PODZEMNE STAMBENE ZGRADE U KONTEKSTU ENERGETSKI EFIKASNIH GRAĐEVINA

EARTH-SHELTERED HOUSING BUILDINGS IN THE ENERGY EFFICIENT STRUCTURES CONTEXT

Aleksandar RUDNIK MILANOVIĆ
Nađa KURTOVIĆ FOLIĆ

PREGLEDNI RAD
REVIEW PAPER
UDK:728.3:643.8]:620.98
doi:10.5937/grmk1703047R

1 UVOD

Razvoj podzemne stambene arhitekture u velikoj meri zavisi od okruženja u kojem su objekti bili izgrađeni (klima, geografsko područje...) ali i od materijala i tehnologije koji su primenjeni prilikom građenja. Većina podzemnih stambenih objekta podignuta je u područjima u kojima su visoka temperatura i retke kiše klimatske karakteristike, a retko su prisutni u hladnijim, planinskim krajevima sa snegom. Istraživanja pokazuju da je podzemno stanovanje veoma zastupljeno u mediteranskim zemljama, Aziji i Africi, Severnoj Americi i delovima Evrope, i to u većem ili manjem obimu u svim istorijskim periodima.

Od praistorije do danas, čovek se prilagođava uslovima i okruženju u kojem obitava, postepeno podižući nivo kvaliteta življenja i funkcije zajednice u kojoj učestvuje kao jedinka. Pećine, planine i pustinjski ambijent nude mogućnosti za različite oblike podzemnih habitata. Od čovekovog napuštanja pećine, on se bori s problemima da savlada prirodu i bira najfunkcionalnije i najprikladnije oblike fizičke strukture da bi zadovoljio svoje potrebe. Podzemni objekti, kao specifičan oblik građevine koja zadovoljava potrebe stanovanja, pojavljuju se na svim delovima naše planete.[1] Njihova tipologija uglavnom najviše zavisi od klimatskih karakteristika područja na kojem čovek živi. [2] Podzemni stambeni objekti suštinski se mogu istraživati putem njihove dve najčešće pojave:

Dr Aleksandar Rudnik Milanović, arhitekta i urbani planer, Direkcija za urbanističko planiranje, Kragujevac, aleksandarrudnik@gmail.com
Dr Nađa Kurtović-Folić,profesor, Univerzitet u Novom Sadu, Trg D. Obradovića, 21000 Novi Sad, nfolic@uns.ac.rs

1 INTRODUCTION

Evolution of underground residential architecture is largely dependent on the environment in which the buildings were constructed (climate, geographical area ...), but also of the materials and technologies used during the construction. Most residential underground facilities were built in areas where the climatic characteristics are high heat and rare rainfall, while they are rarely present in colder, mountainous areas with snow. Researches indicate that the underground dwellings were built in many Mediterranean countries, Asia and Africa, North America and Europe, with a greater or lesser extent, through all historical periods.

From prehistory to nowadays, man adapts to the conditions and environment in which he resides, gradually raising the quality of life and the function of the community he acts as an individual. Caves, mountains, and desert ambients offered opportunities for different forms of underground habitats. From the man's exodus from the cave, he is struggling with the problems of overcoming nature and choosing the most functional and most suitable form of physical structure for the fulfillment of his own needs. Underground objects as a specific form of structure for meeting the needs of housing, appear in all parts of our planet. [1] Their typology was mostly dependent on the climatic characteristics of the climate that man lived. [2] Earth-sheltered housing objects can essentially be viewed through their two most commonly occurring forms;

Dr Aleksandar Rudnik Milanovic, architect and urban planner, Directorate for Urban Planning, Kragujevac, aleksandarrudnik@gmail.com
Dr Nadja Kurtovic-Folic, professor, University of Novi Sad, Trg D. Obradovića, 21000 Novi Sad, nfolic@uns.ac.rs

• podzemni stambeni objekti smešteni u prirodnom okruženju s minimalnom intervencijom ljudi;

• podzemni stambeni objekti koje ljudi stvaraju, menjajući karakterisitike prirodnog okruženja pri čemu nove strukture prilagođavaju prirodnom okruženju.

Za razliku od praistorijskog čoveka, čovek XXI veka ima veće tehnološke mogućnosti da prilagodi život u podzemnim građevinama svojim potrebama, bez obzira na to da li se radi o jednom ili drugom načinu navedenog oblika njihovog stvaranja.[3]

Podzemni objekti predstavljaju kombinovani održivi model koji prvenstveno funkcioniše na bazi recikliranja atmosferske vode s površine zelenih krovova, koristeći energiju koja dolazi iz zemlje ili podzemnih voda za potrebe zagrevanja ili hlađenja. Usled ograničenih prostornih kapaciteta u gradovima za primenu principa bioklimatskog dizajna, u razvoju podzemnih građevina izvan naselja koja nisu infrastrukturno obezbeđena, moguće je postići maksimalnu energetsku efikasnost uvođenjem solarnih sistema, kao trećeg dodatnog oblika snabdevanja energijom. Neposredni rezultat primene modela podzemnih objekata u urbanizovanim okruženjima jeste zadržavanje ukupne površine tla pod vegetacijom, čime se postiže maksimalni efekat povoljnog uticaja na kvalitet i kvantitet ekosistema koji se može sačuvati ovim specifičnim tipom građenja. [4]

Evoluirajući od pećina i drugih sličnih oblika, danas u podzemnim stambenim objektima živi preko 50 miliona ljudi. Nova podzemna stambena arhitektura stvara se sa izraženom brigom zbog povećanja energetske potrošnje i gradi se na osnovu iskustva anonimnih graditelja podzemnih objekata, čiji su koncepti danas inovativna rešenja za probleme ljudi XXI stoleća. [5]

U ovom članku mi ukazujemo na značajno povoljnije energetske aspekte ukoliko podzemna gradnja postane učestalija.

2 PODZEMNE STAMBENE ZGRADE U KONTEKSTU ENERGETSKI EFIKASNIH GRAĐEVINA

S ciljem da se smanji uticaj atmosferskih padavina i taloženja, posebnu pažnju tokom gradnje podzemnih stambenih objekata treba obratiti na:

• izbor mesta za građenje;

• pravljenje drenaže u skladu s lokacijom i vodootpornim slojevima terena u svim aspektima dodira objekta sa zemljom.

Vegetacija na mestu građenja može biti od višestruke koristi za buduće ponašanje objekta. Zeleni fond se može posmatrati iz više aspekata u odnosu na uticaj koji ima na podzemno stanovanje. Jedan je, svakako, značajna štednja energije koja se može postići postojanjem ili sađenjem drveća na mestu planiranom za gradnju podzemnog stanovanja. Testovi vezani za količinu uštede energije sa zelenim zasadima još nisu urađeni, ali iz prakse je poznato da zasadi na južnoj strani podzemne stambene zgrade mogu tokom leta znatno smanjiti temperaturu unutar zgrade.

U Americi se istraživanje o energetskoj efikasnosti podzemnih stambenih objekata sprovodi od osamdesetih godina prošlog veka. Parametri koji konkretno ukazuju na potrebu da se definišu propisi za izgradnju ovih objekata, na osnovu činjenica koje su merljive, potvrđuju da podzemni stanovi predstavljaju kuće s vrlo

• Underground residential buildings located in a natural environment with minimal human intervention;

• underground residential buildings that man creates by changing the characteristics of the natural environment and the new structure adapts to the natural environment.

Unlike a prehistoric man, a man of the 21st century has far greater technological abilities to compare life in underground facilities to his needs, whether it is one or the other mentioned approach to the use of these facilities. [3]

Underground structures represent a combined sustainable model, which functions primarily on the recycling of atmospheric waters from the surface of green roofs, using energy derived from earth or groundwater for heating and cooling purposes. Due to limited spatial capabilities in cities for the application of bioclimatic design principles, by affirming the development of subterranean buildings outside settlements that are not infrastructural supplied, it is possible to achieve maximum energy efficiency by introducing solar systems as the third supplementary form of energy supply. The direct result of applying the model of underground facilities in urbanized environments is to maintain the total area of the soil under vegetation, thus achieving the maximum effect of achieving favourable impacts on the quality and the quantity of ecosystems that can be preserved using this form of specific construction type. [4]

Evolving from the caves and other different types, over 50 million people live today in earth-sheltered housing. New underground residential architecture is created with great awareness for increased energy consumption and built on the experiences of anonymous builders of underground facilities, whose concepts today are innovative solutions to the problems of a man of the 21st century. [5]

In this article, we suggest significantly more favourable energy aspects if underground structures becomes more common.

2 EARTH-SHELTERED HOUSING BUILDINGS IN THE ENERGY EFFICIENT STRUCTURES CONTEXT

Special attention during the construction of underground residential facilities with the aim of reducing the impact of atmospheric precipitation should be paid to:

• Selection of the site for construction

• Making drainage in accordance with the location and terrain waterproofing layers in all aspects of contact with the ground facility.

The vegetation on the site for construction can have multiple benefits for future operation of the facility. Green Fund can be viewed from several aspects in terms of its impact on the underground dwellings. One, of course, is a significant energy saving that can be achieved with the existence or planting trees at the site planned for the construction of an underground dwelling. The tests related to the amount of energy saving with green plantations are not yet done, but it is known from practice that the plantations on the southern front of the underground residential building can significantly reduce the temperature inside the building in summer.

In America, research on energy efficiency underdobrim energetskim performansama. Istraživanje energetske efikasnosti prvenstveno podrazumeva određivanje parametara koji dovode do procene koristi od izgradnje podzemnog objekta u odnosu na nadzemne strukture. Isti rezultati se mogu dobiti u smanjenju emisija CO_2 korišćenjem energetski efikasnih modela kao što su podzemne konstrukcije.[6]

Prema bazi podataka koja je sastavljena tokom pomenutog istraživanja, „može se reći da kuće pokrivene zemljom pokazuju znatno bolje energetske performanse nego kuće standardnih fasada". Tvrdnja da se potrošnja energije za ovu vrstu kuća može smanjiti do 75%, može se dokazati korišćenjem podataka koji se odnose na praćenje parametra faktora termičkog integriteta, koji u slučaju kuća pokrivenih zemljom iznosi 28.40 KV / m^2 dnevno, dok isti parametar u slučaju tradicionalnih nadzemnih kuća iznosi 113.56 KV / m^2".[7]

Prilikom istraživanja koje je sprovedeno na dve južno orijentisane strukture: jednoj podzemnoj stambenoj kući i standardnoj nadzemnoj kući na istom području, Stanjec i Novak iz Odeljenja za građevinarstvo na Tehnološkom univerzitetu u Vroclavu, zaključili su da gubici i dobici stoje u određenim razmerama, s vrlo sličnim pokazateljima. Utvrdili su, takođe, da se, ako se parametri vrednosti za hlađenje i grejanje analiziraju zasebno, primećuju značajne razlike. [8]

Ova pojava uzrokovana je činjenicom da je toplotni gubitak u podzemnom objektu znatno manji nego u nadzemnim zgradama, ali samo u toku grejne sezone, te da je tokom letnje sezone toplotni gubitak u pozemnim objektima veći. Pošto je temperatura tla u letnjem periodu niža od temperature vazduha, posledica je hlađenje objekta. Ovo je jedan od glavnih razloga zašto podzemne konstrukcije zahtevaju znatno manje energije od površinskih. Primetili su, takođe, da su u toku grejne sezone „toplotni gubici u podzemnim stambenim zgradama od 14%, 8% i 5% manji za 5 cm, 10 cm i 20 cm debljine toplotne izolacije. Povećanje debljine slojeva zemlje iznad krovnog pokrivača smanjuje gubitke toplote za 20-25%, 10-15% i 5% primenom toplotne izolacije od 5 cm, 10 cm i 20 cm u poređenju s toplotnom izolacijom od 0.5 m". U ovom smislu može se zaključiti da su toplotni dobici u podzemnim stambenim zgradama do 40% veći nego u površinskim strukturama.[9]

Da bi dokazali teze iz njihovog istraživanja s jasnim uporednim odnosima prosečnih vrednosti, Stanjec i Novak su razvili „dijagram gubitaka toplote" koji predstavlja uporednu analizu za nadzemne i podzemne objekte, u zavisnosti od debljine izolacije i debljine slojeva zemlje iznad podzemnih objekata, koji su predstavljeni kao prosečne vrednosti, vrednosti tokom grejne sezone i sezone hlađenja.

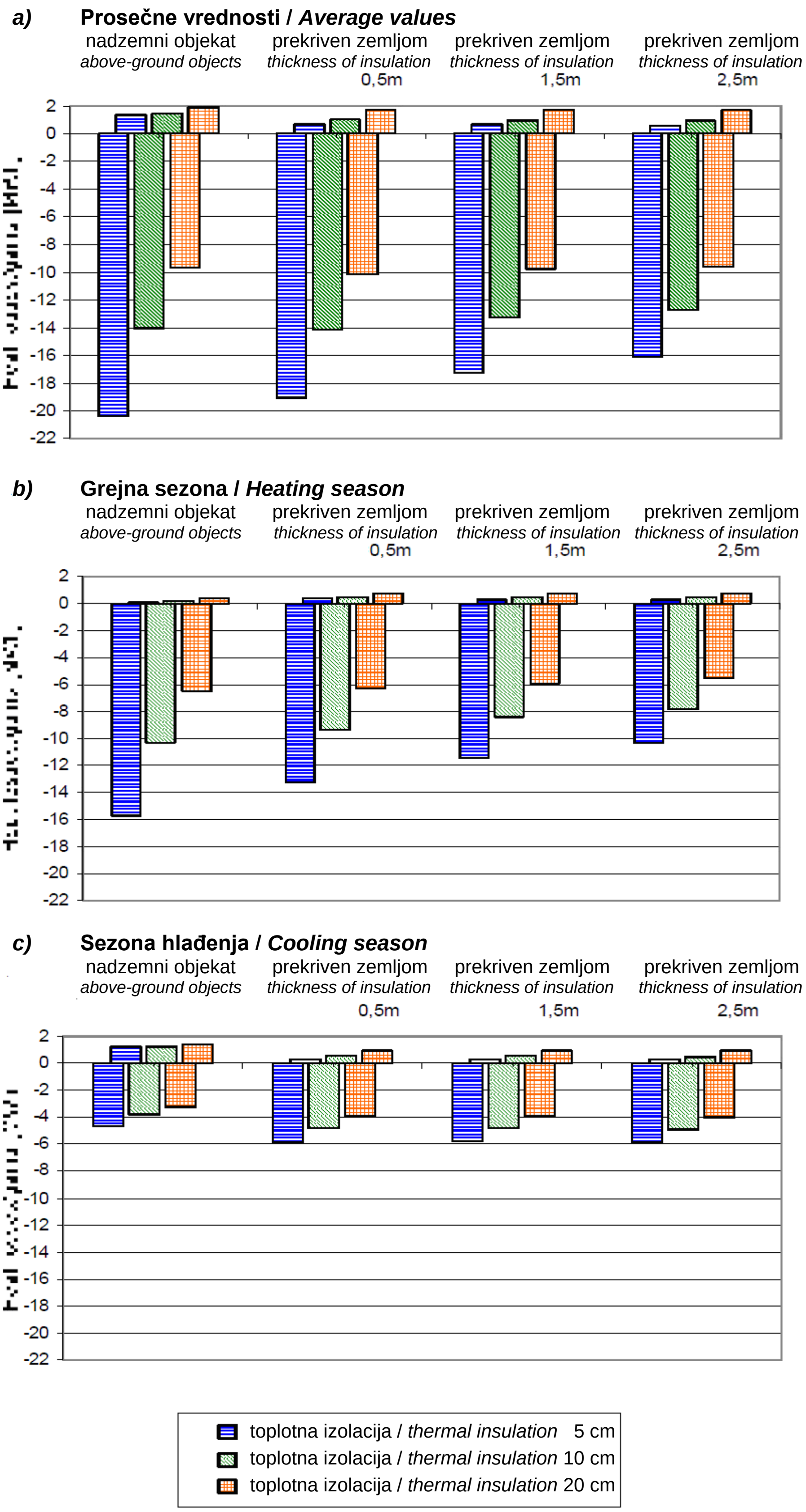
Istraživanja sprovedena na Državnom univerzitetu Oklahoma [10] i Vendt-ova istraživanja [7] potvrđuju da su podzemne stambene zgrade energetski efikasne zgrade i da su bile od velike važnosti za odnos prema proceni energetske efikasnosti kao jedne od najvažnijih komponenti u vrednovanju opšte efikasnosti podzemnih zgrada.

ground residential facilities is conducted since the 80th of the last century. Parameters that specifically point to the need to define regulations for the construction of these facilities, based on the facts that are measurable, and which indicate that the underground dwellings are houses with very good energy performance. Research on energy efficiency; primarily implies to determine the parameters which lead to the assessment of the benefits of building underground in relation to the above-ground structures. The same results could be obtained in reducing CO_2 emissions by using more energy-efficient models such as underground structures. [6]

According to the database compiled during the mentioned research "it can be said that the houses covered with earth exhibited considerably better energy performances than the standard surface houses". The claim that the energy consumption for this type of houses can be reduced up to 75%, can be proved using the data related to monitoring the thermal integrity factor parameter, which in case of the houses covered with soil averages 28.40 KW/m^2 daily, while the same parameter in case of traditional surface houses averages 113.56 KW/m^2 ". [7]

On the event of the research conducted on two south-oriented structures: one being earth-sheltered elevated housing and the standard surface house of the same area the Staniec and Nowak from the Department of Civil Engineering at the University of Technology of Wroclaw, concluded that the losses and gains stand in certain proportions, with very similar indicators. They also determined that if value parameters for cooling and heating are separately analyzed, considerable differences are observed. [8]

They found that they arise due to the fact that the thermal loss in an earth-sheltered housing is considerably less than in the surface housing, but only during the heating season and that during the summer season, thermal loss in the earth-sheltered housing is higher. Since the temperature of soil in the summer is lower than the air temperature, this causes cooling of the structure. it is one of the main reasons why underground structures require considerably less energy than the surface ones. They also noticed that during the heating season "thermal losses in underground residential buildings by 14%, 8%, and 5% are less by the 5cm, 10cm and 20cm thickness of thermal insulation. Increasing the thickness of the layers of the earth above the roof panel reduces heat losses by 20-25%, 10-15% and 5% for 5cm, 10cm and 20cm thermal insulation compared to 0.5m thermal insulation". The [9] in this sense, it can be concluded that heat gains in the underground housing structures are up to 40% higher than in the surface structures.



Slika 1. Uporedna analiza nadzemnih i podzemnih objekata, u zavisnosti od debljine izolacije i debljine zemljanog sloja iznad podzemnog objekta (prema [8])

Figure 1. Comparative analysis of the above-ground and underground objects, depending on the thickness of the insulation and the thickness of the ground layers in underground objects (after [8])

Kada se statistika kao što je ova posmatra u svetlu kvalitativnih polaznih razloga za promenu čitavog skupa dokumenata vezanih za područja planiranja i izgradnje, može se očekivati promocija široko prihvaćene podzemne arhitekture stanova, s jednim od primarnih ciljeva današnjice, a to je planiranje i izgradnja podzemnih pojedinačnih zgrada, ali i čitavih naselja, pri čemu se ova tipologija stambenog prostora može odlično implementirati radi stvaranja budućih energetski efikasnih naselja u Republici Srbiji. [11] [12]

In order to show the theses from their research with clear comparative relationships of average values Stanjec and Novak developed a "heat loss diagram" which represents a comparative analysis of the above-ground and underground objects, depending on the thickness of the insulation and the thickness of the ground layers in underground objects, presented as average values, values during the heating season and the cooling season.

The research conducted by Oklahoma State University [10], and Wendt [7] confirm underground residential buildings as energy-efficient buildings and were of great importance for the relationship to the assessment of the energy efficiency as one of the most important components of general efficiency of underground buildings.

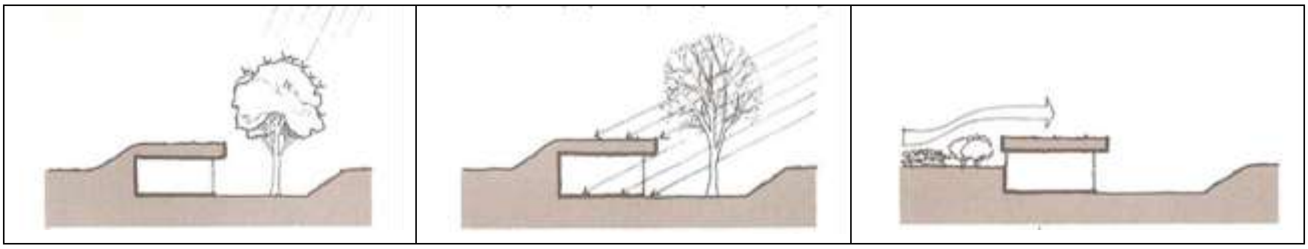
When the statistics such as this is viewed in the light of qualitative initial reasons for the change of an entire set of documents related to planning and construction areas, one can expect promotion of a more widely present underground housing architecture, with one of the primary goals of the present times, which is planning and construction of individual buildings, but also of entire settlements, where this housing typology can be implemented with an aim of creation of future energy efficient settlements in the Republic of Serbia. [11] [12]

3 UTICAJ BIODIVERZITETA NA PODZEMNO STANOVANJE

Prisustvo vegetacije na mestu građenja može pružiti višestruke pogodnosti za buduće funkcionisanje objekta.[13] Zelenilo se može posmatrati s nekoliko stanovišta, s obzirom na njegov uticaj na podzemne stambene zgrade. Jedan od nesumnjivo važnih aspekata jeste ušteda energije, koja se može postići postojećim stablima ili njihovim postavljanjem na lokaciji koja je planirana za izgradnju podzemne stambene zgrade zaštićene zemljom. Testovi koji se odnose na količinu energije ušteđene sađenjem zelenila još nisu dovoljno zastupljeni, ali iz prakse je poznato da biljke na južnoj strani zgrade zaštićene zemljom mogu pružiti značajno smanjenje temperature unutar zgrade tokom letnje sezone.

3 IMPACT OF BIODIVERSITY ON EARTH-SHELTERED HOUSING

The presence of vegetation at the construction site can provide multiple benefits for the future functioning of the structure. [13] The greenery can be observed from several viewpoints, regarding its impact on the earth-sheltered housing buildings. One certainly important aspect is energy saving which can be achieved by having or planting trees on the location planned for construction of earth-sheltered housing building. The tests related to the amount of energy saved by planting the greenery have not been conducted yet, but it is known from the practice that plants on the south side of the earth-sheltered building can provide the significant reduction of the temperature inside the building in the summer season.



Slika 2. Primeri uticaja biodiverziteta na podzemne građevine: a. vegetacija štiti od sunčanih zraka tokom letnje sezone; b. vegetacija propušta sunčane zrake tokom zimske sezone; c. vegetacija štiti od vetra. (prema [14])

Figure 2. Examples of biodiversity impacts on the earth sheltered buildings: a. vegetation blocks solar radiation in summer season; b. vegetation lets through solar radiation in the winter season; c. vegetation as a protection from wind. (after [14])

Ako se sade nove biljke, potrebno je da se na južnoj strani objekta zasade listopadne biljke, kako bi se omogućilo prodiranje sunčeve svetlosti kroz ogoljene krune drveća u zimskom periodu. Vetar, takođe, može

If new plants are planted, it is necessary to plant deciduous trees on the south side of the structure, so as to allow sunlight penetration through bare tree crowns in winter. The wind can also impact the building temperauticati na temperaturu zgrade, tako da se, u zavisnosti od smera duvanja vetra, može saditi nova vegetacija ili se može koristiti postojeća, sprečavajući tako direktan udar vetra na objekat.

U izveštaju Agencije za energetiku države Minesote u vezi sa istraživanjem u Južnoj Dakoti, navodi se: „kada se uporede parametri za dva identična objekta (jednog sa zelenilom u neposrednom okruženju, a drugog bez zelenila), zaključuje se sledeće:

– kuća koja je imala zelenilo u neposrednom okruženju zgrade, imala je uštedu do 40% energije u odnosu na kuću bez zelenila”.[15]

Istraživanje je takođe ukazalo na to da postoji uticaj vegetacije na štednju prilikom upotrebe podzemnog stanovanja, tako da je prilikom izgradnje takvih struktura neophodno planirati vegetaciju u skladu s građevinskom orijentacijom i lokalnim zahtevima.

4 PRIKAZ OSNOVNIH UTICAJA NA FUNKCIONISANJE PODZEMNIH STAMBENIH OBJEKATA

4.1 Uticaj padavina na podzemno stanovanje

Prilikom izgradnje podzemnih stambenih zgrada posebnu pažnju treba obratiti na:

- izbor mesta za izgradnju građevine;
- postavljanje drenažnog sistema, u odnosu na mesto i konfiguraciju zemljišta;
- postavljanje vodootpornih slojeva na mestu dodira objekta sa zemljom kako bi se otklonio uticaj padavina i vode uopšte.

Uticaj atmosferskih padavina na podzemnu stambenu arhitekturu jeste jedan od najvećih rizika za njihovu eksploataciju. Tipologija podzemnih objekata predstavlja mogućnost za manje ili veće uticaje atmosferskih voda. Prema Reju Skotu, autoru knjige „Kako izgraditi svoj podzemni objekat” (*How to build your own underground home*) najveću opasnost po podzemne objekte predstavljaju ukopani objekti, jer ovaj tip objekata omogućava pojavu nekontrolisane količine vode pri obilnim padavinama. [16] [17]

ture, so depending on the wind blowing direction, vegetation can be planted or the existing vegetation can be used, preventing direct impact of the wind on the structure

In the report of the Agency for Energy of Minnesota, related to the research in South Dakota, it is stated that "when comparing the parameters for two identical objects (one with greenery in the immediate environment and the other without greenery), the following conclusions were reached:

– House that had greenery in the immediate surroundings of the building, had savings of up to 40% energy in relation to a house without greenery”. [15]

That research also indicated that there is an impact of the vegetation on the saving in the usage of earth-sheltered housing so that when constructing such structures, it is necessary to plan the vegetation in accordance with the building orientation and local requirements.

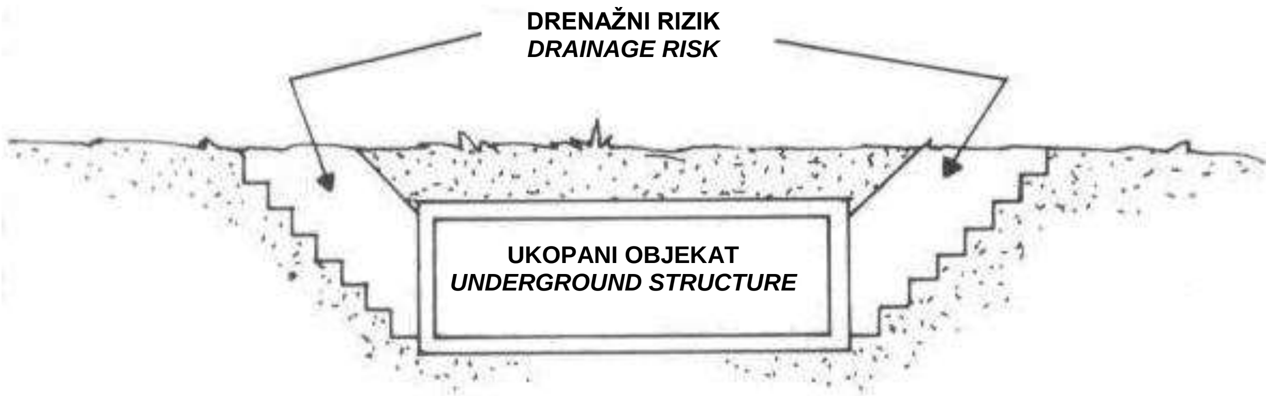
4 PRESENTATION OF THE BASIC IMPACTS ON ENERGY FUNCTIONING OF EARTH - SHELTERED STRUCTURES

4.1 Impact of rainfall on underground housing

When constructing underground housing, a special attention must be paid to:

- The choice of location of construction of the structure
- Construction of a drainage system, regarding the location and land configuration
- Construction of waterproofing layers at the contact of the structure with soil In order to reduce the rainfall impacts.

The impact of rainfall on an underground housing structure is one of the greatest risks for the operation of such buildings. The typology of underground structures represents the potential for a weak and the strong impact of rainfall. According to Ray G. Scott, author of the book "How to build your own underground home" "The greatest danger to underground objects is buried objects because this type of objects allows the appearance of uncontrolled water in abundant precipitation". [16] [17]



Slika 3. Detalj preseka kroz ukopani-prodirući tip podzemnog objekta, s prikazom rizika prilikom dreniranja (prema [18]).
Figure 3. A cross section detail of an envelope/true underground structure, with the presented drainage risks (after [18]).

Poseban problem koji prouzrokuje potencijalnu štetu zbog pritiska kiše koji prolazi kroz slojeve zemlje do objekta javlja se u podzemnim zgradama u onim slučajevima kada nema kanalizacionih kanala i mrežnog sistema s drenažnim cevima, kojima bi se odvodila voda nakupljena na zidu prema nagibu. [18]

Pored rizika od bočnih uliva atmosferske vode, osnovni problem koji su podzemni objekti imali s velikom količinom vode i vlage u objektu, nastajao bi kada bi se, pri projektovanju, odabrao pogrešan tip objekta u odnosu na teren. Jedan od takvih primera upravo je objekat atrijumske ukopane kuće u Arizoni, građene osamdesetih godina prošlog veka. Prema izjavama samih vlasnika, objekat je u najvećem broju slučajeva imao probleme s nekontrolisanim prodorom atmosferske vode, usled položaja pristupa objektu, koji se odvija preko atrijuma, formiranog ispod saobraćajnice, i to na nižoj koti u odnosu na put s kojeg se pristupa objektu. [19]

A particular problem causing potential damage due to the rainfall pressure flowing to the house through the earth layers is found in elevation – in-hill underground buildings, in those cases when no drainage canals and drainage pipe network system is provided, which would drain the water accumulated on the wall towards the slope. [18]

Apart from the risk form the lateral penetration of rainfall, the basic problem the earth sheltered buildings had in terms of excess water and dampness in the structure was caused by the improper choice of structure for the land configuration in the design phase. [One of such examples is the atrium envelope house in Arizona, built in the 80's of the previous century. According to the owners themselves, the building in most of the case had a problem with the uncontrolled penetration of rainfall, which is caused by the position of the access to the house, which is organized via an atrium created below a road, at a lower level than the road used for accessing the house. [19]

Slika 4. Podzemna kuća sa atrijumom u Arizoni: a. pozicija pristupa objektu; b. pogled na objekat ukopanog tipa sa atrijumom (prema [19])

Figure 4. The atrium envelope house in Arizona: a. Building access position, b. View of the envelope/true underground building (after [19])

Pojava privremenih podzemnih voda pri prelasku iz jednog u drugo godišnje doba, „može stvoriti problem usled velikog nagomilavanja vode u situacijama kada je nepripremljen objekat izložen pritisku vode" [20], koji se može znatno smanjiti preduzimanjem svih potrebnih koraka prilikom same izgradnje objekta.

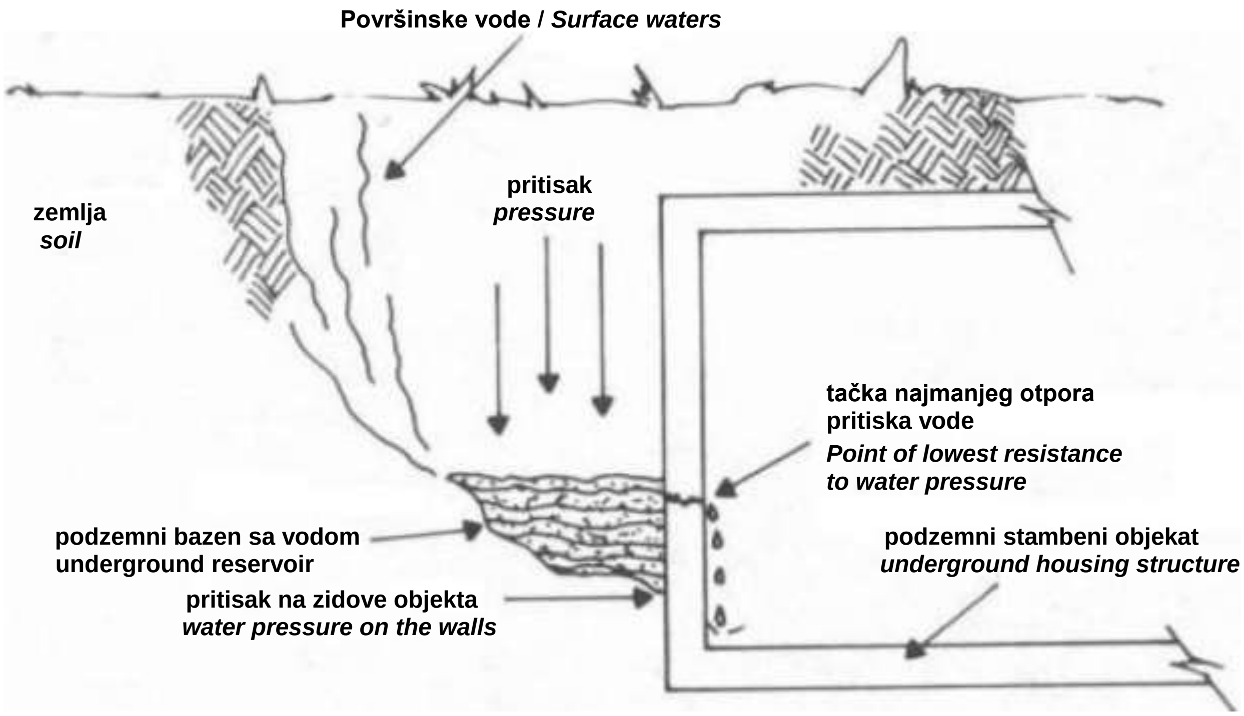
Pored standardnih pristupa izradi hidroizolacionih slojeva kod podzemnih stambenih objekata, negativni uticaji se, danas, svakako značajno mogu umanjiti postavljanjem gumiranih membrana, koje ne samo što utiču na nemogućnost prodiranja vode ka objektu, već istovremeno služe za zadržavanje vode radi navodnjavanja vegetabilnog sistema iznad krovne konstrukcije objekta.

Provera geoloških slojeva zemlje, uz informacije o stabilnosti i slojevima podzemnih voda, može znatno sprečiti moguće negativne pojave prilikom eksploatacije objekta.

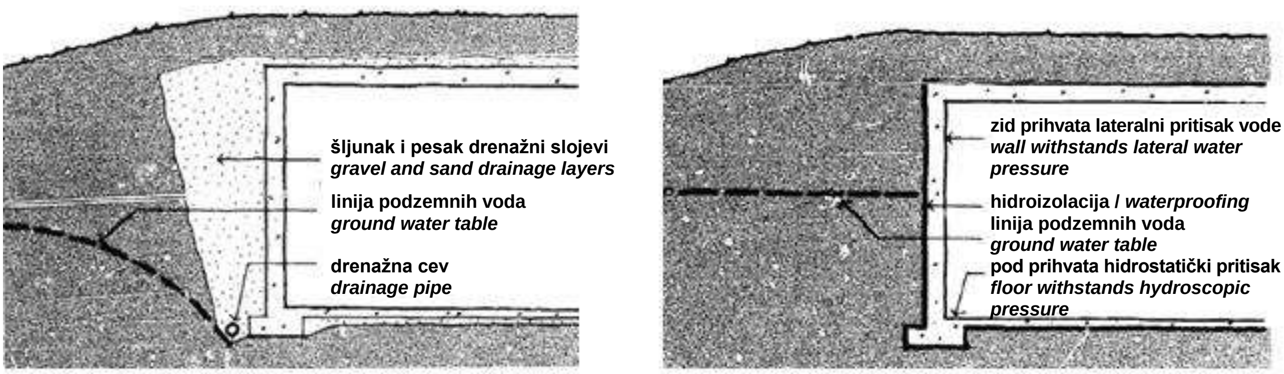
The occurrence of temporary underground waters when the season's change, "can create a problem due to the large accumulation of water in situations where the unprepared object is exposed to water pressure" [20], which can be significantly reduced when all necessary steps when constructing the building are taken.

By creating a drainage layer made of sand and gravel and by placing a drainage pipe around the building potential for damage to the structure and penetration of rainfall water is considerably reduced.

In addition to the standard approaches to the building of waterproofing layers of the underground structures roofs, the negative impacts can be considerably reduced nowadays by installing rubber membranes, which not only prevent water from penetrating the structure but retain water so that vegetation system above the roof structure can use it.



Slika 5. Detalj zone pritiska atmosferske vode (prema [20])
Figure. 5. A detail of the rainfall water pressure zone (after [20])

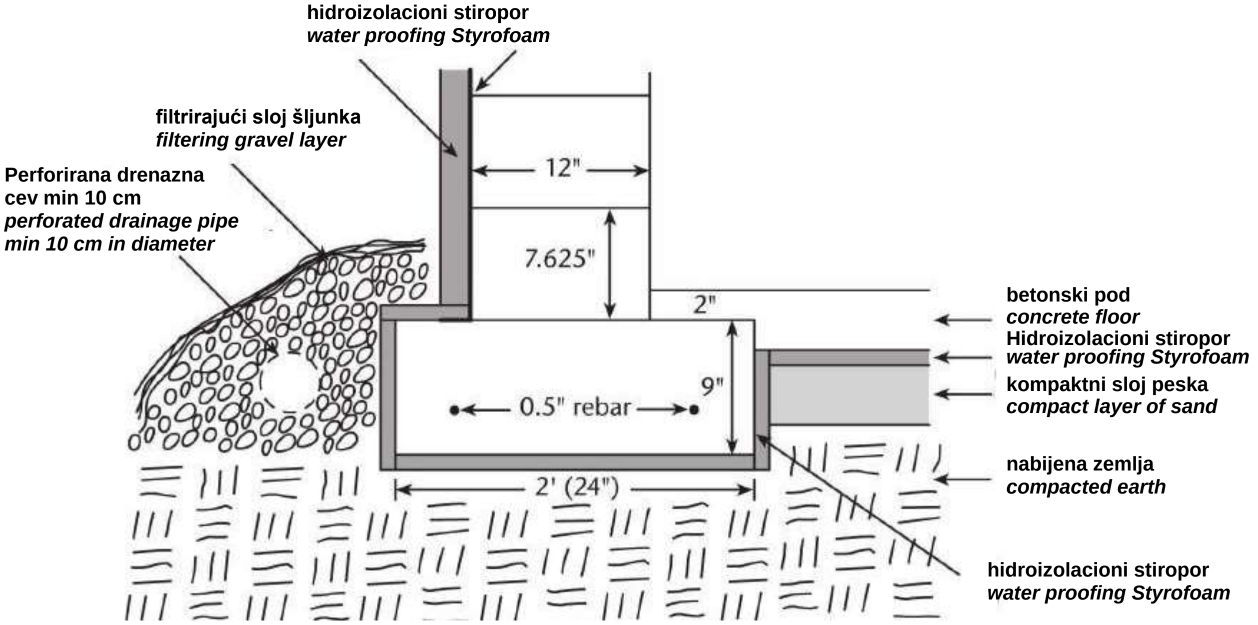


Slika 6. a. Detalj zgrade bez hidroizolacionog sloja; b. Detalj zgrade sa hidroizolacionim slojem
Figure 6. a. A detail of the building without the waterproofing layer; b. A detail of the building with the waterproofing

Istraživanja energetske efikasnosti podrazumevaju pre svega utvrđivanje parametara kojima se dolazi do ocene povoljnosti izgradnje podzemnih u odnosu na nadzemne objekte, ali i nasutih u odnosu na ukopane objekte u terenu. U zavisnosti od unetih parametara i karakteristika objekata koji se istražuju, mogu se dobiti i različiti rezultati. Ipak, značajno je istaći da su podaci koji se dobijaju egzaktni i dobijeni računskim putem, jer se koriste specijalizovani softveri koji su upravo namenjeni takvim proračunima. Pored podataka o toplotnoj sprovodljivosti, energetska efikasnost zavisi i od niza drugih faktora, koji zbirno utiču na ocenu o energetskoj kategoriji podzemnog stambenog objekta, kao što se vidi iz Tabele 1.

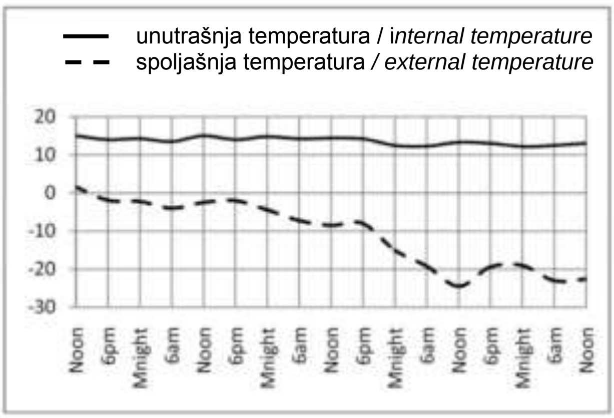
A survey of the geological layers of earth, along with information on the stability and layers of ground waters can prevent potential negative situations during the building service life.

Research of energy efficiency, comprise the primarily identification of parameters used to assess advantages of construction of earth sheltered structures over the surface structure, but also of buried structures in comparison with envelope/true underground structures. Depending on the input parameters and characteristics of researched structures, different results can be obtained. Yet, it is interesting to point out that the obtained data are exact and computational, obtained using specialized software. In addition to data about thermal conductivity, energy efficiency depends on a number of other factors, which cumulatively affect the assessment of energy category of an underground housing building as could be seen in Table 1.



Slika 7. Detalj preseka kroz temeljnu zonu zida podzemnog objekta
Figure 7. A detail of the cross section through the foundation zone of the underground structure wall

Slika 8. a. Gumirana hidroizolaciona membrana; b. Primer termičke izolacije
Figure 8. a. Waterproofing rubberized membrane; b. Thermal insulation example



Slika 9. Odnos promena spoljašnje i unutrašnje temperature na primeru podzemnog objekta u Misuriju, SAD
Figure 9. Relation of variation of external and internal temperature for an underground structure in Missouri, USA

Tabela 1. Stepen energetske efikasnosti u odnosu na tipologiju objekta
Table 1. Degree of efficiency regarding the structure typology

Faktor / *Factor*	Tip podzemnog stambenog objekta / *Type of earth-sheltered dwelling building*			
	nasuti / *covered with the earth*		u terenu / *buried in to the soil*	
Pasivni solarni potencijal *Passive solar potential*	odlican / *excellent*		manje efikasan / *less efficient*	
Termalna stabilnost *Thermal stability*	manje efikasan / *less efficient*		odlican / *excellent*	
Prirodni osvetlja potencijala *Potential of natural light*	efikasan / *efficient*		manje efikasan / *less efficient*	
Zastita od vetra *Wind protection*	manje efikasan / *less efficient*		odlican / *excellent*	
Zastita od buke *Protection against noise*	manje efikasan / *less efficient*		odlican / *excellent*	
Vizuelizacija / *Visualization*	odlican / *excellent*		manje efikasan / *less efficient*	
Klimatski uslovi *Climate conditions*	efikasan za umerenu klimu *efficient for moderate climate*		efikasan za tropsku klimu *efficient for tropical climate*	
Strukturni troskovi *Structural costs*	moderan dizajn *modern design*	tradicionalna *traditional*	moderan dizajn *modern design*	tradicionalna *traditional*
	prosecan *average*	manji troskovi *lower costs*	visoki troskovi *high* *costs*	manji troskovi *lower costs*

Istraživanja termalnih pokazatelja, obavljena na nasutoj podzemnoj stambenoj kući u Misuriju, predstavljaju **„**parametre praćenja temperature u tom objektu u periodu od četiri dana sa intervalima merenja od šest sati, prilikom kojih je uočena konstantna unutrašnja temperatura, u odnosu na promene spoljne temperature". [21] Ti podaci konkretno ukazuju na prednosti izgradnje podzemnog nasutog stambenog objekta, posebno uzimajući u obzir činjenicu da za održavanje konstatne temperature prilikom merenja nisu postojali niti su korišćeni sistemi za zagrevanje objekta.

The research of thermal indicators, conducted on the bermed earth sheltered house in Missouri represent "parameters for monitoring the temperature of this object for a period of 4 days with 6-hour measurement intervals, during which a constant internal temperature is detected, in relation to the changes in the outdoor temperature". [21] Those data indicate advantages of construction of bermed housing buildings, especially taking into consideration the fact that for retaining of constant temperature during measuring, no building heating systems were used.

4.2 Podzemni stambeni objekti u kontekstu smanjenja negativnih ekoloških uticaja na životnu sredinu

Od 1900. godine i francuskog arhitekte Ežena Enara [21], koji je objavio manifest u kojem zastupa sistem podzemnog saobraćaja na nekoliko nivoa, preko Frenka Lojda Rajta, koji je 1930. godine uspostavio sistem perifernih gradova [22], do današnjih gradova s neboderima, kao karakterističnim tipovima visokih zgrada XXI veka, došlo se do tačke razvoja zajednice kada je neophodno smanjivanje negativnih uticaja na životnu sredinu, putem modela povratka prirodi i životu izvan zagađene urbane centralne zone, što, najverovatnije, može biti izvedeno neposrednom interakcijom s prirodnim okruženjem. [23] Podzemne stambene strukture u ovom kontekstu mogu se smatrati strukturalnim posrednicima u epicentru takvih interakcija.

Statistički podaci ukazuju na konkretne pokazatelje, prema kojima u gradu danas živi više ljudi, nego u njegovom okruženju ili samoj prirodi. Poslednjih sto godina zabeležen je protok stanovništva i migracija sa imanja na sela, od sela ka gradovima i od gradova ka metropolama. Poznato je da gradovi koriste do 75 posto globalnih izvora energije i proizvode većinu otpadnih materijala. [24] S takvom stopom potrošnje energije,

4.2 Earth sheltered housing buildings in the context of reduction of negative environmental impacts

Since 1900 and the French architect Eugene Hénard [21], who had a manifest advocating the system of underground traffic at several levels, through Frank Lloyd Wright who in 1930 established a system of peripheral cities [22], up to the present day cities with towers, as a characteristic typology of tall building of 21st century we have come to the point of community development where the necessity to reduce negative environmental impacts, through the model of return to nature and life outside polluted urban central zone, can most likely be effected by a direct interaction with natural environment. [23] Underground housing structures in this context can be considered as structural mediators in the epicenter of such interactions.

The statistics indicate concrete data, according to which there are more people nowadays living in the cities, then in their environment, or in nature. In the last one hundred years, the flow of population and migration from the countryside towards villages, and from the villages towards cities and from the cities towards metropolises was recorded. It is known that cities use up to 75 per cent of global energy resources and produce gradovi postaju generatori negativnog uticaja globalnog zagrevanja na planetu Zemlju.

"Posmatrajući statistiku koja upućuje na činjenicu da komercijalni i stambeni objekti emituju 39 posto CO_2 u atmosferu, a da u skoro 70% slučajeva ovi potrošači troše električnu energiju (prema analizi sprovedenoj u SAD), jasno je da su upotreba energije za hlađenje i grejanje od ključnog značaja za uticaj na životnu sredinu okruženja u kojoj se objekti nalaze." [25]

Da bi se uporedili troškovi energije za grejanje koje su imali prosečna nadzemna i podzemna stambena zgrada, napravljena je studija slučaja za zgradu od 135 m^2. Ova studija je potvrdila da arhitektura podzemnog stambenog prostora može ostvariti smanjenje od 72% potrošnje energije u poređenju sa standardnom nadzemnom kućom.

most of the waste materials. [24] With such energy consumption rate, the cities become generators of the negative impact of the global warming on the planet Earth.

"Observing statistics that point to the fact that commercial and residential objects in CO_2 emissions in the atmosphere account for 39 percent, and that in almost 70% of cases these consumers are consumers of electricity (taking an example of analysis conducted in the US), it is clear that the use of energy for cooling and heating are of key importance for the environmental impacts that objects perform in their environment." [25]

In order to compare heating energy costs incurred by an average surface and an underground housing building, a case study for the building of 135m^2 was made. This study confirmed that underground housing architecture can result in the reduction of 72% of energy consumption in comparison with a standard surface house.

Tabla 2. Odnos potrošnje energije nadzemnih u odnosu na podzemne objekte
Table 2. Ratio of energy consumption, standard surface house in comparison with underground structures

merna jedinica *measurement unit*	**nadzemni stambeni objekti** ***above ground residential buildings***	**podzemni stabeni objekti** ***earth sheltered residential buildings***
zima / ***winter*** **:**		
gas / *gas*	2,656.9 m^3 ($65.80)	871.5 m^3 ($27.60)
nafta / *oil*	710 ($129.90)	233 ($42.60)
elektricna energija / electricity	23,157 ($428.80)	7,596 ($191.10)
leto / ***summer*****:**		
elektr. ener. / *electricity*	3,962 ($98.40)	0

Posmatrajući ove podatke, može se zaključiti da je potrošnja energije podzemnog objekta u letnjem periodu za trećinu niža od one za nadzemnu zgradu, dok je potrošnja energije tokom leta nula, što znači veoma mnogo u smislu zaštite životne sredine, jer su uticaji znatno smanjeni. [26] U slučajevima kada su korišćene druge vrste energije za grejanje, kao što su gas ili ulje, može se primetiti da su korišteni tri do četiri puta manje, tako da se ukupna količina energije tokom zime može smatrati finansijskom uštedom, ali predstavlja i ekološki prihvatljiv metod, u pogledu ukupnog uticaja na životnu sredinu. Mogućnost formiranja veštačkih zelenih krovova primenjiva je za obe tipološke grupe stambenih zgrada, tako da se kontekst ekološki prihvatljivog oblika zgrade može pozitivno posmatrati i na ovaj način, uzimajući u obzir činjenicu da zelena krovna struktura utiče na povećanje površine ispod vegetacije ili zadržavanje postojeće vegetacije u građevinskoj zoni.

By observing these data, it can be concluded that the energy consumption in the summer period is for third lower than that of a surface housing building, while the energy consumption in the summer is zero, which means a lot in environmental terms, as impacts are considerably reduced. [26] In cases where other kinds of heating energy were used, such as gas or oil, it can be noticed that they were used 3 to 4 times less, so the total amount of energy during winter can be considered financial saving but also the environmentally acceptable method, regarding the total environmental impact. The potential for formation of artificial green roofs is a possibility of both typological groups of housing buildings, so the context of environmentally acceptable form of buildings can be positively observed separately, taking into account the fact that he green roof structure affects the increase of area under vegetation or retention of the existing vegetation in the construction zone.

5 ZAVRŠNE NAPOMENE

Podzemna arhitektura stanovanja predstavlja energetski efikasnu vrstu objekata. Ovaj specifičan tip stambene izgradnje preporučuje se umesto standardnih nadzemnih zgrada zbog svojih energetski efikasnih svojstava i kvaliteta.

Svi tipološki oblici arhitekture podzemne stambene kuće do sada su bili uglavnom pojedinačni, eksperimentalni napori. Nisu postojali, takođe, ni propisi za efikasan nadzor nad izgradnjom ovih objekata. Za srpsku teoriju i praksu međunarodno iskustvo je od ključnog značaja za dalji razvoj i usklađivanje s proce-

5 CONCLUDING REMARKS

Underground housing architecture represents an energy efficient type of structures. This specific type of housing construction is recommended for the standard surface buildings because of its more energy efficient properties and its quality.

All the typological forms of underground housing architecture up to date were mostly individual, experimental endeavors. Construction had no regulations for efficient monitoring of construction of these structures. For Serbian theory and practice international experience is crucial for further durama prilikom projektovanja i izgradnje podzemnih stambenih objekata, iz sledećih razloga:

- u većini proučenih primera, podzemni pristup izgradnji ukazao je na značajne uštede koje su ostvarili takvi građevinski modeli;
- kombinovanje zelenih krovova sa strukturama nasutog elevacionog tipa najčešći je građevinski model u Srbiji;
- izgradnja ovih objekata umnogome je izražena u Vojvodini koja već ima tradiciju stvaranja takvog tipa zgrada;
- prosečne temperature u podzemnim stambenim zgradama kreću se od 16 do 20 stepeni Celzijusove skale;
- zeleni krovovi, sa srednjim zahtevima, poluintenzivni, procenjuju se kao tip koji može obezbediti dobre efekte tokom celog leta [27] [28], tako da se ovaj tip zelenog krova može smatrati adekvatnim za objekte nasutog elevacionog tipa;
- maksimalne uštede ostvaruju se sa zelenim slojem krovnog vrta, pri čemu je sloj tla debeo od 100 do 900 mm; - optimalna vrsta krovnog vrta ima bujnu vegetaciju - sloj tla debljine od 300 mm sa grmovima iznad može uštedeti do 15% godišnje potrošnje energije, odnosno 79% uštede energije za hlađenje zgrade;
- krovne bašte smanjuju toplotni tok za 52–57% u odnosu na keramičke ili metalne krovove; [29] [30]

− za potrebe održavanja konstantne temperature tokom zimskog perioda neophodno je projektovati i alternativne hibridne sisteme za snabdevanje objekata potrebnom količinom energije i to u kombinaciji vetrogeneratora i solarnih kolektora.

Prednosti izgradnje podzemne stambene arhitekture jesu smanjenje efekata toplotnih ostrva i ušteda energije u zgradama, jer podzemni stambeni objekti smanjuju godišnju potrebu za grejanjem i hlađenjem. [31] S druge strane, s obzirom na činjenicu da je sunčevo zračenje daleko većeg intenziteta leti, podzemni stambeni objekti igraju važnu ulogu u redukovanju energetske potrošnje za hlađenje u odnosu na standardne nadzemne termički izolovane objekte.[32]

Na osnovu opisanih istraživanja, mogu se formulisati preporuke za projektovanje objekata nasutog elevacionog tipa. Ovu preporuku treba povezati s pravilnim izborom korišćenih materijala i tehnikama gradnje, čime se generišu rezultati koji se primenjuju prilikom procene izbora novih dizajnerskih kreacija, kojima se obogaćuje tipologija podzemnih stambenih objekata.

Prikazana istraživanja nesumnjivo dokazuju da podzemni stambeni objekti predstavljaju adekvatan i veoma kvalitetan model stanovanja, koji se dobro prilagođava i može se primenjivati na teritoriji cele Republike Srbije.

Zahvalnost: U članku je predstavljen deo istraživanja koja se obavljaju u okviru projekta TR36042, a koji finansira Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije.

development and harmonization with procedures during designing and construction of underground housing structures for the following reasons:

- In almost all presented examples, the underground construction approach indicated considerable savings accomplished by such construction models;
- Combining of green roofs with the bermed elevation structures is the most common construction model in Serbia;
- Construction of these structures is to a great extent present in Vojvodina, which already has a tradition of construction of such buildings;
- Average temperatures in underground housing buildings range between 16 -20 degrees Celsius;
- Green roofs, with medium requirements, semi-intensive, are assessed as the type which can provide good effects during the entire summer [27] [28] so this type of the green roof can be observed as an adequate for bermed underground housing;.
- Maximum savings are accomplished with a green layer of the roof garden, where the soil layer is from 100 to 900 mm thick; - the optimal type of roof garden has bush vegetations – 300 mm thick layer of soil with shrubbery can save up to 15% of yearly energy consumption, that is, 79% saving of building cooling energy;
- Roof gardens reduce the heat flux for 52–57% in comparison to ceramic or metal roofs. [29] [30]

In order to maintain constant temperature during winter period, it is necessary to design alternative hybrid systems for supplying structures with the necessary amount of energy, as a combination of wind power generators and solar panels;

The advantages of implementation of underground housing architecture are the reduction of heat islands effects and saving energy in buildings (underground housing buildings reduce yearly heating and cooling energy demands), [31]. On the other hand, regarding the fact that solar radiation has considerably higher intensity in the summer, underground housing buildings play an important role in the reduction of the cooling energy consumption in comparison to the standard surface thermally insulated buildings. [32]

On the basis of the described research, the recommendations for the design of the bermed elevation type buildings can be formulated. This recommendation should be related to the proper choice of the used materials and construction techniques, which generate the results which are implemented on the assessment of new designs which enrich typology of underground housing structures.

The conducted research prove that underground housing structures represent an adequate and very good quality housing model which is very adaptable and can be implemented across the entire territory of the Republic of Serbia.

Acknowledgment: The article is part of the project TR36042 financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

6 LITERATURA REFERENCES

[1] Roy, R.L. The Complete Book of Underground Houses, How to Build a Low-cost Home, Sterling Publishing Company, 1994;

[2] Wells, M. The Earth-Sheltered House: An Architect's Sketchbook, Chelsea Green Publishing, 2009;

[3] Steele; J. The Greenwood Encyclopaedia of Homes through World History, Greenwood Press, 2009;

[4] Miloradović, N. Termički aspekti gradnje kuća, istorijat i perspektive, Beograd, Građevinska knjiga, 2009;

[5] Fardo, S.W., Patrick, D.R, Richardson, R.E., Fardo, B.W. Energy Conservation Guide Book, Third Edition, Lulu com, 2015;

[6] Čokić, M. et al. "Analysis of the Embeded Energy and the CO_2 Emission in Construction Process of a Bridge Structure from the Aspect of Sustainability", Building Materials and Structures, Vol.58/2015, No. 2, pp. 3–20;

[7] Wendt, R. L. "Energy division earth-sheltered housing, an evaluation of energy – conservation potential", Oak Ridge National Laboratory, (Tennessee), Union Carbide Corporation (Nuclear Division) for the Department of energy, 1982. pp. 1–49;

[8] Staniec, M, Nowak, H. "Analysis of the energy performance of earth – sheltered houses with southern elevation exposed", Proceedings of 11th International IBPSA Conference Glasgow, Scotland, July 27-30, 2009. Pp. 1907–1913;

[9] Anselm, A.J. Earth Shelters; A Review of Energy Conservation Properties in Earth Sheltered Housing, INTECH.OPEN, 2012, pp. 125-148. http://dx.doi.org/10.5772/51873 (accesed May 2017);

[10] Eoyer, L. L. and Grondzik, W.T. Habitability and Energy Performance of Earth- Sheltered Dwelliwgs, Oklahoma State University, 1980;

[11] Energy Law, Official Gazette of the RS, No. 145/2014;

[12] REPUBLIC OF SERBIA Ministry of Energy, Development and Environmental Protection NATIONAL RENEWABLE ENERGY ACTION PLAN OF THE REPUBLIC OF SERBIA (In accordance with the template foreseen in the Directive 2008/29/EC- Decision 2009/548/EC) Belgrade, 2013;

[13] Sekulić, M., Kurtović Folić, N. „Krovni vrt kao fasadni omotač", Zbornik radova Konferencije „Fasade i krovovi u zgradarstvu – savremeni i tradicionalni materijali i sistemi u funkciji energetske efikasnosti, trajnosti i estetike", 25. oktobar 2013, Društvo za ispitivanje, istraživanje materijala i konstrukcija Srbije, Institut IMS, Inženjerska komora Srbije, Beograd, 2013, 143–157;

[14] Earth Sheltered Design: Guidelines, Examples, and References Paperback, Undergound Space Center, Minessota, 1979;

[15] http://hubpages.com/living/The-Pitfalls-of-an-Underground-House (accessed April 2015);

[16] Scott, R.G. *How to Built Yours Own Underground Home, Tab Books, 1979;*

[17] Tundrea, H. et Al. *"Environmental Impact Assessment and Thermal Performances of Modern Earth Sheltered Houses", Environmental Engineering and Management Journal, Vol.19.No 9. 2014, pp.2363–2369;*

[18] [Mermarian, G.H., Brown, F. "The Shared Charecteristics of Iranian and Arabian Coutyard Houses", in *Courtyard Housing Past, Present and Future*, (Edwards, B, Ed), Ney York, Taylor&Francis, 2006. Pp.21–30;

[19] Roy, R. *Earth*-Sheltered *Houses: How to Build an Affordable house*, Earth-Sheltered *Houses*, Mother Earth News Wiser Living Series (Book 4), Vancouver, New Society Publishers, 2006;

[20] http://www.intechopen.com/books/energy-conservation/earth-shelters-a-review-of-energy-conservation-properties-in-earth-sheltered-housing (accessed June 2015);

[21] Hénard, Eugène; Cohen, Jean-Louis. *Etudes sur les transformations de Paris, et autres écrits sur l'urbanisme*, reprint in Collection "Formes urbaines", L'Equerre, 1982

[22] Le Gates, R.T, and Stout, F. (Eds.). The City Reader, Urban Reader Series, 5th edition, London, Routledge, 2011;

[23] Topličić-Čurćić, G et al. "Environmental Importance, Composition and Properties of Pervious Concrete", Building Materials and Structures, Vol 59/2016, No 2, pp.13–27;

[24] Braiterman J. "City Branding through New Green Spaces". In: Dinnie K. (eds) City Branding. London, Palgrave Macmillan, 2011;

[25] Knox, N**.** *Green building and climate change*, The *U.S. Green Building Council* (*USGBC*), published 4 Mart 2015, http://www.usgbc.org/articles/green-building-and-climate-change (accessed June 2015);

[26] Kumar R, Sachdevab S, Kaushik S.C, (2007) "Dynamic earth-contact building: A sustainable low-energy technology", Building and Environment V.42, n6: 2450–2460, June 2007;

[27] Theodosiou,T.G. "Summer Period Analysis of the Performance of a Planted Roofs as a Possitive Cooling Technique", Energy and Building, Vol.35, Issue 35, October 2003, pp. 909–917;

[28] Yamada, M. and Heaton, T. "Real-time Estimation of Fault Rupture Extent using Envelopes of Acceleration". Bulletin of the Seismological Society of America, No.98-2, pp. 607-619;

[29] Wong, N.H et Al. "Investigation of Thermal Benefits of Rooftop Garden in the Tropical Environment", Building and Environment, Vol.38, Issues 2, Februar 2003, pp.261–270;

[30] Zinzi, M, Agnoli, S. "Cool and Green Roofs. An Energy and Comfort Comparison Between Passive Cooling and Mitigation Urban Heat Island Tehnique for Residential Building in the Mediterrenean Region, Energy and Building, Vol.55, December 2012, pp.66–76.

[31] Liu, K, Baskoran, B. "Thermal Performance of Green Roofs through Field Evaluation", Proceedings for the Firsth North American Green Roof Infrastructures Conference, Awards and Trade Show, Chicago, May 29-30, 2003, National Research Council Canada, pp. 1–10.

REZIME

PODZEMNE STAMBENE ZGRADE U KONTEKSTU ENERGETSKI EFIKASNIH GRAĐEVINA

Aleksandar RUDNIK MILANOVIĆ
Nađa KURTOVIĆ FOLIĆ

Podzemna stambena arhitektura predstavlja energetski efikasnu vrstu struktura. Ova specifična vrsta stambene izgradnje preporučuje se više od standardnih nadzemnih zgrada zbog svojih energetski efikasnih svojstava i kvaliteta.

Svi tipološki oblici arhitekture podzemnih stambenih zgrada do sada su uglavnom bili pojedinačni, eksperimentalni napori. Izgradnja podzemnih stambenih objekata uglavnom nema propise za efikasan nadzor nad izgradnjom ovih specifičnih tipova objekata. Za srpsku teoriju i praksu, međunarodno iskustvo, prikazano i obrazlagano u članku, presudno je za dalji razvoj i usklađivanje s procedurama prilikom projektovanja i izgradnje podzemnih stambenih objekata u nas.

Kada se međunarodno iskustvo posmatra u svetlu kvalitativnih inicijalnih razloga za promenu čitavog skupa dokumenata vezanih za planiranje i područja izgradnje, može se očekivati promocija široko prisutne podzemne stambene arhitekture, s jednim od primarnih ciljeva sadašnjeg vremena, koji se odnosi na planiranje i izgradnju pojedinačnih zgrada, ali i čitavih naselja, u kojima se ova specifična tipologija stambenog prostora može realizovati radi stvaranja budućih energetski efikasnih naselja u Republici Srbiji.

Ključne reči: podzemno stanovanje, energetski efikasni objekti, uticaj biodiversiteta, osnovni uticaji na podzemne objekte, smanjenje negativnih uticaja okruženja.

SUMMARY

EARTH-SHELTERED HOUSING BUILDINGS IN THE ENERGY EFFICIENT STRUCTURES CONTEXT

Aleksandar RUDNIK MILANOVIC
Nadja KURTOVIC FOLIC

Underground housing architecture represents an energy efficient type of structures. This specific type of housing construction is recommended for the standard surface buildings because of its more energy efficient properties and its quality.

All the typological forms of underground housing architecture up to date were mostly individual, experimental endeavors. Construction had no regulations for efficient monitoring of construction of these structures. For Serbian theory and practice international experience reviewed in the article is crucial for further development and harmonization with procedures during designing and construction of underground housing structures.

When the international experience is viewed in the light of qualitative initial reasons for the change of an entire set of documents related to planning and construction areas, one can expect promotion of a more widely present underground housing architecture, with one of the primary goals of the present times, which is planning and construction of individual buildings, but also of entire settlements, where this housing typology can be implemented with an aim of creation of future energy efficient settlements in the Republic of Serbia.

Key words: earth-sheltered housing, energy efficient structures, impact of biodiversity, basic impacts on earth-sheltered structures, reduction of negative environmental impacts.