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MODERN MATERIALS AND STRUCTURES USED IN HOUSING CONSTRUCTION: INTERNATIONAL EXPERIENCE

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Abstract
Introduction: The article addresses the possibility of using universal energy-efficient engineering and technological solutions in mass housing construction, regardless of the climatic region of construction, with account for modern development in Saint Petersburg (Russian Federation) and Münster (Germany). The article not only considers improvements in building technologies used in modern housing construction but also offers an overview of the latest energy-efficient materials and structures. **Purpose of the study:** We aimed to introduce energy-efficient solutions in housing construction using innovative technologies and materials. In addition to theoretical materials, practical calculations will be presented, clearly showing the advantages and disadvantages of various engineering and technical solutions. **Methods:** In the course of the study, we used **a)** a comparative analysis of physical and thermal properties as well as strength characteristics of building materials used in mass housing construction; **b)** a problem-logical method to analyze possible typical space-planning and structural solutions for the design and construction of buildings, with account for climatic conditions and geographical features of the construction region, in compliance with the basic principles of modern sustainable construction, energy and environmental standards, economic efficiency of the solutions used, in accordance with international European LEED and BREEAM and Russian GREEN ZOOM standards. **Results:** We propose to introduce, along with the already well-known and time-tested ones, innovative patented solutions in materials and construction technologies both in private and mass housing construction in the countries under consideration: Russian Federation and Germany. **Discussion:** The discussion of field tests and implementation of the latest building materials in housing construction clearly demonstrates the importance of international cooperation in this field at various levels. As a consequence of the growing volume of housing construction and energy consumption, there emerge new stricter requirements and standards for the quality of materials produced and their technical characteristics, as well as a variety of decorative solutions enabling the construction market to be competitive and meet the over-demand requirements of the rapidly developing industrial society, while necessarily taking environmental protection measures, including those on conservation and mindful use of natural resources.

Keywords
Energy efficiency, housing construction, modern building materials, reinforced concrete structures.

Introduction

Currently, innovative technologies and engineering advances are actively introduced into all spheres of everyday life of society. In this respect, the field of design and construction is by no means an exception.

The development of energy saving and energy efficiency in construction as well as housing and utility sector can be seen as one of the priorities in every country. In the construction industry of the Russian Federation and leading European countries, the efficient and rational use of energy and more active utilization of renewable energy sources, reducing greenhouse gas emissions, are considered important measures. A smart state policy in this area will undoubtedly improve the quality of life in general (Elistratov et al., 2019; Kiseleva and Pastukh, 2017).

Modern building materials allow architects and designers to put a lot of creative out-of-the-box ideas into practice in cooperation with civil engineers competent in the operation and technology of assembly in respect of any building design, required for project implementation.

The technology of housing construction with the use of prefabricated reinforced concrete panels ensures the maximum speed of assembly of residential buildings, which gives it an advantage over traditional construction technologies (Krikun and Tzay, 2020). Various countries of the European Union and the Russian Federation have accumulated experience in using this technology. As it is well known, in the 1950s, several European countries adopted state policies intended to resolve the housing problem quickly. First in Denmark and France and later in other countries, prefabricated housing construction, i.e., the in-plant manufacturing of reinforced concrete building elements and the subsequent structure assembly at a construction site, served as the technological basis for housing construction. This technology implies the use of prefabricated reinforced concrete panels as walls and floor slabs, including room-size slabs.

The prefabricated housing construction technology ensured the maximum speed of assembly, which gave it an advantage over traditional construction technologies.

In the Soviet Union, this technology gained widespread use. The preferences given to this type of construction by the state in terms of obtaining land plots and loans made it possible to meet acute social housing needs (Ivanov and Golovina, 2015). Due to the administrative-command system of economic management, up to 90% of housing in cities were built with the use of reinforced concrete prefabrication technologies. However, despite the high manufacturability of prefab panels, the architectural appearance of such buildings and the urban environment could hardly be considered aesthetically pleasing.

In Western Europe, they started addressing the issue of providing adequate housing conditions for urban residents at the end of the 20th century. When the acute housing availability problem was resolved, in particular, in the 1980s, the demolition and reconstruction of buildings constructed industrially with the use of reinforced concrete prefabrication technologies started. However, it was not physical depreciation but obsolescence that caused the reconstruction of urban areas in Europe in the 1960s. In this regard, the following accompanying circumstances can be considered: stricter requirements for energy saving in the operation of residential buildings, the emergence of a mass effective demand for a higher-quality urban environment, prevailing studies on life in high-rise, high-density housing, which established damage to health and social relations in case particular design parameters and operating conditions are exceeded (Deilmann et al., 1977).

Depending on the economic situation in a specific country or city, two approaches to reconstruction were used. The first approach constitutes total or partial demolition of prefab buildings and subsequent construction of new buildings at the cleared sites. The second approach constitues total or partial preservation of load-bearing structures in buildings erected in the 1960s but with the transformation of the appearance of a building.

Materials and Methods

To retrofit the housing stock, save energy and rationally use natural resources, the authorities of various countries have developed state programs for the renovation of dilapidated housing. These programs are intended for long-term implementation. They establish measures aimed not only at improving housing conditions but also at increasing social cohesion among residents of districts (Elistratov et al., 2019).

The study addressed the experience in the construction of residential buildings in the cities under consideration, located in different climatic zones but having similar needs in terms of the energy efficiency of building structures and construction quality (Mähner et al., 2016).

The use of modern building materials in the construction of residential buildings (prefabricated, cast-in-situ, or mixed) will not only significantly improve the technical characteristics of load-bearing and enclosing structures but also take care of the environment, in compliance with the European (LEED and BREEAM) and Russian Federation (GREEN ZOOM) standards (Pastukh et al., 2021a).

It is possible to increase the area utilization efficiency by adding new residential space to existing buildings with a height of 2−5 floors and new construction facilities, e.g., a section inserted between existing buildings or attached end sections.

An increase in the housing stock due to additions and inserted sections should not exceed 25%. On the one hand, this ensures a sufficient number of new apartments allocated for sale, and on the other hand, such additions and inserted sections do not significantly affect the existing social and engineering infrastructure. The balance of income and expenditure serves as a criterion of success (Linov and Ivanov, 2018).

In addition to new construction, reconstruction and repair activities performed in mid-rise residential buildings should include the following:

- provision of elevators and entrances adjacent to staircases;
- addition of recessed balconies on metal supports to attach to existing buildings, which is not usually provided for in the typical series of residential buildings;
- conversion of the first floors with the arrangement of apartments with separate entrances for people with reduced mobility;
- arrangement of one-story covered parking lots adjacent to the first floors, with rooftop playgrounds for children, sports grounds and recreational areas for adults;
- allocation of storage areas for residents on the converted first floors;
- facade insulation and finishing;
- replacement of the thermal insulation of external building apertures;
- replacement and repair of in-house utilities and equipment.

Utilities and design features can be upgraded with the use of modern energy-efficient materials and technologies: air conditioning, thermal insulation, energy- and water-saving equipment. In countries with cold climate, the modernization of residential buildings involves increasing the energy efficiency, i.e., using modern engineering technologies aimed at reducing energy consumption for heating, water and power supply by ensuring microclimate control.

A good example is the installation of solar panels on parapets, serving as decorative elements of the facade and providing the residential building with additional energy. The installation of radiators with individual energy meters in a multi-apartment building provides a convenient system that enables accurate cost allocation and increase the energy efficiency of the building. As for excess heat, the problem can be solved by the arrangement of sun protection structures, such as recessed balconies, canopies, etc. and ventilation equipment installation. Waste heat from apartments and passive solar rays can be passed through a controlled ventilation system and integrated into an element of the technological system. According to the European documents on the National Strategy for the Reconstruction of Buildings to Improve Energy Efficiency, it is required to install ventilation systems with heat recovery in buildings of certain energy efficiency classes.

In the current situation in the construction industry, which occurred as a result of the intensive transformation of the living environment in major Russian Federation (e.g., Saint Petersburg) and European (e.g., some urban settlements in Germany) cities, the technological aspect of construction and renovation of buildings is gaining particular importance in terms of the effective use of house-building technology.

We aimed to investigate the scope of rational use of house-building as well as repair-and-construction technologies and compare the stages of modern development of the architectural-and-planning structure in Russian Federation and European cities using Saint Petersburg (Russian Federation) and Münster (Germany) as case studies.

In this regard, of great interest are large-panel, cast-in-situ, and masonry construction technologies used for the assembly of residential buildings. These technologies were formed following the development of load-carrying devices for construction mechanization and emergence of new building materials, which can be clearly seen in the development of house-building technologies in Saint Petersburg (Figure 1).

Results

1. Housing construction in Russian Federation

The study of housing construction in Saint Petersburg revealed a widespread use of global advanced technologies and materials: precast and cast-in-situ reinforced concrete, steel and wooden structures, brick, effective insulation materials, etc.

Reinforced concrete elements, which are load-bearing, as well as enclosing structures are also widely used in the construction of industrial and civil buildings and structures. They include load-bearing columns, walls, structural floors and cladding, as well as other constructions of buildings and structures of various purposes.

The further development of the house-building industry in Saint Petersburg led to the application of the cast-in-situ and precast construction technology. A distinctive feature of this technology is the use of prefabricated vertical (except for vertical stiffening diaphragms, which are cast-in-situ) and cast-in-situ horizontal structures — rigid slabs, which ensure the spatial rigidity of the building (Figure 2). In this case, wall panels can be single-layer or multi-layer.

Typically, external walls are built of precast reinforced-concrete three-layer (sandwich) panels supported by internal load-bearing walls or floors. The inner load-bearing layer of a panel is made of heavy concrete (at least 100 mm thick), while the outside layer is made of light or heavy concrete (at least 50 mm thick), with the surface matching the architectural design of the facade. In the middle of the panel, there is a layer of effective insulation material (approximetely 150-180 mm thick), which meets the requirements of thermal conductivity analysis for Saint Petersburg (Figure 3). Based on this technology, several residential complexes were built in Saint Petersburg and Leningrad Region: IQ Gatchina, Yutteri, Jaanila Drive, Novaya Dubrovka, etc.

The flexibility of modular systems combined with the variety of changes introduced into the morphogenetic building volume enables creating an individual architectural appearance for each project with aesthetically distinguished structural solutions.

In Saint Petersburg, in addition to precast reinforced concrete panels, the ventilated facade technology is applied (Kovalenko and Pastukh, 2017) in the design of load-bearing and enclosing structures. In accordance with this technology, aluminum plates, ceramic granite slabs, and other materials are used as the external cladding layer (Figure 4).

The technological capabilities of computer-aided design as well as modern additive construction technologies prompted the authors of the article to review the use of modern materials and technologies in the construction of residential buildings in Russian Federation (using Saint Petersburg as a case study) and Europe (using Münster, Germany, as a case study) (Figure 5) (Kiseleva and Pastukh, 2017; Pastukh, 2018).

Construction works in the historical urban environment, which includes many central districts

Figure 1. Construction of a multi-apartment residential building with integrated premises with the use of the cast-in-situ and precast technology. Saint Petersburg, 2022. Photo by O. A. Pastukh

a. b.

Figure 2. Cast-in-situ floor slabs with precast walls: a — a general view of the floor slab assembly; b — a formwork with a reinforcement grid, 2021. Photos by O. A. Pastukh (a) and V. N. Elistratov (b)

of Saint Petersburg, result from the requirement to expand infrastructure and preserve existing residential and public facilities, protecting them against settlement during the construction of new buildings in their proximity. The above explains why modern architects and builders tend to apply the brick / cast-in-situ concrete construction technology, which implies the use of such technologies as slurry walls, bottom-up underground construction, bored cast-in-situ piles, cast-in-situ construction of underground and above-ground structures. These technologies ensure foundation stability upon deep pit excavation and underground space development and are implemented at small construction sites

a. b.

Figure 3. Three-layer reinforced-concrete panels: a — by K-33 Group of Companies; b — by Gatchina House-Building Plant, 2017–2018. Photo by V. N. Elistratov

a. b.

Figure 4. A ventilated facade made of ceramic granite slabs on the walls of residential buildings with structural solutions in ceramic granite slabs: a, b — Europe City residential complex, 4 Medikov Prospekt (developer: Vozrozhdenie Saint Petersburg construction company, contractor: LSR Group, architect: S. Tchoban, architectural bureau: Rech). Saint Petersburg, 2015. Photo by V. N. Elistratov

with a minimum stock of building materials.

When converting of buildings located in the historical city center to another use, specialists often choose to cover courtyard spaces with dome structures. It is quite acceptable to use light supporting geodesic domes made of wooden rods connected with fiberglass joints (Zhivotov and Pastukh, 2020).

2. Housing construction in Germany

In Germany, the requirements for thermal insulation are regulated by technical specifications (DIN 4108 (Beuth Verlag, 2013)) and energy saving regulations (ENEV 2016).

The requirements for winter thermal insulation can be met with single-shell masonry walls in combination with bricks that have a very low thermal conductivity.

Earlier, joints between bricks were 1–1.2 cm thick. Currently, thin bed joints of 1–3 mm in thickness are being used more and more frequently for load-bearing inner shells. Such a joint design has a number of advantages: a higher load-bearing capacity of the wall, resistance to moisture penetration into the building structure, and better thermal insulation properties (Sielicki and Łodygowski, 2019).

In double-shell constructions, the distance between the inner and outer shells is about 15–20 cm. The space in between is filled with thermal insulation. In many cases, an air layer of at least 4 cm thick is also incorporated, which allows air to circulate within the construction and, thus, minimizes possible moisture damage. Along the air layer, dewatering or drainage of possible moisture ingress due to driving rain can also be ensured.

Usually, mineral or rock wool is used as the material for thermal insulation (Yörükoğlu et al., 2020). This material is often laid in two layers, which are staggered to avoid possible thermal bridges. If no air layer is planned, the thickness of thermal insulation can be up to 20 cm according to current technical constraints. The two masonry shells are joined by stainless wire anchors (5–7 anchors/m²) with a thickness of 4–6 mm.

Recently, efforts in the use of renewable raw materials for thermal insulation have increased. Various reserches are currently underway to this end, and the long-term durability of the material should also be studied. Among the examples of alternative materials for thermal insulation, the following can be mentioned: cellulose, hemp, flax, and wood chips. Figure 6 shows a double-shell outer wall at the base. Here, it is especially important to provide a moisture barrier against the effects of rain, spray water, and moisture penetration into the construction.

Due to recent fires involving such external wall constructions, some issues have become apparent when flammable thermal insulation is used. In most cases, the applied plaster can prevent fire spread. To prevent such incidents, fire barriers made of mineral or rock wool should be installed at regular intervals or the entire thermal insulation should be non-combustible.

Furthermore, such external wall constructions it can be problematic to recycle. It is quite difficult to separate individual materials because of the bond between them. At present, Germany lacks suitable disposal concepts. This issue is currently addressed in several research projects.

Such a design solution for external walls is often used in Saint Petersburg for the construction of multi-storey cast-in-situ buildings (Figure 6) (Mähner et al., 2013).

In Germany and Russian Federation, ceiling constructions are usually made of reinforced concrete. They are characterized by good fireproof and sound insulation properties. Wooden beam ceilings are rarely used. This kind of application is mainly limited to small single-family houses. Constructions with steel beams to transfer the load are used very rarely in residential construction.

In-situ concrete solutions can be used for concrete ceilings. In this case, bottom and top

Figure 5. Construction of a multi-story residential building in Saint Petersburg (Legenda na Institutskom residential complex), 16 Institutsky Prospekt, (Legenda Intelligent Development, construction of the above-ground structures), 2020. Photo by A. N. Panin

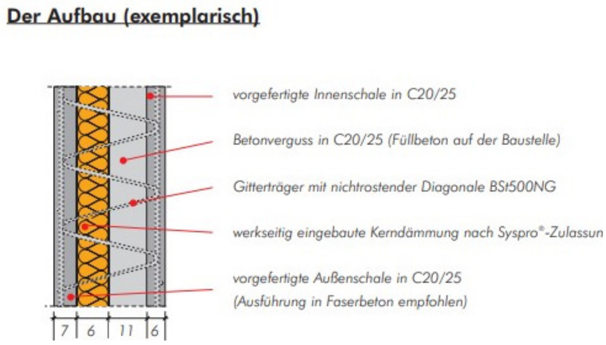

Figure 6. Double-shell outer wall at the base

Figure 7. Precast reinforced-concrete ceiling with in-situ concrete added. Photo by D. Mähner

Figure 8. Precast reinforced-concrete ceiling with in-situ concrete added. Photo by D. Mähner

Figure 9. Non-ventilated flat roof. Photo by D. Mähner

reinforcement (for continuous slabs) is laid on a prepared continuous flat formwork at a construction site. Then in-situ concrete is placed (López-Mesa et al., 2009).

For reasons of streamlining and economic efficiency, slabs are often designed as prefabricated reinforced-concrete slabs with in-situ concrete added. In this case, a precast slab with bottom reinforcement (with a thickness of approximetely 5–7 cm) is manufactured at a precast factory. The surface of those slabs is roughened or profiled to ensure adhesion. At a construction site, slabs do not require continuous formwork. They require only wooden supports (Figure 7). Top support reinforcement is laid on ceiling slabs and then in-situ concrete is placed as the top layer (Mähner and Pitscheider, 2001).

This system can also be combined with larger main and secondary beams of reinforced concrete (Figure 8). In this case, beams are completely formworked and reinforced, and a precast reinforced-concrete slab is constructed as described above.

Flat and pitched roofs can be used for residential buildings. As for flat roofing, non-ventilated roofs (“warm roofs” (Figure 9)) are commonly used (Triano-Juárez et al., 2020). A non-ventilated flat roof has a vapor barrier on the outside of the ceiling (usually of reinforced concrete) to prevent moisture from the building from entering the insulation. Then thermal insulation is glued on. A vapor pressure equalization layer and final sealing are installed on top. Surface protection usually applied to the insulation layer (concrete slabs, gravel pack, top layer of polymer-bitumen membranes, etc.) dampens temperature fluctuations, provides additional protection against mechanical damage or UV radiation, and increases the service life of roof waterproofing. In recent years, there has also been a trend toward green roofs integrating more nature in urban areas.

Discussion

In this article, we highlighted a range of engineering and technological issues making it possible to solve a number of important tasks regarding the preservation and development of the architectural-and-planning structure in cities due to the proper application of basic manufacturing and assembly technologies of residential building construction, modern energy-efficient materials, as well as innovative structural solutions. Particular attention was paid to methods and technologies based on the widespread use of local building materials, light-weight structures, and new domestic technologies.

In recent years, the construction industry in Russian Federation and Germany has been applying widely used technologies of precast as well as cast-in-situ and precast construction (with a partial use of prefabricated structures).

The use of distribution booms installed on tower columns to feed a concrete mix in confined conditions is an innovative trend in cast-in-situ and precast construction. A concrete mix is pumped by concrete pumps to the distribution booms through a pipeline. The issue of automation and, in the future, robotic automation of concrete mix feeding and distribution in the construction of cast-in-situ buildings using the sliding formwork method is highly relevant.

When erecting buildings in the existing urban environment, it is very important to correctly select and apply various housing construction technologies, which can have a direct positive impact on the preservation and development of the architectural-and-planning structure of the city.

In order to renovate the housing stock, save energy, and rationally use natural resources, authorities of all the capital cities of the World Green Building Council member nations (the USA, Australia, Spain, the UK, Japan, the UAE, Russian Federation, and Canada) launched an urban development program. This program is designed for the long term abd aimed at not only renovating the old housing stock and preserving historical monuments but also improving living conditions and promoting a greater sense of community among citizens (Pastukh et al., 2021a).

Green standards are aimed at regulating a sustainable approach to construction, assessing the extent to which buildings meet the basic principles, and accelerating the transition from traditional building design and construction technologies to sustainable practices. The basic principles of sustainable construction are the following:

- providing conditions ensuring health and wellbeing of residents;
- reducing or eliminating the negative impact on the environment;
- keeping in mind possible interests of future generations.

The environmental situation in the world has not changed significantly for the better over the past decades. Continuous breakouts of natural disasters are forcing mankind to think about the need to reduce CO_2 emissions and develop technical solutions aimed at the use of natural materials with minimal waste in the production process. Sustainably harvested wood and wood-based materials are considered such natural building materials. It is a constantly renewable resource, it is easy to handle, and it does not leave any inorganic waste after having been used (Pastukh et al., 2020).

Polymer materials are of interest as well for their technical and physical-mechanical properties. The wide range of properties of these materials, modified by various production methods, opens up many possibilities for scientific and technical solutions in the future.

Solutions for designing geodesic domes from metal and reinforced concrete structures are widely used in modern practice. We believe that the combination of wood and polymer materials in the construction of geodesic domes is highly advantageous in all areas: engineering, financial, economic, energy, and even environmental ones (Pastukh et al., 2021b).

Conclusions

Our main goal was to perform a comparative analysis of the materials and technologies used in housing construction in Russian Federation and Germany, using specific construction sites as examples.

The considered examples of residential buildings constructed with the use of energy-efficient materials, modern structures and technologies of housing construction, allowed us to conclude that, in most cases, identical universal engineering solutions can be used at various construction sites in Germany and Russian Federation, despite different climatic zones.

Therefore, we consider that it is reasonable to continue cooperation between the two countries

a.

b.

Figure 10. Examples of certified design and construction of buildings in Russian Federation and Germany in accordance with international quality and energy efficiency standards: a — the patented “warm wall” technology by Mähner and colleagues (Mähner and Pitscheider, 2001); b — a residential building project in Saint Petersburg, built in 2020, with a LEED quality certificate; the complete list of projects is available at https://arhmc.ru/projects/zelenoe-stroitelstvo/

in the research and implementation of modern innovative solutions for the construction of buildings and structures based on the development of standard design and technical solutions for a large number of different types of building structures that meet the requirements of current regulations and climatic characteristics of the construction region. Particular attention should be paid to compliance with the requirements of sustainable construction, environmental and energy efficiency standards, which will make it possible to take care of the environment in accordance with European LEED and BREEAM standards, as well as Russian Federation GREEN ZOOM standards. Figure 10 shows the title page of the information booklet describing the “warm wall” technology patented in Germany, authored by Dietmar Mähner and colleagues.

In the course of the study, the purpose of cooperation was to share modern rational methods and technologies of erecting residential buildings, ensuring the preservation and progressive development of the architectural-and-planning structure of cities with the use of modern innovations in construction, with specialists at various levels.

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References

Beuth Verlag (2013). *DIN 4108-2. Thermal protection and energy economy in buildings - Part 2: Minimum requirements to thermal insulation*. Beuth Verlag, 34 p.

Deilmann, H., Bickenbach, G., and Pfeifer, H. (1977). *Wohnbereiche Wohnquartiere. Housing Groups. Zones d'habitat*. Stuttgart: Karl Krämer Verlag, 144 p.

Elistratov, V., Pastukh, O., Golovina, S., and Elistratov, N. (2019). Renovation of the block in Madrid in accordance with criteria of Isover MultiComfort House. *E3S Web of Conferences*, Vol. 91, 02005. DOI: 10.1051/e3sconf/20199102005.

Federal Ministry of Justice and Consumer Protection (2013). *Ordinance on the energy saving thermal insulation and facilities technology in buildings (Energieeinsparverordnung-EnEV)*. 50 p.

Gagliano, A. and Aneli, S. (2020). Analysis of the energy performance of an Opaque Ventilated Façade under winter and summer weather conditions. *Solar Energy*, Vol. 205, pp. 531–544. DOI: 10.1016/j.solener.2020.05.078.

Ivanov, D. S. and Golovina, S. G. (2015). Foreign experience of renovation of residential buildings. In: Smirnov, Ye. B. (ed.). *Architecture – Construction – Transport. Proceedings of the 71st Research Conference of Professors, Lecturers, Researchers, Engineers, and PhD Students of the University*. In 3 parts. Part 1. Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, pp. 191–197.

Kiseleva, P. Yu. and Pastukh, O. A. (2017). Modernization of facades in large-panel buildings using the German experience as a case study. In: *Challenging Issues of Architecture. Proceedings of the 70th All-Russian Research and Practice Conference of Students, PhD Students, and Young Scientists*. In 3 parts. Part 3. Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, pp. 145–153.

Kovalenko, V. O. and Pastukh, O. A. (2017). Modern technologies of facade cladding. In: *Challenging Issues of Architecture. Proceedings of the 70th All-Russian Research and Practice Conference of Students, PhD Students, and Young Scientists*. In 3 parts. Part 3. Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, pp. 153–159.

Krikun, A. A. and Tzay, K. V. (2020). Renovation of space-planning and design solutions of residential large-panel buildings on the example of foreign experience. In: Voloshina, Ye. N. (ed.) *Challenging Issues of Modern Construction. Collection of Research Papers of Students, PhD Students, and Young Scientists*. In 2 parts. Part 1. Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, pp. 100–118.

Linov, V. and Ivanov, D. (2018). Building up: creating new homes on top of refurbished post-war estates. *Proceedings of the Institution of Civil Engineers - Civil Engineering*, Vol. 171, Issue 4, pp. 186–192. DOI: 10.1680/jcien.18.00006.

López-Mesa, B., Pitarch, A., Tomás, A., and Gallego, T. (2009). Comparison of environmental impacts of building structures with in situ cast floors and with precast concrete floors. *Building and Environment*, Vol. 44 , Issue 4, pp. 699–712. DOI: 10.1016/j.buildenv.2008.05.017.

Mähner, D., Lengers, J., and Brand, C. (2016). "Energieklinker" – System zur Nutzung solarer Wärmeenergie in Klinkerfassaden. *Bauphysik*, Vol. 38, Issue 2, pp. 81–87. DOI: 10.1002/BAPI.201610009.

Mähner, D. and Pitscheider, W. (2001). Konstruktive und bauverfahrenstechnische Einflüsse auf die Bewehrung von wasserdruckhaltenden Stahlbetontunnelschalen. *Beton- und Stahlbetonbau*, Vol. 96, Issue 5, pp. 343–349. DOI: 10.1002/BEST.200100360.

Mähner, D., Thünemann, S., and Becker, M. (2013). Nachweis von Strukturdefekten und Einbauteilen in Elementwänden mittels zerstörungsfreier Prüfverfahren. *Beton□ und Stahlbetonbau*, Vol. 108, Issue 12, pp. 854–864. DOI: 10.1002/BEST.201300018.

Pastukh, O. A. (2018). The question of reorganization of industrial zones on the example of automobile plant ZIL in Moscow. In: Granstrem, M. A. and Zolotareva, M. V. (eds.). *Modern Problems of History and Theory of Architecture. Proceedings of the 4th Research and Practice Conference.* Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, pp. 111–117.

Pastukh, O., Gray, T., and Golovina, S. (2020). Restored layers: reconstruction of historical sites and restoration of architectural heritage: the experience of the United States and Russia (case study of St. Petersburg). *Architecture and Engineering*, Vol. 5, Issue 2, pp. 17–24: DOI: 10.23968/2500-0055-2020-5-2-17-24.

Pastukh, O., Gray, T. C., and Golovina, S. (2021a). Reconstruction and restoration of historical monuments: international experience. *Architecture and Engineering*, Vol. 6, Issue 1, pp. 32–41. DOI: 10.23968/2500-0055-2021-6-1-40-49.

Pastukh, O., Zhivotov, D., Vaitens, A., and Yablonskii, L. (2021b). The use of modern polymer materials and wood in the construction of buildings in the form of geodesic domes. *E3S Web of Conferences*, Vol. 274, 01024. DOI: 10.1051/e3sconf/202127401024.

Sielicki, P. W. and Łodygowski, T. (2019). Masonry wall behaviour under explosive loading. *Engineering Failure Analysis*, Vol. 104, pp. 274–291. DOI: 10.1016/j.engfailanal.2019.05.030.

Triano-Juárez, J., Macias-Melo, E. V., Hernández-Pérez, I., Aguilar-Castro, K. M., and Xamán, J. (2020). Thermal behavior of a phase change material in a building roof with and without reflective coating in a warm humid zone. *Journal of Building Engineering*, Vol. 32, 101648. DOI: 10.1016/j.jobe.2020.101648.

Yörükoğlu, A., Akkurt, F., and Çulha, S. (2020). Investigation of boron usability in rock wool production. *Construction and Building Materials*, Vol. 243, 118222. DOI: 10.1016/j.conbuildmat.2020.118222.

Zhivotov, D. and Pastukh, O. (2020). Construction of geodesic domes made of wood and composite materials during restoration and conservation of cultural heritage objects. *ES3 Web of Conferences*, Vol. 164, 02020. DOI: 10.1051/e3sconf/202016402020.

СОВРЕМЕННЫЕ МАТЕРИАЛЫ И КОНСТРУКЦИИ, ИСПОЛЬЗУЕМЫЕ В ЖИЛИЩНОМ СТРОИТЕЛЬСТВЕ: МЕЖДУНАРОДНЫЙ ОПЫТ

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Аннотация
Предметом данного исследования является возможность применения универсальных энергоэффективных инженерно-технологических решений в массовом жилищном строительстве вне зависимости от климатического региона строительства на примере современной застройки Санкт-Петербурга (Российская Федерация) и Мюнстер (Германия). Помимо совершенствования строительных технологий, применяемых в современном жилищном строительстве, в настоящем документе основное внимание будет уделено обзору новейших энергоэффективных материалов и конструкций. **Целью исследования** является внедрение энергоэффективных решений в жилищное строительство с помощью инновационных технологий и материалов. В дополнении к теоретическим материалам будут приведены практические расчеты, наглядно показывающие преимущества и недостатки тех или иных инженерно-технических решений. **Были использованы следующие методы: а)** метод сравнительного анализа физических, теплотехнических свойств и прочностных характеристик используемых строительных материалов в области массового жилищного строительства; **б)** проблемно-логический метод анализа возможных типовых объемно-планировочные и конструктивные решения проектирования и строительства зданий с учетом климатических условий и географических особенностей региона строительства, с соблюдением основных принципов современного устойчивого строительства, энергетических стандартов, экономической эффективности применяемых решений и экологичности с учетом международных (европейских и российских) стандартов LEED, BREEAM. GREEN ZOOM. **В результате** авторы предлагают внедрять, наряду с уже известными и проверенными временем, инновационные запатентованные решения в материалах и технологиях возведения как в частном домостроении, так и в массовом жилищном строительстве рассматриваемых стран: Российской Федерации и Германии. **Обсуждение** опыта практических испытаний и процесса внедрения новейших строительных материалов в жилищное строительство наглядно показывает важность международного взаимодействия в данной области на различных уровнях. Растущий объем жилищного строительства и энергопотребления устанавливает новые требования и стандарты к качеству производимых материалов, их техническим характеристикам и разнообразию декоративных решений, позволяющих строительному рынку быть конкурентноспособным и соответствовать завышенным требованиям быстроразвивающегося индустриального общества, не забывая заботиться об экологии окружающей среды, сохранении и бережном использовании природных ресурсов.

Ключевые слова
Энергоэффективность, жилищное строительство, современные строительные материалы, железобетонные конструкции.