Human Comfort in Underground Buildings

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Abstract

There is a worldwide growing demand for underground living due to increasing information about high energy efficiency of underground buildings. "Why can't we design underground buildings for living?" This question can be made for each person when he or she informs about advantages of underground construction.

This paper will inform readers about influence of underground construction on energy efficiency of building and human comfort. Also it will bring together a new era of thinking about living underground as well as improving the learning experience. The paper will include a consideration of aspects which shape the decision making process, issues which conflict with underground buildings, opportunities to use past and current technology to create an external environment perception and a discussion to articulate the possibilities of occupying long term underground buildings.

Key subjects to be discussed will include, but will not limit to: natural lighting, thermal comfort, indoor environmental quality, architectural issues and in general, energy dilemmas and solutions in underground buildings.

Key words: Human Comfort, Underground Buildings, Energy Efficiency, Indoor Environmental Quality

1. Introduction

"The underground has enormous potential for realizing spatial benefits." *Sir Norman Foster*

In the globalization era, the most important obstacles which mankind is faced with are climate change, energy resources shortage and population increase. Scientists recommended lots of methods to bring out human from these obstacles. One of these methods is living underground where average mean temperature is almost steady and equal to ground surface average mean yearly temperature. Thus, in such an appropriate circumstance, climate change has less

influence and energy consumption is very less than other conditions. Underground living provides a comfortable, tranquil, weather-resistant atmosphere. There are varieties of investigations that indicate underground buildings have appropriate performance during natural and unnatural disasters. Indeed, underground places are ideal for improving the environment and supporting the principles of Sustainable Development and at the same time, it is a safe place in nuclear attack, earthquake, hurricane and tsunami.
Energy resources shortage has spurred the search for new and better ways to increase energy efficiency in human dwellings. One exciting solution is to reduce energy needs by building underground. Underground buildings are safe, attractive, useful, and comfortable places to frequent and live. Unlike a common misconception, most are dry and warm, and they can be sun-filled, however, appropriate indoor environmental quality happens by design not by accident. It means that by a little thinking and observation, it is possible to make underground buildings more adaptable to human living when they use less external energy than common buildings.
By reviewing traditional architecture, it would be founded that ancient architects, in appropriate places where had low underground water height and tough soil, had used underground buildings for long term use by occupants and that places were well human-adapted. A vast spectrum of structures was presented, ranging from stunning examples of hidden opulence to humble subterranean cubbyholes where unassuming people immerse themselves in nature's simplicity. Some underground cities such as Derinkuyu in Cappadocia region of Turkey are protected for more than 1500 years, up to now. On the other hand, caves were the first home for human and cave function is similar to underground building when talking about energy performance of buildings. Indeed, prehistoric cave dwellers, seeking warmth and protection from wild animals and severe weather, chose an existing natural earth form-the cave-that provided those needs. Ancient underground buildings can be divided to three main subdivisions: Semi underground, subsurface and completely underground. (Fig. 1)

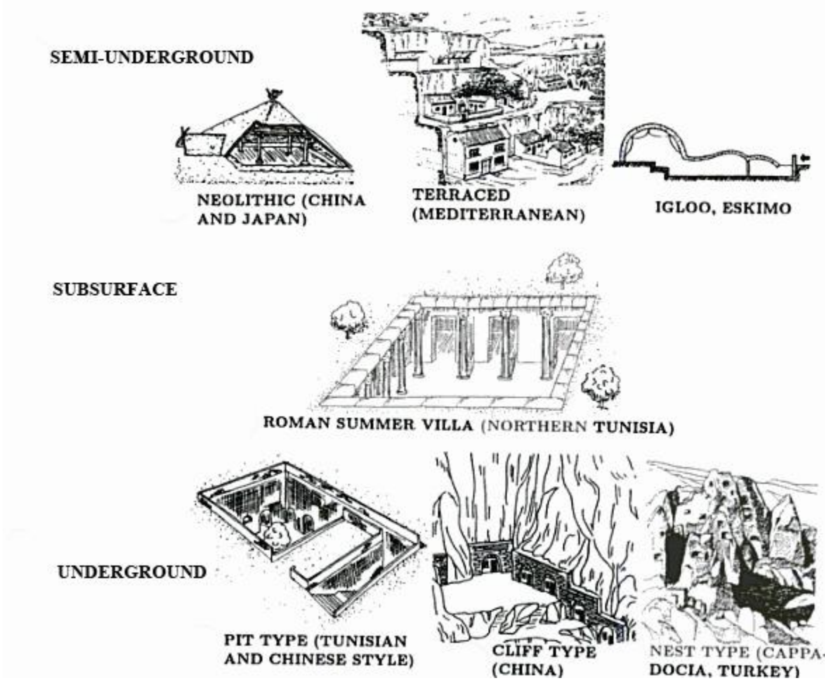
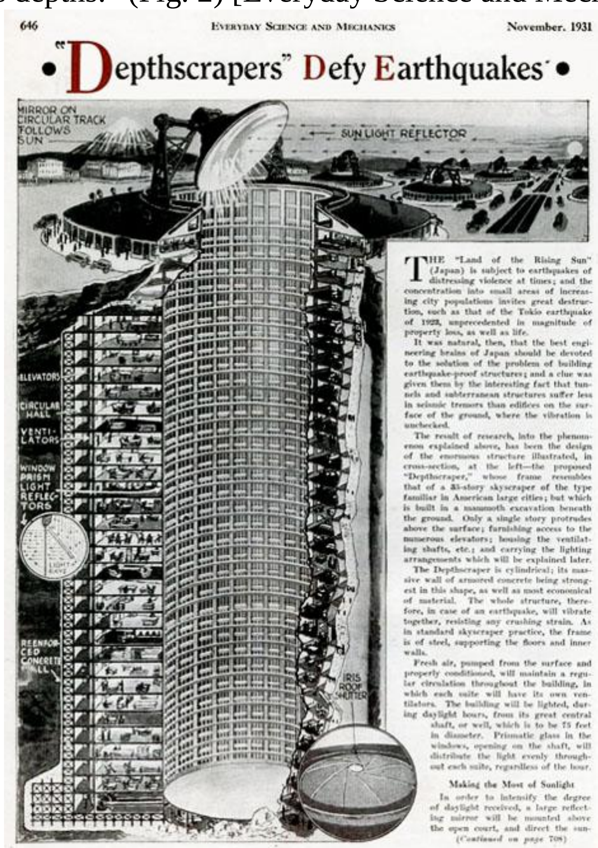


Fig 1: Typology of underground buildings.

Furthermore, originally published by Everyday Science and Mechanics, in November 1931, the Depthscraper was proposed as a residential engineering solution for surviving earthquakes in Japan. The structure, "whose frame resembles that of a 35-story skyscraper of the type familiar in American large cities," would actually be constructed "in a mammoth excavation beneath the ground." The following sentences were written to describe the related project:
“Only a single story protrudes above the surface; furnishing access to the numerous elevators; housing the ventilating shafts, etc.; and carrying the lighting arrangements. The Depthscraper is cylindrical; its massive wall of armored concrete being strongest in this shape, as well as most economical of material. The whole structure, therefore, in case of an earthquake, will vibrate together, resisting any crushing strain. As in standard skyscraper practice, the frame is of steel, supporting the floors and inner walls. In order to intensify the degree of daylight received, a large reflecting mirror will be mounted above the open court, and direct the sunlight directly into its depths.” (Fig. 2) [Everyday Science and Mechanics, 1931]


646 EVERYDAY SCIENCE AND MECHANICS November, 1931

• "Depthscrapers" Defy Earthquakes •

THE "Land of the Rising Sun" (Japan) is subject to earthquakes of distressing violence at times; and the concentration into small areas of increasing city populations invites great destruction, such as that of the Tokio earthquake of 1923, unprecedented in magnitude of property loss, as well as life.

It was natural, then, that the best engineering brains of Japan should be devoted to the solution of the problem of building earthquake-proof structures; and a clue was given them by the interesting fact that tunnels and subterranean structures suffer less in seismic tremors than edifices on the surface of the ground, where the vibration is unchecked.

The result of research, into the phenomenon explained above, has been the design of the enormous structure illustrated, in cross-section, at the left—the proposed "Depthscraper," whose frame resembles that of a 35-story skyscraper of the type familiar in American large cities; but which is built in a mammoth excavation beneath the ground. Only a single story protrudes above the surface; furnishing access to the numerous elevators; housing the ventilating shafts, etc.; and carrying the lighting arrangements which will be explained later.

The Depthscraper is cylindrical; its massive wall of armored concrete being strongest in this shape, as well as most economical of material. The whole structure, therefore, in case of an earthquake, will vibrate together, resisting any crushing strain. As in standard skyscraper practice, the frame is of steel, supporting the floors and inner walls.

Fresh air, pumped from the surface and properly conditioned, will maintain a regular circulation throughout the building, in which each suite will have its own ventilators. The building will be lighted, during daylight hours, from its great central shaft, or well, which is to be 75 feet in diameter. Prismatic glass in the windows, opening on the shaft, will distribute the light evenly throughout each suite, regardless of the hour.

Making the Most of Sunlight

In order to intensify the degree of daylight received, a large reflecting mirror will be mounted above the open court, and direct the sun-

(Continued on page 708)

Fig 2: Depthscraper as indicated in Everyday Science and Mechanics magazine.

In the midst of a long, and fascinating, tour through the 20th century's wartime underworlds, Tom Vanderbilt author of “Survival City: Adventures Among the Ruins of Atomic America” writes of how "the confined underground space becomes a concentrated breeding ground for social dysfunction as the once-submerged id rages unchecked." Living inside "massive underground fortifications" whether fortified against enemy attack or against spontaneous movements of the earth's surface might even produce new psychiatric conditions, Vanderbilt writes.

2. Advantages of Underground Buildings

There are many advantages to underground construction. Underground buildings are less susceptible to the impact of extreme outdoor air temperatures, so they won't be felt the effects of adverse weather as much as in conventional buildings. Temperatures inside them are more stable than in conventional buildings, and with less temperature variability, interior spaces seem more comfortable.

Because earth covers part or entire of their exterior, underground buildings require less outside maintenance, such as painting and cleaning gutters or other exterior material. Constructing a building that is dug into the earth or surrounded by earth, builds in some natural soundproofing. Plans for most underground buildings "blend" the buildings into the landscape more harmoniously than conventional buildings. And also, their design offers extra protection against high winds, hailstorms, and natural disasters such as tornados, hurricanes and earthquakes.

A big advantage of building repositories underground is that the environment is very stable. (Teygeler 2001)

According to Mark Oehler, author of "The $50 and Up Underground House Book", advantages of underground buildings are as follows:

1. No foundation. 2. Less building material. 3. Less Labor. 4. Most aesthetically pleasing. 5. Less tax. 6. Warm in winter. 7. Cool in summer. 8. Better view. 9. Built-in greenhouse. 10. Ecologically sound. 11. Increased yard space. 12. Fallout shelter. 13. Cuts atmospheric radiation. 14. Defensible. 15. Concealment. 16. Closer to source of water. 17. Relatively fireproof. 18. Pipes never freeze. 19. Superior flooring. 20. Can be built by anyone. 21. Weatherproof. 22. Less maintenance. 23. Soundproof. [Oehler M. 1997]

In a five-year survey of annual temperature differences at the Torazuka old tomb north-east of Tokyo, Kenjo found the temperature difference to be very small throughout the year: while the average highest temperature was 30°C and the lowest temperature was 5°C in the open air, in the tomb the average highest temperature was 17°C and the lowest 15°C. (Teygeler 2001)

It is estimated that underground buildings cut heating and cooling cost approximately 80 percent or even more. With the earth covering most of the envelope of a building, the building can be made more airtight. In surface structures, up to 35% of heat loss can often be attributed to air infiltration. However, too "tight" construction can cause the build-up of indoor air pollutants, which some experts say can be far unhealthier than the worst outdoor urban smog. An earth-sheltered building offers greater opportunity to control the rate of outside air supply to the interior of a building. (Barker 1986)

Combining these advantages with disaster resistance and nuclear defensibility features of related buildings convinced everyone that underground is more appropriate than up ground to live.

3. Disadvantages of Underground Buildings

There are few disadvantages about underground buildings which can be dispelled by appropriate design. Humidity which is advantages in arid climate in some cases can be disadvantages, hence, the level of care required to avoid moisture problems, during both the construction and the life of the building. Nevertheless, with certain precautions, like special waterproofing, the humidity can be controlled. Also, Principal downsides are the initial cost of construction, which may be up to 20% higher than ordinary construction.

Some of the drawbacks and negative associations with the underground that are mentioned in Carmody and Sterling (1993) are:
· Darkness combined with humid air;
· Underground is also related to death and burial;
· Fear of entrapment from structural collapse;
· Disorientation;
· Loss of connection with the natural world;
· Lack of natural light and poor ventilation;
Today's technology has been able to cope with and overcome many of the above mentioned aspects, and expectations are that in the future it will deal with such problems even more effectively and efficiently. [Durmisevic S. 1999]

4. Underground Temperature

The depth between zero and 10 meters is characterized by insulation from outdoor temperatures, by increasing seasonal temperature stability, and by cool temperatures in the summer and warm temperatures in the winter. The shallow zone also experiences seasonal temperature fluctuation. As depth increases toward 10 meters, temperature stability increases, while at 10 meters, temperature is stable seasonally. Because this range is immediately below the soil surface, feelings of claustrophobia (a common concern when discussing underground space) are less. Thus, it is recommended that this depth level should be the zone that accommodates the most human diurnal activities, because it is most comfortable physically and psychologically. (Fig. 3) [Golany G. S. 1996]

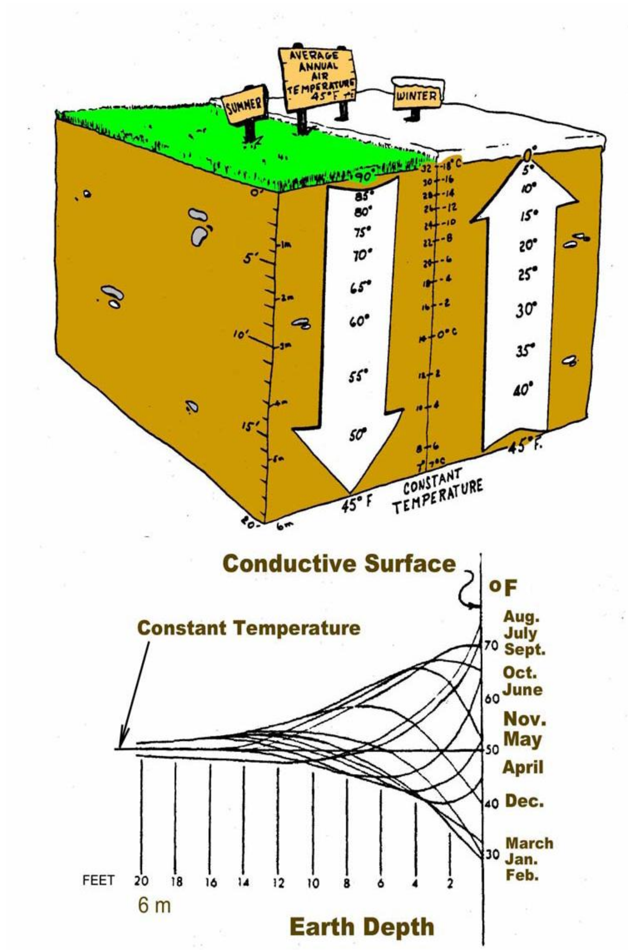


Fig 3: Ground surface and underground temperature relation. [Hait J. 2005]

At the depth between 10 and 50 meters composition and geological structure will vary from site to site. Generally, the temperature is relatively stable, thus providing suitable space for specific types of industry and house. This is the zone where segregated land-use types can be introduced, although some human diurnal activities may still be adopted here.

In January 1981, a major feature of Passive Annual Heat Storage (an insulation/ watershed umbrella) was incorporated into the design of an earth-sheltered home, which called Geodome due to its shape, in Missoula, Montana USA. After construction, the building had been examined; the result was published as follow:

"The building is monitored by 48 temperature, and 5 moisture sensors. By the autumn of 1981, the temperature 10 feet (3 m) under the surface, 12 feet (3.7 m) behind the north wall, and two feet (0.6 m) beyond the insulation itself, had been heated by excess summer heat from its usual 45°F to 64°F (7-18°C). The two-foot (0.6 m) deep portion of insulated earth on the roof was warmed up to 77°F (25°C), while two feet under the floor it was 68°F (20°C). Throughout the first year, the north wall temperature on the second floor of the home varied only 6 degrees...from a high of 72°F (22°C) in September to a low of 66°F (19°C) the next February. Thus the home has been snugly wrapped with a nearly 70°F (21°C) layer of earth, several feet thick (1 m), which has kept the home comfortable all winter. Even though the insulation umbrella is only half as big as we now know it should be, the earth around the home remains warm and dry!" [Hait J. 2005] (Fig. 4)

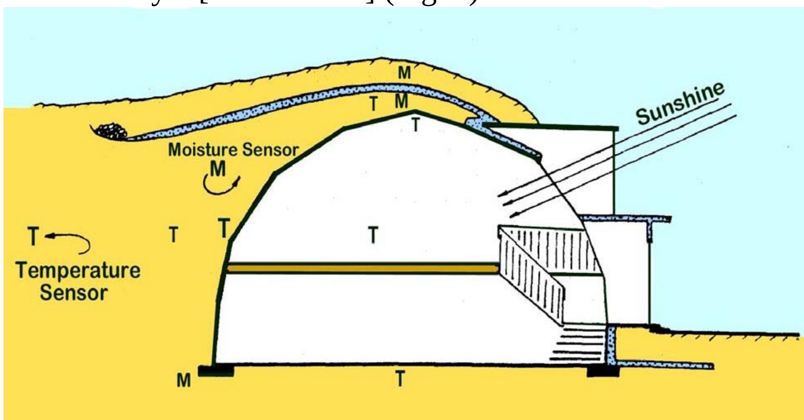


Fig 4: The Geodome cross-section showing the first (although small) insulation/watershed umbrella, and the locations of the important temperature and moisture sensors. [Hait J. 2005]

This unique method for maintaining a deep-earth constant temperature of about 70° F (21° C) is based on several principles of physics:

1. Heat flows by conduction from warm places to cool places, and will only return when the original source cools to a temperature which is below the storage temperature.
2. Far more solar heat is available in the summertime than in the wintertime.
3. Earth is an ideal thermal mass for storing heat over time periods well in excess of 6months.
4. The constant temperature 20 feet (6 m) into the earth is a reflection of the average annual air temperature.
5. It takes six months to conduct heat 20 feet (6 m) through the earth. [Hait J. 2005]

5. Facts related to Human Comfort in Underground Buildings

The feeling of comfort or more accurately, discomfort, is based on a network of sense organs: the eyes, ears, nose, tactile sensors, heat sensors, and brain. In general, human comfort depends on variety of factors. Temperature, humidity, air velocity, solar radiation, illumination rate, environmental condition, air contamination and quality, odor, noise, ventilation and also body metabolism have direct influence on human comfort. All factors except body metabolism, which is different person to person, need to pay enough attention during design process. Some conditions which may occur in underground buildings and influence human comfort are as follow:

- Human can feel uncomfortably "hot" during the summer if the relative humidity is high, because of evaporative cooling of the body due to sweating.
- Human feel more comfortable and do not develop cracked or dry skin problems if the winter time relative humidity is not too low.
- Depends on the thickness and compact rate of exterior soil, ventilation can reduce or increase. Also, humidity can influence on necessary ventilation rate.
- Indoor air quality in underground buildings is more appropriate than up ground buildings due to the fact that today’s cities air have a lot of contamination and is smog.
- Thermal comfort can be provided easily owing to the fact that soil is appropriate thermal mass.

- Solar radiation has less influence there and can be more pleasant in the case of appropriate design. Indeed, there isn't direct radiation and it can be very smooth.
- Illumination rate should take more attention due to less and indirect outdoor radiation.
- Wind has fewer effects there and cannot increase air velocity rate. However, less air velocity can cause feeling discomfort.
- Due to being underground, there is less unpleasant noise. Related buildings have natural acoustic system.
- Indoor environmental conditions absolutely depends on design in underground building, however, outdoor environment has appropriate potential to feel comfortable due to less interfere in nature.

6. Conclusion

Our environment needs to pay enough attention in the period that human is coping with climate change, energy shortage and population explosion. Underground buildings not only provide appropriate conditions to live but also is natural adapted and has less influence on environment. In the case of natural disaster, related buildings have appropriate performance and can be appropriate shelter for homeless people, in such a severe circumstance, these buildings can provide enough human comfort with less amount of energy. Nevertheless, a lot of investigation should be done to find all features of underground living.

For long time use, underground buildings have lots of advantages. They can save enough energy for whole year usage and need less energy than other buildings type to provide human comfort. These buildings have only two matters, the first one is providing natural light and the second one is dispelling the humidity which is produced indoor. By appropriate design, all of disadvantages can be solved. Also, claustrophobia is types of psychological illness which can be entangle human in underground buildings, but the rate of this illness at the depth between zero and 10 meters is very low. The depth between 10 and 50 meters, where features vary from site to site, is suitable space for specific types of industry and house, although some human diurnal activities may still be adopted here.

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