International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 21 (2017) pp. 10848-10855

Engineering Composition Factors Optimization & Classification in the Earth Sheltered Housing Design

Boris Leonidovich Krundyshev

Saint-Petersburg Mining University, 21-ya liniya, 2, St Petersburg, Russia.

Orcid: 0000-0002-9222-8138

Abstract

The article analyzes the earth sheltered housing design experience that were created with the use of the earths heat protection properties. Viewed architectural and constructive solutions for various natural conditions and terrains. The work classifies the main requirements that affect the design of a buried residence. A comprehensive analysis of environmental factors allowed us to develop a methodology for calculating the basic dimensional parameters of buried residential buildings with an internal atrium. These positions are equally relevant for both individual buildings and multi-apartment complexes.

Keywords: earth sheltered housing, building construction, optimal planning schemes

INTRODUCTION

Actualization of the problem

Deepened construction of residential buildings is the direction of architectural and technical activity for the direct use of land properties, for reducing heat losses, for maintaining a constant temperature of the air indoors, to conserve the necessary area of greened areas of the earth. The deep construction of the dwelling has been widely used in recent decades [1-3].

The main forms of buried residential buildings can be attributed to two main types: 1) buildings with a significant backfilling of the entire volume of the structure with the organization of lighting through open areas of external walls; 2) buildings with full backfilling of the external contour of the structure and lighting through the walls of the internal courtyard.

One of the most serious aspects of buried housing is the reliability of waterproofing, the emergence of internal condensate, the chemical resistance of building materials, the specifics of reinforced structures, the insufficient number of qualified construction companies, topography, climate, specificity of the vegetation layer, groundwater types.

For a relief with a flat outline, the type of a buried house with an internal courtyard is typical. For a hilly relief, the slope determines the location of the wall with window openings.

With the help of the earth sheltered dwelling, new opportunities appear to adapt to the harsh winter conditions in the northern hemisphere, efficient preservation of winter heat, orientation to the sun and protection from cold winds.

Thus, recessed construction of residential buildings is most effective in regions with high heating needs, as well as with large differences in the daily outdoor air temperature. In areas with high humidity, it is also necessary to take into account the increased condensation of air on the internal wall surfaces. In this connection, various systems of natural and artificial ventilation are used [4-6].

Another important factor is the vegetation cover on the surrounding area of the recessed house. The root system of trees can help to remove water and strengthen the slopes, to prevent landslides.

In the design of a buried dwelling an essential factor of reliability is the type of soil. Soil must provide adequate load capacity and drainage, and also contribute to the preservation of heat. With regard to drainage, the most suitable type of soil to cover the ground is a mixture of sand and gravel. Sand and clay can be prone to erosion. Clay soils, although least prone to erosion, often do not allow proper drainage and are more exposed to frosts and are more prone to thermal shrinkage and expansion. Fine-grained soils retain moisture well and require additional drainage measures. To protect against this, the distribution of foundations below the freezing zone or the warming of the soil surface around the outer contour of the building, the replacement of frost-sensitive soils with granular material, and the incorporation of a drainage layer of coarse material into existing soil is common. Drainage, both superficial and underground, should be carried out in the most careful way. Well collects and removes excess water drainage pipe along the perimeter of the roof edge. To drain water around the house, drainage wells, ravines, gravel trenches with drainage tiles can be built.

It is also necessary to take into account the stability of the soil, especially when planning an inclined site. These slopes can be strong enough, if not to break their structural stability during construction work. To strengthen the soil, use retaining walls with a cover filling.

The advantage of using a recessed residential house is not only in its effective thermal insulation performance. The

house protected by the earth is well combined with the natural environment, the relative area of the yard is increased and space for natural flora is preserved [7-9].

Thus, in recent years the general questions arising in the ground sheltered housing development have been analyzed quite thoroughly [10-11]:

a) elements of energy saving in housing;

b) thermal integrity conditions;

c) methods for optimizing the thermal loads necessary for comfortable conditions in passively heated or passively cooled earth shelters;

d) the suitability of the soil, the depth of placement and design methods.

All these factors are aimed at finding the optimal parameters and structural integrity of the buried building construction.

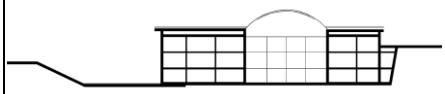
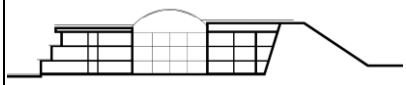
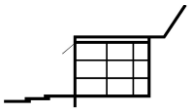
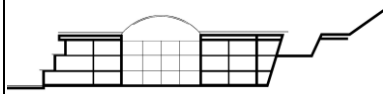
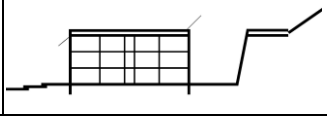
METHODOLOGY

Assessment

The methodology is based on the means study that influence the formation of a buried dwelling. The main of these are the following:

1. Orientation in relation to the sun, surrounding landscape and sight spots
2. Wind - recessed buildings, including those with a courtyard, can be protected from the prevailing north-west winds;
3. Topographical characteristics of the terrain - calm or falling, steepness, orientation of the slopes (table 1);

Table 1: Classification of the environmental impact of natural factors on production of buried buildings

	The section of the building	The impact of prevailing adverse winds	The influence of topographic situation	The value of the surrounding vegetation
1		The building, protected from cold winds and partial penetration	Flat terrain	Green roof merges with the surrounding green landscape
2		The building, protected from cold winds and backfilling		Gardening strengthens an artificial filling
3		The building, protected from cold and storm-winds corresponding to the orientation of the slope	Unilateral steep slope	Gardening strengthens and protects the building from the surface layer of steep terrain
4			Unilateral gentle slope	Green roof merges with the surrounding green landscape
5				Vertical greening slope compensates for the lack of promising viewpoints

4. Vegetation - as an additional measure to conserve energy and strengthen the slopes;
5. Soils and groundwater. An important role is given to solving problems of soils or soils with low bearing capacity, the presence of groundwater
6. Influence of neighboring sites and neighboring buildings
7. The factor of economic feasibility in the process of conceptual design of a buried dwelling

Therefore, well-designed Earth-sheltered Homes must take into account a set of factors that can be the basis for studying promising trends in obtaining new knowledge [12].

As a methodological base for the research, it is expedient to analyze the main aspects of architectural and engineering design. The following is a brief description of the most significant design tasks.

1. The main solution choice, first of all it is connected to the optimization of the people's life - future consumers. It is necessary to conduct a preliminary requirements typification for the most typical residential groups. The next step is the unification of functional requirements for the spatial parameters of the structure. Essential importance is the spatial requirements for the placement of technical services necessary for the life support of the building.

2. Determination of specific moments in the design of the recessed building:

2.1 The conservation of energy is directly related to the determination of the building's configuration - the compactness of the layout and the maximum possible volume of the building. Naturally, buildings with the same floor area can have different surface areas.

2.2 Building regulation - any living room should have natural lighting, ventilation and an emergency exit for people's evacuation.

2.3. The choice of constructive solutions corresponding to underground construction, increased loads from the roof top filling and the complicated forms of stress distribution in structural elements. Constructive decisions greatly influence the building's configuration. For example, increased loads can be effectively redistributed with spherical and vaulted structures of concrete and steel. The materials used to build a house protected by earth must be capable of withstanding the load from the surrounding land. Loads on walls and ceilings from the soil increase depending on its wetting or freezing, from increasing depth of location from the ground, from the selected building material.

2.4. The relationship of submerged buildings with the surface (communication), the relationship with the surrounding landscape, viewpoints

2.5. Typical planning solutions or typology of the earth sheltered housing. Typological classification includes three main compositions: 1) a towering one-sidedly oriented building, in which all the windows face one side of the horizon, the rest of the sides are covered with earth; 2) a building with an internal yard space, window openings are located along the perimeter of the yard space, and the outer walls are adjacent to the ground; 3) transversal (window openings can be located in different parts of the building) - this, in fact, a complex version of the previous two.

3. Detailing of individual fragments of the complex is aimed at fulfilling a number of design conditions:

3.1. The need to provide natural light and access to sunlight to all rooms of permanent residence of people. For rooms that are remote from the outer wall, you can use sky lanterns or inclined roofs.

3.2. Acoustic comfort - the decision of a buried building can be quite appropriate in areas with an increased noise regime (highways, airports, etc.).

3.3. Natural environment Preservation or an artificial landscape formation. The characteristic of the landscape is directly connected with the constructive scheme of the whole building. It is important to determine the necessary thickness of soil for specific plant species used in the covering layers of the soil. If the thickness of the soil is sufficient for the grass cover, then 60-80 cm thick for fertile land is necessary for shrubs, for large shrubs and trees - 150 cm. According to our calculations, the load on the structure at 150 cm thick soil reaches 3,500 kg per m2.

3.4. Specificity of energy losses is related to the thermal conductivity of load-bearing structures

3.5. The kinetic structural elements use, for example, in the organization of a transformable patio cover, etc.

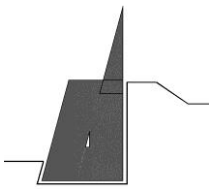
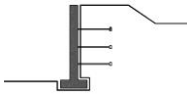
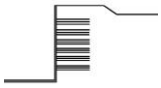
4. The use of energy from the side of optimizing the thermal characteristics of buried buildings

A common misconception is that the earth is a good insulator [13-14]. In fact, here we mean the property of the earth to be a good condenser, which is able to absorb and store heat. The depth of the building's penetration is directly proportional to the temperature background of the surrounding space. For the allocated volumes of buildings above the ground surface, the air temperature is taken into account, for parts of buildings below the ground surface - the soil temperature at the corresponding depth mark. As you know, for St. Petersburg, the freezing level of the soil in the coldest period of the year is at the level of 1.4 m -1.5 m. The earth smoothes the temperature of both day and year fluctuations. At a depth of 5 to 10 m, the temperature is at a constant 10 degree level. The value of the thermal massiveness of the building is important here. It is determined by the amount of heat to raise the temperature of the building by 1 degree. A building that has a large thermal massiveness of insulation can save more energy.

5. The soil effects on the structural elements solution

Analysis of the work under the loads of various structural elements allowed to identify the most common types of fastening of buried walls: massive buttress, cantilever construction, anchorage, reinforced soil, step system of individual block, vertical block system. The retaining walls differ from the outer walls in that it is difficult to use additional supporting walls or disks in the floor's plate to unload them (table 2);.

Table 2: Typological examples of solutions retaining walls

1		A massive retaining wall. It is advisable to use for strengthening the possible shift of bulk of soil
2		Frame-monolithic type of the retaining wall. It is advisable to apply for the sunken buildings on a flat terrain
3		Cantilever type retaining walls with extended sole implies additional consumption of rebar, but there is an opportunity to increase the General working area constructions
4		Cantilever type retaining walls with double-sided outsole provides maximum increase in the General working area constructions
5		Anchor retaining wall gentle to steep rocky slopes can be effectively applied in the restoration work
6		Reinforced soil with subsequent foam injection works well for the excavation grounds

In buried buildings it is advisable to use curvilinear spatial shell structural systems. The geometry of these structures allows for a higher load-carrying capacity with less material consumption.

The inner shell of buildings, made of polymeric materials, can have very high strength properties, be light, waterproof and be assembled from prefabricated modular elements [8, 15].

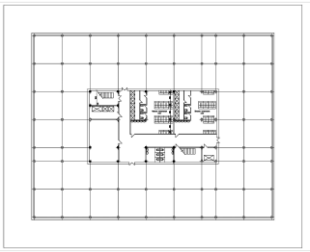
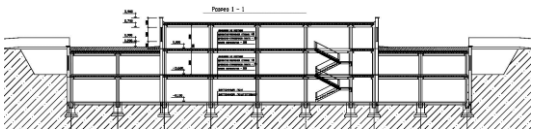
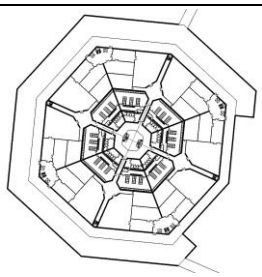
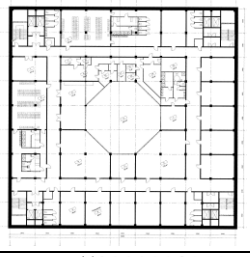
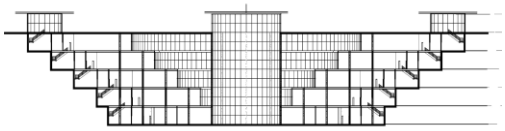
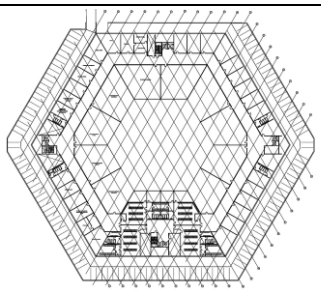
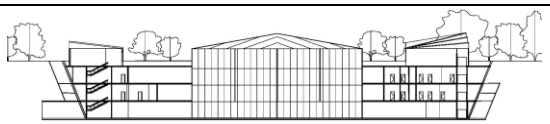
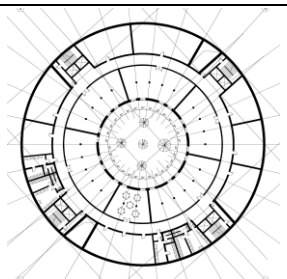
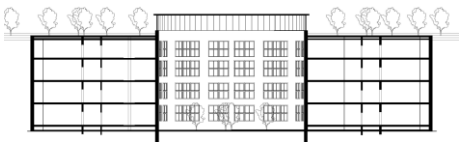
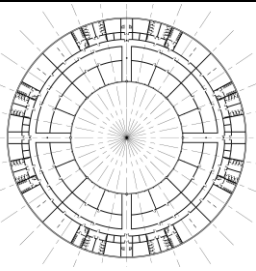
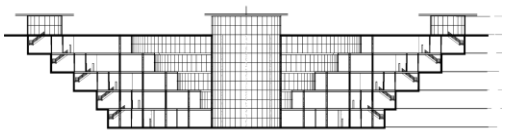
The main requirements for the structural elements of an earth sheltered building that directly affect the spatial parameters of the structure, from our point of view, are as follows:

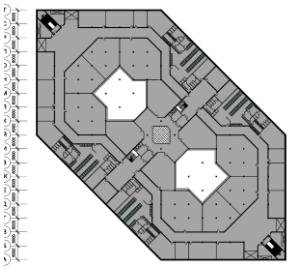
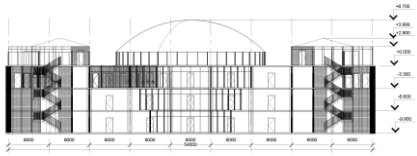
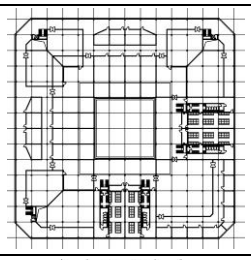
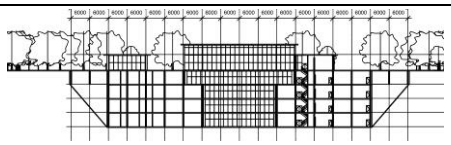
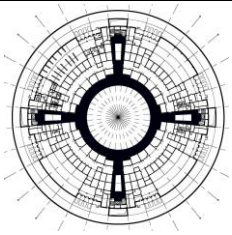
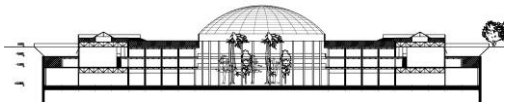
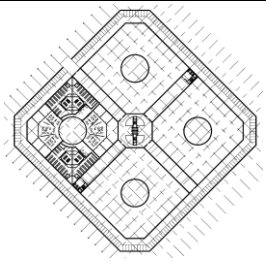
1. The roof should work as a diaphragm of spatial firmness;
2. The shape of the roof can be flat, sloping or sheltering; the height of the earth filling should provide good conditions for drainage of water, be sufficient for the development of the root system of plants and provide optimal thermal performance indicators;
3. In counterweight for the canopy of the main open facade, it is advisable to arrange a counterweight on opposite wall sections;
4. The lateral and rear sections of the submerged building form the plates of the floor and the ceiling structure;
5. Side walls work under the coating load and make the diaphragm of rigidity;
6. Between the walls of buildings and independent structural elements with other thermal insulation properties, it is necessary to arrange temperature expansion joints;
7. Critical conditions include the ratio of the simultaneous load on the roof from the earth filling and on the cover disk (floor). First of all, this refers to buildings of transversal type;
8. Walls that are under the influence of turning moments desirable to design without large openings;
9. Loads from ground pressure in the recessed parts of buildings are more balanced than of a rising type;
10. The large dimensions of the atrium suggest higher loads from the earth fill. This causes a significant two-sided stress.
11. One of the main requirements for structural elements is associated with the water pressure on the outer shell of the submerged building, make of a reliable waterproofing and drainage for surface and internal drains.

DISCUSSION

The main evaluation criterion for the above statements is the analysis of design studies. For the definition of layout schemes and basic design parameters, have been implemented schemes of buried buildings with a public function, made on a flat relief (table 3). As a boundary for the design solutions for the comparative analysis, three composite variants were adopted: 1) a recessed building illuminated through external walls and located along the perimeter light wells; 2) a recessed building illuminated through the inner walls of the atrium space of the patio; 3) a complex variant, which includes a combination of the first two lighting schemes through the inner atrium and the outer perimeter wells.

Table 3: Floor plan options of an earth sheltered housing

Composition Scheme Characteristics		Analyzed project solution Examples	
		Typical floor plan drawing	Section drawing
1	recessed building of rectangular shape, illuminated through external walls and a light well located along the perimeter		
2	recessed building of polygonal shape, illuminated through external walls and a light well located along the perimeter		
3	recessed building of rectangular shape, illuminated through the inner walls of the atrium space of the patio		
4	recessed building of a polygonal outline illuminated through the inner walls of the atrium space of the patio		
5	recessed building round in plan outlines, illuminated through the inner walls of the atrium space of the courtyard		
6	recessed building round in plan outlines, illuminated through the inner walls of the atrium space of the courtyard		

7	recessed building of a polygonal outline, illuminated through the inner walls of two atrium spaces of patios		
8	recessed building rectangular in plan outlines, illuminated through the walls of the atrium space of the patio and the outer perimeter lightwell		
9	recessed building of a round in plan outlines, illuminated through the walls of the atrium space of the patio and the outer perimeter lightwell		
10	recessed building rectangular in plan outlines, illuminated through the walls of the atrium space of several inner courtyards and an outer perimeter lightwell		

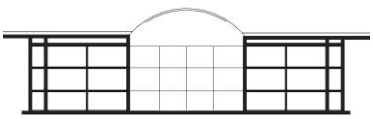
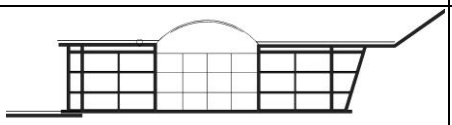
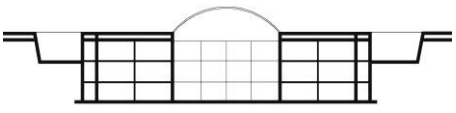
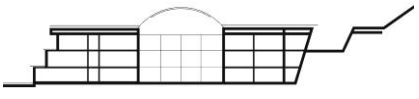
As the constructive plan drawings in Table 3 show, from the decision to illuminate rooms for people permanent stay, not only depend the spatial dimensions of the entire building, but also the uniformity of distribution and the optimization of power loads for individual structural elements.

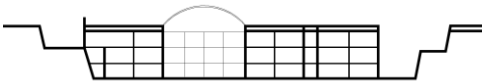
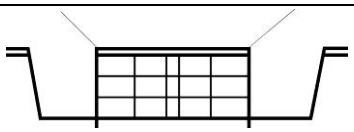
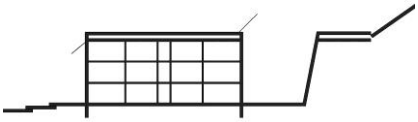
The definition of design schemes and the step bearing elements is connected with the possible dynamics of the functional purpose of a building [17, 18].

RESULTS

The result of the presented study is the typification of elementary constructive composition schemes of a recessed residential and public building, and also the establishment of an algorithm for determining the design formula for the optimal spatial parameters of a structure.

Table 4: The main types of earth sheltered housing

option	Building section drawings		Comments
	On a flat landscape	On a one sided slope	
1			With internal atrium space
2			The combination of an internal atrium space and an external light well for the upper floors

3			The combination of an internal atrium space and an external light well to the entire height of the building
4			Without an internal atrium space

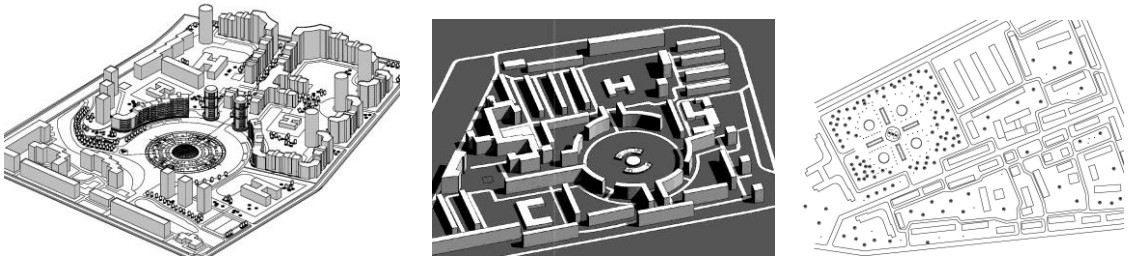


Figure 1: Project proposals for the reconstruction of a microdistrict with the inclusion in the central part of the buried functional block of public purpose and with the arrangement of a greened park zone on its surface

For example, the calculated formula for the depth of the case for the first variant of the location of the apartments on flat terrain adopt the following algorithm: depth illuminated spaces + depth non-illuminated areas + the corridor width+ depth non-illuminated areas+ depth of the illuminated space + courtyard+ .....

20м+20м+20м=60м

For the location of residential buildings on steep terrain for the first variant, the sequence of actions can be as follows:

20м+20м+11м=51м

CONCLUSION

Therefore, the definition of the most suitable building configuration should be carried out taking into account specific parameters of the site design, local natural conditions, orientation of the scope of the structure, functional purpose and economic constraints.

As shown by the results of preliminary design calculations, in addition to a number of engineering and economic advantages, the inclusion of earth sheltered buildings in the structure of residential micro districts also has a social significance: it allows increasing the area of green spaces, organizing central parks, and more rationally using the site area (Fig 1). Optimization in the design of earth sheltered buildings is directly related to the development of engineering factors.

REFERENCES

[1] Earth Sheltered Housing Design: Guidelines, Examples, and References Paperback, 1979. By Minnesota Underground Space Center (Compiler)

[2] The Fifty Dollar and Up Underground House Book 4th Edition. 2017. By Mike Oehler (Author), Chris Royer (Illustrator)

[3] The Earth Sheltered Solar Greenhouse Book Paperback – June 1, 2007. By Mike Oehler (Author, Editor)

[4] Efficient Earth-Sheltered Homes. 2017.

[5] Miller, David E. 2005.Toward a New Regionalism. University of Washington Press. https://energy.gov/ energysaver/efficient-earth-sheltered-homes

[6] Roy, Robert. 2006. Earth Sheltered Houses. New Society Publishers.

[7] Earth Sheltered Homes/ Post by Keiren • Last Updated: July 28, 2017, https://www.niftyhomestead.com /blog/earth-sheltered-homes/

[8] Here's the dirt on a prefabricated plastic earth sheltered home design you can buy off the shelf. November 30, 2015. https://www.treehugger.com/green-architecture/ green-magic-homes-are-probably-neither.html

[9] How to Build an Underground, Off-Grid, Virtually Indestructible Home. 2012. Off the Grid News http://www.offthegridnews.com/grid-threats/the-surprising-facts-about-earth-sheltered-living/

[10] Earth Shelters; A review of Energy Conservation Properties in Earth Sheltered Housing. 2017. Akubue

Jideo for Anselm1 Architecture Department, University of Nigeria, Nigeria

https://www.intechopen.com/books/energy-conservation/earth-shelters-a-review-of-energy-conservation-properties-in-earth-sheltered-housing

[11] David B. South & Freda Parker. Published on Jan 22, 2009. Underground Homes – Good or Bad? • • Monolithic Homes: New Developments http://www.monolithic.org/homes/home/underground-homes-good-or-bad

[12] Earth-sheltered Homes. October/November 2006. Besides energy efficient, well-designed earth-sheltered homes are bright, airy, dry and quiet By Rob Roy. | https://www.motherearthnews.com/green-homes/earth-sheltered-homes-zmaz06onzraw

[13] Benefits of an Earth Berm or Earth Sheltered Home by Kate Esposito, http://www.lifeunplugged.net/ greenbuilding/earth-berm-and-earth-sheltered-home.aspx

[14] Earth Sheltered Basics / "Earth Sheltered". 2017, http://www.homeintheearth.com/tech_notes/basics-of-earthsheltering/

[15] Building the Earth Sheltered House/ Earth Sheltered Housing pp 105-144/ Authors and affiliations Max R. Terman / https://link.springer.com/chapter/10.1007%2F978-1-4684-6644-7_5

[16] Earth-Sheltered Houses An Energy Factsheet. http://www.uaf.edu/files/ces/publications-db/catalog/eeh/EEM-01359.pdf

[17] Boris Krundyshev. 2017. Universal Environment of Vital Activity for Low-Mobile Groups of Population. //International Journal of Applied Environmental Sciences. Volume 12, Number 2 , (2017) pp. 371-382

[18] Boris Krundyshev. 2017. The Constructive Schemes, the Durability and the Consumer Properties of Multi-Story Residential Buildings// International Journal of Applied Engineering Research (IJAER). - Volume 12, Number 1 (2017), pp. 101-109