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EARTH-SHELTERED BUILDINGS

INTRODUCTION

Earth-sheltering refers to using earth as part of a building's thermal control system Earth-sheltered buildings can be either built into the earth or an existing hillside, or can be built above grade, and earth bermed around the exterior after construction. Earth-sheltered buildings can be built entirely underground, but are more often only partially earth-sheltered to allow adequate natural light into the interior. These buildings are most widely recognized for their energy efficiency, due to the insulating capacity of the earth and lower air infiltration through the earth-sheltered surfaces. In addition, earth-sheltered buildings also offer superior protection from storms, insulation from outside noise, lower maintenance costs, and less impact on the surrounding landscape.

Concrete masonry is often the material of choice for earth-sheltered buildings. In addition to strength, durability, low maintenance and resistance to fire, soil gas, termites and other pests, the wide range of concrete masonry colors and textures provides an unlimited palette for the interior. Earth-sheltered buildings can also be constructed of conventional gray units, and easily finished with furring strips and drywall, since masonry is constructed square and plumb.

Earth-sheltered buildings are typically designed with passive solar features to further reduce mechanical heating and cooling requirements. In these designs, the concrete masonry absorbs solar energy, preventing interior overheating and providing heat after the sun sets. Types of passive solar systems and design considerations are covered in more detail in *Passive Solar Design*, TEK 06-05A (ref. 1).

Many design and construction considerations for earth-sheltered buildings are the same as those for basements. For this reason, the reader is referred to *Basement Manual: Design and Construction Using Concrete Masonry* (ref. 2), which includes detailed information on structural design, water penetration resistance, crack control, insect protection, soil gas resistance as well as construction recommendations.

ENERGY EFFICIENCY

Earth-sheltered buildings save energy in several ways when compared to conventional structures. First, earth-sheltered buildings have a lower infiltration, or air leakage, rate. In homes, up to 20% of the total heating requirement can be due to infiltration. Almost half of that figure results from air leakage through walls other than windows or door openings. The earth covering effectively eliminates these losses.

Earth-sheltered construction also saves energy by reducing conduction heat losses through the walls and roof. The temperature difference between the building and the adjacent ground is typically much less than between an above grade structure and the outside air. In other words, the earth moderates the outdoor temperature swings, so that the earth-sheltered building is not subjected to as harsh an environment. In hot climates, the earth acts an a heat sink, helping keep the interior cooler.

CLIMATE AND SITE CONSIDERATIONS

Local climate can effect the practicality of earth-sheltering. Studies have shown that earth-sheltered houses are more cost-effective in climates with larger daily temperature swings and low humidity, such as the northern Great Plains and the Rocky Mountains (ref. 3). In these locations, the earth temperature tends to be more stable than air temperatures, which allows the earth to act as a heat sink in hot weather and to insulate the building during cold weather.

Climate should also be considered when deciding on the type of earth-sheltered structure to build.

The site should be evaluated for water drainage. Choosing a site where the water will naturally drain away from the building is ideal. The finished grade should slope away from the building at least 6 in. in 10 ft (152 mm in 3.05 m) to carry surface water away. Where the topography is such that water flows towards the building, a shallow swale or trench can be constructed to intercept the water and divert it away from the structure.

In addition to the effect on water runoff, the site's slope can significantly impact construction and design. Steeply sloping sites require much less excavation than flat or slightly sloping sites. South-facing slopes work well in climates with a longer heating season, because the building can be easily designed with south-facing windows for direct solar gain (see also ref. 1). In climates with milder winters and hot summers, a north-facing slope may be preferable.

BUILDING MATERIALS

The choice of construction materials should consider the type of structure, depth below grade and soil type. Deeply buried buildings require stronger, more durable construction materials. The following is a brief list of recommendations for below-grade concrete masonry construction. *Basement Manual: Design and Construction Using Concrete Masonry* (ref. 2) contains more detailed recommendations as well as minimum requirements.

- Concrete masonry units should be 8-in. (203-mm) or larger, depending on structural requirements. Use of unit shapes such as “A” or “H” facilitates unit placement around vertical reinforcing bars.
- Type S mortar is generally recommended.
- Joint reinforcement or horizontal reinforcing bars may be required to reduce potential shrinkage cracking and meet certain code requirements.
- Grout, if used, must have a minimum compressive strength of 2,000 psi (13.8 MPa).
- The concrete slab is typically a minimum of 2,500 psi (17.2 MPa) and 4 in. (102 mm) thick to allow the slab to span over weak soil areas without excessive cracking. Follow industry recommendations for subslab aggregate base and vapor barrier.
- Backfill should preferably be free-draining material and should only be placed after the wall has gained sufficient strength and has been properly braced or supported.

TYPES OF EARTH-SHELTERED BUILDINGS

Earth-sheltered buildings can be constructed completely below grade or with part of the building above grade. An earth-sheltered building constructed completely below grade is referred to as an underground structure. More typically, though, the building is built partially or fully above grade, then earth is bermed up around one or more exterior walls. These bermed structures can in general accommodate more conventional building plans.

Underground Structures

Underground structures are most often designed using an atrium or courtyard design. This floorplan uses a subgrade central open area as the entry and focal point, and achieves an open feeling because it has four walls exposed to daylight. The structure is built completely below grade, typically on a flat site, and the interior spaces are arranged around a central outdoor courtyard. Windows and glass doors opening into the courtyard supply light, solar heat, natural ventilation, views and access to the ground level. Atrium/courtyard buildings are typically covered with less than 3 ft (0.91 m) of earth. Greater depths do not significantly improve the energy efficiency.

The atrium design provides minimal interruption to the natural landscape, good protection from winter winds and exterior noise, and a private outdoor space. Design considerations specific to atrium/courtyard structures are courtyard drainage and snow removal, as well as possibly limited passive solar gains, depending on the courtyard size and depth below grade.

Bermed Structures

Two general types of bermed structures are elevational and penetrational. Elevational floorplans have one whole building face exposed, while the other sides, and sometimes the roof, are covered with earth. The covered sides protect and insulate, while the exposed face, typically facing south, provides views, natural light and solar heat. This type of structure is typically set into the side of a hill, and tends to be the easiest type of earth sheltered building to construct, and therefore the most economical. Skylights and/or additional ventilation may need to be considered for the north-facing interior spaces.

Penetrational designs are built above grade, with earth bermed around and on top of it. The entire building is covered, except at windows and doors, where the earth is retained. This design allows natural light from all walls of the building, as well as cross-ventilation.

INSULATION PLACEMENT

Not all experts agree on the amount of insulation required nor the optimum placement around the structure, but two points are generally well agreed on:

(1) It is generally not cost-effective to insulate below the floor slab in an earth-sheltered building. Edge insulation is a good investment on walls that are not bermed.

(2) Insulation should be placed on the exterior side of the walls. Exterior insulation protects the waterproofing from abrasion damage and allows the thermal mass of the below-grade concrete masonry walls to contribute to the energy savings and indoor temperature moderation.

Because of the insulating effect of the soil, insulation is more effective for buildings located closer to the surface of the ground. Normally, for earth cover less than 5 ft (1.52 m) over the ceiling, the ceiling should be insulated. In most cases, it is less expensive to insulate the ceiling than to increase the roof capacity to carry the load of the additional earth.

Figure 1 shows four variations of insulation placement, with some general performance guidelines for underground buildings. Note that in some cases, insulation which is effective at reducing winter heat losses can actually be detrimental when cooling needs are considered. For this reason, it is important to match the insulation strategy to the heating and cooling needs of the building.

WATER PENETRATION RESISTANCE

All below-grade spaces are potentially vulnerable to water penetration from rainfall, melting snow, irrigation and natural groundwater, regardless of the construction materials used. For

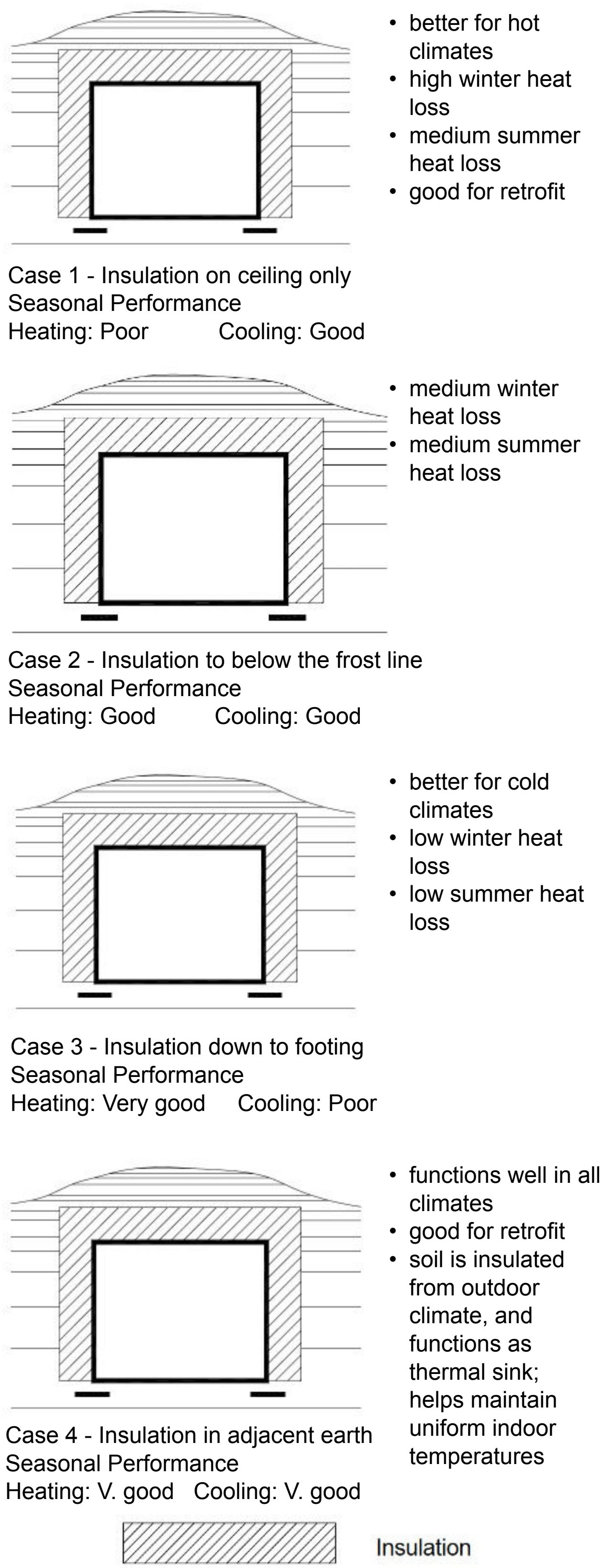

Figure 1—Insulation Strategies for Underground Buildings (ref. 5)

adequate protection, the following should be employed (see ref. 2 for a complete discussion):

- Identify the water sources (precipitation, irrigation, groundwater and/or condensation) and address potential water entry points prior to construction.
- Follow proper construction techniques and details
- Provide drainage to direct surface and roof water away from the structure.
- Install a subsurface drainage system to collect and direct water away from the foundation.
- Apply damp-proofing or waterproofing systems to the masonry walls. A drainage board can also be used to drain water quickly and reduce backfill pressure.

OTHER CONSIDERATIONS

Earth-sheltered buildings require all of the considerations typically associated with basement design and construction, such as structural capacity, insect protection and soil gas protection. In addition, considerations such as adequate ventilation, egress and natural light may also be considerations for earth-sheltered structures.

Adequate ventilation must be carefully planned for earth-sheltered buildings. Ventilation is the exchange of indoor air for outdoor air, and reduces indoor pollutants, odors and moisture. For buildings with low air leakage, such as earth-sheltered buildings, natural ventilation alone should not be relied upon. Instead, the building should utilize a mechanical ventilation system. ASHRAE recommends balanced air-to-air systems with heat recovery for very air-tight homes (ref. 6).

The *International Residential Code* (IRC) (ref. 7) requires all habitable rooms to have a minimum glazing area of 8% of the room's floor area, with minimum openable area of 4% of the floor area to provide natural ventilation. For earth-sheltered homes, if these requirements cannot be met using windows, doors, window wells and skylights, the IRC includes exceptions for homes with mechanical ventilation capable of providing 0.35 air changes per hour in the room or a whole-house system capable of supplying 15 ft^3/min. (7.08 L/s) of outdoor air per occupant. Supplementary artificial lighting may also be required.

In addition, bedrooms are required to have at least one openable emergency escape and rescue opening with a minimum net clear opening of 5.7 ft^2 (0.530 m^2). Window wells must have a horizontal area at least 9 ft^2 (0.84 m^2), with a minimum projection and width of 36 in. (914 mm). These emergency egress requirements may drive the building layout. Homes designed using an "elevational" floorplan, for example, tend to be long and narrow, so that the bedrooms and main living spaces are aligned along the above-grade wall.

Indoor humidity can increase during the summer, which can lead to problems such as condensation and mold if not addressed. Exterior insulation on the walls prevents the walls from cooling down to the earth temperature, but also reduces the heat sink effect for summer cooling. Mechanical dehumidification or air conditioning may be required to control indoor humidity levels.

REFERENCES

1. *Passive Solar Design*, TEK 06-05A, Concrete Masonry & Hardscapes Association, 2006.
2. *Basement Manual: Design and Construction Using Concrete Masonry,* CMU-MAN-002-01, Concrete Masonry & Hardscapes Association, 2001.
3. *EERE Consumers Guide: Site-Specific Factors for Earth-Sheltered Home Design*. U. S. Department of Energy, 2005.
4. *Earth-Sheltered Home Design*. U. S. Department of Energy, http://www.eere.energy.gov/consumer/your_home/designing_remodeling/index.cfm/mytopic=10100.
5. Forowicz, T. Z. *An Anlaysis of Different Insulation Strategies for Earth-Sheltered Buildings*. ASHRAE Transactions, Vol. 100 Part 2, 1994.
6. *2005 ASHRAE Handbook Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2005.
7. 2003 *International Residential Code for One- and Two-Family Dwellings. International Code Council, 2003.*