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The Effect of Six Distinct Insulation Techniques on Earth Sheltered Houses: a Sensitivity Analysis

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Abstract

This paper attempts to compare six insulation techniques for earth sheltered houses under the climate of Athens in Greece. The lack of numerical evidence in literature triggered author’s interest to create a source of credible comparison among different insulation techniques which at the past have been tested in different climates and as a consequence they were not suitable for comparison. The climate of Athens, soil temperatures and the nature of soil surface were some of the most important components that were taken into account in this research. The suitability of each technique emerged from their failure percentage according to the adaptive comfort temperatures for Athens’ climate.

Keywords: insulation, passive annual heat storage, earth sheltered, soil temperature, Greece

1 Introduction

Several insulation techniques have been proposed for earth sheltered houses on previous years, although there was a lack of actual comparison of their performance under the same climate conditions. For that reason, the Mediterranean climate of Athens in Greece has been chosen as the place which the sensitivity analysis would take place. It should be mentioned that the aim of this research is to investigate the performance of six distinct insulation strategies and not to create a comfortable earth sheltered house. In other words, a typical and simple shaped house has been designed in order to examine the capabilities of each insulation technique.

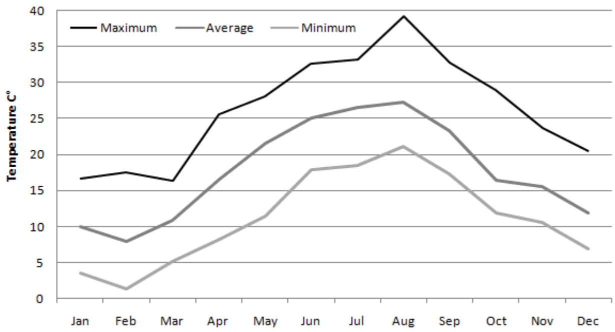


Figure 1.Typical Mediterranean climate – Athens

2.1 Soil

Soil temperatures and its thermal principles would influence research outcomes. According to Golany [1], the thermal conductivity and retention of soil is affected mostly by its density, the size and the shape of its particles and by its moisture content along with site’s climate conditions.

Soil temperature is related mostly to two parameters, its thermal conductivity and the depth. Heat moves slowly through the soil and as a consequence, temperature swings (daily or annually) are limited as we go deeper within it [1, 2]. As Hait [2] argued, the soil temperature remains stable throughout the year in a depth of six meters and this value represents the average annual soil temperature. In addition, Givoni [3] claimed that the values of average annual air and soil temperature could be considered as the same. These arguments are correlated, as heat requires an estimated period of six months to be transmitted from air to six meters deep into the soil. As a result, there is a contrast between the seasonal temperature of air and soil. For example, during winter the soil temperature under six meters depth is approximately the same as the air's summer temperature.

Soil temperature is affected by the nature of its surface too. As Jacovides et al. [4] proved, there can be differences on the annual pattern of soil temperatures between the bare and the short grass covered soil surfaces. According to Mihalakakou et al. [5], the average annual soil temperature of bare and short grass covered soil in Athens is 20.9 C° and 17 C° respectively. Givoni [3] has created an equation based on several experimental studies to predict the soil temperature in any depth and in any day during the year:

$T_s = T + A_o * e^{(-F*z)} * \sin(0.986 * N - 125 - L * z)$ where: (refer to Appendix 1)

By using Mihalakakou's et al. findings through Givoni's equation the pattern of annual soil temperature in **3 m** depth has been produced (Fig. 2).

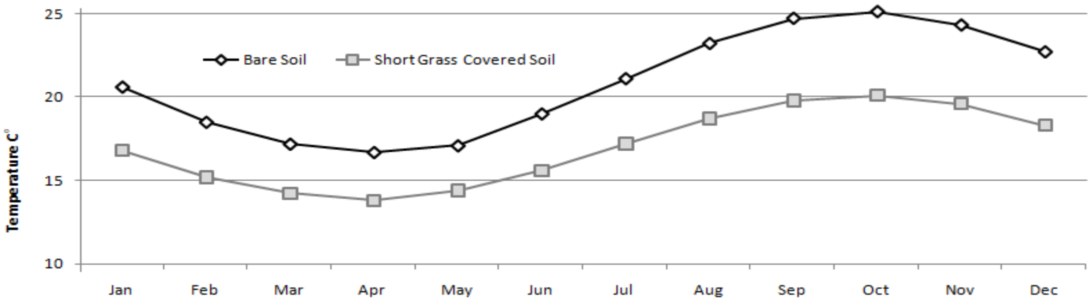


Figure 1. Annual Soil Temperature in 3m depth – Athens

The depth of 3 m has been chosen as a representative depth into the soil as the temperature there would influence the structure. Figure 2 clearly illustrates that the short grass covered soil creates lower temperatures throughout the year. Another interesting outcome would be the onward movement of soil temperatures approximately by three months, compared to air temperatures (Fig. 1).

Golany [1] stated that soil is considered incorrectly as an effective insulator for the earth sheltered structures. The thermal conductivity of soil is approximately 25 times greater than the recent insulation materials on the market. In other words, soil should be considered as an effective thermal **moderator** and not insulator [2].

2.2 Insulation techniques

As the Underground space centre of University of Minnesota [6] stated, the question of how much insulation is required on the walls and where it should be placed is an important consideration for earth sheltered houses. It seems that the position of the insulation in relation to the structure as well as the size of the insulation itself have some impacts on the inside air temperature of the structure.

Although the insulation on the floor seems as common sense, a closer look should lead us to the conclusion that a treatment on the floor is of second importance. The University of Minnesota [6] claimed that the floor on earth sheltered house is located on a relatively steady environment where temperature swings are narrow and heat losses or gains are limited. This occurs because of the deep position (e.g. 4 meters underground) of the floor inside the soil, thus temperature ranges are limited. According to the University of Minnesota [6], the position of 2.5 cm insulation on the floor would reduce the total building heat losses by 1%, while the same amount of insulation on the roof would reduce total heat losses by 11%. As a conclusion, from an energy point of view, the insulation on the floor is a superfluous expenditure.

The University of Minnesota [6] stated that by insulating the entire house you isolate it from its environment and as a result it cannot take advantage of the soil thermal mass around it. After some site experimental studies and computer simulations that took place in 1987 by the University of Minnesota [6], it is claimed that it would be more sufficient in terms of energy consumption to leave the lower part of walls uninsulated (Fig. 3). In that way, a thermal balance between the soil and the air temperature of the space is achieved and as a result heat losses through the walls are limited. Soil stores heat proportionally to its depth, consequently the temperature range at the depth of the uninsulated wall is narrow daily or annually. As a result, the structure takes advantage of the moderate soil temperature at the depth of the uninsulated wall, hence the room temperature will be always closer to the comfort band compared to the outside air temperature.

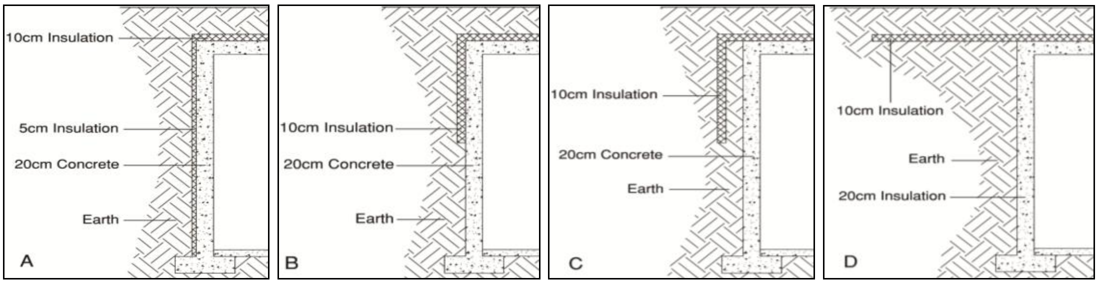


Figure 3. Insulation techniques by the University of Minnesota.

The conductive path between the surface and the roof or the upper part of walls is much shorter compared to the lower part of walls or the floor. Therefore, these points are much more sensitive to variations of climate conditions, hence they should be insulated.

Figure 3 illustrates the insulation techniques they were tested by the University of Minnesota in 1987. This research was based on the fundamental principle of keeping the amount of insulation stable throughout these four steps [6]. It has been proved that both of C and D techniques were better compared to A and B. Moreover, it has been proved that D technique has the potential to win this unofficial competition, although it has not been clearly stated [6]. Furthermore, D technique would provide efficient watershed from rainwater hence it would increase the thermal performance of the house. As Al-Temeemi [7] stated, water leakage is a common problem on underground structures. The moisture content of soil can reduce significantly its thermal storage capacity and its temperature and therefore it should be a very important part on the design process for earth sheltered [2, 8].

2.3 Passive annual heat storage (PAHS)

Step D can be characterized as the precursor of the passive annual heat storage technique, which is developed by John Hait. According to Hait [2], PAHS is based on the principle that thermal properties of the earth are cumulative. In other words, the longer the conductive path or depth, the greater the temperature moderation inside soil. Unfortunately, it is almost impossible to create a house 6 meters underground, where the temperature is always stable and close to the comfort band, for multiple reasons (e.g. cost, natural lighting, natural ventilation, extensive soil weight and psychological reasons of people). As Hait [2] claimed, the technique of passive annual heat storage arranges artificially a 6 meters conductive path (Fig. 4).

The installation of an insulator inside a conductor like the earth will force heat to flow **around** the insulation. Furthermore, the small cumulative resistance of the earth will cause thermal lag. As a result, 6 months of thermal lag between the soil surface and the walls of the structure can be created hence house takes advantage of the summer “heat” during the winter period and winter “coolth” during the summer period. Moreover, as step D (Fig. 3) from the University of Minnesota [6], PAHS protects the structure from rainwater problems acting like an umbrella [2].

According to Hait [2], the technique separates the surrounding earth into three zones; **the moderation zone**, **the isolation zone** and the **storage zone** (Fig. 5). The moderation zone is only a sufficient layer of soil above the insulation umbrella which isolates the storage mass below it and protects the insulation layer. Its width should range from 0.5m to 0.6m, otherwise the construction cost of an earth sheltered house which can stand more than that, would be high [2]. The isolation zone on the other hand plays an important role. It actually replaces the need of an extensive (and expensive) insulation layer which should wrap the entire storing body of earth around the house. Heat conduct through the isolation zone before it reaches the storage zone and finally walls. Conventional earth sheltered houses lack of a storage zone as they built actually with a moderation zone and with an isolation zone. According to Hait [2], the insulation should extend approximately 6m away from walls in order to create a storage zone of 6m width. The storage zone has multiple usages as it stores heat or “coolth” and it dissipates that heat or “coolth” back to the structure, when is needed.

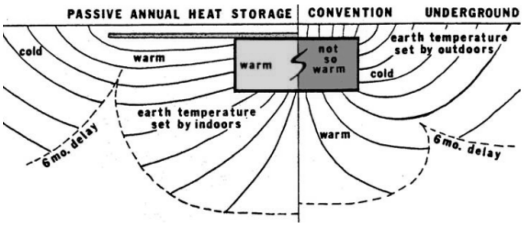


Figure 4. The principle of heat flow on PAHS. [2]

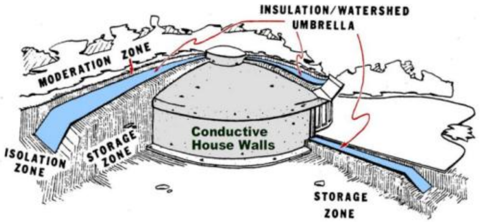
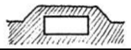
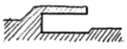
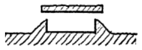
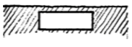
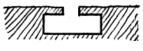
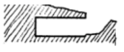
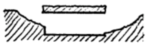


Figure 5. Explanation of zones in PAHS. [2]

3. Methodology

By using ECOTECT Analysis, a 3-dimmensional chamber atrium model has been created (Table 1). The model is composed of two zones, the zone which represents our structure-house and the zone which represents the earth around our structure. Data has been produced through the exporting function of ECOTECT to HTB2 as HTB2 produce more accurate results when thermal lag occurs.

Table 1. Earth sheltered construction types by Labs. [9]

	1.True underground	2.Atrium/Courtyard	3.Elevation	4.Side wall penetration
Berned				
Chamber				

The idea is to compare all of the above insulation techniques under the same structure type and climate. Therefore, steps A to C from the University of Minnesota along with the passive annual heat storage (Fig. 6) technique and two more techniques (Fig. 6) were placed on the same graph for comparison. Moreover, these insulation techniques were tested under bare and the short grass covered soil. As it is explained earlier, soil temperatures for both surfaces have been calculated in depth of 3 meters (Fig. 2).

The insulation material should be the same in order to get comparable results. Therefore, a typical Polystyrene insulation has been used in all insulation techniques. Although Hait [2] has set some regulations and he optimized the shape of the insulation in PAHS, he did it mostly for low cost and water proof reasons and as a result, his technique was modelled in a simplified way (Fig 6.).

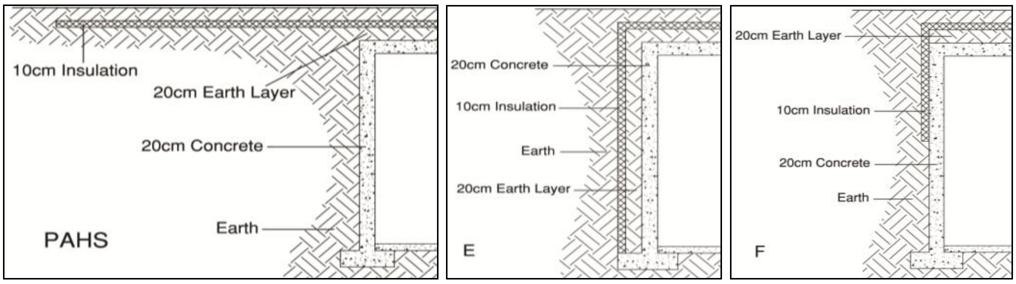


Figure 6. Simplified model of passive annual heat storage and further insulation techniques ideas

The effectiveness of each technique has been measured according to the air temperature of the "house". As the research was based on free-running structures, the Humphrey's equation for adaptive comfort temperatures has been used (Table 2).

$T_h = 11.9 + 0.534 * T$ where: T_h = the monthly comfort temperature
T = the average monthly outside air temperature

Table 2. The adaptive monthly comfortable temperatures according to Humphrey's equation

Months	Jan	Fed	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T(C°)	10	8	11	17	22	25	27	27	23	17	16	12
T_h(C°)	17.3	16.2	17.8	21	23.6	25.3	26.3	26.3	24.2	21	20.5	18.3

Each monthly average inside air temperature difference with the monthly comfortable temperature was accompanied with a "failure" percentage in order to come up with the annual "failure" percentage for each technique.

4. Results and discussion

As it was expected, the temperatures in Figure 9 are much lower compared to the temperatures in Figure 8 as the lower temperatures of a short grass covered soil influence the inside air temperature of the house. Although each technique has benefits and drawbacks, it appears that the most successful technique is **Step B** (Fig. 3, B) on bare soil, as its failure percentage is 5.84% (refer Appendix). In contrast, the most unsuccessful technique in both types of soil is the passive annual heat storage, as its failure percentages were 7.88% and 10.05% on bare and short grass covered soil respectively. Although the PAHS technique would create the most uncomfortable conditions inside the house, a closer look on graphs might prove something interesting. As it is swan in Figure 8, for the environment of Athens the six months forced time lag is inappropriate. Therefore, the PAHS technique would have the potential to be the most successful for the bare soil of Athens, if another forced time lag was arranged properly. On the contrary, although the technique fails generally on the short grass covered soil (Fig. 9), it appears that its performance during the late winter and spring period produces a very comfortable environment. Although Step B on bare soil proved to be the most successful among the others and in total, **Step E** (Fig. 6) is the most successful technique for the short grass covered soil of Athens with a failure percentage of 7.72%. Second in performance comes Step C (Fig. 3) with a slightly higher failure percentage of 7.85%. In general, it appears that the bare soil produce better conditions in an earth sheltered house in Athens throughout the year.

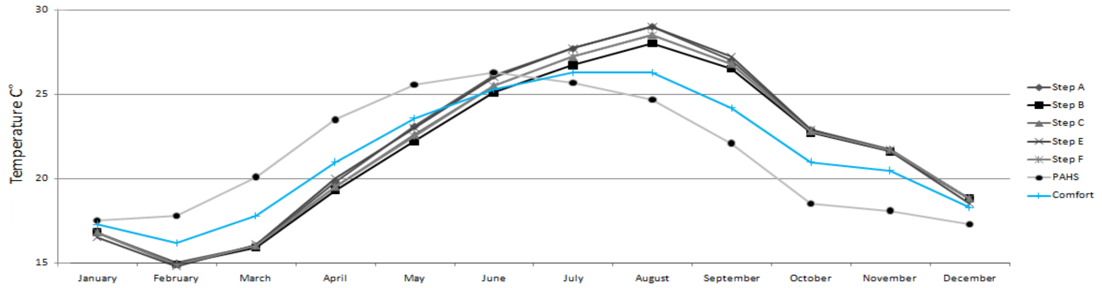


Figure 8. Results for bare soil

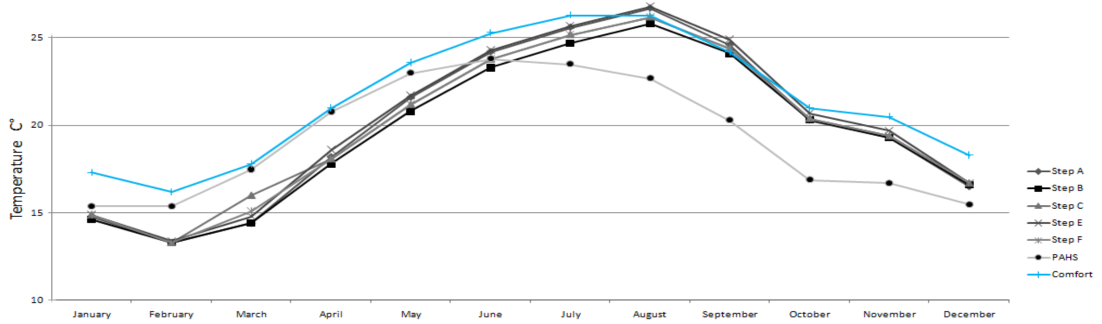


Figure 9. Result for short grass covered soil.

5. Conclusion

As a general conclusion, this model based research has shown that although some sources claim that their propositions are the most appropriate techniques, this should not be appreciated as a rule. It depends on the context of the research and the site. In other words, the most successful insulation treatment for a house in Minnesota might be the worst treatment for a house in Greece. Therefore, although the most appropriate insulation technique has emerged, such a technique might prove to be the most inappropriate for another place.

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Appendix

1. Explanation of Givoni's equation [3, p.234]

T_S = Soil temperature on day N at depth D (C°)
T = Annual average of the soil's temperature (C°)
A_o = Annual amplitude of the soil's surface temperature (annual range/2)
F = Range damping factor, depends on climate and soil type.
z = Depth under the surface (meters)
L = Time lag per meter depth, depends on climate and soil type (days)
0.986 = Days of the expressed in degrees (360/365)
N = Day's ordering number (January 1st = 1)
125 = April 25. According to the experimental observation, April 25 was chosen as the day number which would put the peak surface temperature at July 25th. In different regions this date may vary a little.

2. Temperatures and Failure Percentages

	Step A	Step B	Step C	Step E	Step F	PAHS	Comfort (C°)
Jan	16.8	16.8	16.8	16.5	16.8	17.5	17.3
Feb	15	14.9	14.9	14.8	14.9	17.8	16.2
Mar	16	15.9	16	16.1	16	20.1	17.8
Apr	19.8	19.3	19.5	20	19.5	23.5	21
May	23.1	22.2	22.6	23	22.5	25.6	23.6
Jun	26.1	25.1	25.5	26	25.5	26.3	25.3
Jul	27.7	26.7	27.2	27.7	27.2	25.7	26.3
Aug	29	28	28.5	29	28.5	24.7	26.3
Sep	27	26.5	26.8	27.2	26.8	22.1	24.2
Oct	22.9	22.7	22.8	22.9	22.8	18.5	21
Nov	21.7	21.6	21.7	21.6	21.7	18.1	20.5
Dec	18.8	18.8	18.8	18.5	18.8	17.3	18.3
Failure (%)	6.35	5.84	6.07	6.37	6.11	7.88	

Figure 10. Results on bare soil

	Step A	Step B	Step C	Step E	Step F	PAHS	Comfort (C°)
Jan	14.8	14.6	14.9	14.9	14.9	15.4	17.3
Feb	13.3	13.3	13.3	13.4	13.3	15.4	16.2
Mar	14.4	14.4	16	14.8	15.1	17.5	17.8
Apr	18.2	17.8	18.1	18.6	18.1	20.8	21
May	21.6	20.8	21.2	21.7	21.2	23	23.6
Jun	24.2	23.3	23.8	24.3	23.8	23.8	25.3
Jul	25.6	24.7	25.2	25.7	25.2	23.5	26.3
Aug	26.7	25.8	26.2	26.8	26.2	22.7	26.3
Sep	24.6	24.1	24.4	24.9	24.4	20.3	24.2
Oct	20.3	20.3	20.4	20.7	20.4	16.9	21
Nov	19.3	19.3	19.4	19.7	19.4	16.7	20.5
Dec	16.5	16.6	16.7	16.7	16.7	15.5	18.3
Failure (%)	8.54	9.68	7.85	7.72	8.27	10.05	

Figure 11. Results on short grass covered soil