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Current educational facilities. Experience in energy-efficient design and modernization of German schools as an analogue for Russia

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Abstract. The problems of improving the consumer properties of buildings designed to accommodate educational institutions in Russia are considered. This is the largest group of social facilities, including kindergartens, schools, colleges and universities. Main tasks of increasing functional and physiological comfort both in the new design and in the modernization of operating buildings identified. The experience of Germany, where for several years the federal program for updating the school fund successfully implemented, demonstrated as an analogue. The approaches that are used by German designers and allow creating comfortable conditions for children and staff in buildings, as well as achieve significant improvements in economic efficiency at the stage of operation by reducing energy consumption are analyzed. The examples are given. The conclusions about the main directions and the need to put into practice formalized quality criteria for design decisions made.

1. Introduction

One of the most important global goals of sustainable development is to provide quality education and to promote lifelong learning opportunities. High-grade education is one of the indicators of quality of life and the foundation of successful economic development of the society. Creating comfortable conditions for learning is a necessary condition for the development of modern educational infrastructure.

Educational facilities are the most widespread typological group of public buildings in Russia [1], which used by almost 30.4 million learners. More than 50 % of them are schoolchildren (table 1). The overwhelming majority of Russian schools built according to various design standards in Soviet period. The development of architectural solutions is determined by range of utilitarian functional problems with frontal teaching methods. During construction, priority is given to advanced construction technologies corresponding to the era of industrialization. As a result, nowadays most of school buildings have an obsolete space-planning structure that does not meet modern requirements for the organization of the educational process. Confirmation of the shortage of school spaces is the official data of the Federal State Statistics Service. So in the 2017–18 academic years, more than 13 % of the schoolchildren were engaged in the second and even the third shift.

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Table 1. Basic statistics on the education system in Russia (2018)

	Preschool education, supervision and childcare institutions	Primary, lower secondary and upper secondary education institutions	Secondary vocational education institutions	Higher education institutions and scientific organizations with bachelor, specialist, master programs
Number of institutions, thousand	48.6	42.0	3.96	0.766
Learners – total, thou. persons	7477.9	15705.9	2944.7	4245.9

Another important problem is the low energy efficiency and instability of the technical systems of school buildings, which does not correspond to modern tasks of maintaining comfort for the successful implementation of the training programs. This leads to an increase in maintenance costs. To solve this problems a number of reorganization measures directed. In 2015, the Ministry of Education and Science of Russia developed new functional requirements for the buildings and premises of educational institutions of the general education system. They are designed to improve the microclimate in schools and create an educational environment that combines the space for learning and personal development. Since 2017, the requirements of the Ministry of Energy regarding mandatory increase in the energy efficiency of buildings, structures and structures with new design and construction, as well as during reconstruction or overhaul of existing facilities, are also applied to schools.

2. Materials and methods

In order to identify scientific approaches to solving the problem during the work, Russian dissertations, books and articles on the architectural and engineering aspects of school design systematized. The most significant contribution to the development of the typology of school buildings in Russia made by A.V. Stepanov (1989), I.V. Kabanov (1990), N.V. Sholukh (1994), O.M. Dyachok (2000), T.K. Magula (2000), S.P. Slavinsky (2007), S.V. Poznyak (2009) and L.L. Nikulshina (2011). Principles and methods of architectural planning the modernization of schools considered by E.V. Pimenova (2003), A.V. Mironyuk (2005), O.A. Bunik (2007), N.M. Evtushenko-Milukaeva (2009) and M.V. Barabash (2016). In the dissertations of engineers A.V. Afanasyeva (2002), V.V. Shcherbakova (2004), N.S. Guryanova (2003), B.S. Pailevalyan (2009) and S.V. Kornienko (2018) ways to increase the energy efficiency of public buildings were proposed. However, in none of the works of Russian scientists, the tasks of improving the architectural solutions of school buildings linked to the improvement of their environmental characteristics. Consequently, the search new environmentally aimed approaches is becoming a promising area of Russian architectural science.

Particular attention in the present study has been given to the systematization of best practices of designing and upgrading facilities. During the work it was revealed that Germany has the most successful experience in solving the problems under consideration. In this country, the federal program for updating the school fund is currently being successfully implemented, including strategic and tactical measures based on pre-project research and monitoring of practical results.

3. Results and Discussion

3.1. Problems of school building design in Russia

In Russia the secondary education from the age of six, designed for 11 years was introduced in 1986. Three-tier structure of training is currently used. The first level is primary education (grades 1–4), the second level is basic education (grades 5–9) and the third level is secondary education (grades 10–11). Educational programs are implemented in institutions with a complete and incomplete organizational and pedagogical structure, when one or two levels of education may be absent. Grammar schools (humanitarian profile) and lyceums (professionally oriented profile) are spread also. Since 2010, as a part of the national educational initiative "Our New School" is identified as the priority area for the development of general education. The main factors determining the search for optimal solutions for new school buildings include the diversification of forms of teaching and pedagogical methods, the development of various types of extracurricular activities, the introduction of information technologies in the educational process and in its management.

At the beginning of the XXI century, Russia resumed the process of introducing reuse projects into the practice of school building construction. By 2019, the database of the Russian Ministry of Construction Industry, Housing and Utilities Sector included more than 260 projects. There are projects of individual buildings, school complexes, attached to the existing facilities of the blocks, as well as schools combined with kindergartens. In these projects, the optimization of the educational environment is performed taking into account the specifics of the urban planning situation, expanding the functional composition of the premises, increasing the size of the recreational group of premises, using more diverse compositional means, etc. In 2018, the Code of Design Rules for General Education Organizations (SP 251.1325800.2016) first established the requirements for improving the energy efficiency of lighting systems, automation and dispatching of building engineering systems. An important innovation related to the condition for the design of such enclosing structures, which make it possible to ensure compliance with the requirements of the building's energy efficiency. The normalized indicators are reduced heat transfer resistance, specific heat-shielding characteristic of a building, specific consumption of thermal energy for heating and ventilation. According to it, the energy saving class of the building is determined. In accordance with Federal Law No. 261 "On Energy Saving ...» the lower limit is class C. Buildings of a lower class prohibited from designing and commissioning. Currently, in Russia, criteria for determining the energy efficiency class of public buildings, including schools, not been developed. The only guideline now is the indicators recommended for multi-unit housing: for buildings of energy efficiency class C, the standard specific heat consumption is 100 kcal·h/m^2. The following table presents some results of a sample analysis of the estimated energy consumption of school buildings, which were introduced into mass practice in the late 1970s (A, B, C), as well as projects developed after 2010 (D, E, F).

Table 2. Selective characteristics of serial school buildings in Russia

	Type design code	Number of schoolchildren	Number of storeys	Total area, m^2	Specific energy consumption for heating, ventilation and hot water supply, kcal · h / m^2
A	222-1-234	784	2–3 (variable)	4268.3	172.6
B	222-1-313	624	1–3 (variable)	3327.46	238.9
C	222-1-315	624	3	3578.0	298.7
D	B-2013/649	792	4	15347.0	127.3
E	238-08-25	825	3	15319.4	179.1
F	06-01/36	1100	2–4 (variable)	24708.6	211.8

Achieving optimal technical and economic characteristics and reducing the specific consumption for heating, ventilation, hot water supply and energy consumption is one of important economic goals. For this next measures recommended: compact space-planning solutions, increase of building width, optimize the orientation of the building and rooms in relation to the sides of the world, take into account the prevailing directions of cold wind and sunlight, apply efficient engineering equipment, as well as automatic or manual regulation of heating, ventilation, hot water supply systems, provide the equipping of engineering systems with sensors and metering devices; use energy-saving lamps, motion and light sensors; to complete the buildings with individual heat points; utilize the heat of exhaust air and waste water, introduce renewable energy sources. In accordance with this, most of the school buildings in Russia need modernization [2]. Consider examples of solving a similar problem in Germany.

3.2. Experience energy-efficient modernization of school buildings in Germany

Most school buildings in Germany, as well as in Russia, were built in the period 1950-1980s or even earlier. Already in the late 1980s, the problem of essentially improvement of the architectural solutions of schools in Germany began to be considered [3, 4]. Over time the need to take into account new aspects has been identified. For example, pedagogical methods have changed: the role of a teacher has ceased to be a leading one, schoolchildren have gained more independence, and the importance of collective work has increased. The introduction of information technology has required new spaces and equipment. In this case, in the «third teacher» concept buildings came to be regarded as an educational factor [5]. Schools have begun to meet the new requirements that contribute to increased learning productivity. Increased attention was paid to ensuring a healthy microclimate (comfortable temperature, humidity, CO_2 concentration in the air, optimal levels of natural and artificial lighting, improved acoustic properties of rooms, etc.). Based on studies conducted by the Frauhofer Institute, it was recognized that it is advisable to optimize all these physical qualities in existing school buildings synchronously, during a simultaneous system modernization. It was emphasized that the involvement of consumers – teachers and schoolchildren into early stages of design, for discussing the details contributes to the success and acceptance of the projects [6].

Significant changes occurred in 2008, when, with the support of the Federal Ministry of Economy and Technology, the implementation of the research project of the foundation "Energieffiziente Schulen" to accompany the energy-efficient modernization of individual demonstration education facilities began. By this time, most of Germany's school buildings were in need of modernization. The project identified key objectives: to identify successful examples of the reconstruction of school buildings in excess of the requirements of the law "On energy saving", as well as the construction of demonstration facilities according to the "3-liter" and "Energy-plus" standards. The ultimate goal is to reduce the total energy consumption of educational facilities on 80 %. The first stage of the project was devoted to the creation of demonstration facilities. Among the first, German-typical schools and colleges located in the cities of seven federal states selected. Of these, two school buildings were newly constructed and five carried out in comprehensive modernization. The main condition for financial support for projects was the use of innovative technologies. During the implementation of the demonstration objects, designers in different combinations used high-performance thermal insulation, triple glazing, electrochromic glazing, automatic mechanical shading, daylight redirection, phase change materials, ventilation system with heat recovery, passive cooling, night-time ventilation, photovoltaics, solar thermal systems, geothermal energy, biogas, biomass, wind power, district heating and building automation. As a result, it managed to achieve energy efficiency indicators that correspond to the two standards - "Energy-plus" (3 buildings) and "3-litre" (4 buildings) [7].

In 2011, Germany, along with Denmark, Italy and Norway, became one of the countries that joined the Seventh framework program of the European Union "School of the Future" (EU 7FP project "School of the Future"). According to the pan-European climate and energy goals of reducing greenhouse gas emissions, increasing energy efficiency and using renewable energy sources, the main objectives of the project were the creation of demonstration school buildings in each of the participating countries. In them, the volume-planning structure optimized and energy-efficient measures implemented. As a result, the buildings meet the requirements of the European Initiative of the European Construction Technology Platform (ECTP) [8]. The project provided for the evaluation of the effectiveness of measures, the subsequent development of recommendations for mass implementation and the active popularization of the most effective technologies, including the organization of vocational training. Needy of modernization key elements of buildings were enclosing structures and engineering systems [9]. In Germany, the complex of buildings of the Solitude Gymnasium in Stuttgart is chosen as an experimental site. Here, four buildings located on the same site used for training, research, creativity and sports. All of them built between 1966 and 1975.

Principal objectives of the modernization were to reduce energy consumption (about 4 times) and improve the quality of the internal environment (air, daylight, acoustic and thermal comfort). This achieved by using thermal insulation of external walls and coverings, replacement of window structures, as well as heating, ventilation and lighting systems. Optimal results obtained through the introduction of hybrid automatic control systems for the climate control of buildings [10].

German Ministry of Economics and Technology implementing the project "EnOB: Research for energy-optimized construction", supports more courageous decisions. Due to this, the Mathias-Thesen School in Rostock became a building that meets the Energy Plus standard and received a new functional planning structure. Instead of a complex of buildings connected in a long chain, a compact volume with an atrium space appeared. The school served by a combined energy supply system: heat supplied centrally, and photovoltaic panels integrated with the building's exterior and interior structures, wind turbines and the Organic Rankine Cycle (ORC) system [11]. The beginning of the project embodiment proposals stimulated the development of flexible models in Germany for assessing the significant parameters of buildings influenced on the consumption of thermal energy. For example, in a study of 105 schools in Stuttgart founded that the presence of a swimming pool leads to an increase in energy consumption by about 84%, in non-compact buildings heat losses increase to 48%, and the change coolant can achieve a reduction in energy consumption by 34 % [12].

The most important condition for verifying the effectiveness of the transition to more rigid energy consumption standards is the monitoring of constructed or modernized objects. For example, a multi-year assessment of the monthly, annual, and specific energy costs for heating, cooling, and powering a school building built to the PassivHouse standard in Bavaria, allowed an international team of researchers to confirm a decline of energy costs and equivalent CO_2 emissions about in two-thirds reduction [13]. Currently, in order to identify objects in modernization need, each administrative unit (city, district, county) monitors current on its balance school fund. Important in this process acquires the issuance of energy passports for every building. In order to improve the physical qualities of school buildings, modernization of heat supply and water supply systems, insulation of the facade and upper floor (roof), replacement of windows, installation of sun protection, improvement of the ventilation system are provided. The package of measures for a specific object is determined individually. Funding is provided from the budgets of cities, districts or counties, and modernization projects are managed by their construction departments. In Berlin, the BIM - Berliner Immobilienmanagement GmbH performs this task for schools are on the balance of the federal state. Many regions have programs that complement the Federal one. For example, BENE in Berlin, aimed at reducing CO_2 emissions, compensates up to 80 % of financial costs. With the help of this programme, projects are supported, in which technical specifications exceed the minimum requirements of the standards.

It should be emphasized that in Germany there are regulations requiring compliance with the principles of sustainable development. Since 2010, the country has been implementing the «Concrete implementation of sustainability into administrative actions» program (Nachhaldigkeit konkret in Verwaltungshandeln umsetzen). Its main requirement is the compliance of the buildings of budgetary organizations with certain levels of the sustainable construction system BNB (Bewertungssystem Nahhaltiges Bauen), developed by the Federal Institute for Research in Construction, Urban Planning and Territorial Development (Bundesinstitut für Bau-, Stadt- und Raumforschung). In addition, all school projects with an estimate of more than 5.0 million Euros must comply with the requirements of another administrative regulation – the "Procurement and Environment Management Rules» (Verwaltungsvorschrift Beschaffung und Umwelt), according to which the most environmentally friendly and socially-oriented proposals are preferred. For example, when replacing window structures, the use of plastic windows (Schulbaurichtlinie) is undesirable. In addition, the choice will be made in favor of the company, which will declare about modernization process without closing the school, which is very important in the absence of school places. The execution of programs, along with increasing the economic and environmental efficiency of school buildings, can increase the prestige of schools, enhance the active motivation of learners and teachers, and increase the level of identification of specific buildings and urban areas. One of the examples of use various modernization opportunities was the Ludwig Renn elementary school in Potsdam (Galandi Schirmer Architekten, Berlin). The school building is typical (Atriumtype). In the 1970s, many similar objects appeared in eastern Germany. The architectural solution characteristic of the socialist period of the country, in 2012 was radically changed: an architectural fantasy of the present aimed at the future was introduced into the rigid spatial structure of the atrium building. The depressing spirit of the panel structure was supplanted with the help of positive colors and high-quality materials. Within two years of the modernization, energy supply systems carried out without interrupting lessons, installed a new solar protection and landscaping was reorganized. Due to the greater penetration of daylight, the conditions for the use of the premises have improved.

4. Conclusion

The study of German experience allows highlighting a number of priority areas that needs increased attention in school infrastructure modernization in the Russian Federation.

First of all, it is the requirement to improve the functional structure of buildings, taking into account the transition to one-shift training and strengthening the role of extracurricular (leisure) activities (cultural, recreational, scientific-educational or sports and recreational). In addition, comprehensive reconstruction activities should focus on environmental principles that contribute to the reduction of resources consumed during the operation of facilities. This complies with modern resource saving concepts such as "appropriate technology", "life cycle assessment", "Cradle to Cradle", "lean manufacturing", "upcycling", etc. In this regard, the next most important condition is the introduction into practice at the federal level of formalized quality criteria for design decisions that reflect comfort. These include, in particular, the energy efficiency class of buildings, the air exchange rate, the range of air temperature differences in rooms, etc. The role of heating, ventilation and air conditioning systems that prevent overheating and overcooling and improve the microclimatic state of buildings is increasing. Probably, at the Federal level, the decision to create a network of demonstration school buildings, both reconstructed and new facilities, in which innovative developments should be implemented that are adapted to local climatic conditions should be recognized as desirable.

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