29 Nontraditional Structures

Objectives

After studying this chapter, you will be able to:

- Explain the purpose of a large thermal mass in earth-sheltered dwellings.
- List important site considerations for earth-sheltered buildings.
- Explain why soil type is a major concern in the design of an earth-sheltered structure.
- Summarize design variations of earth-sheltered dwellings.
- Explain why a dome structure generally has less heat loss than a conventional structure of comparable size.
- Diagram how a typical dome provides free interior space.
- Describe how a typical dome is constructed.
- List several advantages and disadvantages of dome homes.

Key Terms

Atrium Design
Geodesic Dome
Heat Loss
Penetrational Design
Riser Walls
Slope Design
Wing Walls

Earth-Sheltered Dwellings

Architects, builders, and designers know that earth (soil) can provide a large thermal mass and act as an insulator. Earth can be used to shield structures from cold winter winds, noise, and undesirable views. In addition, earth has received consideration as a major element in the basic design of housing. Increased heating costs, improved and innovative building materials, new building technology, and the desire to find new solutions to old problems have sparked new interest in this subject. The primary considerations in planning earth-sheltered dwellings are covered in this chapter.

Site Considerations

Design of an earth-sheltered dwelling involves several important aspects that may not be important in the design of a conventional, above-grade structure. Basic site considerations such as orientation to sun and wind, topography, soil type, and groundwater level are especially relevant for this type of structure, Figure 29-1. In addition, the load-bearing elements of the structure must be specifically designed to withstand the tremendous pressure of earth and heavy roof loads, which are approximately 100 to 120 pounds on each square foot of the roof for each foot of earth above.

Figure 29-1. The topography of this site was analyzed when determining the placement and orientation of this earth-sheltered home. (Jeff Burgin Builders)

Orientation on the site

Proper orientation of the structure with respect to the sun and wind will provide energy savings as well as impact the quality of the life inside the dwelling. Orientation to the sun is one of the most important considerations in the design of energy-efficient dwellings. Radiant energy from the sun can help heat the interior space through active and/or passive heating. If sun alone were considered, the best site orientation in a northern climate for any earth-sheltered dwelling would be a south-facing orientation. All windows would be on the south side and the three remaining sides of the structure covered with earth, Figure 29-2. However, other factors sometimes prevent the optimum orientation with respect to the sun. It should be noted that maximum sunlight is desirable in the winter, but not in summer. Therefore, vegetation, shutters, and overhangs can be used to reduce solar heat gain in summer, Figure 29-3.

Wind is also an important consideration for the orientation of an earth-sheltered dwelling. Heat loss increases dramatically when a building is exposed to cold winter winds. An orientation that minimizes the effect of wind will reduce heat loss. Winter

Figure 29-2. All windows in this large, earth-sheltered home face south. The three remaining sides of the home are covered with earth. (Jeff Burgin Builders)

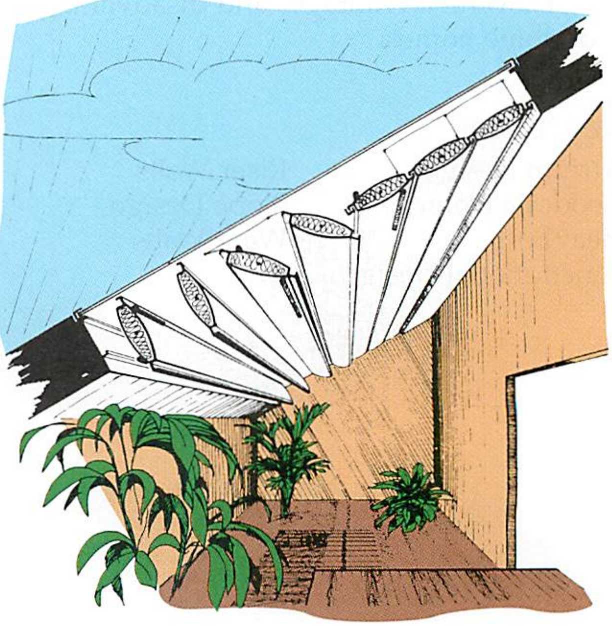


Figure 29-3. Shutters help control the amount of sunlight entering a home.

winds in the northern hemisphere are primarily from the northwest. Therefore, if energy efficiency is important, few windows or doors should be placed on the north and west sides of the dwelling. Earth sheltering provides a unique opportunity to shield the structure from winter winds and, at the same time, provide for ventilation in the summer. Generally, summer breezes are from the southeast.

The view may also be a concern when planning the orientation of an earth-sheltered dwelling. Various basic designs allow for maximization of the view or just the opposite when the view is undesirable. As in planning any dwelling, the site should be selected first so that the building design and site will complement each other.

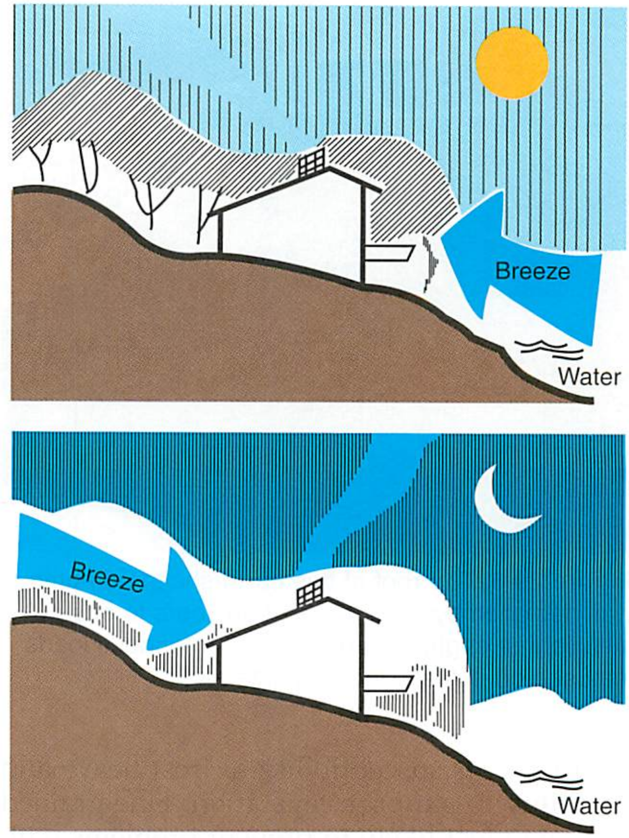


Figure 29-4. Wind patterns around the structure may be affected by changes in the terrain.

Topography

Topography of a site includes contour of the land, trees, streams, and other natural features. The design of an earth-sheltered dwelling may be affected in several ways by the site topography. Wind patterns and temperature around the structure may be affected by changes in the terrain. For example, a south-sloping site encourages breezes to move up the hill during the day and down the hill at night, Figure 29-4. When a body of water is nearby, breezes move from the water to land during the day and from the land toward the water at night. Site contours also determine patterns of water runoff. However, the most important impact of topography on design is whether the site is sloped or flat.

Flat sites present several problems for earth-sheltered structures. Building codes almost always require window openings for light, ventilation, and emergency escape. Therefore, it is assumed that the dwelling will be at least partially exposed to the outdoors. Sloping sites provide many more opportunities in design for earth-sheltered structures than do flat sites.

Vegetation on the site is desirable for beautification, as well as for erosion and noise reduction. Deciduous trees provide shade in the summer and allow sun penetration in winter. Evergreens, when located properly, shield the building from winter winds.

Soil and groundwater

Earth-sheltered structures usually require special evaluation of soils and groundwater conditions on the site. Most dwellings of this type are much heavier and generally placed deeper in the earth than conventional housing. Some sites are not suitable choices for earth-sheltered dwellings because of the type of soil or groundwater conditions.

Two important soil characteristics to be evaluated are its bearing capacity and tendency to expand when wet. There are many variables in determining bearing capacity, such as earth loads and pressures. Calculations should not be attempted by an amateur. A professional engineer should calculate earth loading conditions and main structural elements of the building to withstand these forces, Figure 29-5.

The implications of soil type for structural components vary with the component being considered. The main concern of the soil on

Figure 29-5. The roof of this earth-sheltered home was designed by professional engineers to ensure sufficient strength to support the tremendous loads imposed on it. (Jeff Burgin Builders)

the roof is its susceptibility to frost heave and its ability to support vegetation. Fine-grained soils are most likely to prevent problems with frost heave.

Walls present greater concerns with respect to type of soil than do roofs. Lateral pressures and ability to drain vary considerably with different soils. Generally, sand or gravel is recommended for backfill against the wall. The soil to avoid is expansive clay. It swells when wet and produces very high pressure that can damage the structure.

The major concern with soil under the foundation is its bearing capacity. Remember, the foundation loads will be much higher than for a conventional structure. Soils not suitable for foundations are soft or loose deposits. Compacted sand or gravel is best. Soil under the floor slab is relatively unimportant unless expansive clay or a high water table is present, or a deep excavation is made in soft clay. These conditions can cause floor uplift loads.

Groundwater around the structure causes extra loads on the dwelling and adds to waterproofing problems. When the soil is saturated with water, it presents a pressure of 62.4 pounds per square foot for each foot of depth. If the soil is less than saturated, the weight of the water must be added to the dry weight of the soil. Good drainage is the most practical solution to groundwater problems. A site with a high water table or poor drainage is not a good choice for an earth-sheltered dwelling.

Energy conservation

The primary reason for designing and building an earth-sheltered dwelling is generally the potential energy savings derived from it. Primarily, two aspects of the design affect energy conservation. The shape or geometry of the plan and the earth mass around the structure both affect how effectively the structure conserves energy.

The geometry of the plan directly affects the heat loss of the structure. ***Heat loss*** in a building is the amount of heat that passes to the outside and is a function of the amount of surface area through which heat can escape. Therefore, if other variables are equal, a dwelling with a larger surface area will have greater heat loss than one with a smaller surface area. Figure 29-6 shows a comparison of four basic shapes that have exactly the same amount of floor space, but differ in the exposed surface area. If reducing heat loss is a design goal, then develop as compact a floor plan as possible to reduce surface area.

The second way that energy conservation affects the basic design is related to the earth mass encasing the dwelling. Earth placed against the walls and on the roof reduces heat loss in winter by effectively reducing the exposed surface area. The best solution to minimize heat loss would be to bury the structure deep in the earth with no area exposed. However, this would most likely be unacceptable as a living environment and would certainly not pass building code requirements. The goal, then, is to maximize the earth cover while meeting code requirements for ventilation, light, and escape routes and creating a pleasant living space. Most building codes require all habitable rooms in residential construction to have an operating window to provide light, ventilation, and a means of escape.

Structural system

The structural system is an important factor in any dwelling design. This is particularly true in an earth-sheltered home because

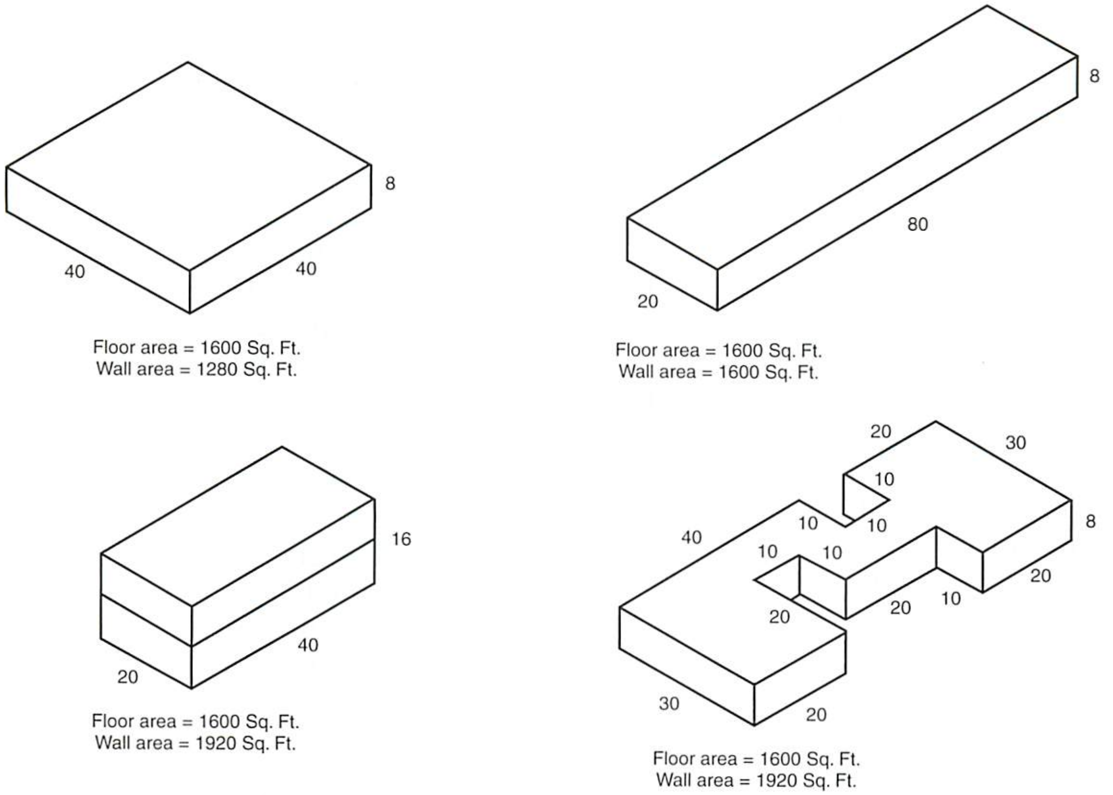


Figure 29-6. Each of these basic shapes has 1600 square feet of floor area. However, notice how the wall area varies.

of heavy roof loads. Two basic systems are used to support the load. These are conventional flat roof systems and somewhat unconventional systems that use vault and dome shapes.

Conventional roof systems use cast-in-place concrete slabs, concrete planks, and wood or steel post and beam systems. The product is usually a rectangular configuration with a flat or sloping roof.

The more unconventional systems can support heavier loads and lend themselves to unique designs. These systems include concrete or steel culvert shapes and domes, Figure 29-7. The advantage is usually greater utilization of the earth mass, but construction may be more difficult or costly.

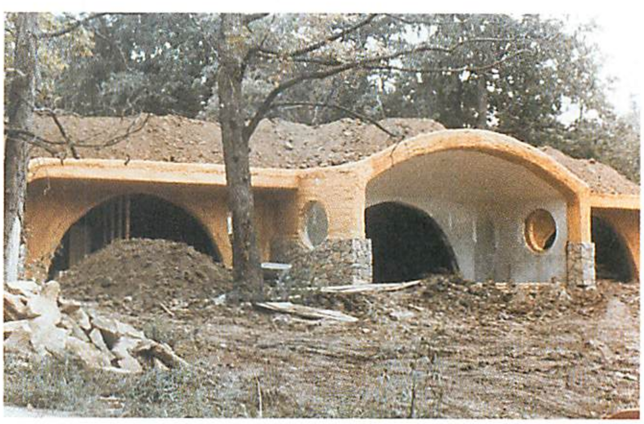


Figure 29-7. This earth-sheltered dwelling, still under construction, uses the dome to provide the roof support needed. (Jeff Burgin Builders)

Cost of earth-sheltered dwellings

The cost of construction for any type of dwelling varies considerably from one section of the country to another. For that reason, it is not practical to try to specify cost per square foot for any design. However, all indications are that the cost of earth-sheltered construction is roughly comparable to good-quality, conventional, above-grade housing. Total cost should, however, consider length of life of the dwelling, maintenance, and energy needs. For example, earth-sheltered dwellings are usually designed to last longer than conventional construction. These factors, when considered, bring the cost of an earth-sheltered dwelling close to conventional construction. One other consideration related to the construction of earth-sheltered dwellings is that many typical residential contractors do not have experience building this type of structure.

Design Variations of Earth-Sheltered Dwellings

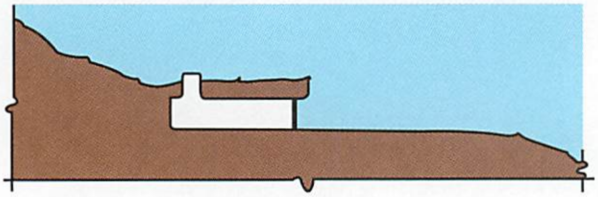
Most design variations of earth-sheltered dwellings are one of three types. These are the slope, atrium, or penetrational design. The basic difference in these types of designs is in the size and orientation of window openings and access points. These designs are covered in the next sections.

Slope design

The ***slope design***, or elevational design, maximizes earth cover around the dwelling by placing all windows and doors on one side of the structure—usually the south side, Figure 29-8. Major living and sleeping areas are then usually arranged along the exposed elevation. Secondary areas that do not require windows, such as baths, utility, and storage, are located behind the living and sleeping areas. The kitchen and dining areas may be placed somewhere between if they are considered part of the front or exposed living area.

The single-level slope design does have the disadvantage that internal traffic circulation may be long, especially for a larger home. Two-level designs allow for a more compact plan that reduces the traffic circulation path. The slope of the site will largely determine which variation is most practical.

The slope design is usually a very energy efficient solution due to the continuous earth mass, windows on the south side, and reduced wind on the structure. However, suitable sites for this design are often difficult to find.



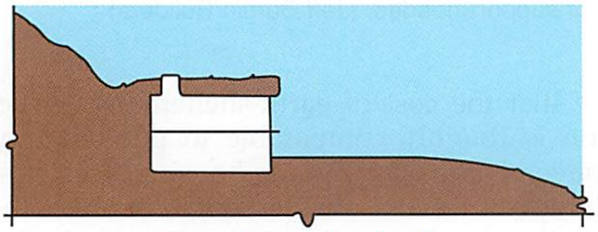


Figure 29-8. These are slope (elevational) designs. All the windows are concentrated on the south side of the structure.

Atrium design

The ***atrium design*** places living areas around a central courtyard with all windows opening into the courtyard, Figure 29-9. The design has more possibilities for warm climates than cool climates because the courtyard can be used for traffic circulation in good weather. If the atrium is covered to create an interior courtyard, then the design has broader applications for cool climates. However, since the living spaces would not open directly to the outside, some codes may prohibit the plan. At best, the atrium design for earth-sheltered dwellings presents traffic circulation problems for cold climate applications.

Even though the atrium design does not face all windows to the south and does not provide for a compact plan, it does tend to hold warm air that is heated by the sun and, therefore, reduces the amount of heat loss. Further, the very private outdoor space makes it a concept worth considering.

Penetrational design

The ***penetrational design*** provides window openings and access at various points

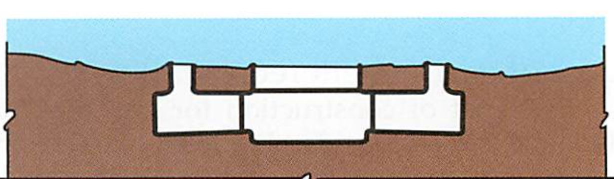


Figure 29-9. This is an atrium design earth-sheltered dwelling.

around the structure facing different directions, Figure 29-10. In concept, the penetrational design varies little from a conventional above-grade dwelling because windows may be located on several sides of the structure. The traffic circulation may also be located in the center of the home.

The location, number, and size of windows must be carefully evaluated if energy conservation is of primary importance. Too many openings will increase heat loss through exposure and wind turbulence. In some cases it may not be possible or desirable to face all windows to the south. In this case, a penetrational design may be the best alternative.

Advantages of Earth-Sheltered Housing

As with any proposed solution to the housing problem, certain advantages become evident. The following is a list of some of the most obvious advantages of earth-sheltered housing.

Figure 29-10. This earth-sheltered dwelling under construction is a penetrational design. Notice the planned openings on each side. (Jeff Burgin Builders)

- The structure will generally be constructed of massive and relatively permanent materials. This provides a long expected life span for the building.
- The amount of energy required to heat or cool an earth-sheltered building is generally much less than a conventional, above-grade dwelling because of reduced heat loss.
- Maintenance costs are generally much less than for a typical dwelling because of less exposure, the type of materials used, and less temperature fluctuations.
- Earth-sheltered dwellings made from concrete have a high resistance to fire damage.

Disadvantages of Earth-Sheltered Housing

There are disadvantages associated with earth-sheltered housing. Some of these include the following.

- A suitable site may be difficult to locate.
- Code restrictions frequently present problems for earth-sheltered house designs.
- Most residential contractors are not familiar with the construction methods required for heavy loads and earth pressures.
- A resistance may exist to "new" housing methods or solutions by banks, builders, and neighbors.

Dome Structures

Several variations of the geodesic dome that was developed by R. Buckminster Fuller have sprung to life on the housing scene, Figure 29-11. Dome structures are not new to architecture, but they are innovative with respect to residential applications. Advocates have described them as the most efficient system of structuring yet developed for housing. This, no doubt, is supported by the fact that domes provide structural superiority, unobstructed floor space, low cost, factory production, and reduced energy needs.

Figure 29-11. A dome home provides an interesting architectural shape and exciting interior. The open floor space lends itself to a wide variety of floor plans. (Monterey Domes)

The basic *geodesic dome* that Fuller developed is an engineered system of triangular spaceframes based on mathematically precise divisions of a sphere. The spaceframes create self-reinforcing roof and wall units. Each triangular spaceframe unit can be manufactured to exact specifications in a factory. The units are then assembled on site by simply bolting them together, which forms the superstructure of the building. This type of structure reduces the quantity of building materials needed per square foot of usable area by about 30% over conventional construction, Figure 29-12. Heat loss is also reduced a comparable amount due to the reduced exterior exposure.

Interior and exterior support systems, such as walls, beams, etc., are not required because the structure of a dome is self supporting. The open interior space generated by this structure provides for a wide variety of floor plans and great flexibility, Figure 29-13. The dome shape provides a living space that is responsive to efficient space utilization, lower energy consumption, and exciting decorative schemes. Further, a dome home can be placed on almost any site. A dome may be constructed on any typical foundation, such as concrete block, cast concrete, or wood foundation.

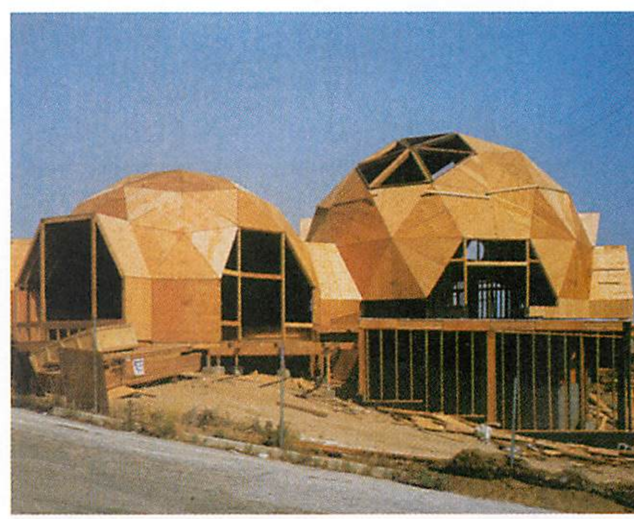


Figure 29-12. The shape of a dome reduces the energy requirements and building materials by approximately 30%. (Monterey Domes)

Manufactured dome homes are available in single-story and two-story models generally ranging from 26′ to 60′ in diameter, Figure 29-14. Two or more units can be positioned adjacent

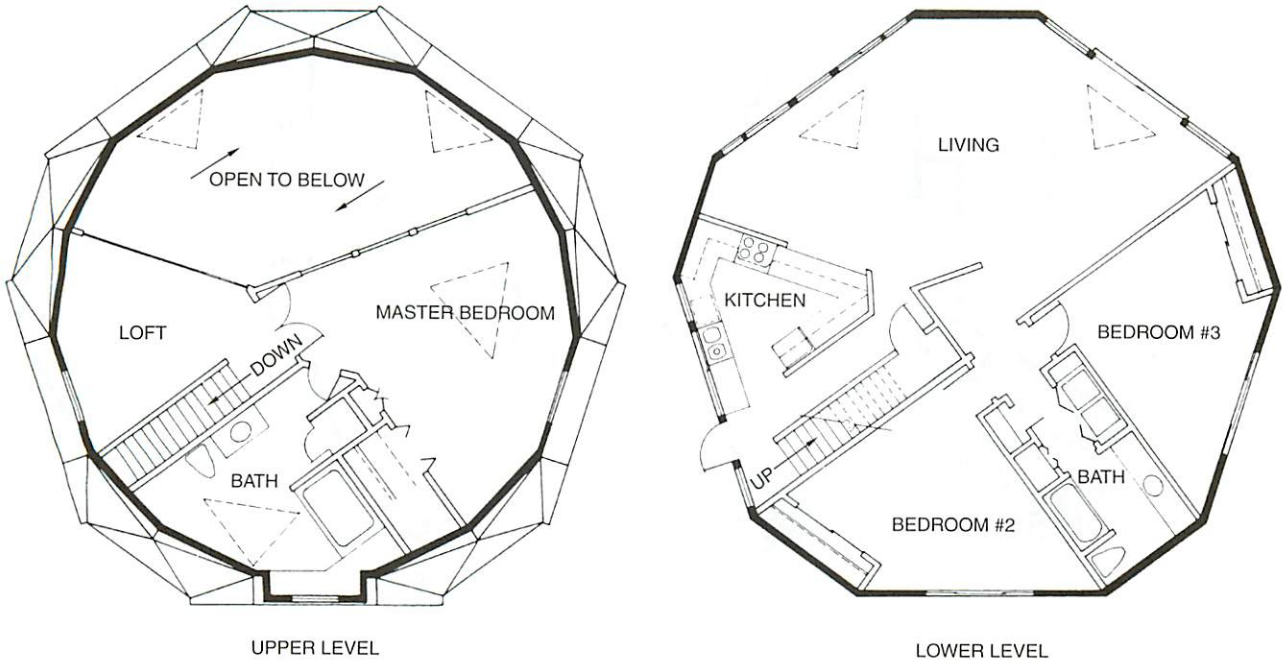


Figure 29-13. This is a typical first and second floor layout for a 45′ diameter dome home. (Cathedralite Domes)

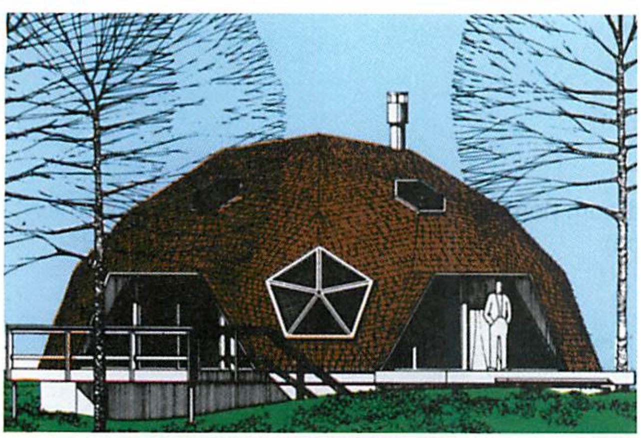


Figure 29-14. This 39′ diameter dome provides 1500 square feet of floor space on two levels. (Domes and Homes, Inc.)

to one another or combined with a conventional structure. Typical roofing materials, such as asphalt shingles and cedar shakes, may be used to weatherproof the exterior.

Dome Variations

Most manufactured dome homes are not true geodesic domes, rather variations that use the central idea of a geodesic dome. The true geodesic dome described by Fuller is produced by dividing the surface of a sphere into a series of small triangles. These are joined together to enclose a space resulting in a dome. Most true geodesic domes have from 60 to 120 triangles.

The large number of components may present problems for home application. Difficulty may also be encountered due to the degree of accuracy required to join a large number of triangles. Also, the small triangles do not lend themselves to large openings for windows and doors.

There are variations of the original geodesic dome that reduce the number of units and incorporate other shapes in addition to triangles. These designs have made the dome concept more feasible to the housing market. One design variation, called the Hexadome, combines 24 triangles and three trapezoids to form a dome up to 32′ in diameter. Each panel unit is constructed from standard construction lumber and plywood. Each unit is also large enough to accept standard windows and doors. Construction of the dome is accomplished by bolting six triangular panels together to form a raised hexagon. Four of these hexagons are required with three trapezoids to complete the dome. Figure 29-15

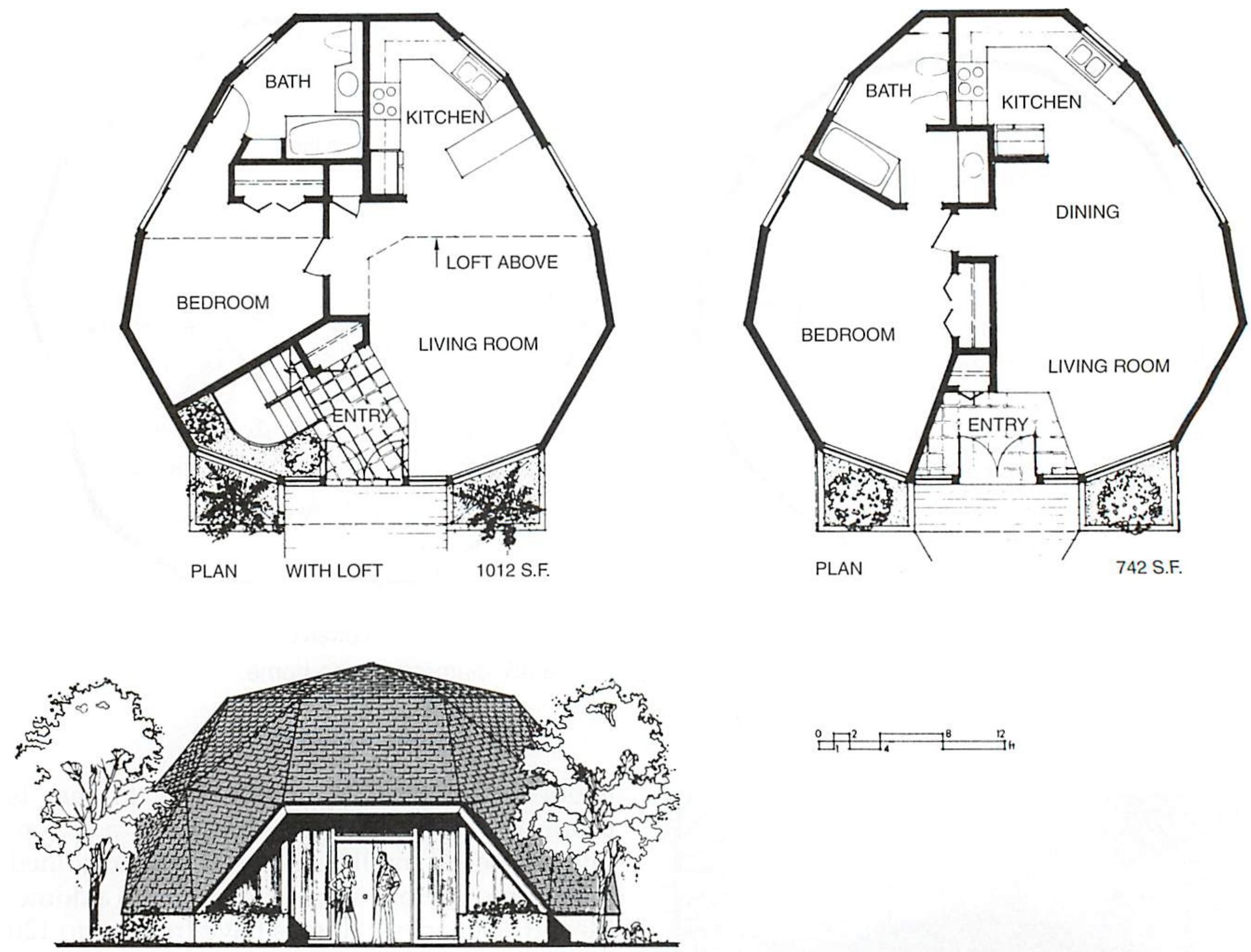


Figure 29-15. A 32′ diameter dome forms a cozy one-bedroom home. A loft can be added to the plan, which could be used as another bedroom. (Hexadome of America)

shows a 32′ diameter Hexadome plan that has 742 square feet of floor space, which can be expanded to 1012 square feet by adding a loft.

Another variation of the geodesic dome uses basic triangular units, but mixes different size triangles to form hexagons and pentagons, which in turn enclose the sphere. The appearance of this dome variation is very similar to the Hexadome. Figure 29-16 clearly illustrates the use of raised hexagons and pentagons in a 39′ diameter dome.

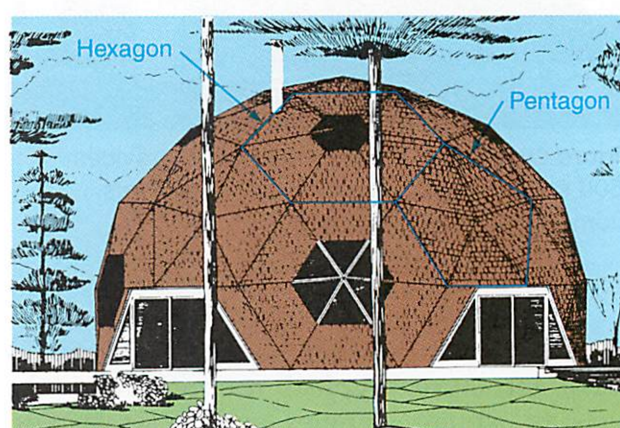


Figure 29-16. Triangular panels are combined to form raised hexagons and pentagons in this 39′ diameter dome. (Domes and Homes, Inc.)

Typical Dome Construction

Most residential dome applications use typical construction techniques and materials to form the basic triangular panels. The panels can be purchased complete and ready to bolt together, precut at the factory and shipped as individual pieces, or built completely on site from standard lumber and plywood. Figure 29-17 shows typical panel designs for a 32′ Hexadome. The frames for the triangles in this example are cut from 4″ × 4″ lumber and a 4″ × 8″ board is used for the base of the trapezoid. Studs are 2″ × 4″ construction with 1/2″ construction-grade exterior plywood sheathing. The sheathing is nailed and glued to the studs.

Once the dome panels are constructed and bolted together, the entire shell of the dome is ready to be placed on the foundation. A crane will be required for this operation. Another procedure is to erect the panels of the dome directly on the foundation. However, a crane will still be required to place the top hexagon in place.

The foundation for a dome structure may be any one of the standard types used for conventional construction. A basement, crawl space, or slab foundation is compatible with dome construction. Once the type of foundation, basic size of dome, and dome style are selected, the foundation shape may be located on the site. Figure 29-18 shows the basic foundation shape for a 32′ diameter Hexadome with openings and walls indicated.

Riser walls support the entire structure while providing additional headroom on the second floor. Remember, however, that the dome itself is self supporting. The Hexadome in Figure 29-15 requires three riser walls to support the dome. Each is 9′-3″ long and made from 2″ × 6″ construction lumber with plywood sheathing, concrete blocks, or cast concrete. The riser walls must be strong and solidly attached to the foundation, Figure 29-19. Wooden riser walls must be solidly braced during placement of the dome to prevent movement of the structure and accidents. *Wing walls* on either side of the riser walls will completely enclose the structure. Wing walls are shown in Figure 29-15 on both sides of the entry door.

The construction of most dome structures is similar to the example discussed here. Completion of the home is the same as for any frame structure.

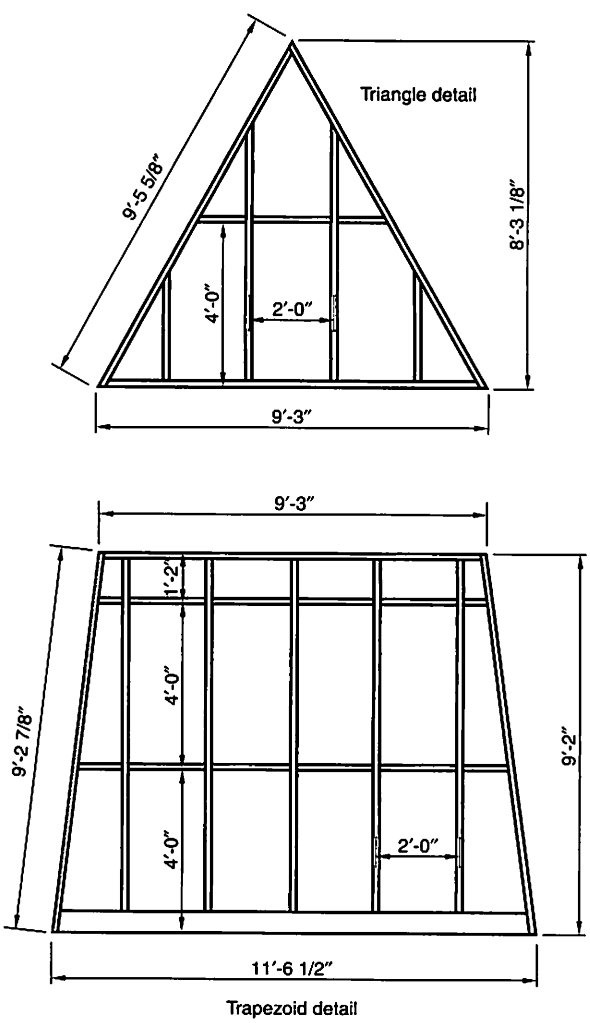


Figure 29-17. Construction details for the two basic panel shapes used in a 32′ diameter Hexadome.

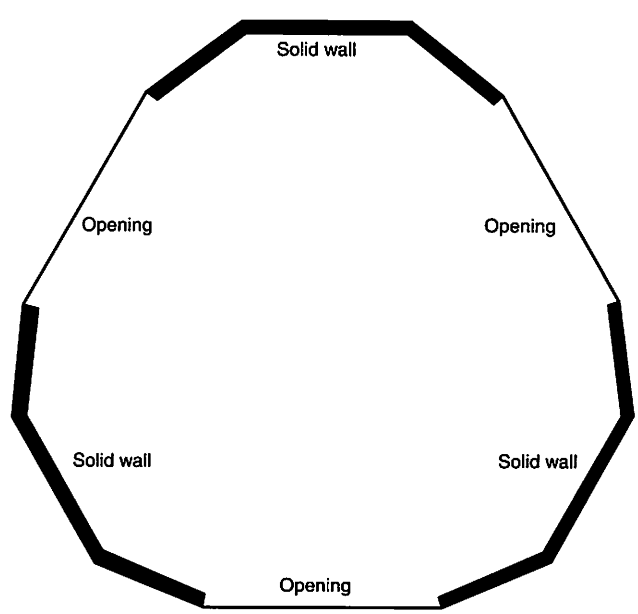


Figure 29-18. This is a basic foundation shape. Walls and openings are located.

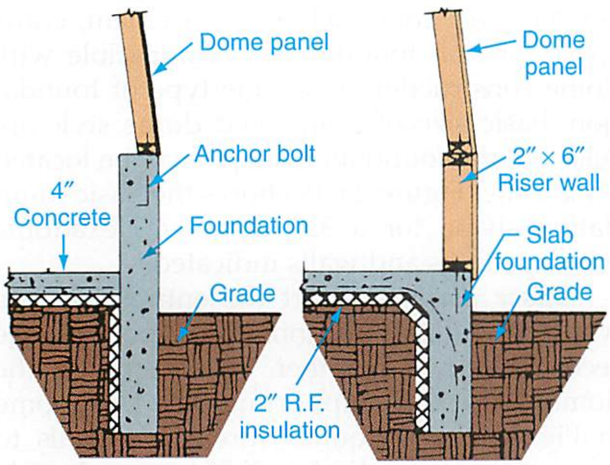


Figure 29-19. Typical foundation details. Left—Raised concrete foundation wall with slab floor. Right—Thickened edge slab with a wood riser wall.

Figure 29-20. The interior space of a dome may be used in any manner since no interior structural support is needed for the shell. (Monterey Domes)

Advantages of Domes

Dome structures have some advantages when compared with typical residential construction. Following are some of the most obvious advantages of domes.

- Domes are a very efficient system that is strong and versatile.
- Domes provide an open, obstruction-free floor space that lends itself to a wide variety of floor plans, Figure 29-20.
- Factory production makes it possible to erect a dome from standard panels in just a few hours.
- The basic dome shape requires less energy for heating and air conditioning than conventional rectangular shapes that cover the same floor space.
- Domes are economical to build since less materials are required.
- The interior of a dome home is exciting and fun to decorate due to the varied shapes and surfaces.

Disadvantages of Domes

Although there are many advantages to domes, there are some disadvantages of dome homes. Disadvantages of dome homes include the following.

- Walls that are not vertical or form square corners may present some problems with typical furniture and appliances.
- More custom built-ins may be required due to the unique design of the structure. Custom work adds cost.
- The dome design may not be compatible with surrounding homes and, therefore, not a good choice in some communities.
- Banks, insurance companies, and building departments are generally not familiar with this type of construction. They may be reluctant to lend money, insure, or approve the design for construction.
- Resale may be more difficult than a conventional home because the dome structure is different.

Internet Resources

www.anchorwall.com
Anchor Retaining Wall Systems

www.bfi.org
The Buckminster Fuller Institute

www.eldoradostone.com
Eldorado Stone, a manufacturer of stone veneers

www.epsmolders.org
EPS Molders Association, an association for the expanded polystyrene industry

www.fibermesh.com
Synthetic Industries Concrete Systems

www.forms.org
Insulating Concrete Form Association

www.increte.com
Increte Systems, a manufacturer of decorative concrete systems

www.keystonewalls.com
Keystone Retaining Wall Systems

www.owenscorning.com
Owens Corning

www.portcement.org
Portland Cement Association

www.recousa.com
The Reinforced Earth Company

Review Questions – Chapter 29

Write your answers on a separate sheet of paper. Do not write in this book.

1. Name several considerations that are important for earth-sheltered dwellings, but may not be for conventional above-grade structures.
2. In a northern location, an earth-sheltered dwelling should face _____.
3. What may be used to shield large glass areas in the summer?
4. Why is wind an important consideration for the orientation of an earth-sheltered dwelling?
5. From which direction do winter winds come in the northern hemisphere?
6. What does the topography of a site include?
7. What is the primary reason for designing and building an earth-sheltered dwelling?
8. Which types of soil are generally unsuitable for building an earth-sheltered dwelling?
9. How much pressure does water-saturated soil exert?
10. Heat loss in a building is a function of the amount of _____ through which heat can escape.
11. Explain why earth placed against walls and on the roof reduces heat loss.
12. Which two basic roof systems are used to support the roof loads in earth-sheltered structures?
13. Name the three design variations used in most earth-sheltered dwellings.
14. Which earth-sheltered design may have openings facing several directions?
15. The _____ design of an earth-sheltered house has the living spaces located around a central courtyard, and all windows open to the court.
16. Who developed the geodesic dome concept?
17. The basic geodesic dome is an engineered system of _____ spaceframes based on mathematically precise divisions of a sphere.
18. List at least four advantages of the dome structure.
19. Why do domes have less heat loss per square foot of floor space over conventional construction?
20. Most manufactured dome homes usually range in size from about _____ to _____.
21. The basic modular shape used in most domes is the _____.
22. The Hexadome variation of the geodesic dome combines 24 triangles and three trapezoids to form a dome up to 32′ in diameter. Another variation mixes different size triangles to form _____ and _____ to enclose the sphere.
23. One piece of heavy equipment may be required on site to assemble a dome home. Name it and explain why it is needed.

24. A dome structure can be built on most any conventional type foundation. Give two examples.
25. Give the two purposes of a riser wall.

Suggested Activities

1. Using CADD, plan and draw an earth-sheltered dwelling using one of the three basic types presented in this chapter as a guide. Build a model of the proposed plan and get a rough estimate of the cost to build the structure from a local builder. Report your results.
2. Visit your local building department or a well-drilling firm to determine the types of soil in your area. Collect samples for display and report on the acceptability of each soil type for earth-sheltered dwellings.
3. Interview a local bank loan officer and a building contractor concerning earth-sheltered dwellings. Obtain the bank and building company policies for these homes. List major reasons for acceptance or rejection for financing, insuring, and/or constructing earth-sheltered dwellings.
4. Go to your local library, bookstore, or magazine stand and secure several books or magazines that list manufacturers of dome homes. The Internet may also be a source. Write to or e-mail three manufacturers and request information about their products. Study the literature and share it with your classmates.
5. Using CADD, plan and draw a simple dome structure. Then, build a scale model of the structure. Explain the advantages and disadvantages of this type of structure.
6. Using a plan supplied by your instructor, obtain information from your local gas and electric company on the cost of heating and cooling a dome home. If needed, modify the plan to increase its energy efficiency. Report your findings to the class.