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Exploited Roof as an Additional Functional and Territorial Resource in a Dense Urban Development

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Abstract. Trends in urban population growth and intensification of urban territory use motivate the search for additional territorial resources, especially in the context of dense historical development. The most common way to solve this problem is to use the underground space of cities and exploited roofs. This article considers the exploited roofs as an additional functional and territorial resource. Substantive differences between the terms "territorial reserve", "territorial resource" and "functional and territorial resource" are formulated. A calculation method for determining the potential territorial resource considering the geometric type of roof, its design features, physical wear of the building and the presence of the status of a cultural heritage site is proposed. Experimental verification (on the example of blocks and separate groups of residential buildings of different construction periods in Kyiv) confirmed that attracting the area of exploited roofs can give an additional 9.4…27.6 %% of the assessed areas. Criteria for assessing the feasibility of using the exploited roofs to increase the level of comfort and cost-effectiveness of buildings and structures are proposed.

INTRODUCTION

Population growth in cities, especially in large and the largest ones, is observed both in the world as a whole and in Ukraine in particular. Urbanization causes a constantly growing deficit of territory, which is necessary for the placement of new housing and public buildings, places of employment, urban infrastructure, and services [1]. Intensification of the use of urban areas along with the negative phenomena (increasing anthropogenic load, increasing the level of motorization and complicating transport links, deteriorating environmental conditions of the urban environment) has positive signs – improving the availability of jobs and services, and, consequently, increasing productivity, intensity of social contacts [2].

The practical lack of vacant land, significant limited reserve areas, and high land value make it almost impossible to locate additional modern facilities, especially in the central areas of cities, in the conditions of historical development, and leads to a decline in the quality of the urban environment. Limited available territorial reserves necessitate the intensification of use and development of the territory, its multifunctionalities, increasing the compactness of the city plan [3, 4].

One of the most common areas of attraction of additional territorial resources is the use of underground space in cities or underground urban planning. The traditional use of underground space for the construction of utilities and transport communications, in particular the subway, has undergone significant transformation in recent decades. The construction of powerful shopping, and entertainment complexes in combination with underground transport hubs, which serve up to 100 thousand people daily [5], actually forms a parallel underground city with its own architecture and public space [6]. Recently, the attention of designers is increasingly turning to the roofs of existing buildings as a potential place to put certain objects. Back in the middle of the last century, the famous French architect Le Corbusier said: "... Indeed, it contradicts any logic when the area equal to the whole city is not used and the slate is left to admire the stars! ... » [7].

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The areas under buildings in large cities ranges from 5… 20% in the areas of manor buildings to 15… 30% in areas of mass development, and in historic areas up to 70… 100% of the area of the blocks [8, 9]. The most typical in the absence of free areas is the placement of greenery and landscaping elements on the roofs of buildings. This not only helps to increase the level of living comfort, but also has a positive effect on the ecological condition of the urban environment [10, 11], 12. The involvement of exploited roofs as one of the possible decisions within search for additional territorial resources will help increase the level of comfort of living and efficient use of urban areas. That is why the inclusion of the roofs' area in the total area of free from development areas is a promising way to increase the territorial resources of cities. The purpose of this study was to develop a calculation method for determining potential territorial resources by attracting the area of exploited roofs. This would allow to analyse the quantitative indicators of potential territorial resources to increase the necessary elements of landscaping and landscaping, engineering and transport infrastructure, other functional facilities during the implementation of detailed planning areas, projects for construction and reconstruction of blocks, microdistricts and individual land plots.

MATERIALS AND METHODS

The development of a method for determining potential territorial resources in a dense urban development is based on the use of general and special research methods. The factual basis for verification of the proposed calculation method for determining potential territorial resources through the involvement of exploited roofs are the materials of the actual state of use and development of blocks and microdistricts of Kyiv.

Basic Definitions

Urban area is characterized by the presence or absence of a territorial reserve. However, a distinction should be made between the concepts of “territorial reserve” and “territorial resource”. The study clarifies the terminological difference between these concepts.

- *Territorial reserve* – the presence of an excess of free territory in relation to the normatively required for this type of use territory.

The situation of lack of territorial reserve is typical mainly for the central and middle zone of the city. It is in the conditions of dense urban development that the issue of multifunctional use of the territory and distribution of functions vertically (vertical urban planning) becomes relevant. One of the promising areas for increasing the capacity and efficiency of urban use is the use of exploited roofs as a functional and territorial resource.

- *Territorial resource* – additional areas that can be attracted using underground space or exploited roofs in the absence of excess of normatively required areas.
- *Functional and territorial resource* – additional areas that can be attracted using underground, underwater space, or exploited roofs to accommodate the necessary or additional facilities of a certain functional type, elements of landscaping and greening.

Additional area with a certain functional load, which may be involved due to the use of underground space or operated roofs in the absence of free areas to accommodate the necessary or additional facilities of a certain functional type, elements of landscaping and greening forms a functional-territorial resource of the estimated planning element – block or plot.

Trends of Intensification of Urban Area Development

A retrospective analysis of the main and relative normative indicators shows that with each stage of urban planning development, an intensification of the use and development of territories, an increase in their territorial capacity, takes place.

The analysis of the dynamics of normative indicators regulating the intensity of use and development of territories has been carried out on the basis of building standards and rules on urban planning of different periods (PiN 1929, SN 41-58, SNiP II-K.2-62, SNiP II-60-75, SNiP II-60-75**, SNiP 2.07.01-89, DBN 360-92**, DBN B 2.2-12: 2019 “Planning and development of territories”).

The dynamics of growth of normative indicators of use and development of residential areas (the population density and the density of housing funds) is shown in Figure 1 and Figure 2.

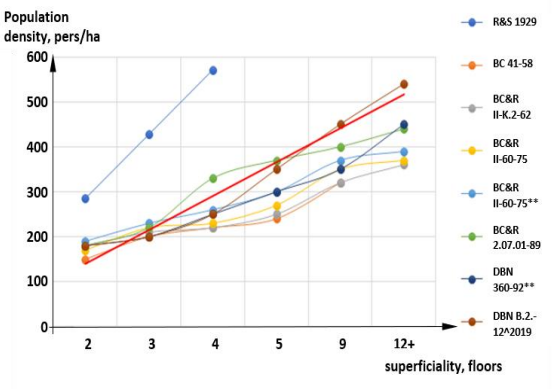

FIGURE 1. The dynamics of standard indicators of population density of microdistricts, persons/ha. *Source* – own research.

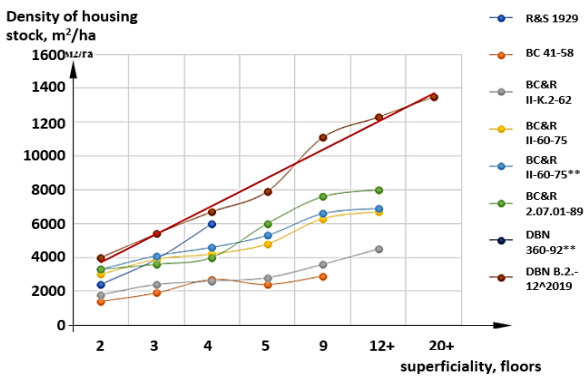

FIGURE 2. The dynamics of standard indicators depending on the density of housing funds stories, m^2/ha. *Source* – own research.

The formation of building areas of the modern city, and in particular the city of Kiev, in different historical periods according to different regulatory requirements has led to a situation of uneven intensity of development of urban areas. This, in turn, led to the unevenness of the existing territorial reserve of existing buildings. The experimental part of the study was based on the analysis of information on the type and intensity of buildings on the example of 51 blocks, microdistricts, groups of buildings (in total – 524 houses) in Kiev. As a cartographic basis, materials of topographic and geodetic surveying of the city of Kyiv M 1: 2000 are used (detailed information can be found in the materials of the author's dissertation research K.Bakun, supervisor – A. Pleshkanovska) [13].

Differentiation of the Exploited Roof

The generalization of theoretical bases and practical foreign and domestic experience of application of the operated roofs allowed to differentiate roofs on geometrical type, on prevailing kinds of functional use, on frequency of visiting of objects which can be placed on the exploited roof.

Differentiation of Roofs by Geometric Type

The variety of roofs of existing buildings in geometric shape can be represented in four groups (see Figure 3):

- *sloping* – single-sloping (flat, slope); multi-slope (double-slope, cross-shaped, broken, tent, trapezoidal, hip, semi-hip);
- *cylindrical* – vaulted, conical, conoidal, toroidal;
- *domed* – dome faceted, petal-shaped or sailing;
- *curvilinear* – tent, double curvature (roofs of shells of positive and negative Gaussian curvature; roofs of hipper components, paraboloid, hyperboloid, and hyperboloid-paraboloid roofs).

Differentiation of Roofs by Types of Functional Use

Summarizing foreign and domestic experience, we can distinguish the following four types of exploited roofs for the main types of functional use, see Figure 4:

- *engineering infrastructure facilities* – "solar" roof (for placement of energy-generating solar panels and hot water sources), "blue" or "blue" roof (for retention and slow release of rainwater, reduction of peak load on storm sewers), roof boilers, mobile antennas;
- *objects of transport infrastructure* – roof-parking (for temporary or permanent storage of motor transport), for the passage of traffic and pedestrian flows;
- *facilities that help increase the energy efficiency of the building* – "cold floor", also known as "white";
- *other functional objects, elements of landscaping and greening* – residential buildings (penthouses), ponds, swimming pools, terraces, cafes, restaurants, exhibition grounds; "Green" roof, for placement of lounge zones, sports, games, economic and other grounds, etc.

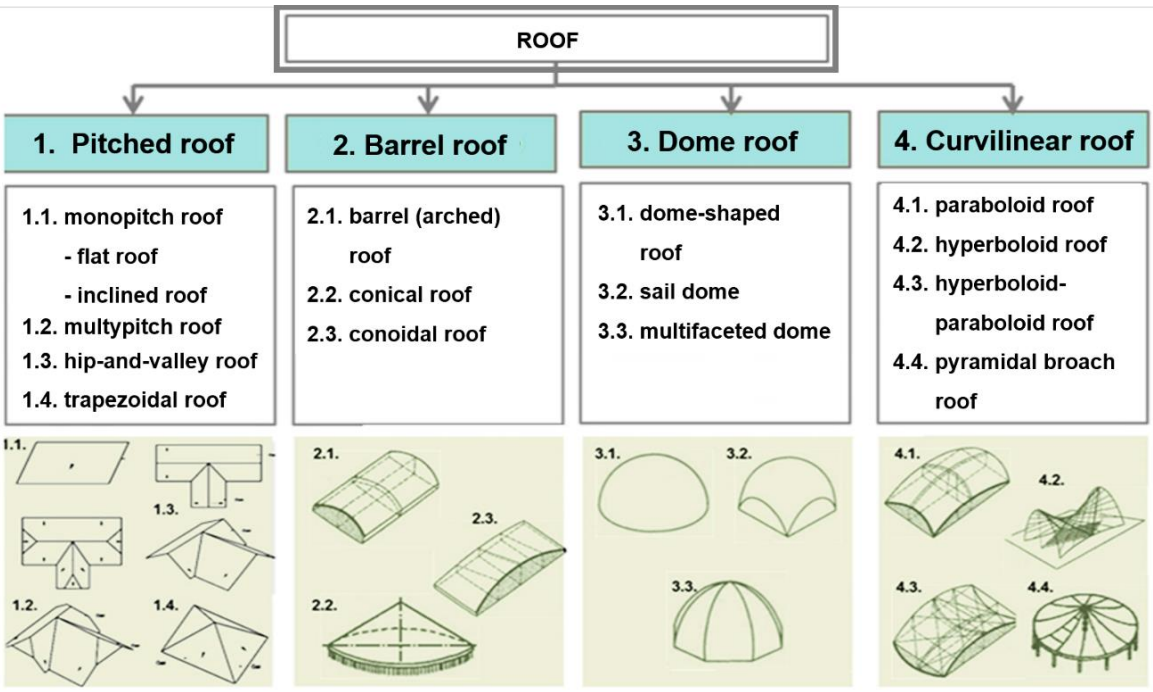

FIGURE 3. Differentiation of roofs by geometric type.
Source – [14], own research; illustrative material – from online sources; designed especially for this paper.

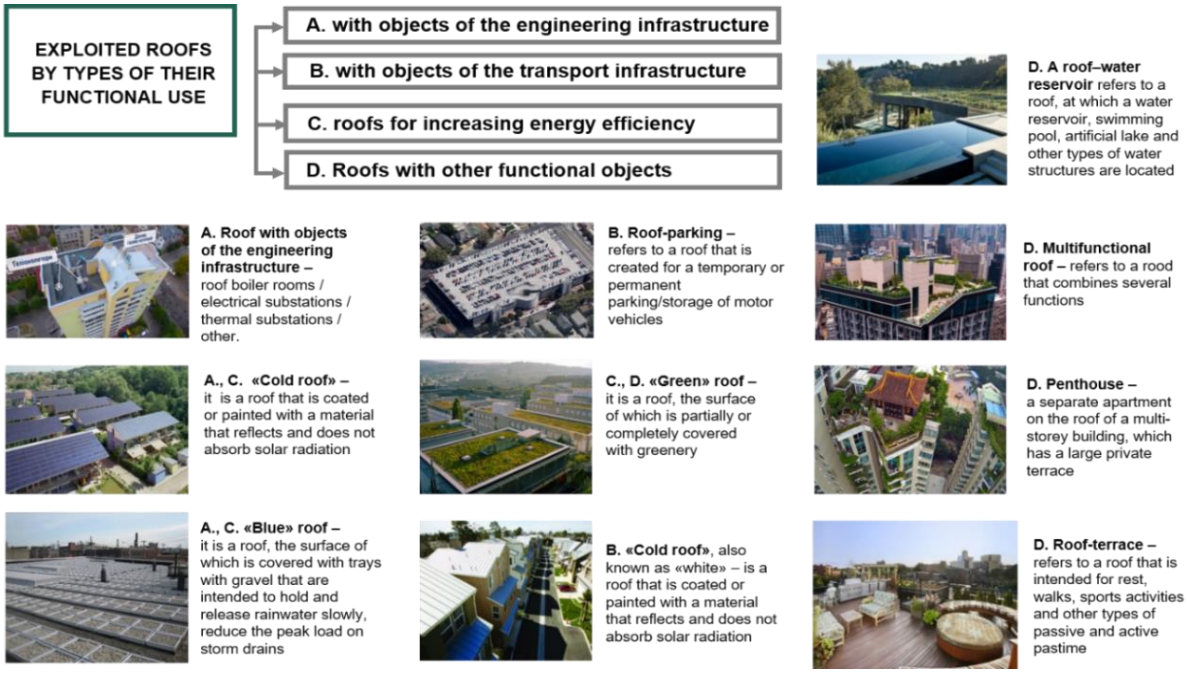

FIGURE 4. Directions of functional use of exploited roofs.
Source – own research, illustrative material – from online sources designed especially for this paper.

Differentiation of Roofs by Frequency of Visits

An important factor influencing the choice of the possible type of functional orientation of the objects to be placed on the roof is the frequency of visiting such an object. Depending on the frequency of visits, the used roofs can be divided into the next:

- with objects of mass attendance;
- with objects of restricted attendance

Under mass attendance it is understood that on a roof people (visitors) will be constantly (or seasonally) present. Roof with restricted attendance is a roof that is designed for a specific purpose, but the presence of people on it is limited, is there can only be service personnel, the roof does not provide additional load from a large number of people and other objects.

RESULTS AND DISCUSSIONS

One of the promising directions for increasing the capacity and efficiency of urban use is to attract the area of exploited roofs as a functional and territorial resource.

The Need of Use of Exploited Roofs

The need to use exploited roofs of buildings and structures should be based on the analysis of the availability of territorial reserves or excess area of the territory within the estimated planning element - a block or a separate land plot. There are two possible options, see formulas (1) and (2):

$$S_{free\ spaces} \geq S_{necessary\ regulatory} \quad (1)$$

$$S_{free\ spaces} > S_{necessary\ regulatory} \quad (2)$$

Where $S_{free\ spaces}$ – is an area free from development within the site under evaluation, that is, the existing territorial reserve; $S_{necessary\ regulatory}$ – area of the site under evaluation that is free from development, that is in accordance with regulatory requirements, is necessary for the placement of facilities for land improvement and landscaping, that is, the territorial reserve is absent.

In the case of a territorial reserve there is no urgent need to use the exploited roofs, but it may be appropriate and possible for:

- improving the energy efficiency of individual houses and buildings in general;
- increasing the environmental friendliness of the environment by increasing the number of greenery (reducing the effect of urban “heat island”);
- increasing the aesthetic appeal and attractiveness of the building.

When the free area is not enough, the territorial reserve is absent, the use of exploited roofs is extremely important for obtaining additional territorial resources. This will allow the possibility, in addition to increasing the energy efficiency, environmental friendliness, aesthetic attachment and attractiveness of objects:

- placement of normatively necessary sites for various functional purposes;
- obtaining additional areas of green spaces of limited use;
- placement of objects accompanying the main ones (objects of engineering and transport infrastructure).

Determining the Potential Territorial Resource of Urban Areas

In order to increase the efficiency of urban use through the use of exploited roofs, the study proposed a new calculation method for determining the potential territorial resource of developed areas, especially in the conditions of the condensed development, in the form of a mathematical model (see formula (3)).

$$S_{pot.\ terr.\ res.} = \alpha\beta\gamma\lambda \times S_{dev.} \quad (3)$$

Where $S_{pot.\ terr.res.}$ – potential territorial resource of the assessed plot (microdistrict, block, land plot), sq. m; $S_{dev.}$ – developed area of the assessed area, sq. m; $\alpha, \beta, \gamma, \lambda$ – coefficients that consider specific conditions and characteristics of the development.

α – the coefficient that considers the geometric type of the roof. Since the predominant geometric type of roof for post-war and modern buildings is a slope (or rather, subtypes: single-, double-sloped, tent roof), it is proposed to determine this coefficient according to the schedule (see Figure 5) depending on the angle of the roof.

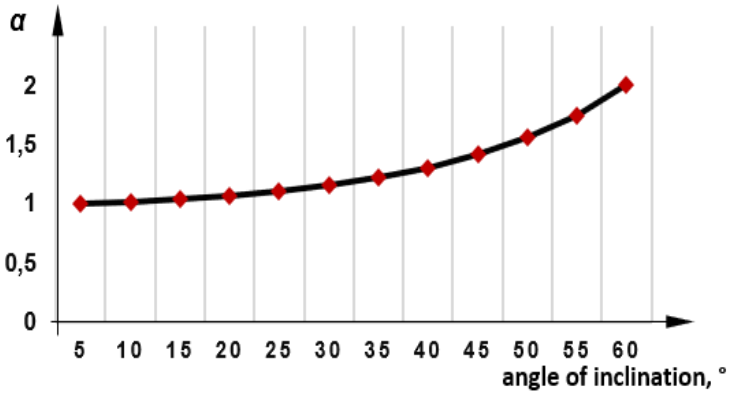

FIGURE 5. Coefficient of increase of the area for one-, two-sloped, tent roof for definition of the actual area of a roof. *Source:* own research, designed especially for this paper.

$$S_{exp.roof} = \alpha \times S_{dev.} \quad (4)$$

Where $S_{exp.roof}$ – area of roof that can potentially be used, sq. m; α – the coefficient, that takes into account the geometric type of roof (angle of inclination); $S_{dev.}$ – developed area of the assessed area, sq. m. β – a factor that considers the design features of the roof, i.e., the useful area of roof (excluding the area of ventilation shafts, elevator shafts, parapets, etc., design features of roofs, the area of which cannot be used) depending on the type of building (see (5)).

$$S_{exp.roof} = \beta \times S_{dev.} \quad (5)$$

Where $S_{exp.roof}$ – area of roof that can potentially be used, sq. m; β – coefficient that takes into account the design features of the roof, depending on the type of building (yield of usable area without taking into account the area of ventilation shafts, elevator shafts, parapets, etc. design features of roof whose area cannot be used); $S_{dev.}$ – developed area of the assessed area, sq. m.

The value of the coefficient β was calculated experimentally for each subtype of post war development. Approximately they are [15]:

- $\beta = 0.7 \ldots 1.25$ for the construction of the first period of industrial housing;
- $\beta = 0.7 \ldots 1.2$ for modern construction.

γ – *coefficient that reflects the weighted average physical wear of the building* within the assessed area. Its essence is that the higher the rate of physical wear of the house, i.e., the loss of load-bearing capacity of structural elements, the lower the probability of using its roof for any additional function. In this case, the area of the exploited roof is determined by formula 6:

$$S_{exp.roof} = \gamma \times S_{dev.} \quad (6)$$

Where $S_{exp.roof}$ – area of coverage that can potentially be used, sq. m; γ – coefficient, coefficient that takes into account the technical condition of the building; $S_{dev.}$ – building area of the assessed area, sq. m. The value of the coefficient γ is determined by formula 7:

$$\tilde{\gamma} = \frac{\sum_{i=1}^{n}(\gamma_i \times S_{dev.i})}{S_{dev}} = \frac{\gamma_1 S_{dev_1} + \gamma_2 S_{dev_2} + \cdots + \gamma_5 S_{dev_5}}{\Sigma S_{dev_i}} \quad (7)$$

Where S_{dev} – developed area of buildings with the corresponding indicator of technical condition (physical wear), sq. m; γ_i – the share of developed area of buildings with the appropriate indicator of technical condition (physical wear) of the total building area within the assessed area; i – respectively:

- *1* – good technical condition (physical wear 0… 20%),
- *2* – technical condition satisfactory (physical wear 21… 40%),
- *3* – technical condition unsatisfactory (physical wear 41… 60%),

- *4* – dilapidated technical condition (physical wear 61… 80%),
- *5* – technical condition is unsuitable (physical wear 81… 100%).

λ – a coefficient that takes into account the share of developed area of buildings that have the status of cultural heritage sites in the total developed area of the assessed area (see formula 8).

$$S_{exp.roof} = \lambda \times S_{dev.} \quad (8)$$

Where $S_{exp.roof}$ – area of coverage that can potentially be used, sq. m; λ – is a coefficient that takes into account the presence of cultural heritage status in the building. Determined by formula 9; $S_{dev.}$ – developed area of the assessed area, sq. m.

$$\lambda = 1 - \frac{S_{her.}}{S_{dev.}}, \quad (8)$$

Where $S_{her.}$. – building area of buildings with the status of a cultural heritage monument, sq. m; $S_{dev.}$ – developed area of the assessed area, sq. m.

The Law of Ukraine "On Protection of Cultural Heritage" prohibits any interference and change in the appearance of a protected object [16]. Therefore, the decision on the possibility of installing exploited roof on such building should be made very carefully and individually, respectively, the developed area of such buildings should be removed from the total developed area of the assessed area.

The proposed mathematical model allows to determine the potential territorial resource of urban areas by including in the operation of roofs of existing and designed buildings. Such analysis can be performed both at the city level when developing master plans, zoning plans of settlements and detailed plans of individual planning entities, and at the local level when implementing pre-project proposals and sketch projects for individual land plots.

CONCLUSION

Trends of intensification of urban area development.

The study confirmed the trend of intensification of use and development of the modern city. Thus, the analysis performed on the example of 51 planning elements - blocks, microdistricts, residential groups of buildings in Kyiv, confirmed this trend (see Figure 6).

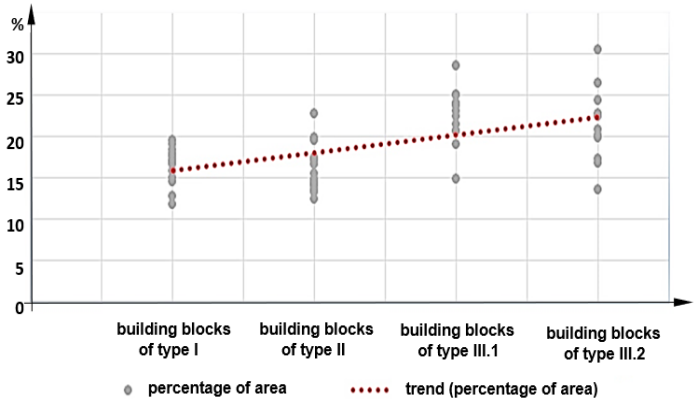

FIGURE 6. Percentage of developed area within the assessed areas of different building periods (consolidated graph)/ *Source:* own research, designed especially for this paper.

The proposed mathematical model allows to determine the potential territorial resource of urban areas due to the inclusion in the operation of exploited roofs of existing and design buildings and structures. The calculation is based on the area of existing buildings and structures and a system of coefficients that consider geometric type of roof, historically formed type of building, technical condition (physical wear) and cultural value of each building within the assessed block.

Experimental Verification of the Proposed Method

Experimental verification of the proposed method shows that the decision to attract exploited roofs as an additional functional and territorial resource makes it possible to obtain from 9,4% to 27,:% (of the area of the estimated planning element – blocks, microdistrict, group of buildings) of additional areas depending on the type of building, namely:

- *Type I* – blocks of buildings of the first mass series of the industrial period of housebuilding (50-60 years of the XX century) – 9,6… 19,3 %%;
- *Type II* – blocks of buildings of mass series in the 70-80s of the XX century – 9.4… 22.1 %%;
- *Type III.1* – modern high-rise buildings (up to 16 floors) – 12.2… 27.5 %%;
- *Type III.2* – modern high-rise buildings (over 16 floors) – 13.0… 27.6 %%;

Substantiation of Expediency of Application of the Operated Roofs

The final decision on the expediency, physical capability, and admissibility of placement of certain objects must be made in each case separately based on the analysis of a set of decision-making factors on the feasibility of using exploited roofs to improve urban use and to raise comfort of living conditions.

When there is not enough free space, there is no territorial reserve, the use of exploited roofs is extremely important to obtain additional territorial resources. This will provide an opportunity, in addition to improving energy efficiency, environmental friendliness, aesthetic appeal and attractiveness of facilities:

- • placement of normatively necessary sites for various functional purposes;
- obtaining additional green areas for limited use;
- location of additional facilities (engineering and transport infrastructure facilities);

When assessing the acceptability of the exploited roofs and areas of their functional use, the following factors should be considered:

- *urban planning* (functional purpose of the territory; type of building; urban planning value; intensity of building; architectural-landscape connection with the environment);
- *structural* (geometric type of roof; technical condition of the building; load-bearing capacity of building structures);
- *economic* (land value; intensity of land use; profitability of the building; increase in the value of facilities and territory);
- *environmental* (microclimate regulation; energy saving requirements; increasing the level of landscaping and greening).

Establishing the feasibility of using exploited roofs as an additional functional and territorial resource of blocks and plots of urban development is determined on the basis of calculating the total economic efficiency from the implementation of the project decision. This assessment is based on three components:

- cost-effectiveness of investing in the implementation of the project solution;
- cost-effectiveness of saving of operating costs in the case of the project solution implementation;
- social efficiency of the implementation of the project solution due to increased comfort and diversification of service facilities.

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