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Underground buildings – caprice or pragmatism

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ABSTRACT:
The purpose of the work is to try to find the answer to the issue in the title. In the paper the examples of structures built underground, which are usually erected on the surface, are presented. These include residential houses and factories. An unusual location is a great challenge for designers and contractors, but it can bring huge benefits. One of them is an increase in the energy efficiency of the building. The basis for the decision to choose an underground construction must be an analysis of the benefits, disadvantages and risks associated with this type of facilities carried out for individual cases.

KEYWORDS:
underground construction; underground house; underground factory; energy efficiency

1. Introduction

Buildings are sometimes erected in unusual forms. Sometimes, it is on an investor's whim, sometimes it is necessity or pragmatism. There are round, mushroom-shaped houses, "crooked houses" (in Sopot) or upside down houses (in Szymbark in the Pomeranian Voivodeship), which, although attracting tourists, are usually not practical. Buildings can be created from unusual materials or elements. Examples include either the construction of residential or office buildings from containers or adaptations of passenger jet planes. On the other hand, underground constructions are usually associated with mining, tanks used as storage for liquids or gases, as well as road and rail tunnels or subways [1].

Underground military facilities, such as shelters, bunkers, weapons and ammunition warehouses, and rocket installations constitute a separate category. There are many such facilities in Poland, mainly the remnants of World War II. Examples of them are: the Riese project in the Owl Mountains and Książ Castle in Lower Silesia [2,3], being the largest underground complex that was built for the needs of the Third Reich.

For obvious reasons, mains supplying city water or sewage collection are also subterranean structures. Increasingly, and here the shortage of investment areas in cities is the contributing factor, parking lots and garages, shopping centers, sports halls and other public facilities are being located below the ground [4].

However, there are underground structures which are usually erected as above-ground facilities. These include residential buildings and industrial plants.

For the purposes of this article, "underground structures" are understood as buildings that are recessed completely underground or more often semi-underground with only the front wall exposed [5,6] (eventually the atrium is included). The choice of the type of such structure affects not only the energy efficiency but also the way the interior is illuminated [7].

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2. Underground residential buildings

Since prehistory, people have lived underground, initially using natural caves, then building dugouts. In the hot climate of Australia, even entire underground cities, Coober Pedy, White Cliffs and Andamooka, have been created, as well as very advanced underground infrastructure beneath cities [4].

A broad review of the literature on underground residential buildings is given in [8] and [9]. While sources listed in [8] focus on advantages, disadvantages and risks of their implementation, a review in terms of energy efficiency is presented in [9]. Energy benefits of underground buildings have also been widely discussed in [10]. Next, the purpose of buildings in the context of them functioning in various climatic conditions is discussed in [11]. Finally [12] demonstrates the results of an experimental setup where a building is made-up of both aboveground and underground compartments.

Locating homes underground may be forced by the building's surroundings – an example here could be bylaws prohibiting disturbances of the landscape in protected areas. Such cases may occur in mountainous areas, where one can easily take advantage of the natural terrain in order to locate a structure underground. The location on a southern slope is of particular preference for areas with low average temperatures since it allows adequate, and foremost natural, illumination of the interior. On the contrary, in a hot climate, the eastern slope will be better, limiting excessive heating of the interior from the sun. Having said that, it is clear that placing a structure underground brings some benefits. Pros include natural insulation provided by the ground. In winter, it is protected from low temperatures, while in summer it provides protection against overheating. In addition to the surface layers, the soil has a relatively constant temperature at a given depth, which gives measurable savings on heating and air-conditioning costs depending on the season.

An example of such a building is the small Dobraca Village House near Kragujevac (Serbia) [13] with an area of about 50 m^2. Figure 1 shows the view and cross-section of this house. Thanks to the underground location, the annual energy consumption is below 2000 kWh. Monitoring of indoor and outdoor temperature and wind speed showed that at an outdoor temperature of between -5°C and 35.4°C, the temperature inside remained relatively constant (between 15.8°C to 20.6°C) ensuring thermal comfort for residents.

Fig. 1. Dobraca Village House – view and cross-section [13]

While globally – especially in the United States and Great Britain - underground houses are no longer extraordinary and are becoming more and more popular, locally in Poland a sceptical view to living underground is still dominant. The psychological barrier and ambiguity of regulations do not facilitate making decisions in this respect.

In 2010, the first underground single-family house was commissioned in Brzezie near Bełchatów [14]. The crescent-shaped building with a total area of 220 m^2 (including 153 m^2 of living space) was almost completely buried underground - only the heavily glazed south-west façade revealed the existence of a house (Fig. 2).

To ensure good lighting, higher-than-usual windows were used, and some rooms were illuminated with tunnel skylights. From the other sides, the building blends in perfectly with the environment - it was hidden in a slope surrounded by forest. The overgrown roof is both a terrace and an amphitheatre. The whole arrangement of space at its north edge mingles with the natural environment of the surrounding forest.

Fig. 2. Underground house in Brzezie [15]

The house consists of a living room, two bedrooms, a work room, kitchen, two bathrooms and two garages. Underfloor heating provides adequate room temperature. The heating system itself draws energy from a ground heat pump. The pump provides also warmth for utility water [15, 16]. Additionally, the energy efficiency of the building is increased by the use of mechanical ventilation by a recuperator tasked with heating the exchanged air. Also, a modern fireplace with a catalyst, performs a supportive function for heating the household thanks to a high combustion temperature. The landlord claims the house is economic in it's operation. The monthly costs of energy and hot water are below PLN 250. Moreover, the monthly total service fees do not exceed PLN 600.

Although comparable with the costs of traditional construction, the investment cost itself were higher than those of similar standard living houses. The increase resulted not only from additional work and materials necessary for constructing the house underground, but also from the use of more expensive technology and the contractor's lack of experience in erecting underground houses, which resulted in reworking and the necessity of corrections to construction - especially when insulating the inverted roof.

Actual implementation of the project has refuted some myths preventing people from living underground. Proper waterproofing combined with mechanical ventilation allows for humidity comfort, and the use of a properly glazed front wall in conjunction with tunnel skylights correctly illuminates the interior.

2. Underground factories

Underground World War II structures have served as armament factories or as military headquarters. They were meant to be imperceptible from the air in order protect people using them as shelters. Today, underground factories are also emerging. Some are of a military nature, but some are also recognising the potential benefits associated with being located underground, and not only in terms of camouflage or protection against aerial attacks, since their locations offer economic and environmental advantages as well. For example, underground facilities offer higher passive safety, lower operating costs and in the event of major accidents, prevention of radioactive contamination of the atmosphere. This is already recognised as some nuclear power plants are built underground (Norway, France). A feasibility analysis for four different types of underground nuclear power plants was carried out in [18].

The industrial underground constructions include a former CNC machine factory transformed in 2019 into a Machine Tool Museum for the centenary of the Yamazaki Mazak Optonics Corporation company that operated the facilities in the past. Visitors are surprised by the inconspicuous but intriguing pyramid (Fig. 3), which is the guest entrance to the underground Phoenix Laboratory complex that once belonged to the firm[19]. The plant, located in Minokamo near Nagoya (Japan), is where 2D and 3D laser cutting machines had been manufactured. The prerequisites for manufacturing such precision devices forced the production rooms to maintain a stable temperature and very high air purity as well as good vibration isolation. High demand for the quality of air entails a huge amounts off electricity for heating or air conditioning and air purification. The location of the production hall underground reduced costs. Additionally, numerous ecological benefits have been noticed.

Fig. 3. Pyramid-shaped entrance to the Phoenix Laboratory, (photo own)

The plant with an area of over 10,000 m^2 was constructed 11 m below ground level. The natural slope of the land surface was used to limit the amount of excavation. Only a relatively small part of the facility (Fig. 4) protrudes above ground. As a result, almost 100% of the land has been built on, beneficial given the land deficit in Japan. Not only is the roof of the factory covered by grass (approx. 50% of the area), but also by shrubs and even a tree, blending the industrial facility into the surroundings.

Fig. 4. Above-ground portion of the facility, (photo own)

A drawback of this solution is the need to use a reinforced roof structure due to the additional weight of the green roof, access roads and parking. The supporting structure of the roof consists of trusses (Fig. 5), whose chords and the cross-braces are made of powerful rolled I-sections. The I-sections are welded directly to the chords without gusset plates. Purlins are supported in the middle of the span with braces made of pipes attached to the lower truss chords. In the truss supporting zone, the lower truss chords were connected with tubular elements in the axes of the 3 extreme purlins, which constituted a vertical bracing of the roof.

The higher cost of constructing an underground factory is compensated by the benefits obtained during operation. High energy efficiency has been achieved by using geothermal heat to control temperature. Regardless of the season, a constant temperature is kept inside the hall at all times. This allows for very precise fitting of machine parts. The calculated demand for energy needed for air conditioning and heating is only 20% of what would be required for a building of similar size built on the surface. In practice, electricity savings reach up to 95%.

Fig. 5. Roof structure, (own photo)

High air quality is easier to ensure in underground constructions due to many factors, including no window and door openings, good insulation from the external environment, centralized air intake and filter station, and no entry of vehicles (which also protects against dirt). The transport of materials needed for production as well as the forwarding of finished machines takes place via a docking station designed in such a way that the crane can go outside for loading or unloading. The opening phases of the docking station are shown in Fig. 6.

Fig. 6. Opening phases of the docking station, (photo own)

After raising the walls of the middle and side parts, the cylinders fold the middle posts outwards, thus allowing the crane to travel freely outside the hall. Even when the dock wall is open, it is not possible for the dirt to get inside due to maintaining the light hypertension inside the facility. Air curtains are placed around the external walls of the entire facility, which constantly pump filtered air into the interior at an amount that completely replaces the needed volume within an hour (at a rate of about 50,000 m^3/h). In addition, employees and visitors had to wear protective clothing. All this contributed to a very clean environment. In a typical production plant, it is assumed that in 1 dm^3 of air there is about 100,000 dust particles below 0.5 μm. The Phoenix Laboratory managed to achieve purity at a level not exceeding 3500 dust particles below 0.5 μm in 1 dm^3 in the general assembly hall, and in the optics assembly rooms thanks to additional filters. This number was reduced to 350 and finally in the mirror assembly area to 35.

Naturally, the construction of a factory underground also provides good sound insulation: no sounds from the external environment can be heard in the interior, and the noise generated during assembly does not get outside. Environment-related vibrations (especially from road transport) have also been minimized, and even earthquake-related vibrations have been reduced.

3. Conclusions

The examples of underground residential and industrial buildings presented in the article might inspire the design and construction of similar facilities. The frills of an investor's will no longer needs to be the deciding factor, as the pragmatism of solutions providing measurable benefits gain importance when considering the location of such structures underground. Energy efficiency, isolation from various adverse environmental influences, and finally harmonious blending with the landscape assure the protection of the natural environment. Some requirements (e.g. regarding air quality) for production facilities are only achievable, at acceptable operating costs, in isolation from the environment, which can be provided by underground construction. Studies of underground buildings indicate some of their disadvantages, but these are usually outweighed by the benefits of their location. However, it is an investor who has to make the decision after analysing his own needs and realizing the chances of better satisfying them by building their investments underground.

Bibliography

[1] Tajduś, A. Budownictwo podziemne szansą rozwoju współczesnych miast, Nowoczesne Budownictwo Inżynieryjne 2016, 3, 48-53.

[2] Rostkowski J. Podziemia III Rzeszy: tajemnice Książa, Wałbrzycha i Szczawna Zdroju, Dom Wydawniczy Rebis, Poznań, 2018.

[3] Szałkowski, A. Sekrety Wałbrzycha, Wydawnictwo Księży Młyn, 2017.

[4] Sterling R., Underground Technologies for Livable Cities, Tunnelling and Underground Space Technology 1997, 12, 4, 479-490.

[5] Lemboa F., Marinoa F.P.R., Calcagnoa C., Semi-underground house models as new concepts for urban sustainable environment, Procedia Engineering 2011, 21, 570-579.

[6] Prelvukaj Z.; Beqiri L.; Jashari R.; Spahiu F., Underground house as a new concept of housing 2018, UBT International Conference, 29.

[7] Beqiri L.; Rexhepi Z.; Sylejmani M.; Sinani B.; Ibrahimi H.; Haziri I.; Faiku F.; Mehmeti A.; Haziri A., Underground houses - systematic approach toward underground construction of living space, UBT International Conference 2017, 5.

[8] Shan M., Hwang B.-G., Wong K.S.N., A preliminary investigation of underground residential buildings: Advantages, disadvantages, and critical risks, Tunnelling and Underground Space Technology 2017, 70, 19-29.

[9] Saqaff A., Alkaff S.A., Sim S.C., Ervina Efzan M.N., A review of underground building towards thermal energy efficiency and sustainable development, Renewable and Sustainable Energy Reviews 2016, 60, 692-713.

[10] Carmody J.C., Meixel G.D., Labs K.B., Shen L.S. Earth Contact Buildings: Applications, Thermal Analysis and Energy Benefits. In: Böer K.W., Duffie J.A. (eds) Advances in Solar Energy. Springer, Boston, MA, 1985.

[11] Van Dronkelaar C., Costola D., Mangkuto R.A., Hensen J.L.M., Heating and cooling energy demand in underground buildings: Potential for saving in various climates and functions, Energy and Buildings 2014, 71, 129-136.

[12] Yoshino H., Matsumoto S., Nagatomo M., Sakanishi T., Five-year measurements of thermal performance for a semi-underground test house, Tunnelling and Underground Space Technology 1992, 7, 4, 339-346.

[13] Milanović A.R., Kurtović Folić N., Folić R., Earth-Sheltered House: A Case Study of Dobraca Village House near Kragujevac, Serbia, Sustainability 2018, 10(10), 3629.

[14] Ziemacki J., Domy podziemne mają przyszłość, www.rp.pl/Mieszkaniowe/303289849-Domy-podziemne-maja-przyszlosc.html (28.10.2019).

[15] Bolanowski Z. S., Bolan, www.bolan.pl/2019/09/24/ziemianka/ (28.10.2019).

[16] Ekologiczny dom, www.ekologia.pl/dom-i-ogrod/ekologiczny-dom/ekologiczny-dom,11328.html (28.10.2019).

[17] Żelkowski M., Pompa ciepła zeszła pod ziemię 2018, www.budujemydom.pl/instalacje/pompy-ciepla/a/11398-pompa-ciepla-zeszla-pod-ziemie (28.10.2019).

[18] Qi H.-B., Niu F.-L., Zhao Y.-G., Yu Y., Wang S.-F., Feasibility of underground NPP and its MCDA-based optimization. Nuclear Science and Techniques 2016, 27.

[19] Kubicki, K., Konstrukcje stalowe z rur wycinanych laserowo, Zeszyty Naukowe Politechniki Częstochowskiej, Budownictwo 2010, 16, 65-76.

Budowle podziemne – kaprys czy pragmatyzm

STRESZCZENIE:
Celem pracy jest próba znalezienia odpowiedzi na kwestię postawioną w tytule. W artykule przedstawiono przykłady konstrukcji wybudowanych pod ziemią, które zwykle wznosi się nad ziemią. Należą do nich domy mieszkalne i fabryki. Nietypowa lokalizacja stawia wiele wyzwań przed projektantami i wykonawcami, ale może przynieść ogromne korzyści. Jedną z nich jest podniesienie efektywności energetycznej budynku. Podstawą decyzji o wyborze budowli podziemnej musi być analiza korzyści, wad i zagrożeń związanych z tego typu obiektami przeprowadzona dla indywidualnych przypadków.

SŁOWA KLUCZOWE:
budowle podziemne; dom podziemny; podziemna fabryka; efektywność energetyczna