ENERGY AND RESOURCE-SAVING CONCEPTS FOR THE RECONSTRUCTION OF RESIDENTIAL AREAS FROM THE 1960S TO THE 1980S IN MINSK, REPUBLIC OF BELARUS

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ABSTRACT:

The article explores issues related to the reconstruction of buildings of the old housing stock. For the first time, an analysis of the physical state of operated buildings of mass series built in the 1970s and 1980s is given, on the basis of which a conclusion was made about the possibility of mass modernization with the addition of additional floors. The article substantiates the possibility of performing work on the compaction of the existing building with the addition of additional floors in 5-storey buildings without increasing the load on the existing engineering networks. The article shows that such an approach to the transformation of the urban environment fully satisfies the principles of sustainable development of the city.

KEYWORDS:

Residential buildings, reconstruction, occupancy, building compaction, water supply, electricity supply, sewerage, heat supply, sustainable development

1 INTRODUCTION

In the complex of tasks for the implementation of housing policy in the countries of the northern belt of Europe, the problems associated with the reconstruction of residential buildings of mass housing development in the 1960s and 1980s are becoming more and more relevant and significant.

Buildings constructed in the 60-80s of the last century are 2 to 3 times more energy intensive in operation than the residential buildings constructed today, and do not meet modern requirements in terms of the most important consumer qualities: space-planning solutions, engineering equipment, architectural appearance of buildings and development in general.

In EU countries, thermal retrofitting of existing housing stock is widely used to reduce energy costs in operation [1], [2], [3], [4]. Facade systems have been developed for thermal insulation of the walls of operated buildings [5], [6]. The proven technical solutions make it possible to retrofit buildings, bringing their thermal performance up to the Passive House standard [7], [8], [9].

One of the possible solutions for buildings of the old housing stock is their disassembly with the subsequent use of structural elements and engineering equipment [10], [11], [12]. For the existing series of buildings in the Republic of Belarus, such an approach is difficult to implement, since the dismantling (decomposition) of buildings is too laborious, and the engineering and plumbing equipment is so worn out that it cannot be reused.

Thermal modernisation of residential buildings has been actively implemented in Belarus since the late 1990s. At present a lot of attention is paid to the financing of the thermal modernization of the existing building stock [13].

However, thermal modernization of buildings is carried out point by point for individual buildings. This reduces the energy efficiency of the measure, as at large heat sources the reduction of heat load from thermal modernisation of a single building is almost imperceptible and does not lead to a reduction of fuel consumption during winter operation.

In solving this problem, in essence, two different directions are used: radical, i.e. demolition of old housing and construction of new and more balanced - its repair and reconstruction.

As practice and calculations performed show, the cost of demolition of residential buildings, per m^2 of the total area, ranges from 40% to 60% of the cost of building new housing.

At the same time, the mass housing development of the 1960s-70s and part of the 1980s consists mainly of residential buildings of 4-5-9 storeys, of high capital construction, with a long residual life expectancy.

One of the tasks to be solved before performing the reconstruction of an old building is the assessment of its physical condition, which the authors pay attention to in [14], [15], [16],

[17]. The main attention is drawn to the state of reinforcement in load-bearing structures [15], [16]. There is no single solution to this issue. In domestic practice, to make a decision on the demolition or reconstruction of a building, a detailed examination of structures, foundations and engineering equipment is performed in accordance with [17].

Given the significant number of industrial housing construction buildings built from 1960 to 1990, preference should be given to the reconstruction of buildings in operation. This approach will allow not only to preserve the existing housing stock, but also to significantly (up to 40% or more) increase its volume by building houses and adding additional volumes to them [18].

The analysis of the normative basis, as well as the town-planning and planning decisions of the residential districts of the five-storey building up in Minsk and the regional centres in 1960-80's shows that the density of the existing residential buildings is inferior to the modern norms, i.e. the areas of the five-storey building up have significant reserves for the construction of new housing. The significant residual life of buildings, their advantageous location in the planning structure of cities, and the availability of well-developed engineering and transport infrastructure increase the urgency of the problem of reconstruction of such residential areas [18], [19].

The above analysis of the results of the survey of the physical condition of the buildings of the old housing stock of mass series confirms the possibility of compacting the existing building development with the addition of additional floors. The article shows that the complex reconstruction of residential areas with the compaction of industrial residential development is fully consistent with the principles of sustainable development formulated in the Proceedings of the UN General Assembly in 1987 [20].

2 METHOD

The industrial housing development of the 60s - 80s of the XX century in Minsk is mainly made up of residential buildings of standard series 1-464, 1-335, 1-335A, 1-447. To determine the possibility of performing work on the reconstruction and superstructure of additional floors in 5-storey old buildings, an analysis of the physical state of the structures of buildings built in the period 1970-1990 was carried out based on the results of a detailed examination of typical series. Based on the analysis performed, it was concluded that it is possible to modernize residential buildings with the addition of additional floors and continue their operation.

A comparative analysis of the standards that were in force in the design of buildings and at the present time has been carried out.

Based on the analysis of regulatory documents and statistical information on the number of residents in Minsk, the building density and population of microdistricts during their construction and the allowable increase in living space in built-up areas at the present time are determined. The results of the analysis made it possible to calculate the possible compaction of the existing development of buildings in the microdistricts of the city without increasing the load on the existing engineering networks of sewerage, water supply, electricity and gas supply.

To determine the possibility of compacting the existing building without increasing the power of the heat source, an analysis was made of the amount of heat energy consumption in the operated buildings of the old housing stock and the possibility of reducing it by performing thermal modernization was shown.

3 RESULTS AND DISCUSSION

In the period from 2000 to 2020, the State Enterprise «Institute of Housing - NIPTIS named after. Ataeva S.S.» a detailed survey of residential buildings of mass series 1-464, 1-335 was carried out to make a decision on demolition or work on the reconstruction and overhaul of buildings in order to continue their operation. The number of surveyed buildings of each series (20) allows us to draw a conclusion about the average performance of building structures of serial buildings of construction in 1979-1990 in terms of their ability to carry out modernization with a superstructure of floors and further operation. The number of surveyed buildings of each series (20) allows us to make a statistically reasonable conclusion about the average indicators of building structures of serial buildings of construction in 1979-1990 in terms of the possibility of upgrading with the addition of floors and their further operation. The average age of the buildings is 46 years.

Let's take a look at the 1-464 series buildings. Structurally, Series 1-464 buildings are frameless with load-bearing external and internal reinforced concrete panel walls and reinforced concrete floor and floor slabs. The cross-wall spacing is 2600 and 3200 mm. The structural system, forms a closed rigid box, taking horizontal and vertical forces, providing rigidity and stability of the building as a whole. The outer walls of buildings 1-464 are made of three-layer panels 250 mm thick. External (40 mm thick) and internal (100 mm thick) layers of reinforced concrete, interconnected by expanded clay concrete ribs, and a layer of mineral wool insulation 110 mm thick located between them. Figure 1 is a typical 1-464 series building.

The photograph shown in Fig. 1 shows the joints between the panels, which show the results of repair work on their sealing. Clearly there was repair work on the caulking between the panels. This picture is typical for all buildings of the 20th century building series.

The opening of the panels of this series of residential buildings revealed the degradation of mineral wool insulation, which after 40-50 years or more turned into mineral wool powder. The calculated resistance to heat transfer of the outer walls from the building, on average, is 0,8-0,9 m^2K/W.

Table 1 presents, based on the results of surveys of 20 buildings, the percentage of physical deterioration of the main load-bearing structures of buildings of the 1-464 series.

Figure 1 - Typical panel building series 1-464

Physical wear of load-bearing structures of internal and external load-bearing walls does not exceed 14%, foundations - 24%, and ceilings - 33%. The residual life of the supporting structures of buildings of series 1 - 464 allows their further operation.

Series 1-335 buildings. The structural solution of the 1-335 series residential building is based on a connection scheme with a full frame. The bearing structures are reinforced concrete columns and girders resting on them in the transverse direction. The transverse walls enclosing the stairwells, and the walls in the locations of the bathrooms and kitchens are made of panels with a widening in the ceiling area to support the floor slabs. Picture 2 is the facade of a typical 1-335 series building.

Table 2 presents data on the physical deterioration of the structures of the surveyed buildings. The average wear of the supporting frame does not exceed 12%, and of the foundations - 20%.

Table 1 Physical deterioration of building structures of buildings of series 1-464.

Physical wear of structures, %								
Series of buildings	n=20	Foundations	Outdoor walls	Int. walls	Partitions	floor slabs	Above the basement	Coating slabs
1-464	Average value	23	13	14	15	24	28	33
	Standard deviation, б	6.4	3	3.3	3.2	5.7	9.8	15

Figure 2 The building series 1-335, Gvardeyskaya st., 1a, Minsk

Table 2. Physical wear of building structures of buildings of series 1-335%

Physical wear of structures, %										
1-335	n=20	Service life, years	Frame elements	Outdoor Walls, panels	Outdoor Walls. Brick	Int. Walls inside Panali	Int. Walls outside. brick	Partitions	floor slabs	Coating slabs
	Average value	49.4	11.7	22.5	30.0	15.3	12.5	20.3	15.5	22.8
	Standard deviation, б	4.6	3.3	7.3	0.0	4.1	2.5	5.0	3.6	6.5

The disadvantages of apartments in residential buildings of series 1-464, 1-335, as well as other houses of industrial construction of the considered series, are the small area of kitchens, combined bathrooms, small areas of hallways, walk-through rooms.

The calculated resistance to heat transfer of external walls with mineral wool insulation along the surface, on average, is 0,85 m^2K/W.

The results of the survey of buildings series 1-464 and 1-335 showed that the physical deterioration of bearing structures: elements of the frame and internal walls does not exceed 15,3%, foundations - 24%.

According to the expert assessment of specialists, the residual life of the supporting structures and foundations of buildings of series 1-464 and 1-335 ensures their further operation.

Taking into consideration that the soils under the foundations compacted during the operation of the buildings (40 - 60 years) will allow to carry the load by 20 - 30% higher than the existing level, we can conclude about the possibility, when modernizing the building, to add 2 - 3 additional floors to the existing 5. During the reconstruction of buildings with a superstructure of floors, as shown by domestic and foreign practice, it is possible to improve the space-planning solutions of existing apartments, and design and build new apartments in superstructure floors in accordance with current regulatory requirements, with modern consumer qualities. In order to reduce the load on the load-bearing structures and foundation of the building, it is advisable to add additional floors using lightweight structural systems and materials [18].

Figure 2, 3 and 4 show a residential building of series 1-335, Gvardeyskaya st. 1a, Minsk, before and after thermal modernization and reconstruction with a two-story superstructure.

External elevators were added to the building from the side of the courtyard. Figure 4 shows the rear facade of the building with additional external elevators attached. After the reconstruction, the building acquired a modern architectural appearance and, in terms of its consumer qualities, meets modern requirements.

Figure 3 typical series 1-335 after reconstruction

The main factors that determine the possibility of compaction of housing development in residential areas of cities include:

- satisfactory physical condition of building structures;
- compliance with building density standards;
- sufficient capacity of the water supply system;
- sufficient capacity of the sewerage system;
- sufficient capacity of the gas supply system;
- sufficient capacity of heat sources;
- sufficient capacity of the source (TS) of power supply;
- Ensuring the standard for the number of parking lots.

Figure 4 The rear facade of the building with additional external elevators attached.

Table 3 shows the values of the allowable density of residential development at the time of building construction [21] and the allowable values at the moment [22], [23].

Table 3 - Possible changes in building density

Density of housing, m² of floor area per 1 ha of residential area, in residential buildings with number of storeys									
	2	3	4	5	6	7	8	9-11	≥12
Existing [21]	2400	2700	3100	3400	3500	3600	3700	3800	4100
Regulatory at the moment [22]	2500	2500	2500	2500	5000	5000	5000	5000	9000
Special specifications [23]	14000 -15000 m²								

The data from Table 3 make it possible to conclude that the addition of two extra floors in a 5-floor building will increase the density of the housing stock from 3,4 to almost 5,0 thousand m^2, i.e. 1,5 times, and with special construction conditions even more.

The question is whether the water, sewerage, electricity and heating networks serving the neighbourhood planned for the densification of the existing development have sufficient capacity.

The water supply system is calculated based on the number of inhabitants living in the housing estate, micro district (house, block). Figure 5 shows a graph of the population density change in Minsk from 1970 up to the present time, constructed according to generalised data from [24], [25], [26]. During the period of the construction of the main mass building stock from 1970 till 1990 the housing availability in Minsk changed from 10 to 15 m²/person. At present it is 23,5 m²/person [25].

Engineering networks were designed for average occupancy conditions at the time of building design. In 1970 - 1990, the occupancy of housing was 10 - 15 m²/person [24], [25]. At present, the average population in Minsk is 23,5 m²/person [26].

Water consumption is calculated, in accordance with [27], 105 l of hot and 130 l of cold per person per day. In recalculation, at the time of building design, this was 10,5 l/m^2 per day for hot water, and 13 l/m^2 per day for cold water.

Consequently, water supply, sewerage, gas supply systems designed to serve the number of people determined from the conditions at the start of design in 1970 - 1990 with a population of 10 - 15 m^2/person have a reserve for today's housing stock with a total area 1,5 - 2 times larger than at the time of designing the microdistrict.

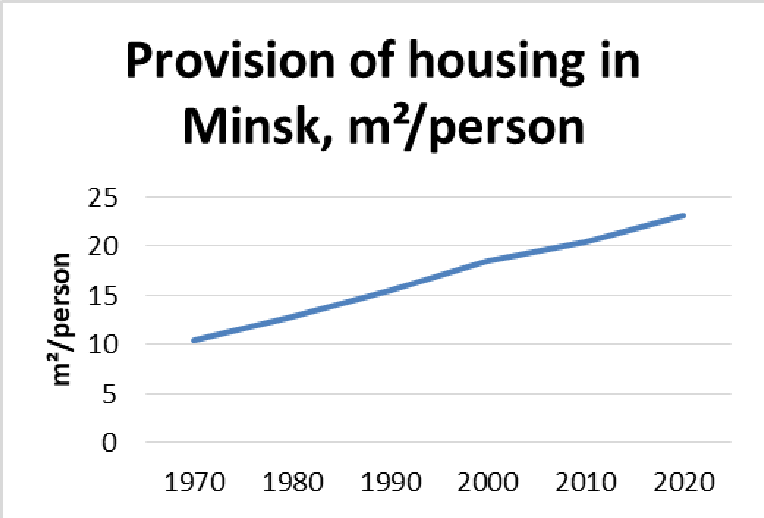

Figure 5- Graph of changes in the provision of housing in Minsk

The capacity of electricity supply systems, taking into account the significant increase in the energy efficiency of household and lighting appliances used by the population, may also be sufficient when the area of the serviced housing is increased by 1,5 - 2 times.

The issue of heat supply of buildings for heating and hot water should be solved by a comprehensive thermal modernization of existing buildings, the application of proven technical solutions to reduce energy consumption in the hot water supply system, as well as the additional construction of energy efficient residential buildings that meet the requirements of current regulatory documents on heat consumption for heating and ventilation [28] using a wastewater thermal energy recovery system to reduce energy consumption in hot water supply systems of buildings [29]. The dynamics of changes in the normative values of thermal resistance of enclosing structures of residential buildings is presented in Table 4.

The data in Table 4 indicate that the standards of resistance to heat of elements of the enclosing structures of residential buildings in force before 1990 are significantly lower than the current ones. The consequence of this is more than 2,5 times higher energy consumption for heating of the old housing stock.

Table 4. Current standards for heat transfer resistance

Validity period	Thermal transmission resistance of the enclosing structure (average values), m2*K/W			
	Walls	Window	Basement	Attic floor
Before 1994 [30]	0.84	0.36	1.20	1.30
1994-2010 [31]	2.2	0.6	1.1	3.0
After 2010 [32], [33]	3.2	1.0	1.85-2.5	6.0

The results of measurement of specific heat consumption for heating in buildings of the old housing stock given in [29] confirmed that the values of energy consumption for heating for the design operating conditions are in the range of 110 - 160 kWh/m^2 per heating season, while after the implementation of thermal modernization works and bringing the heat transfer resistance of building envelopes to the current standards [33] the value of specific heat consumption for heating of buildings in Belarus will decrease to the level 50 kWh/m^2 per heating season. The capacity of the heating system for a cold five-day period, for a temperature of -24 C, will also be reduced by more than 2 times.

According to the calculation, at the time of the design of old buildings, taking into account the occupancy [24], [25]. and the norms of hot water consumption [26], the energy consumption for the preparation of hot water amounted to 150 kWh/m ^{2} per year. In fact, the consumption of hot water is significantly below the normative value and is about 70 l per person per day [29]. Taking into account the current occupancy in Minsk [26] the energy consumption for hot water preparation will be 49 kWh/m^2 per year. The use of waste water heat recovery system in building reconstruction projects will allow to save up to 20% of energy for hot water preparation [29], which will reduce the energy consumption for this purpose to 39 kWh/m^2 per year. Thus, in compacting the residential buildings with simultaneous work on thermal modernization of buildings and the use of wastewater heat recovery system, the average thermal energy consumption in the operation of buildings can be 89 kWh/m^2 per year with a design value of 288 kWh/(m^2/yr) at the time of construction, that is, reduced by more than 3 times compared with the current level.

Taking into account that the thermal energy indicators of additional residential areas as a result of the superstructure of 5-story buildings and the construction of new ones will comply with current standards [33], we can predict that even with an increase of residential area in the built-up area by 2 times the capacity of existing energy sources will be enough to supply them with energy.

In general, taking into account the above analysis, it is possible to conclude that with the compaction of the existing buildings of the 70s - 90s of the last century, the total living area in the residential areas of Minsk can be increased by at least:

- by 50%, based on existing standards for residential density;
- By 130% based on the possibility of engineering networks serving the microdistricts;

- 300% on the basis of the necessary energy for heating and hot water supply of buildings, subject to the implementation of works on thermal modernization and the use of waste water heat recovery.

At the same time, the decision to compact the residential environment of a microdistrict (residential area) should be preceded by a detailed examination of the physical condition of the housing stock, engineering networks and the development of a feasibility study, taking into account the specific situation in the microdistrict (residential area), the current regulatory and legislative framework.

In 1987, the UN General Assembly determined [20] that "sustainable development must meet the needs of the present without compromising the ability of future generations to meet their own needs”.

As an illustration of the conditions for sustainable development, the diagram presented in Figure 6 was given in [34]. The diagram shows that sustainable development is the result of the coincidence of three factors:

- economic development of society, providing an increase in the standard of living;
- social development that respects human rights and develops human potential;
- harmonious development of the environment, ensuring the preservation of the ecological balance.

Thus, the sustainable development of cities involves solving the problem of giving the old housing stock modern consumer qualities and thereby improving the environment, ecology, social sphere and engineering and transport infrastructure of microdistricts. The development of old housing estates, through residential densification and upgrading of existing buildings, also aims to prevent urban sprawl and increase resource efficiency through energy efficiency and renewable energy sources.

The presented justification for the possibility of compacting the existing residential development of the 70s - 90s of the last century indicates that it is possible without increasing the load on the existing engineering infrastructure: heat supply, water supply, electricity and sewerage systems.

Thus, in the microdistrict there is the possibility of additional construction of up to 100% of residential areas (in relation to those existing in the microdistrict). The consumer qualities of the new apartments will meet modern requirements both in terms of comfort and their thermal and energy performance. After the thermal modernization, the buildings of the old housing stock will approach the thermal energy performance and comfort of living to the buildings of the new construction. Densification of residential development will achieve a positive social effect, the problem of environmental protection will be solved, as new residential areas will not require in their operation additional consumption of natural resources and energy, and a significant increase in housing in large cities will be provided without increasing the area of urban areas. When using the existing engineering infrastructure, the cost of building additional residential areas may be less than when building on a new territory.

Thus, the compaction of the existing housing development in microdistricts is fully consistent with the principles of sustainable development formulated in [20], and can become one of the main directions in the housing construction strategy for the next five years.

Figure 6 Diagram of "Sustainable Development".

4 CONCLUSION

The article outlines the principles of sustainable development of the urban environment, which are based on the comprehensive reconstruction of residential buildings in the 60s - 80s of the twentieth century. The proposed approach to the reconstruction of microdistricts involves the compaction of residential development with an increase in the living area of buildings by more than 1,5 times, the preservation of the existing engineering infrastructure without increasing its capacity.

For the first time, based on the results of a detailed survey, an analysis was made of the physical state of the structures of buildings of mass construction series: 1-464 and 1-335, on the basis of which it was concluded that, on average, the state of load-bearing structures and foundations allows the reconstruction of buildings with superstructure 2 - 3 floors. The sample size used for the analysis of the physical condition of the buildings makes it possible to extend its results to all operated buildings of the considered series.

The following conditions are formulated to ensure the possibility of compacting housing development in the city:

- satisfactory physical condition of building structures;
- compliance with building density standards;

- sufficient capacity of the water supply system;
- sufficient capacity of the sewerage system;
- sufficient capacity of the gas supply system;
- sufficient capacity of heat sources;
- sufficient capacity of the source (TS) of power supply;
- Ensuring the standard for the number of parking lots.

Based on the formulated conditions for the possibility of compacting residential development, the total living area in residential areas of Minsk can be increased by at least:

- by 50%, based on existing standards for the density of residential development;
- by 130%, based on the possibility of engineering networks serving microdistricts;
- by 300%, based on the required energy for heating and hot water supply of buildings, subject to the completion of thermal modernization and the use of waste water heat recovery.

It is shown that the proposed approach to the integrated reconstruction of residential areas fully satisfies the principles of "Sustainable Development" of cities: when compacting residential development, a positive social effect will be achieved, the problem of environmental protection will be solved, since new residential areas will not require additional costs of natural resources during their operation and energy, the compaction of residential development also solves the problem of cost savings during construction, will provide an increase in new living space without expanding the territories of cities.

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