must be presented to the appropriate government authorities for public hearings and approval before mining can begin. Although it varies widely, the design process up to this point usually lasts from three months to two years.

If the mining phase of the project lasts for several years, conditions may deviate from those assumptions recorded previously, and the master plan must be revised.

During the multi-year mining and construction period, many newcomers will be involved with the design and regulatory process. The recording of the initial assumptions and decisions in the process is essential to show the newcomer the basis for prior decisions and present conditions. If master-plan revisions are significant, major changes usually must be presented to the appropriate agencies for approval.
This type of development offers some unique advantages which outweigh some of the problems earth-sheltered housing has had in the past when getting financing. The main objection in the past has been a lack of confidence in the relatively new building type. But, couple it with a long term land reclamation project and the situation changes. Because of the long period of development lenders are more encouraged to help because they feel more comfortable with a long term investment and are not worried about you being a fly-by-night developer.

Likewise, local and federal governments are helpful for the same reason. And they are also interested in getting this land reclaimed and to be productive again (i.e. higher land value more taxes). They are so much so interested, they will provide low interest loans and tax incentives to those who will develop these lands.

Couple the incentives given above and add those given for energy-conscious design and you can begin to realize the potentials of this type of development. For example, if the design of the housing development uses geothermal heating using lake water for water to water heat pumps, as the excavation of gravel is done the lake is formed, you can then claim an energy credit for providing the source for the geothermal heating, while selling the gravel at the same time.

In addition, long term bonds could be given by the local authorities for the development, similar to school bonds. If so, this bond money could be invested while excavation was going on, building up equity to cover construction cost and have substantial profit left over for those who developed the project so they may in turn can afford to lower their housing units selling costs to home buyers, thus making it a good deal for all concerned.
In conclusion, I would like to stress the prototypical nature of gravel pit reclamation into earth-sheltered housing sites. There are many gravel pits suitable in Indiana suitable for earth-sheltered housing. There are approximately a dozen such sites in the Muncie area alone. With the need of good housing increasing everyday, and with the amount of usable land decreasing, this type of development should not be ignored.
Schelle & Rogier
Site Utilization & Rehabilitation Practices
Published by the National Sand & Gravel
Association 1963
-This book along with others by the N.S.G.A.
gives basic information on reclamation of
sand and gravel pits, along with case
studies of reclaimed areas illustrating
some of the possibilities of development
with the exception of earth sheltered
projects to which I propose to fill this
void.

Robinette, Gary O.
Landscape Planning for Energy Conservation
Van Nostrand Reinhold Co. 1983
-This book presents, to designers, con-
cepts to reduce energy use by careful
site planning with the environment. Illus-
trates the optimum landforms and land-
scape configurations for energy efficiency.

Sterling, Carmody, Elnicky
Underground Space Center
University of Minnesota
Earth Sheltered Community Design
Energy Efficient Residential Development
Van Nostrand Reinhold Co. 1981
-The most important resource available for
earth sheltered community design. Illus-
trates the advantages and disadvantages of
earth sheltered housing. Outlines some
basic guidelines for it's development.

Barrett, Epstein, Haar
Financing the Solar Home
Lexington Books 1977
-This book discusses the different possible
ways to finance energy projects and the
federal tax credit incentive program for
energy efficient design.

Underground Space Center
Earth Sheltered Housing: Code, Zoning, and
Financing Issues
Prepared for the U.S. Department of Housing
and Urban Development.
Washington, D.C.: Department of Housing and
Urban Development.
-This book discusses financing along with
codes and zoning aspects of earth shel-
tered housing.
OBJECTIVES

To study various energy-conscious houses with a post-occupancy survey, and establish basic standards or criteria concerning the type of individuals who live in these homes.
-by living in these houses, are there changes in the lifestyle of the occupants.
-what preconceptions are proven false by the occupancy of the house.
-establish guidelines for possible simplification or improvement of the houses, for the better use of its occupants.

I. SURVEY OPINIONS ON ENERGY-CONSCIOUS DESIGN
A. Those with less technical knowledge have a more pessimistic attitude on the future of energy sources.
B. Majority of people are undecided on the incorporation of greenhouses into the design; if used would have to be a living space, not just a place for growing plants.

II. ADVANTAGES AND DISADVANTAGES
A. Maintenance is more important to those without technical background.
B. Some people experience disappointment after living in an energy-conscious house; not all they expected it to be.
C. Most experienced trouble; either too hot in summer or too cold in winter. There was also troubles with water pumps, moisture problems, noise problems, and ventilation problems.
III. PERSONAL CHARACTERISTICS OF OWNERS
   A. Most wanted to live in the country, those that wanted to live in the city wanted to live in a wooded area.
   B. Plants became important focus in the house.
   C. Rooms most used were the kitchen and living room.
   D. People spent an average of twelve hours in their house a day.
   E. People do view energy-conscious design as having aesthetic quality, and some felt a heightened sense of being more in tune with nature.
   F. Major criteria for building or buying was the location of the house or site.

IV. OVERALL RECOMMENDATIONS
   A. Improved understanding of the workings and limitations of energy conscious design (have no false preconceptions).
   B. Change image of house to that of aesthetic quality without neglecting energy design.
   C. Simplify techniques of providing energy efficiency (make more feasible) and affordable to more people.
   D. Educate contractors/builders/owners on how to build energy conscious homes.
      - sealing space for less infiltration
      - more insulation
      - double or triple glazing and some type of movable insulation
      - passive gain sunspaces
      - window shading in summer
      - natural ventilation and cooling in summer
      - earth-sheltered for temperature moderation, cooler in summer, warmer in winter
Constructs for Design

The following are constructs I used in the design of this project. They helped to form a base to work from and to better define the problems and goals of the project.
CONSTRUCT

The percentage of glazing oriented toward a pleasant view, in the prime activity space, directly correlates to the inhabitants awareness of the exterior environment.

This will also increase the strength of the indoor/outdoor relationship of the space.

PRINCIPLES FOR PROGRAMMING

Use a larger amount of glazing when it is oriented toward a good view and when you want inhabitants to be aware of the outside environment.

Use a larger amount of glazing when a good view is to be seen in the prime activity space.
CONSTRUCT

In climates with cold winters, individuals who spend a few hours a week in a sunspace have
A. better help
B. lower stress

PRINCIPLES FOR PROGRAMMING

Include sunspaces in homes and hospitals and other buildings where people spend a great deal of their time.
CONSTRUCTS

Spontaneous conversation is more likely to occur in a sunspace than a space without the abundance of sunlight and plants.

-helps people to feel more comfortable and at ease.

PRINCIPLES FOR PROGRAMMING

When interaction between people is desired, design in greenhouse/sunspaces with places to sit and enjoy them.

Could be used in malls, reception and lobby areas, and dining areas.
CONSTRUCT

A stronger indoor/outdoor relationship is possible if a sunspace is used adjacent to or in the primary activity space and has an exit to the outside.

PRINCIPLES FOR PROGRAMMING

If a strong indoor/outdoor relationship is desired, locate the sunspace next to the living room and near the kitchen or visa versa.
CONSTRUCT

A sunspace/dining area with a good view is more likely to have a greater number of hours use than a dining area with an average amount of glazing looking at the same view without the plants.

PRINCIPLES FOR PROGRAMMING

Allow dining to occur in the sunspace; this requires the sunspace to be adjacent to the kitchen.
CONSTRUCT

Earth sheltered homes must be perceived as "custom built" to compare favorably with conventional homes to overcome peoples preconceived ideas.

PRINCIPLES FOR PROGRAMMING

Requires user participation in programming phase or enough options available to allow the user to tailor his abode to his wishes.

A modular system could be used with different interchangeable component parts.
CONSTRUCT

Residents who live in earth sheltered homes are more likely to participate in environmentally related activities and spend a higher portion of their income on said activities than people who live in conventional "ranch burger" housing.

PRINCIPLES FOR PROGRAMMING

When designing an earth sheltered home, keep this in mind; try to keep the site more natural.

- spend more attention to landscaping
- play down the automobile, so it has a lessened impact.
CONSTRUCT

By reclaiming a sand and gravel pit, recreational activities are more likely than the typical flat site.

PRINCIPLES FOR PROGRAMMING

If recreation activities (such as swimming, fishing, and other lake activities) are needed, check out a gravel pit for a possible site, as they often have such attractive features as man-made lakes and varied topography.
CONSTRUCT

A person chooses to use a derelict site realizing that enough natural land has been destroyed. This gives him higher self esteem and higher pride in his home.

PRINCIPLES FOR PROGRAMMING

Encourage clients to think about using derelict sites, exploring the advantages and what can be gained.
CONSTRUCT

A community which shares a common view overlooking a lake or river is more likely to have a strong community identity.

PRINCIPLES FOR PROGRAMMING

When planning new communities try to keep this concept in mind and if possible locate the new community development where such site characteristics exist.
Energy Analysis

Before I go into the energy analysis of a typical condominium unit in this project, I would like to review the various passive and active systems which are utilized.

To begin with, each unit has a sunspace which provides passive solar heat. In the daytime hours, when there is an excess of heat, a heat return duct is operated, drawing the hot air down into a rock bed under the sunspace slab. The warmth from the air is transmitted to the large gravel, where at night it's stored energy can be siphoned back into the living areas. The sunspace may be completely sealed off from the other spaces, but is designed to be a living space whenever needed, so sun control is provided by solar blinds and overhangs.

Natural ventilation is also emphasized. A solar chimney is formed in the greenhouse, between the two panes of glass, forming an 18" air space. The air space includes solar blinds, which keep the sun from overheating the sunspace. The solar chimney helps induce air flow through the sunspace and the rest of the unit during the day. At night, the 'venturi' window may be pivoted open, allowing in cool breezes from the lake.

The back-up cooling and heating system is a geo-thermal heat pump utilizing the deep lake water (approx. 55°F year round) as its base. A water heat pump is about four times more efficient than other heat pumps using much less electricity. Two geo-thermal heat pumps should be used so that in case one breaks down the other one can cover for it.

I would now like to show some of the basic principles of the previously discussed concepts with some simple diagrams out of Solar Heating by the editors of Sunset books, from pages 10-33.

After this the energy analysis computations and results will be given, proving the efficiency of the passive solar sunspace/greenhouse used in each condominium. The computation follows the method prescribed in A Passive Solar Design Handbook for Wisconsin by Steiger, Keiffer, and Tipler. The final result of these computations is the % of heating that the sunspace provides, and is accurate within 5%.
**Drawing 40: Greenhouse heating**

Attached solar greenhouse is wonder worker: it heats itself by gathering and storing sun's heat, reradiating it at night; it also adds heat to main house by conduction through wall and convection through doors, windows. If greenhouse's temperature swing is great, main house may be insulated from greenhouse, closed off at night to prevent heat loss to gradually cooling greenhouse. If greenhouse stores enough heat, or if wall between house and greenhouse acts as Trombe wall (see page 17), house need not be shut off, but may gather additional nighttime heat from greenhouse.

**Drawing 41: Greenhouse cooling**

To avoid summer overheating, greenhouse's vents and windows, high on east and west sides and across front of overhang, are opened. Sun's heat creates "chimney effect": hot air rises out of greenhouse, pulling cooler air by convection in through house's north windows, across room, and through open doors and windows into greenhouse. Opaque overhang shades house to prevent heat buildup in wall (especially important if wall is not insulated from house).
**Drawing 14:** Berm styles: mounded

Earth is piled against house to keep heat inside; landscaping holds earth in place.

**Drawing 15:** Berm styles: wall-supported

Piled earth is held against house by retaining wall; berm helps keep house warm.

**Drawing 16:** Berm styles: hillside

House is dug into south-facing hillside for stable temperatures.

**Drawing 17:** Climate control with berms

South windows for light & direct heat gain.

**Drawing 18:** Underground house

Perforated drain pipe, massive thermal storage wall below.

**Drawing 19:** House with sod roof

Low berm, protected courtyard,prevailing wind.

North wall rises above berm, sod roof above berm.
**Drawing 65: Rock heat storage**

- Sheet metal insulation
- Plywood
- Air space above rocks
- Exterior insulation
- Buried concrete bin
- Rock or pebble fill

**Heat from outdoor air**

1. Hot air out of duct to house
2. Expansion valve
3. Outdoor heat exchanger
4. Indoor heat exchanger
5. Fan
6. Cool air into duct from house

**Drawing 66: Active solar water heater**

- Collector: heat water returns to storage
- Backup water heater
- Solar storage tank
- Pump circulates water to collectors
- Water preheater tank buried in rock storage
- Backup water heater with heat exchanger in duct

**Drawing 67: Heat pump heating cycle**

Liquid refrigerant is expanded to cold liquid and pushed outdoors (1). Heat from outdoor air moves into cold liquid in heat exchanger, boiling liquid to warm vapor (2). As vapor is compressed, it becomes hotter and is pushed indoors (3). Heat transfers to air blown past heat exchanger in duct, heat loss causes vapor to condense to liquid (4).

**Drawing 68: Domestic water preheat in air space-heating system**

Two options exist for preheating domestic water with an air type space-heating system: a preheater tank buried in rock storage, or a heat exchanger installed in return duct from collectors. Water is cycled through for heating, on its way to backup water heater.

**Drawing 69: Convection cooling**

- Low north windows or vents open to let convection pull cool air into house.
- High south windows or vents open to let hot air rise out of house, starting convection current.

**Drawing 70: Night cooling of rock storage**

- Dampers open rock storage to outdoors to let heat escape to night sky. (Or fan may pull cool air in through rocks to cool them.)
A 3 bedroom unit is used for the analysis with a total square footage of 2720.

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TOTAL CONDUCTION LOSS = 11.8

TOTAL INFILTRATION LOSS:

AC % VOLUME % SPECIFIC HEAT OF AIR
0.3 % 31,160 % .018 = 168

TOTAL CONDUCTION + INfiltration LOSS = 11.8 + 16.8 = 28.6

HEAT LOSS/HR.

24 HOURS X HEAT LOSS/HR. = 6865

BUILDING LOAD COEFFICIENT

BTU'S/HR

24 HOURS X 286 = 6865

TD BASE = TSET - Q_INT / BLC

= 65 - [(4 x 29000) / 6865]

= 65 - 12 = 53 ~> USE 55°F
data vs, L-D, DD

SEP OCT NOV DEC JAN FEB MAR APR MAY

INDIANAPOLIS

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MODIFICATION CURVES

**A**
Effect of orientation for a vertical wall.

**B**
Effect of tilt for due south orientation.

**C**
Transmitted vs. incident radiation, tilt = 45°.
MONTHLY SOLAR SAVINGS FRACTION

SUNSPACE-GEOMETRY
(INSULATED ENDS)

...WITH R9 NIGHT INSULATION
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<th>C</th>
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**ANNUAL AUXILIARY HEAT REQUIRED = 2054764**

**ANNUAL SSF = 1 - (BLC x DD AN / BLC x COLLECT AREA)**

**BLC = 6 (PI)**

**ANNUAL DD = 3403**

**LCR = 5.7 = BLC / COLLECTOR AREA**

**ANNUAL SSF = 0.91**

91% of total heating needs are provided by the passive solar sunspace.