

Sustainable underground development: innovation and regulation (example of solar transmission systems)

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Abstract. The review of features of development of underground space in the large cities of the country and practice of introduction for this purpose of innovations is resulted. The article presents the results of the study, the subject of which is to consider the shortcomings of legal regulation and standardization in the field of transmission of daylight (solar) light under the ground through the use of light guides and other devices. The purpose of this study was to find ways to improve these areas of state regulation. To assess the current situation in the field of regulation under consideration, the analysis of the effectiveness of the main regulatory legal acts, documents on standardization, as well as a review of a number of literature sources. The assessment of the implementation of individual projects is taken into account. According to the results of the analytical stage and taking into account the forecast of modern strategic directions of development of the construction industry, proposals are given to improve the situation (amendments and additions to normative legal acts, documents on standardization, etc.). The implementation of such proposals will require coordinated work of the Ministry of construction of Russia and other authorized agencies and organizations. The implementation of the results of the study can contribute to the sustainability and efficiency of the development of underground space in our cities.

1 Introduction

The accelerating growth of urbanization in the context of global climate change is becoming one of the main environmental challenges of our time. Its public awareness dictates the need to change the paradigm of spatial development of cities in the direction of improving their security, resilience and sustainability. In the strategic context, this is expressed, for example, by the adoption of special UN HABITAT documents [1], where one of the key areas of change in urban policy is the policy of creating compact cities with high connectivity. This model contributes not only to the achievement of targets, but also increases the efficiency and competitiveness of cities [1, 2]. In Russia, the principle of sustainable development of the territory as a fundamental enshrined, for example, in the

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Urban development code of the Russian Federation [3]. This principle assumes the safety and comfort of the urban environment, not only at the moment, but also in subsequent years (subject to the exclusion of negative man-made environmental impact).

An obvious way to improve the compactness and connectivity of the city, and hence the sustainability of its development is urban development of underground space (hereinafter also - US). This option simultaneously reduces the negative aspects of such a model (the effect of the "curse of the compact city"), providing a healthy level of building density. Under the term "development of US" we understand the development of the underground part of the city, carried out by creating underground buildings and structures (hereinafter also-UBS), which are capital construction projects. The term "territory", in turn, can be defined as some spatial limits of the set of natural environments (resources), limited by vertical projections of the city boundaries and under the "public" jurisdiction. The evidence of this method of territorial development is supported by the practice of many cities around the world in countries such as Canada, Finland, USA, China, Singapore, Hong Kong, Japan, South Korea, etc. Another global trend – the innovative integrated urban development of US. It is considered as a process aimed at integral (joint) maximum use of the potential not only of space as a container of UBS, but also of other resources and services, such as groundwater, geo-engineering, developed geo-materials, etc. [4].

It should be recognized that for a number of historical and other reasons, the vast majority of Russian cities can hardly be considered compact and connected. The vector of public administration is not yet deployed in the direction of this progressive urban model, as, in general, in the direction of the integral development of US. In addition, in recent years in Russia there has been an unfortunate trend of some decrease in the interest of the authorities and investors to the underground urbanism, despite the growing need for its formation in Moscow and other major cities of the country (the growth of the construction of metro facilities, transport hubs, parking in areas of renovation of housing, etc.). This situation is just one example of the imperfection of the public administration system in the management of territorial development, associated with a number of reasons, both objective and subjective [5].

It should be noted that along with the well-known advantages of urban US development (environmental friendliness, land savings, etc.), there are also disadvantages that reduce the level of comfort and safety of the environment of people's life. These are, first of all, the spatial isolation of the UBS, their isolation from the daytime surface, the absence of sunlight under the ground. The traditional purpose of window openings as the main conductor of daylight under the ground makes no sense (UBS of basement type are not considered in this article). Artificial electric lighting, as it is known, due to its physiological and psychological parameters can not adequately replace sunlight, at least by the fact that it is not able to activate the photochromic pigment melanopsin, necessary for human health. In addition, the use of such lighting is in contradiction with the modern requirements of energy efficiency, dictating the search for new energy-saving technologies.

These factors certainly cause a negative psycho-emotional effect, especially in people predisposed to specific pathologies (claustrophobia, etc.). This should be taken into account in the underground architecture when creating metro facilities, underground shopping and entertainment centers, parking lots, other UBS and their complexes, including, for example, even school facilities. At the same time, it is advisable to be guided by one of the fundamental principles of underground urbanism – the principle of compensation for the objective damage of a person's stay underground. It particularly subordinated underground architecture, which is a separate direction, correlated with green architecture.

A radical option to reduce this damage is the transfer of daylight (sunlight) under the ground by using light guides and other devices. Technological introduction of daylight to the UBS, in our opinion, should be attributed to the visual type of complexity of the

development of US. The same type includes the establishment of visual communication between the ground urban environment and the UBS by using special planning and design solutions, as well as by introducing elements of landscaping into the UBS. Along with traditional methods of transmission of natural light underground to a shallow depth (transparent roofs, internal atriums, skylights and windows in the roof), new solutions are used, including systems of hollow tubular light guides (hereinafter also - HTL). Moreover, they are used for more buried UBS. Such technologies are fundamentally innovative in nature, continue to develop and are already being used in urban construction in a number of countries (USA, Canada, Australia, Italy, UK, Germany, China, South Korea, the Netherlands, Belarus, etc.). However, in Russia they are only beginning to be implemented (so far on single underground facilities).

In our opinion, the wider application of the method of transmission of sunlight in the UBS is to some extent constrained by the imperfection of the system of legal regulation and technical regulation (standardization) in this area. Confirmation of this hypothesis on the example of hybrid lighting systems technology (hereinafter also - HLS) and the search for ways to improve regulation was the purpose of the research study, the results of which are reflected in this article.

In addition, the article attempts to consider the relevance and some areas of specific practical application of methods of transmission of daylight (sunlight) in the UBS in relation to the conditions of Russian cities.

Taking into account the specifics of the subject of research, the main normative legal acts (hereinafter – the NLA) and normative technical documents: Sets of rules (hereinafter – the NTD) are considered. We analyzed the results of several case studies of such Russian authors as J. B. Aizenberg, A. K. Soloviev, A. T. Ovcharov, Yu. N. Selyanin, Y. Antsupov V., Kupriyanov V. N., Shashin R. E., Gorbunov A. P., A. N. Remizov, P. O. Yegoryev, S. V. Stetsky, etc., and also some foreign authors (G. Brakale, A-L. Mohirta, E. Kaymaz, etc.). Just note that the work of domestic authors concerned mainly technological, design, architectural and economic issues and considered regulatory aspect of the problem, especially in relation to the UBS, was disclosed very poorly. Studies of this aspect by foreign authors (with the exception of single publications of specialists from the countries of the former Soviet republics) relate to their national systems. Despite the differences in control systems, in the future it would be useful to conduct additional studies with a comparative analysis of world practices of rationing of solar light transmission systems in US.

2 Materials and methods

To assess the legal regulation and technical rationing situation in terms of the transmission of sunlight to the UBS, the collection, systemization, analysis and monitoring of NPA information (review of some of the rules of major federal laws) and NTD. Assessment of their effectiveness (unity of terminology, completeness, consistency and adequacy of parameterization requirements, compliance with legislation, orientation to innovation and best world practices) with analysis of negative trends legal regulation and standardization. First of all, the subject national documents on standardization were considered, as well as an overview of the main domestic and selected foreign literary sources concerning the transmission of sunlight. Elements of the ontological approach have been applied.

3 Results and discussion

The above noted features and shortcomings for the development of the US, including the use of the method of artificial lighting traditionally recommended by domestic rules have

defined a new direction for the delivery of natural light into the UBS and the development of a number of innovative both passive and active (synchronized with the movement of the sun) light-transporting systems (reflective tube, an optical fiber, heliostats, mirror system, etc.). The article considers the problems of regulation of their use on the example of the use of HTL and HLS [6, 7, 8, 9, 10, 11].

HTL technology, as already noted, in recent decades has been actively used and developed around the world (North America, Europe, South-East Asia). Its main advantages are high efficiency of collection and concentration of natural light, targeted transmission of light to a considerable depth and soft (without the effect of blinding) scattering in the internal space of the UBS. The ability to capture sunlight regardless of the orientation of the object, transmit it without distortion of spectral components with a minimum of energy losses makes the HTL technology essentially uncontested for use in underground construction. At the same time, it has not yet received wide practical application in Russia, domestic technologies and production facilities are in the initial stage of development. However, it is already used in the implementation of a number of underground construction projects (Sochi, Nizhny Novgorod, Kogalym, etc.).

Currently, in the domestic market of natural lighting, hollow light guides are represented by several foreign companies: Solatube® Daylighting Systems of the American (USA) company Solatube International Inc. [7], as well as the system Solarspot® of the Italian company Solarspot International S. r.l. and the system ALLUX Czech company Lightway [10].

Modern lighting systems of natural light on the basis of HTL of the leading firms of the world are brought to a high level of perfection and are completed with options for creation of comfortable light climate indoors, including underground. It should be noted the structural similarity and approximately equal level of technical perfection and options systems. In this situation, the leadership in the market of natural lighting systems will be determined by the advantages of technological, operational and price order. At the same time, for example, solar lighting systems Solatube® have some features and bonuses in their basic design elements. In particular, the light-receiving dome reduces the number of reflections due to special notches and increases the efficiency of light transportation. Seamless metal adapter-flushing is adapted for pairing with different types of roofing, providing proper hydro-and thermal insulation, has a protective coating. The light guide (a set of joined aluminum tubes of various configurations) is covered from the inside with a multilayer polymer film with a maximum reflection capacity. Finally, the light diffuser, arranged in the ceilings of the UBS, provides a high level of natural light scattering and eliminates glare.

Due to the quality of materials and components HTL Solatube® have a light transmission efficiency of up to 99, 7%, with a total system efficiency of up to 83%. This allows for the transport of light deeper into the earth by more than 20m. They are also characterized by a significant reduction in heat losses in the cold periods of the year and heat receipts in the summer, which means additional energy savings for heating, ventilation and cooling of the UBS. But the main thing is that this reduces the cost of electric lighting UBS (in the daytime up to 75%). Efficiency estimates show that it is 50 times more economical to transmit solar radiation into the interior of the room than to create artificial lighting for this purpose. In general, the extension of the use of natural light for 1 hour during the day only for industrial buildings allows to save about 3 million kWh per year in Russia.

The main objective disadvantage of HTL systems is the daily imbalance of illumination (its deficit in the dark). A logical step to overcome it is the development of combined lighting systems (hereinafter also - SSO). The impetus for their development was the active introduction of HTL and LEDs, respectively, in the system of natural artificial lighting.

This, in turn, was facilitated by the emergence of breakthrough technologies in the creation of materials with almost absolute values (99.7%) of the reflection coefficient.

It is gratifying that such development of SSO was carried out in Russia on the basis of integration of natural light resources (HTL Solatube® as a basic component) and energy-efficient artificial lighting (led source), United by an automatic control system (hereinafter also-ACS). Moreover, each component of the hybrid lighting complex (HLS) performs its role: HTL conducts a natural light unit with modern led light is equivalent to supplements (compensates) a natural component in dark time of day, ACS continuously and smoothly (invisible to the eye) governs the dynamics of light emission HLS [7, 12, 13]. It is in terms of quality ACS developed and patented complex has advantages over traditional lighting and even foreign counterparts.

Despite the difficulties, including those related to the state regulation of the project development (obtaining special technical conditions, etc.), passing its examination and implementation (some of them are discussed below), the experimental implementation of this technology was carried out during the reconstruction of one of the large objects - the family shopping center "MEGA Adygea". According to the results of the pilot project, a technical and economic analysis was performed, which showed high levels of payback of capital investments in HLS (payback period is less than 3 years) and its energy efficiency [13].

What factors are currently preventing the widespread introduction of such advanced technologies in Russia? Let us consider further this problem in the context of the main sections of public administration: policy-organizational aspect of management-legal regulation-standardization.

It is established that the branch state management should be carried out on the basis of the relevant documents of strategic planning establishing policy in branches [14]. The considered process of creation of solar light transmission facilities relates to the preparation and implementation of project documentation, that is, it is carried out within the framework of urban development [3]. At the same time, of course, we are talking about innovative technologies. At the moment, modern documents of strategic planning are absent both in the construction industry and in "related" industries.

In this situation, of particular interest is the attempt to develop a sectoral construction strategy of the Russian Federation (hereinafter also-the draft Strategy) [15]. Of course, the status of this document does not provide for consideration of the specifics of a particular innovative technology. However, we believe that the main problems of their implementation should be analyzed, recorded and outlined strategic directions for their solution. Unfortunately, so far in the draft Strategy, this has not been observed to the proper extent either in terms of daylight transmission technology or in terms of the development of underground urbanism. Thus the only priority direction of the state policy pursued by the Ministry of construction of the Russian Federation in the sphere of introduction of new technologies is offered to recognize updating of the existing and development of new NTD. Moreover, it is proposed to preserve proven and effective technologies, along with the creation of new technologies that take into account world best practices (which, in particular, directly concerns the above case with HLS). Recognizing the importance of developing the NTD system, in our opinion, the problem of innovation in the strategic context requires a broader, systemic solution. For example, it was planned within the framework of the Technological platform "Construction and architecture" (identification of the needs of the main stakeholders, ontological and exploratory research, mutual coordination in the context of national projects, the development of R & d, preferences, import substitution, interdepartmental cooperation, etc.) [16].

Considering the aspect of legal regulation, it is advisable, first of all, to briefly dwell on the safety requirements in terms of designing the creation of UBS and in terms of lighting.

Direct mention in the technical regulations on the safety of buildings and structures [17] refers to the requirements of creating in the underground floors exclusively artificial lighting, sufficient to prevent the threat of harm to human health (Art. 23). We believe that this outdated formulation of the norm becomes the main legal barrier to the introduction of the innovations in question, as it is repelled by both subordinate legal acts detailing this Technical regulation and the relevant RPA. It is obvious that this rule should be supplemented by a clarification regarding the confirmed practice of the possible transmission of natural sunlight to the UBS using optical fibers. We also believe that it is extremely important in the draft Strategy [5], the action plan ("road map") for the implementation of the strategy, as well as in developing its RPA to reflect the increase in the effectiveness of sectoral legal monitoring. This will ensure the timely improvement of both urban planning and related "legislation in such cases.

The Federal law on sanitary and epidemiological welfare of the population also does not contain special rules regarding the creation of the UBS [18]. At the same time, it contains a number of requirements of a General, universal nature to the processes of design, construction, reconstruction of buildings, structures aimed at creating favorable conditions for life and health of the population. In this case, the Law as a norm of reference nature requires compliance with sanitary and epidemiological rules and regulations (hereinafter - SRR), which are discussed below in the context of the study. Despite the increased thus (due to the law) the status of SRR in [19] specifically state the need to ensure that illumination of construction sites to sanitary requirements only for residential premises, that is, requires additional resolution, also with regard to other classes of objects. It should be noted that the totality of the legislation on sanitary and epidemiological welfare of the population and legislation on technical regulation of SRR are the rules of mandatory application in contrast to many requirements of documents on standardization in the construction industry.

A separate problem is the harmonization of Federal legislation (urban planning, land, civil, subsoil, etc.) for the development of US. On our initiative, this issue has been submitted to the government of the Russian Federation. The necessary instructions have been given and the Moscow government has now formed a working group to improve legislation (with the participation of representatives of Federal ministries). The proposals of the author of this article as a member of this working group will, among other things, relate to the removal of the legal barriers discussed above.

In the part concerning the issues considered in this article, it is also advisable in accordance with the legislation on technical regulation to separately investigate and assess the completeness of legal regulation (as part of technical regulations or other RPA) of radiation safety; biological safety and other types of energy efficiency. as well as other NLA regulating relations in the field of "green" technologies which, of course, include the considered systems of HTL and HLS. As a result of such an assessment, it is likely that changes and additions to the NLA will be required.

Regarding the organizational aspect of management, we note only that the Ministry of Construction of the Russian Federation, authorized to develop systems of legal and regulatory technical regulation, it is advisable to consider the option of organizing in its composition specialized units, holistically responsible for the sphere of underground urbanism, scientific support and promotion of innovations. It is necessary to ensure their coordinated interaction (including within the framework of the Technological platform "Construction and architecture") with adjacent departments (the Ministry of industry and trade, Ministry of economic development of Russia, etc.), and also with the Russian Academy of architecture and construction Sciences, other basic research and educational organizations, with the National Association of builders and the National Association of prospectors and designers.

As for the issues of standardization, in the field of development of US in the course of special scientific work on monitoring and analysis of NTD, we identified a number of systemic problems (gaps, conflicts, duplication in NTD) and made proposals for the future composition and structure of the complex of relevant NTD. They were taken into account by the Ministry of construction of Russia (unfortunately, not fully) and currently developed the first edition of the draft Set of rules "Urban planning. Planning and development of underground space". There are a number of fundamental comments to the project, including those concerning the lack of consideration of the considered innovations on HTL and HLS. In this regard, systematic work is required to make appropriate changes and additions to the NTD and the draft Set of rules.

Separately, it is necessary to dwell on the Set of rules 52.13330.2011 "Natural and artificial lighting" [19]. When updating this set of rules in 2016, some requirements for the use of light guides were introduced. The definition of this term as a device that directs natural light into the building is given. It is possible to use optical fibers as a source of natural light, but only in the combined lighting system and as a top light (side lighting option is ignored, see below about false windows). The presence of these requirements, despite the obvious need for their development in relation to the UBS, already allows the use of HTL systems in the construction and reconstruction of facilities.

A different picture is formed with the practical application of HLS systems, including for underground construction. The Set of rules [20] mechanically duplicated the requirement of the SRR [21] that the premises with a permanent stay of people should have only natural light. Thus, both documents exclude the possibility of applying HLS systems.

It is obvious that such gaps in regulations, which create unjustified barriers in practice, are associated with the management problems noted above. In particular, we are talking about the lack of monitoring of technical innovations (in this case, the fact of the patented existence of the HLS system [13] is not taken into account) and inefficient monitoring of documents on standardization. They also include the above-mentioned disadvantages of the legal regulation (in this case concerning the differences in the statuses, Regulations and codes of practice), contributing to the emergence of such gaps in the standardization system. Of course, it is necessary to initiate simultaneous changes and additions to both documents. They also, in our opinion, should concern the ontological structuring and addition of basic concepts, for example, in terms of the correct attribution of HLS systems to sources of combined lighting (now the component of artificial lighting in it is limited only by the period of the working day [19, 20]).

Similar changes and additions require the standardization documents in the area of creating UBS for other purposes. To make them it is necessary not only to specified Regulations and Set of rules, but in other similar documents relating to the design of the underground part of the industrial, agricultural, and other special purposes, as well as in the documents "related" problems, such as SRR requirements of lighting [21].

4 Conclusions

To ensure sustainable territorial development of cities, it is necessary to make better use of the potential of US. However, this should be combined with the creation of the necessary conditions for human activity. It is expedient for the Ministry of construction and other authorized agencies to focus on a systematic approach when regulating the development of US, ensuring the introduction of modern innovative domestic solutions into practice. These include the transmission of natural light in the UBS as a necessary condition for a comfortable and safe stay of people under the ground with the help of a new source of combined light (hybrid lighting system) as a universal technical means of natural and combined lighting.

The results of the study confirmed the working hypothesis about the lack of efficiency of state regulation and, above all, in terms of legal regulation and standardization of daylight transmission under the ground (especially in terms of hybrid lighting model). Selection and implementation of recommended areas of improvement of the relevant legal act, normative in terms of establishing the appropriate strategic development of the sector and in mutual relation to other "related" activities will enhance the sustainability of spatial development in key areas, in particular, will enhance the level of safety and the quality of the urban human environment. Systematic and mutually linked adjustment of the NLA and NTD should be carried out within the framework of the ongoing "regulatory guillotine".

It is necessary to initiate inclusion of models of HTL and HLS in Federal and regional lists (registers and catalogs): energy-efficient equipment, innovative technologies and technical solutions, construction products, experimental design and construction, and also to include subjects on their improvement and practical application in plans of development of scientific justification and development of NTD of the Ministry of Construction of Russia.

The directions of further studies besides those in the text above can be, for example, include the rationale for the use of systems in UBS title and mining part of metro facilities, transport hubs, schools, hospitals, industrial, agricultural, residential, recreational and other facilities, the rationale for their use in green architecture and design (projects formation of a virtual environment, false windows, etc.), a study of the influence of the spectral characteristics of light on human health, on plants, etc.

The use of HTL and HLS in underground construction, along with the achievement of significant savings in lighting costs, brings the most important social and humanitarian effect, forming a healthy and environmentally safe light environment for human life

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