

TECHNOLOGY, CREATIVITY, IMPLEMENTATION

USE OF PROTECTIVE STRUCTURES OF CIVIL PROTECTION IN URBAN DEVELOPMENT

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Summary

The presence of protective structures in the immediate vicinity of residential buildings where people live provides an additional opportunity for the civilian population to hide during rocket attacks. In this regard, it is very important to design storage facilities in such a way that the evacuation time of the population does not exceed four minutes. The purpose of this article is the analysis of world examples of the construction of protective structures and the implementation of this experience in the construction of new residential buildings in Ukraine. The article provides a general description of protective structures according to Ukrainian regulatory documents. The main requirements for the location of protective structures in the urban development are presented. The advantages and disadvantages of the presence of protective structures in the countries of the world are determined. Recommendations are provided for the construction of houses with the location of protective rooms in residential buildings. The principle scheme of a high-rise building resistant to destruction and the creation of a protected space in it is proposed. A SWOT analysis of the location of protective premises in residential buildings is presented.

Key words: protective structures, protective rooms, protected space, shelter, civil protection.

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1. Introduction

On July 29, 2022, the Verkhovna Rada of Ukraine adopted draft law No. 7398 (*Zakon Ukrainy, Document 2486-IX, 2022*) amending the Civil Protection Code of Ukraine. According to this law, design and construction documentation must necessarily contain a section on engineering and technical measures of civil protection. This law may provide for the construction of protective structures of civil protection or dual-purpose structures, as well as project decisions regarding the consideration of fire and man-made safety requirements, for:

– construction objects, which according to the class of consequences (responsibility) belong to objects with medium (CC2) and significant (CC3) consequences, where more than 50 individuals will be permanently present or more than 100 individuals will periodically be present;

– other construction objects according to the list determined by the Cabinet of Ministers of Ukraine.

The draft law also emphasizes that project decisions of the civil protection engineering and technical measures section must ensure compliance with accessibility requirements for persons with limited physical capabilities.

The largest cities of Ukraine that are in close proximity (from 22 to 75 km) to the Russian Federation include: Kyiv, Chernihiv, Sumy, Kharkiv. According to the analytical portal “Word and Deed” (www.slovoidilo.ua, 2022), as of the beginning of 2023, there are 514 shelters in Kyiv, including those that are not ready and partially ready for operation. There are also 4,400 dual purpose buildings in Kyiv. These are basements, underground car parks, underground passages, subway, etc. In the city of Chernihiv there are 61 bomb shelters and anti-radiation shelters, in Kharkiv – 300 units, of which 6 are anti-radiation and 4.6 thousand dual-purpose structures, in Sumy – 120 shelters, of which 19 are anti-radiation (see Fig. 1).

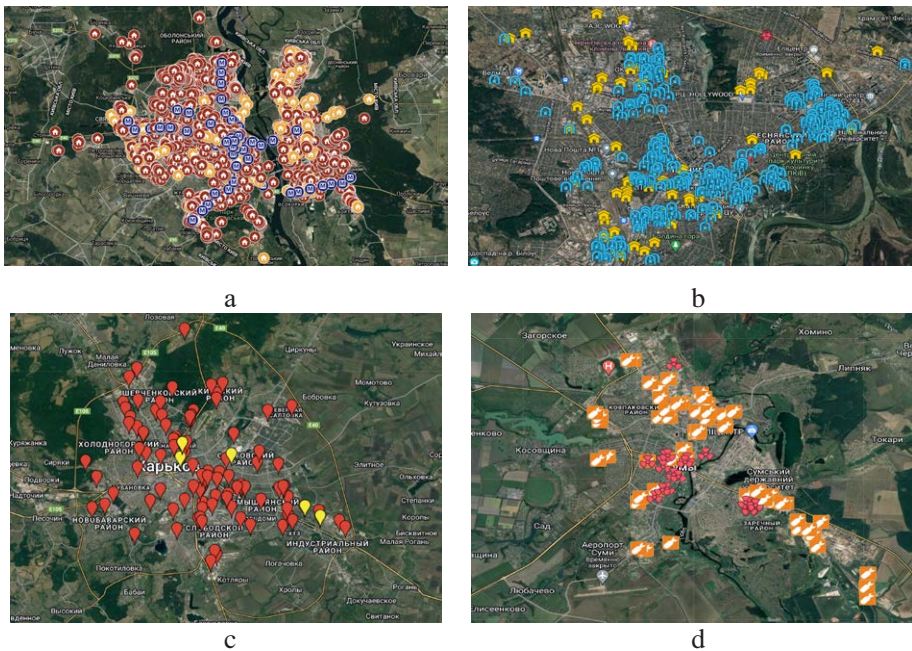












Fig. 1. Map of protective structures: a – Kyiv, b – Chernihiv, c – Kharkiv, d – Sumy

- Legend:
-   Repositories
 -   Dual purpose storage
 -   Metro stations and anti-radiation refuge
 -   Basement premises
 -   Anti-radiation repositories

Considering the total number of residents, the population of Kyiv is 2.966 million people (as of December 1, 2019). One shelter accommodates 5,770 people. Chernihiv has a population of 282,700. (as of 01/01/2022) there are 4,634 people per shelter. Kharkiv has a population of 1.421 million people. (as of January 1, 2022) there are 4,736 people per shelter. Sumy has a population of 256,500 people. (as of January 1, 2022) there are 2,137 people per shelter. These data indicate that the total number of shelters is not able to provide all residents of the most vulnerable cities.

2. Theoretical background

Many scientists and specialists abroad and in Ukraine consider the problem of using protective structures of civil defense in urban development in their works. Different approaches to solving this problem, the expediency of using urban underground infrastructure, the underground construction of residential premises, the integration of above-ground and underground spaces were considered by Rudina Breçani, Loretta von der Tann, Lulzim B. (*Breçani R. et al., 2019; Tann L. et al., 2020; Beqiri L. et al., 2017*). But today, in Ukraine, which is in a state of war, and not on its sovereign territory, active hostilities continue, the result of which is the destruction of urban infrastructure and buildings, the most relevant are the research (*Besner J., 2017; Admiral H. et al., 2020; Admiral H. et al., 2016; Saqaff, A., et al., 2016*) related to the issue of the presence of protective spaces in the immediate vicinity of residential buildings where people live.

In his research (*www.trendhunter.com, 2013*), Tana Makmanee emphasizes the relevance and advantages of using underground territories, provides examples of objects of various purposes organized in underground spaces, from underground exhibition galleries, underground bunkers with tunnels to underground tropical gardens. In his work (*Yixuan W. et al., 2020*), Yixuan Wei analyzes the issue of designing shelter facilities when the country faces problems related to natural phenomena (earthquakes or floods). At the same time, instructions are provided for future construction based on the experience and knowledge of other countries.

3. Purpose of the research

Analysis of world examples of the construction of protective structures and implementation of this experience in the construction of new residential buildings in Ukraine.

4. Analysis and discussion

According to the Civil Protection Code of Ukraine (document 5403-VI, revision dated 10/29/2022) (*Kodeks tsyvilnoho zakhystu Ukrainy, Dokument 5403-VI, 2022*) there are several types of shelters. The main ones include: shelters, anti-radiation shelters, dual purpose structures and the simplest shelter. Let's define the main structural features of these structures and the conditions of their use.

A storage facility is a hermetic structure for the protection of people, in which conditions are created for a certain time, which exclude the influence of dangerous factors arising as a result of an emergency situation, military (combat) actions and terrorist acts.

Anti-radiation shelter – a non-hermetic structure for the protection of people, in which conditions are created that exclude the impact of ionizing radiation on them in the event of radioactive contamination of the area and the action of conventional means of destruction.

Dual purpose buildings – above ground or underground buildings/structures or their individual parts, which are designed or adapted to be used for the main functional purpose, including for the protection of the population, and in which conditions are created for the temporary stay of people.

The simplest shelter is a fortification structure, which reduces the combined damage to people from the dangerous consequences of emergency situations, as well as from the action of means of destruction in a special period.

On July 18, 2022, the restricted access culture was removed from DBN V.2.2-5-97 "Protective structures of civil protection" (DBN V.2.2-5-97, 1997). Now you can familiarize yourself with this document up to the last change No 4 in 2019 namely:

1. Protective structures of civil protection are intended for protection in peacetime of personnel who are hiding from the consequences of accidents, disasters and natural disasters. In wartime – from modern weapons of mass destruction. During peacetime, protective structures are used for economic purposes.

2. The storage should be placed in the places of the greatest concentration of personnel who are in the room and within reach and, if possible, should be placed: built-in – under low-rise buildings from those being built on this site; separately located – at a distance from buildings and structures equal to their height.

3. The level of the shelters floor should be no less than 1.5 m from the planning mark of the land. It is not allowed to lay the transit lines of utility networks through the shelters. Engineering networks that pass over shelters must be laid in special collectors (concrete or reinforced concrete channels).

4. Protective structures should be located close to the location of the majority of the population that needs to hide.

5. There should be no large tanks with highly poisonous substances near the protective structure.

6. It is forbidden to place shelters:

- under production and warehouse premises;
- in premises with engineering networks;
- on slopes subject to landslides or other geological processes;
- closer than 30 m from warehouses with combustible materials.

After the Second World War, every country in one way or another thought about how to organize the protection of the civilian population as a result of the start of a possible war in the future. Some countries after 1945 did not have hostilities on their territory and this allowed them to almost completely abandon protective structures. And some countries were in a very tense region and had a constant threat to the lives of the civilian population. These threats forced them to build an active network of defensive structures in many cities. Next, it is suggested to get acquainted with the most common options for the construction of protective systems in the world.

Israeli experience. After the first war in the Persian Gulf in the early 1990s, the government made the decision to build home bomb shelters mandatory for new construction of residential buildings. In that war, Israel was hit by long-range rockets fired from Iraq. Rockets mainly reached the center of the country. It became necessary to strengthen and improve the defense of the Israeli rear. A home bomb shelter in Israel is one of the premises of an apartment

with reinforced walls and additional impact-resistant windows and doors. They are designed to prevent the penetration of shock waves and debris, as well as to seal the room (*Shapiro M. et al., 2017; Shir-Vertesh et al., D. 2015; Armstrong M. 2018*).

There are several types of shelter in Israel: MAMAD (MMD) is a protected space in an apartment; MAMAK (MMK) is a protected room on the first floor; MAMAM (MMM) is a protective space in institutions and public buildings.

Basic requirements for the construction of protective structures:

- the MMD area should be more than 9 m² (the floor area without walls). The height of the ceiling should be 2.5–2.8 m, and the width of the room should be at least 1.6 m;
- the rate of stay of people in MMD premises – 1.25 m² per person. The minimum is 4 m² per person for a small room (up to 100 m²) or 5 m² per person for large rooms (over 100 m²);
- MMD must have two ventilation holes, one of which must be located in the outer wall at a height of 1.5 m from the floor;
- the building must be built as a whole, without columns and beams.

Concrete must be additionally reinforced. Walls shall be at least 250 mm thick on external walls and at least 200 mm thick on internal walls, excluding walls where a window is installed. The number of external walls should not exceed 2 units;

- MMD must have an armored hermetic door that can withstand the blast wave.

Swiss experience. Switzerland is a unique country because it has enough nuclear storage facilities for the entire population. Owners of multi-apartment buildings are obliged to build and equip protective rooms in all new dwellings in accordance with Articles 45 and 46 of the Swiss Federal Law on Civil Defense (*Silvia B. 2017; Silvia B. 2017*). Because of this, most buildings built after the 1960s have nuclear-proof rooms.

A protective structure in Switzerland is mandatory in every capital building in cities where more than 1,000 people live. Every 5 years, bomb shelters are checked for operational efficiency.

In 2006, there were 300,000 protective structures in Swiss homes, institutions and hospitals, which can provide protection for 8.6 million people, which is 114% of the country's total population.

American experience. The USA is the main country participating in the Cold War, which could face nuclear attacks first in the world. Since the end of the Second World War, the Americans have been engaged in the construction of protective structures and bomb shelters, which exclusively save from nuclear threats (*Bishop T. 2019; Dillon M. et al., 2022; Taylor A. 2021*). Exact data on quantity and quality are not available. There is no accurate data on the number and quality of protective structures.

The Pentagon quickly decided that conventional bomb shelters would not be enough to protect against a nuclear attack. In addition, shelters were needed for large masses of the population from million megacities. RAND research center analyst Herman Kahn, who worked for the government, proposed creating an independent network of hostels and communications under the 50 largest US cities, and each shelter would provide life for millions of people. This is how the system of protective structures appeared, which provides protection for millions of people.

German experience. During the Second World War, thousands of well-fortified bunkers were built on the territory of the Reich to protect the population. About 500 such structures have survived in West Germany. During the Cold War, they were strengthened and kept in working condition until the late 1980s. In 2007, the German authorities, believing that there were no more threats, decided not to keep the bomb shelters, to exclude them from the civil defense system and to allow any use of the buildings. Savings amounted to about 2 million euros per

year. Most often protective structures in Germany – these are well-fortified protective structures designed to protect the population, which are not hidden underground, but those that rise above it (Kristina H. et al., 2009).

Each of these options for building protective systems has its own disadvantages and advantages, which are shown in Table 1.

Table 1

**Advantages and disadvantages of the construction of protective structures
in the countries of the world**

Israel	Switzerland	USA	Germany
Advantages			
A large number of protective structures in the country	A large number of protective structures in the country for various purposes	A large number of protective structures in the country for various purposes	Little use of funds for the maintenance of all protective structures
Different types of protective structures	Protective structures can accommodate 114% of the country's population	A large number of protective structures for the leadership of the country	Great benefit from the renovation of protective structures in peacetime
Informing the population about the location of protective structures	Most of the protective structures have the status of nuclear	Informing the population about the location of protective structures	
Availability of protective structures at public transport stops	Very strict control over the maintenance of protective structures in proper condition	Lack of information on the state and number of protective structures in the country	
Re-equipment of premises in houses for protective rooms		Well-equipped protective structures	
Disadvantages			
Large costs for the construction of protective structures	Large costs for the construction of protective structures	Large costs for the construction of protective structures	A small number of protective structures in the country
Sometimes not the presentation view of buildings with protective structures	High costs for the maintenance of protective structures	High costs for the maintenance of protective structures	The total number of protective structures is not calculated for the entire population
		Construction of individual protective structures on own plots of land	Openness regarding the condition and number of protective structures
			Obsolete equipment

After the war, about 2.34 million houses were destroyed in West Germany and West Berlin, which was about 22% of the housing stock in 1939. The need for the created housing space was estimated at approximately 5 million apartments, and since the beginning of the 1950s at 6.5 million apartments.

In 1947, the European reconstruction program was adopted, the so-called “Marshall Plan” (Tarnoff C. 2018). In 1949, the first unified and centralized program of housing construction in West Germany after the war was adopted. The main feature of this program was the construction of social housing in Germany. This is the construction of housing subsidized by the state, especially for social groups that cannot meet their housing needs in the housing market. In addition to personal requirements, tenants in Germany must provide proof of the right to housing. There is a maximum allowable rent that is regulated by the Compulsory Housing Act in Germany.

Almost the same situation as in Germany developed in Ukraine in the territories where military operations took place. On December 15, 2022, the analytical team of the Kyiv School of Economics (KSE) published an updated assessment of the documented damage to the housing infrastructure of Ukraine (<https://kse.ua>, 2022). The number of destroyed and damaged private and apartment buildings as of December 1, 2022 is 143,800. Of them, 126,700 are private (individual) houses, 16,800 are apartment buildings; almost 0,3 thousand – dormitories. Now all these houses need to be reconstructed, and the built-up area is subject to ecological rehabilitation and social revitalization (Hayko Y. 2021; Hayko Y. 2018).

Analyzing the mass rocket attacks on the country's cities during the first year of the war, we can say with confidence that 2–4 minutes pass from the beginning of the notification of the population about the missile threat to the beginning of shelling of the city. This time is extremely insufficient to hide in a protective structure located even close to a residential building. Therefore, after analyzing the world experience in the construction of protective structures and implementing the resolution of the draft law on the availability of mandatory engineering and technical measures of civil protection during new construction, it is proposed to start the construction of buildings with built-in protective rooms. In addition, residential apartments in such buildings must have the status of social housing as is common in Germany. They should be received first of all by the residents of destroyed buildings as compensation or as rent among the less protected sections of the population.

It is proposed to introduce a schematic diagram of a high-rise building resistant to destruction and to create a protected space in it. The main structural axis of the building should be a strong monolithic trunk, where stairwells, elevator shafts, engineering communications and an elevator hall should be located. This part of the building will be located in the so-called first protective zone. It is also proposed to place armored rooms for common use in this zone. This part of the building should be protected as much as possible from destruction using monolithic reinforced concrete walls with reinforced reinforcement. The first protective zone must be designed for a missile strike. Maximum protection of evacuation routes will allow residents to leave the building without problems in the event of its destruction.

The second protective zone should include common corridors on the floor, bathrooms in the apartments and armored rooms in the apartments for safe stay during the shelling. This part of the building should also be protected by monolithic reinforced concrete walls. Armored rooms must be equipped with built-in security windows and armored doors. These rooms can be located both outside the apartment and as one of the living rooms of the apartment.

The largest area of apartments will be located in the unprotected outer circle – the third protective zone. The main premises of the apartment are located here: living room, nursery, office, dining room, bedroom, etc. Damage to this part of the house will not lead to its destruction. An example of the location of a protected space in a multi-storey residential building is shown in Figure 2.

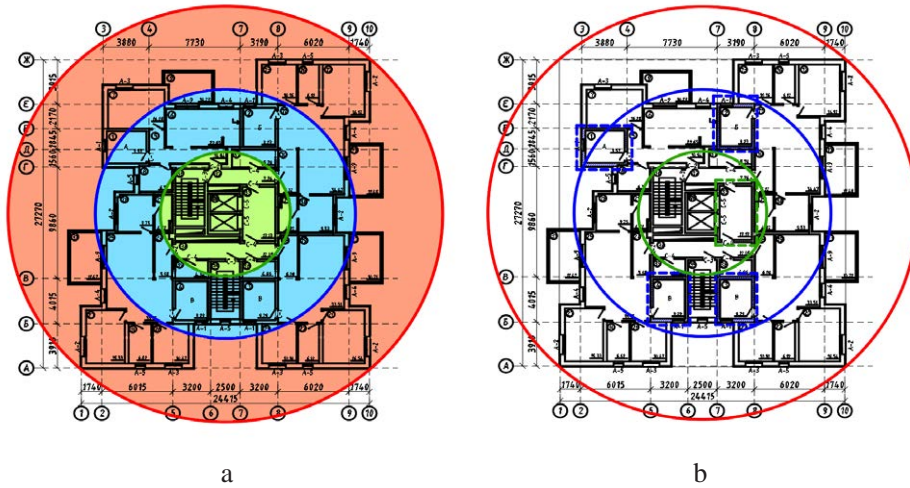


Fig. 2. An example of creating a protected space in a multi-storey building residential building: a – zones, b – location of armored rooms

- Legend:
- The first protective zone
 - The second protective zone
 - The third protective zone
 - Booked rooms in the apartment
 - Booked rooms on the floor

It is this scheme of the location of protective zones in the building that will allow residents to hide in protective rooms in 2–4 minutes and wait out the rocket attack. And the mandatory construction of protective premises in new buildings will allow to avoid a large number of victims among the civilian population during rocket attacks in the future.

This variant of the location of protective premises in a residential building has its strengths and weaknesses, opportunities and threats. All these components are given in the SWOT analysis of the location of protective rooms in residential buildings (Table 2).

Table 2

SWOT analysis is location of protective rooms in residential buildings

Strengths	Weak sides
Adoption of a new law on the mandatory availability of engineering and technical measures of civil protection during new construction	The regulatory framework regarding the location of protective structures in urban buildings is outdated
Removing the vulture of limited access to DBN B.2.2-5-97 “Protective structures of civil protection”	Lack of a clear classification of protective structures in DBN B.2.2-5-97 “Protective structures of civil protection”

Table 1 (continuance)

A large number of protective structures in cities of various purposes	A large number of non-specific protective structures in cities
Protection of residents of homes from sudden threats	Small norm of the area of the premises per person of protective structures
	A large number of specially equipped premises that must be located in protective structures
	Additional cost for the construction of protective structures
Opportunities	Threats
Location of protective rooms inside residential buildings	It is not possible to quickly build protective structures due to the outdated regulatory framework
Evacuate the population to protective rooms in 2–4 minutes	Increase in the cost of construction of houses
Provide a protected space for a large number of people	

5. Conclusions

Air defense of Ukraine significantly reduced the number of dead and injured and somewhat reduced direct material damage, but this is not enough to completely eliminate human casualties among the civilian population. In addition, the cost of creating a closed airspace from enemy missiles, such as the Israeli "Iron Dome", requires significant financial investments, which a country in a state of war is not enough.

The article analyzes world examples of the construction of protective structures, but their effectiveness differs significantly depending on possible threats. The experience of countries that have been in the stage of military conflict for many years obliges them to build both bomb shelters and protected spaces in every residential building throughout the country. The creation of a protected space in residential buildings will allow the residents of these buildings to live in safety and to hide within 2–4 minutes in the event of shelling of the city.

Analyzing the experience of countries with rich experience in the construction of protective structures, a principle scheme of a multi-storey building resistant to destruction and the creation of a protected space in it is proposed. The building structures of such a building must be designed in such a way as to withstand the impact of missiles. Escape routes, stairs and elevator shafts must be reliably protected from damage and destruction. When developing the basic scheme of a high-rise building resistant to destruction, the arrangement of protective zones must be provided within the apartment or floor. All protective rooms should be equipped with armored windows and doors, and the walls should have a monolithic reinforced concrete structure with reinforced reinforcement.

It is recommended to start the construction of new buildings with sheltered premises at the expense of the state, with the subsequent renting of apartments among the less protected strata of the population or as compensation for the residents of destroyed buildings.

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