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Sustainable Renovation of Soviet Buildings of First Mass Series: Possibilities for Energy Efficiency

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The research project was carried out in order to determine the need and potential for renovation and reconstruction of Soviet buildings of first mass series, as well as to define the most optimal renovation solution in terms of improving the building's overall performance, reducing energy consumption, and reaching the current requirements for energy efficiency in the buildings. The goal was also to find out the minimal energy-efficient measures that can lead to such improvements.

The project was carried out by conducting a broad theory research with different perspectives on the solutions for the topic, and an analysis of possible renovation solutions in terms of their energy and cost efficiency. The analysis was performed as a case study of a particular building of the most common series with the greatest potential for renovation in St Petersburg.

The result of the project is the determination of the need for renovation and reconstruction measures for buildings of first mass series in Russia. The calculations showed a great potential of renovation and its economic feasibility. With the help of energy and cost-efficiency calculations it was possible to determine the most optimal and sustainable option for renovation for the studied building. The proposed solution includes complex reconstruction with the construction of an extra upper floor on an existing building as well as few energy-efficient measures, such as extra thermal insulation of the building envelope and mechanical heat recovery ventilation.

The carried-out research project proved that the renovation of the buildings of first mass series is necessary and economically viable. The proposed solutions can be applied not only to the chosen series with the greatest potential for reconstruction, but also for many other buildings of first mass series. The proposed solution could be further studied and applied to some buildings in the form of pilot projects to test the calculated potentials in the real-life situation.

Keywords	energy-efficient renovation, reconstruction of buildings, energy efficiency and cost-efficiency

Contents

1 Introduction

Renovation of serial Soviet buildings is a topical issue in Russia. A major question is the future of houses built in the 1960s, the so-called first mass series buildings or Khrushchev buildings. The housing stock of them is very vast and most of the buildings are in need of major repairs. However, they still have a great potential and they have not used up their service life period. Some of the serial buildings are more durable and are still in a good condition, so they cannot be considered to be in an emergency condition. The urban significance of the existing buildings is also quite high in many cities.

Because of their potential, the buildings should not be demolished. Instead, measures should be taken to renovate or reconstruct them. The poor condition of the buildings, however, should be addressed with great care when planning the renovation works. The typical problems usually include poor quality of insulation, unsatisfactory condition of sanitary services, poor quality of joints between wall panels, small apartments, low ceilings, and poor sound insulation. Many of the existing buildings show quite deficient energy performance that does not comply with the current standards.

Because of these reasons, it is important to carry out a massive renovation and reconstruction programme to solve the problems of the buildings. The measures should be technically feasible and the least costly from a financial point of view for a successful implementation of such a programme. At the same time, the energy-efficiency of the buildings should achieve the new standards. The reconstruction of the buildings of first mass series has a very significant potential in terms of energy savings.

The problem of the renovation of the housing stock is seen nowadays in St Petersburg. There are many buildings of the first mass series that have a large margin of structural safety, but in many aspects they have become obsolete. Complex modernization is needed. However, it is important to find the optimal ways of implementation of such activities.

Considering the scale of the problem and possible limitations for the implementation of many renovation projects, the following research questions were asked:

- Whether there is a need and real potential for renovation?
- What are the feasible options available for renovation and reconstruction?
- What minimal and cost-efficient energy-efficient measures can be used in order to boost a building's performance up to the current norms and standards?

To answer the first research question, the need and potential for renovation was suggested to study by evaluating the current renovation situation of the first mass series buildings in Russia. The second research question was investigated by comparing and evaluating the renovation and reconstruction options in terms of their potential to improve the building's performance, to reduce the energy consumption, and to meet the modern requirements. The third research question was answered by an analysis and evaluation of energy-efficient measures in terms of their energy and cost-efficiency and other factors of sustainability.

Sustainable renovation can be understood not only as possible energy savings. There are also a variety of other positive benefits arising from renovation or modernization activities. Factors that are associated with sustainable renovation include economic benefits, which relate to energy savings and budget considerations, ecological benefits for the environment, and social benefits for people, associated with comfort, health, and better living standards. These factors need to be considered when deciding of the need for renovation or reconstruction, and of the possible measures used for renovation activities.

To answer the research questions, chapter 2 discusses the historical background and the current state of the existing first mass series buildings, existing renovation methods and programmes, as well as completed projects. Then, information is provided about the new laws on energy efficiency in Russia and possible energy-efficient solutions. The current situation with the buildings of the first mass series in St Petersburg is also discussed. Then, based on the theoretical research, the methods and materials for the analysis part of the project are presented in chapter 3. The thesis continues with a detailed description of the analysis and its results.

2 Theoretical Background

2.1 First Mass Series: History and Current State

Series of buildings are groups of residential buildings that are usually identical within each group in architectural design, apartment layouts, structural solutions, and materials used in construction. The series are also united into types of houses by time basis, which is the year of development and construction of a typical project, or wall material. The materials used for construction of different series are reinforced concrete panels, concrete or brick blocks, and brickwork. [1.]

Types of serial buildings in Russia can be divided into approximately five periods of construction. The first period started in the early 1950s, and the buildings can still be called as “Stalin buildings”, as the first attempts to start mass production of such houses began when Stalin was the leader of the Soviet Union. The second construction period coincided with another ruler, and such houses are usually referred to as “Khrushchev houses”. These houses are mostly five-story buildings with walls made of panels, blocks, or bricks. The period last from 1957 to 1962. The third period started around 1963 and was marked by the appearance of the first nine-story and twelve-story buildings. They are also called by the name of the leader of the country as “Brezhnev buildings”. The fourth period started in the mid-1970s and lasted for the rest of the Soviet era. Such houses are usually called as “improved series” as they differ quite much from the earlier ones in terms of construction solutions and they have, on average, more convenient apartment layouts. Some series of such buildings are still currently being built. The fifth period of construction of series of buildings started in the mid-1990s and lasts till present time. [1.]

As for the Khrushchev buildings, the most common series could be divided into four typical design schemes: buildings with transverse and longitudinal bearing walls with small spans, buildings with external bearing walls and internal frame, buildings with three longitudinal bearing walls, and buildings with transverse load-bearing walls with large spans. [2.]

There is also a variety of configurations of the series, which differ for each region. Various planning and design solutions were made according to the climatic and geological conditions, as well as the materials and technical base of housing construction that existed in a given area. [2.]

2.1.1. Architectural Concept of Serial Construction

The Khrushchev houses mark the global modernist project of transition to industrial construction in the Soviet Union. The project of mass construction to eliminate the housing shortage became successful precisely because of the development of serial projects of houses. The first attempt of mass serial construction was made even earlier, however, it did not solve the existing problems. The country needed a quick and effective solution for an existing problem in the conditions of resource shortage. In the discussions of the 1960s, the new trends of “rationality” and “efficiency of the means used” played a significant role in the invention of the mass construction project. The trends were, however, mostly associated with cheapness and simplicity as well as how the project could justify the costs. [3.] That required also a revision of established methods of construction, design standards, and norms. The need was seen as to build fast, cheap, and in a massive scale. The result was the origin of typical house projects, in which the new standards for housing were established. The new houses had a very simple architectural form, the inner layout was designed based only on functionality. House designs did not imply any architectural excesses and nowadays the built areas can look rather monotonous. Not only these could now be seen as the major drawbacks of existing buildings, but other characteristics of these houses were criticized in many ways. These are the small size of apartments, inconvenient layouts of apartments, tiny hallways and kitchens, passage rooms, low ceilings, and poor quality of construction. [4.]

However, it was these qualities that made it possible to construct buildings in such a large scale and helped to resolve the problems with the accommodation of so many Soviet people. The main idea of the massive project was to provide an apartment for each family, and it was done in the way it was possible at the time. [2.]

2.1.2 Condition of Existing Buildings

The current condition of the existing buildings is quite poor in many cases and largely influenced by inappropriate exploitation and the absence of repairs [5]. For this reason, such houses do not meet modern requirements in terms of energy consumption, architectural planning, and many other factors. As a result, some of the buildings are already being demolished. On the other hand, a number of technical surveys show that the bearing structures of most of large-panel and brick buildings are still in a normal condition and have significant reserves of bearing capacity. Separate elements of buildings such as balconies, on the contrary, are in emergency condition in many buildings. In addition, the engineering systems and equipment are worn out and obsolete and require replacement. [6.]

Common problems in most of series of buildings can be divided into two main categories: building envelope elements and building services. The most problematic part of the houses are external walls, especially in paneled buildings. Other common problems are leakages in the walls, moisture problems, insufficient insulation. The heating systems of the buildings often perform quite poorly because of leakages in district heating networks, variations in pressure levels and difficulties in balancing and controlling the building systems, poor quality of water, and a lack of proper maintenance and control. [7.]

2.1.3. Need for Modernization

The modernization of the Soviet building stock described above can be implemented in two ways: either modernization with a renovation or reconstruction of existing buildings, or modernization that requires the complete demolition of existing buildings and a construction of new ones. The choice depends usually on which series the building belongs to and largely on the building’s condition. The question of which modernization way to prefer for each particular case is a topic for debate in Russia these days. Each point of view has it own strong points. Several researchers believe that the renovation of buildings has no economic feasibility due to the complexity of its implementation. Others think that demolition is not a rational choice for such buildings. Both opinions are partly true, as it is not possible to state that all buildings can be renovated, nor can all of them be demolished. Approximately 25% of the buildings of the first mass series have reached such a level of wear that they cannot be renovated efficiently. But the rest of buildings could still be considered for renovation or reconstruction projects, although an individual approach is required in the decision-making process. [8.]

The decision of demolition of existing buildings might be an optimal option, if it is more efficient and beneficial for the local community or a city district than renovation or reconstruction of existing buildings [9]. However, from the financial side, the demolition should ensure the break-even implementation of such project. Also, the construction of new housing needs to be carried out before the demolition of existing buildings. [10.] The whole programme might last for decades for this reason, and the disposal of demolition waste might become a serious issue for a city [11]. All this makes such a scenario of modernization quite complicated and needs a thorough planning and suitable conditions. Therefore, the programme of mass demolition of the Khrushchev buildings that is implemented in Moscow nowadays might not be a suitable option for other Russian regions. [12.]

It is also worth mentioning that the districts of buildings of first mass series are already established urban structure with a developed infrastructure, the construction of which took many years. The development of new urban spaces or the inclusion of new buildings into areas with existing ones might also be a great obstacle for decision on demolition. [13.] Given the discussed issues, many specialists say that renovation or reconstruction of buildings would be a more optimal solution for the existing problem [14]. It is also argued that demolition is the only way for modernization because of the weak condition of the buildings. Over the years of operation, almost none of the Khrushchev buildings came to such condition that can threaten the lives of people and the majority of buildings possesses substantial reserves of structural strenth and stability. The repair is needed for minor elements. It is technically possible and there are a variety of renovation methods. [15.]

The main advantage of renovation over new construction is the lack for constructing foundations, which saves cost of the project. In addition, there is no need to build the new district networks, and no need to buy or rent the land for construction, which is becoming a serious problem in big cities and, especially, in good, well-developed districts, where the Khrushchev houses are usually located. [16.]

As for the buildings that might have the greatest potential for renovation, the most attention could be given to the brick series of buildings. They have not yet exhausted their physical resources given the long service life for brick buildings (125 years) [17], and they can undergo any reconstruction given their structural properties. In addition, the cost of repairs for brick buildings can range from 20% to 50 % of the cost of new construction. [18.]

The statistical data shows that the minimal necessary volumes of renovation of residential buildings in Russia are more than 700 million square metres of the total area, and more than 250 million square metres of these are buildings of the first mass series [19]. Such a great scale requires complex measures to solve the main problems of implementation of renovation programmes. At the moment, there are not enough measures taken to create mass renovation programmes. However, the initiation of new governmental law on energy efficiency creates a favorable situation for future actions. [20.]

The benefits of renovation should be also taken into account when deciding on the modernization programme for a building. Renovation will improve the conditions of the buildings and help to eliminate the physical wear, it will help to reduce the energy loss and consumption costs, and also increase the comfort and architectural quality of the building. [21.]

2.2 Renovation and Reconstruction in Russia

In the Russian context, renovation means the restoration or replacement of individual parts or entire structures of the building envelope and building services systems. It is done to eliminate their physical deterioration or destruction, restore their condition and performance. The repair work aims at the elimination of physical and functional depreciation of the building. [22.]

Reconstruction involves the reconstruction of the building with a change in the building volume, purpose, or appearance. An extra upper floor or a new part of the building may be attached to the building. During reconstruction, the renovation works and the works on new construction are performed simultaneously. [17.]

Modernization of the building can be understood as the works to improve the building's performance in order to keep it up to date to the current standards [17].

2.2.1 Goals of Renovation and Reconstruction

Renovation and reconstruction can achieve positive social and economic results [23]. They may result in an increase of the constructive and operational reliability of buildings by means of general repair works, obtaining additional living spaces in the case of extra construction to an existing building, and a reduction of energy consumption in buildings due to thermal insulation of the building envelope elements. These measures improve the living conditions of people, quality of service, and the urban environment. [17.]

According to Fedorov et al, the social orientation should be the main goal of renovation works. However, successful implementation depends on many other factors. The technical and economic feasibility of a project is one of the key factors that influence the decision on renovation or reconstruction. The feasibility is defined during the planning and design stage of the project, taking into account the technical solutions and the costs and benefits of different design options. [17.]

The legal and regulatory framework also provides a basis for the renovation and reconstruction works. The works should be carried out in accordance with the Town Planning Code, Housing Code, and Land Code of the Russian Federation. Other standards include codes of practice and state standards of the Russian Federation, general technical and special technical regulations, territorial norms and rules, and many other documents. [24.]

2.2.2. Existing Methods

Each building requires its own method and technology of reconstruction, but for a series of buildings, a suitable option for one building of one series will probably be suitable for another as well. In this case, the renovation or reconstruction method can be expanded to each series of the buildings. [25.]

Renovation usually includes the general repair of building's structures, complete or partial restoration or replacement of structural elements or equipment, improvement of building's appearance, landscaping works. The modernization of a building can be carried out during renovation works and will usually include such measures, as installation of new engineering equipment, the modernization of apartment layouts, and increasing thermal protection of the building. [17.]

Reconstruction can be implemented in different forms and methods. First of all, reconstruction works usually include the same procedures as the basic renovation and can also include the modernization of separate building elements or the whole building. Then, there are different methods that can be included in the reconstruction works: changing the overall design, changing only the apartment layouts, not changing any design solutions; increasing the total area and volume of the building by adding a mansard floor or extension; reconstruction with resettling residents or without resettling residents; with a change of function and purpose of the building or without a change. [25.]

The ways to add extra area and volume to existing buildings can also be done with various methods. One technique is to build an extra structure on top of the building, which can be either an attic floor or a full floor. Second option can be the construction of an extension to the building, if there is enough space around the existing buildings. Third option is a combination of the construction of extra upper floors and extensions. The choice of a particular option is made based on the goals for renovation projects, and what is more, on budget considerations. It is calculated that by selling the apartments in the extra construction it is possible to carry out the complex reconstruction and modernization of a building with a certain profitability. For this reason, it is advisable to do a complete renovation and modernization of the building together with a construction of extra upper floors or extensions. [10.] It is also worth noting, that the total cost of complex reconstruction of a building, amounts to no more than 75 to 85 percent of the cost of a new construction of the same area [17].

The construction of extra upper floors can be made according to town planning requirements and economic considerations. The existing five-storied Khrushchev buildings can undergo a construction of extra two-three floors without foundation reinforcement. Total area added accounts for about 13-14% of the total area of the building if one or two floors are added. In addition, attic floors allow to get housing at a cost of 25-40% percent cheaper than new home. [17.]

There are three types of extra floor construction:

- Attic floor, where the living space is located on the site of a converted attic space
- Full extra floor, an extension of the existing building's floors to one or several floors
- Special rooms or recreational spaces that are placed on the roof. [17.]

The structural solutions for adding an extra floor also differ. To generalise, the options can be built either on existing load bearing walls, or on extra built columns, or using an independent frame system. [17.] Building materials, such as wood, concrete, metals can be used in construction. The lightweight materials are more preferable. [26.]

There is already some experience of extra floors construction on five-storied buildings, and it was already proved that this method of reconstruction is the most effective in terms of adding more total area to the building and expanding the housing stock. It does not require an increase in the land plot, and the bearing potential of existing buildings make such constructions possible. [27.]

The high profitability of the attic floor construction for potential investors was also identified in an analysis of completed projects. Another advantage is that such construction can be carried out without resettlement of house residents. In that case, however, there are some special requirements for the execution of the construction works at the building site. [11.] In addition, each building should be examined and checked in order to determine the condition of supporting building elements and the potential for reconstruction [28].

2.2.3 Renovation Programmes

The attempts to solve the problem with the existing building stock of first mass Khrushchev buildings have been made in Russia since the late 1980s. That time the first reconstruction of a building series 1-335 already took place in Leningrad (Saint Petersburg) in 1987. [29.] The necessity for such measures was brought forward by the deteriorating state of that particular series of buildings. During the 1990s and the beginning of the 2000s a number of other renovation and reconstruction projects were carried out throughout the country. The massive reconstruction programme was initiated in 2000 in St Petersburg and had the task to modernize the existing five-story serial buildings using the method of extra floor construction and basic renovation measures. Unfortunately, the programme was not implemented and only few buildings were renovated. In Moscow several Khrushchev buildings were also renovated or reconstructed. [30.]

Another perspective on the solution to the housing problem emerged in Moscow in 2006 with a massive demolition programme of five-story Khrushchev buildings. The plan of the programme was to dismantle the most unsatisfactory series of buildings, which are K-7, 1MG-300, 1605-AM, II-32. By taking such measures, the programme was aimed at the renewal of the urban environment and development and improvement of housing stock. [31.] The course of the programme was not very successful in the beginning due to the lack of financing and the finish of the project was constantly postponed. Nevertheless, during last couple of years the programme was restarted and many houses have already begun to be demolished. [32.]

An almost identical program of modernization of urban spaces was launched in Saint-Petersburg in 2008 and was postponed due to same reasons as in Moscow. The plan of this programme, however, had the task to demolish only the buildings with very high percentage of physical wear. To date, the programme is still experiencing difficulties. [33.] The current discussions of above mentioned programmes can draw a conclusion that the project of mass renovation and reconstruction does not seem to be very relevant despite the discussed advantages of such measures. After the year 2016, there has been no plans at the official level about the possibilities for reconstruction programmes. [34.] Moreover, the government of Saint-Petersburg recently initiated a draft law on housing modernization like the Moscow case for the whole country. This was proposed given the fact that in most regions there might be not enough funds and technical possibilities to conduct such complex programme. [35.]

2.2.4 Completed Projects in Russia

Despite the difficulties with financing and legal issues, a number of renovation and reconstruction projects have been implemented in Russia over the past decades. The project of reconstruction with an addition of extra attic floor was implemented in the city of Lytkarino, Moscow Region in 1997-1998. The existing four-story building of the brick 1-447 series was chosen for this pilot project. The renovation measures included some general repair as well as the modernization of the building with the inclusion of thermal insulation to the outer walls, replacement of the heating system with the installation of a heating system substation and automatic controls. [28.]

In the late 1990s and early 2000s a joint reconstruction programme with several companies like Rockwool, Danfoss and Velux was executed in the Moscow Region and Saint-Petersburg. The works included the modernization of the Khrushchev buildings and the construction of an occupied attic floor. The experience was claimed by the government as to be successful and it was continued in other Russian cities. Nevertheless, the programme did not become a large scale one for the reasons of low profitability, lack of benefits for residents, and ambiguous legislation. [36.]

A similar project was carried out in Ufa in 2005-2007. The reconstruction of the five-storied paneled building included the construction of two extra floors, heating system modernization, replacement of windows and balcony doors, modernization of hot and cold water networks, energy meters installation, and a basic façade repair with the installation of a layer of thermal insulation. The building after reconstruction can be observed in figure 1.

Figure 1. Reconstruction of the building in Ufa [37].

Unfortunately, the project was not successful. The investor company from the Czech Republic left the project unfinished due to financial problems, and the completion of reconstruction took more time than planned. After such results of the project, other projects of reconstruction of the adjacent houses were cancelled. [38.] For the last several years, a Regional City Programme of renovation of buildings takes place in Ufa [39]. An example of such renovations can be seen in figure 2. This building apart from basic renovation measures was also thermally insulated, and the repair of façade with the construction of ventilated façade system was carried out.

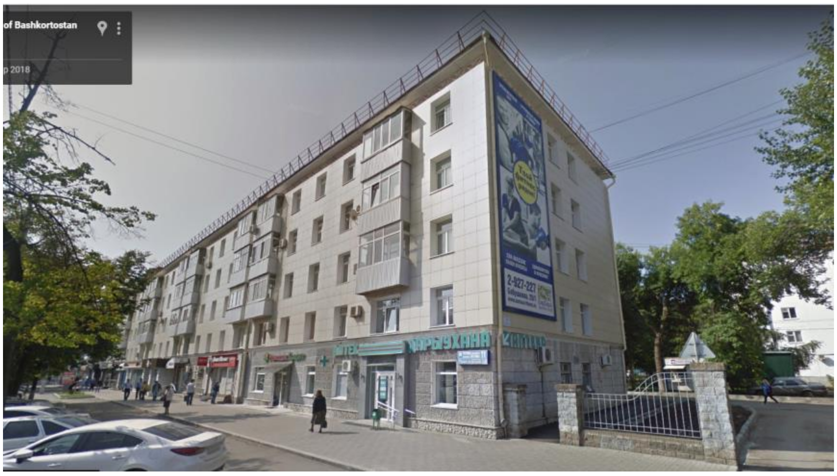

Figure 2. Example of renovated building in Ufa [39].

Another example of the reconstruction of a building of the first mass series can be seen in figure 3. The building is located in the city of Novocherkassk. The renovation measures included the insulation of facades, modernization of engineering equipment, and construction of attic floor. [13.]

Figure 3. Reconstruction of the building in Novocherkassk [13].

The above-mentioned reconstruction projects show a positive trend for the future development of the reconstruction programme in Russia despite the number of typical problems each of such projects has encountered.

2.3 Energy-Efficient Renovation

Energy-efficient renovation is not a new concept in Russia, but it has recently received more attention due to the introduction of a new Federal Law on Energy Efficiency No. 261 Ф34. Improving the performance of a building in terms of their energy efficiency is no longer just a recommendation. Thus, of great importance is the solution of this task for already existing buildings. The high energy consumption and poor thermal qualities of the buildings of the first mass series can show that immediate action should be taken in order to improve the condition of these buildings. [40.] It can be also said that if the energy efficiency is upgraded at the same time with basic renovation, it is the most cost-effective option [41].

Energy efficient renovation or modernization can be explained as a combination of measures aimed at restoring or replacing building structures and engineering systems in order to improve the thermal qualities and energy performance of the building. [40.]

2.3.1 Federal Law on Energy Efficiency No. 261 Φ34

Federal Law No. 261 Φ34 "On energy saving and on increasing energy efficiency and on introducing amendments to certain legislative acts of the Russian Federation" determines the energy performance requirements of buildings. It also defines the procedure for assigning and confirming the energy efficiency class of both new and already existing buildings. According to Law 261, energy efficiency classes must be assigned to all newly built buildings. The energy class of an existing building can be defined on a voluntary basis. The specific energy consumption of a house should be determined when calculating the energy class. The actual energy costs are compared with baseline numbers, and according to the difference between these values the energy class is assigned. The highest level is A ++, and the lowest is G. The assigned energy class is given for 5 years for each building, and should be confirmed after each five years. The tables for the determination of energy classes can be found in Appendix 1. [42,43]

The energy performance requirements of buildings according to the Federal Law are:

> "automatic regulation of heat energy consumption in heating and ventilation systems depending on changes in the outside air temperature, preparing hot water and maintaining the set temperature in the hot water system" (top priority); "integration of an alternative energy sources and secondary energy resources into the energy balance of buildings", "limiting the standardized specific total consumption of primary energy in relation to the standardized indicators characterizing the annual specific value of the consumption of energy resources in the building" (additional measures). [44.]

The energy efficiency requirements of a building are fulfilled by achieving the value of the specific characteristic of the consumption of thermal energy for heating, ventilation, hot water and electricity, or the specific characteristic of the thermal energy consumption for heating and ventilation [45].

2.3.2 Energy-Efficient Measures

The optimal measures to achieve minimal energy consumption are connected with the reduction of heat losses from a building and improving the efficiency of the building services. More radical measures for a significant reduction of energy consumption can be implemented with a design that has minimum air leakages, very insulated structure with no thermal bridges, windows and doors with low U-values, heat recovery ventilation, use of passive solar gains, and the use of renewable energy sources. [46.]

Talking about energy-efficient measures in more detail, it should be noted that when planning the integration of such measures into a renovation project, it is important to consider the influence of each measure on the building performance both alone and together with other measures. For instance, when planning for extra thermal insulation, attention should be paid to the proper ventilation of the apartments as well. [20.] In addition, a cost-effective option is when the improvements to the building envelope and services are done together with other repairs. This in turns can lead to even greater energy savings. [7.]

The summary of energy-efficient measures that can be applied to the series of buildings in Russia is the following [7,47]:

- Thermal insulation of building envelope and installation of better performing windows and external doors
- Modernization of heating systems
- Modernization of domestic hot water supply systems
- Integration of mechanical heat recovery ventilation
- Better electrical appliances and lighting
- Passive and active use of solar energy
- Installation of energy meters in the apartments
- Use of renewable energy

2.3.3 Energy Efficiency in Russian Buildings

The buildings of the first mass series are not satisfactory performing according to the current norms on energy consumption. The need for thermal energy in such buildings is usually about 2-2.5 times higher than the normal value. It was also estimated by the researchers that the calculated specific characteristic of the consumption of thermal energy for heating and ventilation of a building before a renovation could exceed the normalized value by 50%, which belongs to Energy Class D (reduced). [40.]

The problem with modernization of such buildings is seen as the necessary measures are only carried out to the minimum, which does not lead to substantial energy improvements. For some reason, the façade repairs are not done to the full degree with the use of insulation materials. The real benefit of the installation of energy meters is also under question if other measures for energy efficiency are not implemented. The replacement of windows with airtight PVC frame windows leads to indoor air quality problems if additional ventilation is not installed. A common measure for individual apartments repairs is the installation of kitchen exhaust fans, which might as well disrupt normal ventilation in the building. [48.]

It could also be noted, that the high heat consumption by the heating and hot water systems in the Khrushchev buildings can be explained by the inefficiency and improper exploitation of the systems, which make the distribution company to supply more heat to the buildings in order for their systems to maintain normal temperatures. This leads to the so called ”overconsumption” in the buildings and the actial energy consumption becomes very high. [49.]

Overall, the low level of energy performance in Russian buildings is caused by the poor thermal qualities of the buildings, inefficiently performing building service systems, especially the heating systems, and some minor violations in each individual apartment [27].

Despite these facts, the Russian building sector has quite significant energy saving potential. In addition, there is a vast potential for using renewable energy. On the other hand, the current share of renewable energy in the building sector reaches only about

0,9%. The barriers for using renewable energy are associated with the already existing grid infrastructure, relatively low prices for district energy, and quite high initial investment of renewable energy applications. [50.]

2.3.4 Energy Efficient Renovation Outside of Russia

There is already quite a lot of experience in reconstruction and energy-efficient renovations in Europe. The buildings of the mass series have been successfully renovated in the Baltic countries. The measures in such projects usually include improving building envelope thermal properties by adding insulation and a modernization of the building services systems. Besides, the appearance of the buildings is also improved by reconstructing the balconies and other external elements and a façade renovation. These actions result in much lower energy consumption by the buildings and better comfort for residents. [51.]

Another good example of a successful implementation of reconstruction programme is the case of Germany. The buildings built during the existence of the GDR are quite similar to the buildings in Russia. The renovation activities also included actions of the thermal insulation of external structures, replacement of doors and windows, modernization of engineering equipment, and installation of mechanical ventilation. Many houses were also reconstructed with the change in the layout, size, and appearance. [23.] An example of such radical reconstructions is seen in figure 4.

Figure 4. Paneled typical building before (left) and after reconstruction (right) [52].

Another part of building stock in Germany experiences the refurbishment, which includes basic renovation activities together with modernization of building systems and elements. As the result of such actions, the substantial energy savings can be observed. [13.]

2.4. Energy-Efficient Renovation Projects in Russia

2.4.1 Technical and Economic Limitations

The main problems that delay the successful execution of massive energy-efficient renovation projects are seen as the price imbalance between the cost of heat energy and electricity as well as the cost of renovation measures together with the very high investment cost of the installation of energy-efficient systems. The payback time of the latter is also long and does not look attractive for inclusion in most of the housing renovation projects. [53.]

There are also some social obstacles that make the renovation process quite complicated. The existing legislation enforces that any renovation or reconstruction project can be cancelled if even one apartment owner in the building is against any changes in the building. This can be explained that people are not willing to pay any extra money and might just not be interested in any changes. The construction works associated with renovation or reconstruction can cause discomfort for residents and a thorough planning of works should be implemented. [28.]

The economic limitation for renovation and reconstruction is mainly the lack of money to conduct a complex project. In addition, such a project does not seem to be very profitable for investors, for whom the demolition of an old building and construction of a new one is considered more favorable. [54.]

The legal barrier is mostly outdated norms that should be still fulfilled for every construction project even nowadays. [7.] The recent Federal Law on energy-efficiency brings a positive trend for a change, however, the above-mentioned problems complicate the implementation of actions to reduce energy consumption in the existing buildings.

2.4.2. Problem Solving

To solve the current problems specific actions should be executed. These involve a programmatic approach to the renovation and reconstruction in cities, pilot projects to be carried out for examining the advantages and disadvantages of different renovation measures, and the creation of new norms and standards that regulate the energy-efficient renovation and reconstruction projects. [23.]

The financial obstacles might be eliminated if the renovation of the building could be partially funded by residents with the assistance of the Federal Fund for Housing. Such financial mechanism of private-budget co-financing projects can become financially feasible and effective. [53.]

An interesting example of successful implementation of an energy-efficient reconstruction project is the project in Tomsk city (figure 5). The building of the first mass series was reconstructed with an addition of an attic floor. The reconstruction was carried out without the relocation of residents. The works included the replacement of all engineering systems, installation of well-performing windows, glazing of balconies, façade repair with insulation, and attachment of vestibules to each entrance of the building. The reconstructed building was assigned the energy class B. The total cost for the reconstruction amounted to 43 million roubles, and 49% of the budget were invested by the federal budget, the regional budget, and the city budget, and the remaining 51% was invested by an investor. [13.]

Figure 5. Reconstruction project in Tomsk city [55].

This project shows that such reconstruction is possible and offers good results in terms of energy efficiency and cost-efficient strategies.

2.4.3 Efficiency of Renovation and Reconstruction

To determine the efficiency of a renovation it is necessary to compare the costs of the renovation of an existing building and the construction of a new building. Then, the obtained positive results of solutions and measures for energy efficiency and cost efficiency of both scenarios are compared. [56.]

Technical and economic efficiency are determined both at the design stage and evaluation and comparison of different design options [17]. It should be noted, that in the case of energy-efficient renovation the main benefit is obtained not by reducing the construction cost, but by a reduction in the operating costs of the building [57]. Although it can also be said that the decision on energy-efficient equipment might not be based on the return on investment only [50].

2.5. Renovation and Reconstruction of Buildings of the First Mass Series in St Petersburg

2.5.1. The Housing Stock of the First Mass Series

The buildings of the first mass series, also known as Khrushchev buildings, were built in Saint Petersburg from 1958 to 1970 and about 2400 houses were constructed during that period. The stock includes several regional series of buildings, which are panel buildings (series 1lg-507, GI, 1-335, ML), and brick and large-block buildings (series 1-528, 1-527). [30.]

The housing stock of the first mass series accounts for about 8.9 million square metres of total area, which is 10% of the total area of the total housing stock of St Petersburg, and 190 million apartments with a population of more than 600,000 people [30].

The specifics of the housing stock of first mass series is shown in table 1 below.

Table 1. Housing stock of the first mass series in St Petersburg [58].

Series of buildings	Construction type	Total area of the apartments, thousand of square metres	Percentage of total area of the apartments in the housing stock of first mass series
1-LG-507	Panel	2700	30
GI	Panel	1510	17
1-335	Panel	1194	13
OD	Panel	908	10
1-528	Brick	2600	30
Total		8912	100

From the table it can be observed that the most widespread series are the panel 1-LG-507 and the brick series 1-528.

The condtion of most of the buildings is satisfactory, many of the houses can be renovated or reconstructed. Many of the buildings have significant safety margins of bearing elements. Nevertheless, the buildings feature a considerable depreciation in terms of planning solutions, appearance of buildings, inconsistency between the building performance and modern norms. Yet, these problems can be also resolved with the help of renovation. [30.]

2.5.2. Renovation and Reconstruction Programmes in St Petersburg

The Regional Programme of Reconstruction of the buildings of first mass series in St Petersburg was issued in 2000. The goals of the programme were the implementation of state policy for the preservation, renovation and increase of the housing stock, reducing expenditures on maintenance and repair of the housing stock, increasing efficiency of land use, and stimulating investment and reconstruction initiatives. The improvements in the efficiency of the use of the housing stock involved energy-efficient modernization of buildings by thermally insulating them and by replacing old systems, and the reconstruction of some buildings by adding attic floors or by constructing extensions. In addition, the new construction in chosen districs was to be accomplished. [30.]

The programme had a time frame of 20 years, and in the period of 2000-2020 the expected outcome of the programme would have been the completion of the reconstruction of houses and areas of construction built in the 1960s. The programme also defined the areas with a greater potential for initial reconstruction and provided a business plan for a pilot project. The reconstruction of residential buildings was to be carried out without the resettlement of residents. [30.]

The following reconstruction measures were planned:

- Insulation of walls and window openings
- Replacement of services networks
- Attic floor construction
- Construction of extensions and elevator shafts [30.]

Unfortunately, this programme of mass reconstruction was not fulfilled. The failure could be partly due to the social aspects that were previously discussed in the previous chapter 2.4, and partly due to the low economic yield for investors. [59.]

In 2008, the programme “Development of Built-up Areas in St Petersburg” replaced the previous program of reconstruction. This new initiative proposed the demolition of old buildings in an emergency condition and the construction of new buildings in place of the old ones. The programme resembled the Moscow scenario for the modernization of urban areas discussed previously in chapter 2.2.3. However, not many buildings of the first mass series were included in the list for demolition. Instead, the programme focused on the particular areas of the city with buildings in a poor condition. [33.] However, the buildings chosen for demolition in those areas should meet the specific criteria of being in an emergency condition, built between 1958 and 1970, being low-rise residential housing, not complying with the city planning regulations, and, what is more, the building should have a high percentage, over 70%, of physical wear. In addition, the programme includes no plans to carry out any renovation or reconstruction for any other buildings. [60.]

The implementation of the 2008 programme cannot be called as very successful. The complications were mainly caused by a lack of detailed survey of the neighborhoods that were included in the list of areas for modernization, a lack of detailed analysis of town-planning possibilities, and a lack of detailed calculations of economic expediency. Among the barriers was also a lack of space to build the first new buildings in most of the chosen districts. That made the outcome a pure densification construction, which was criticized by the public. The budget considerations also played a role in postponing the programme. [61.]

By 2016, the programme of development of built-up areas was completed for less than 1%, and by 2017 only 11 new buildings were completed. In the end of 2017, the Court extended the programme for another 10 years despite the failure of the programme in terms of timing and volume of completed works. The latest news show that there is still discussion upon the acceptability of such programme for the city. [62.]

In June 2018, Saint Petersburg State University of Architecture and Construction proposed a project of reconstruction for the buildings of the first mass series. The project includes the reconstruction of houses with the addition of two upper floors, as well as complex modernization that on a building level includes façade renovation, addition of elevator shafts, storage spaces, and extensions of loggias. The project is planned to be carried out without relocation of residents. [63.]

Проект реконструкции пятиэтажек, предложенный СПбГАСУ

Figure 6. Project of reconstruction in St Petersburg [63].

A particular district with a potential for such activities was chosen for the project. The figure 6 above shows the proposed architectural solution for the buildings. [63.]

2.5.3 Completed Projects in St Petersburg

The very first reconstruction of a Khrushchev building was carried out during the Soviet era in 1987. The building of series 1-335, which was built in 1962, was reconstructed. Actions had to be taken for the reason of very poor quality of construction of this particular series of buildings. The main focus was given to the reconstruction of the building façades in order to improve the thermal performance and the appearance of the building. The results can be observed in figure 7. [29.]

Figure 7. The first reconstruction project in St Petersburg [29].

In the period 2000–2012, about 40 buildings of other mass series were renovated in various parts of the city. Only one reconstruction with addition of attic floor was implemented for a building of series 1-LG-507 located at 16, Torzhkovskaya Street (figure 8). The works were carried out for façade renovation, thermal insulation, sealing windows, and the modernization of the heating system. All these measures led to energy savings. [64.]

Figure 8. Reconstructed building series 1-LG-507 [64].

An example of a basic renovation is a building at 7, Prospekt Narodnogo Opolcheniya of series GI. The building can be seen in figure 9 below.

Figure 9. Renovation of building of series GI [66].

The measures done at the address included the thermal insulation of façades, replacement of windows, repair of roof, modernization of building systems, and installation of energy meters [65]. The renovation increased the cost of apartments and improved the living conditions of residents [66].

The only one found renovation for the building of series 1-528 was carried out for the building at 12/4, Prospekt Nauki. The building can be seen in figure 10.

Figure 10. Renovation of building of series 1-528.

Works included facade insulation and repair, roof complex repair, and installation of individual substation for the building heating system. Renovation measures resulted in the reduction of the total heating energy consumption of the building almost to the level of standards of that time. [67.]

2.6. Buildings Suitable for Renovation

The two of the most widespread series of Khrushchev buildings in St Petersburg are series 1-LG-507 and 1-528, each accounts for 30% of the total area of the apartments of the first mass series in the city. The buildings have almost similar planning solutions. However, it is proved that brick buildings of 1-528 series have significantly better thermal properties than the panel series [68], and it might be more effective to execute a complex modernization of the building as only minor things can be improved.

Based on the discussed earlier in this thesis great potentials for reconstruction of brick buildings and the lack of action of city officials in terms of future plans for these buildings, it is proposed to choose for future study the brick series 1-528.

2.6.1 Background for Series 1-528

The 1-528 series was designed by the Leningrad Institute for Standard and Experimental Design of Residential and Public Buildings for the northern climatic zone. The houses were built during the period of 1957-1972. The buildings are located in fairly prestigious areas in St Petersburg, as well as there can be found many buildings in the outskirts of the city and in some other cities as well. The approximate locations of the buildings can be observed from the map, figure 11. [68.] The total number of the buildings in St Petersburg is about 712 [30].

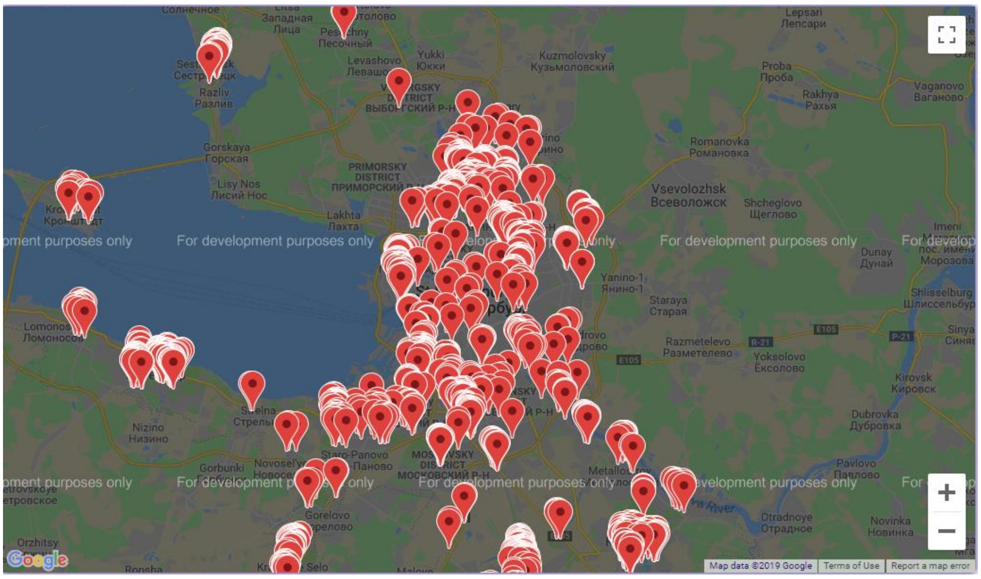

Figure 11. Approximate locations of the buildings of series 1-528 [69].

The series has an enormous number of different configurations, which vary in the number of floors, stairwells, and the arrangement of the first floor, which is either residential or used for commercial purposes [69]. The buildings are quite recognizable with their grey untreated brick facades. Some of the buildings have the bay windows instead of balconies (figure 12).

Figure 12. Series 1-528 with different configurations [68;71].

The main advantages of the 1-528 series are high-quality parquet floors, wooden window frames, relatively high ceilings, balconies in every apartment. The disadvantages are relatively small kitchens and hallways, passage rooms in apartments. [70,71.]

2.6.2 Technical Characteristics

Building envelope composition

The buildings of 1-528 series have a structural scheme with three longitudinal bearing walls. The load bearing walls are made of brick, the external walls thickness is 640 mm, internal load bearing wall thickness is 380 mm. The floor slabs are precast reinforced concrete hollow-core floor slabs with the thickness of 220 mm. The height of the ceiling is 2.7 m. The interior partitions are made of gypsum plasterboard with the thickness of 80 mm. [24.] A typical section of the building is shown in figure 13.

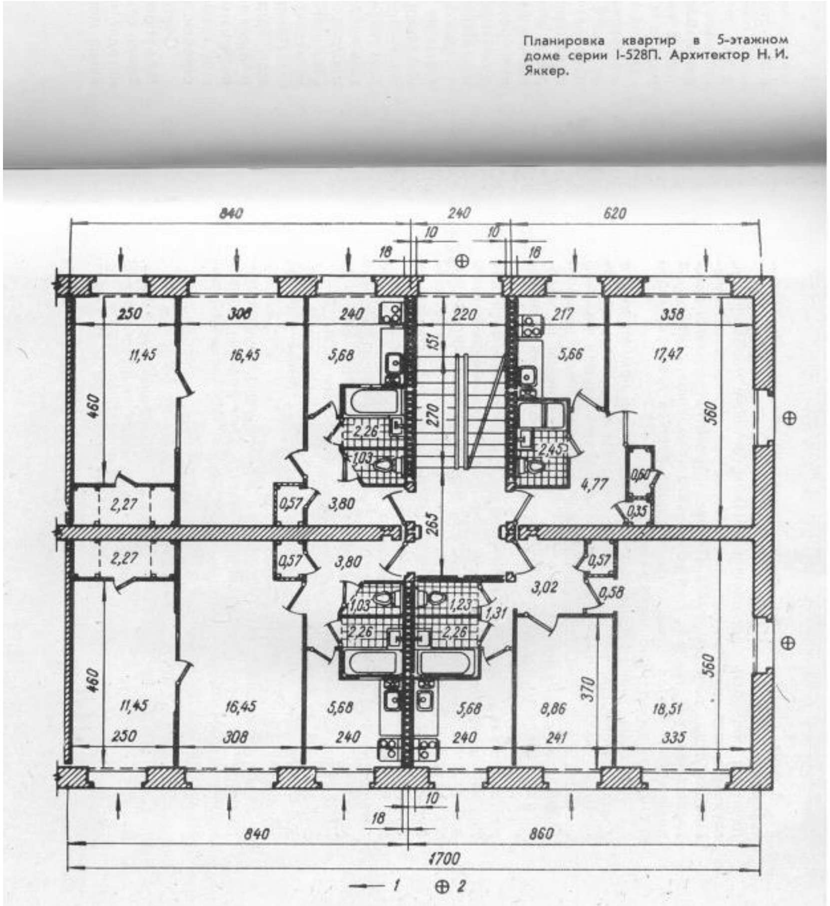

Figure 13. Typical section of the building series 1-528 [71].

Buildings of the series 1-528 might have either balconies or bay windows. The window frames are made of wood. The roof structure is a pitched roof with a low slope. [71.]

<u>Building services</u>

The 1-528 series buildings have a one-pipe heating system, the main supply pipelines are laid in the attic, the return pipe is in the basement. Radiators with double-sided connection and open circuits are made of iron. The system of hot and cold water supply has the main supply pipelines laid in the basement, supply of cold and hot water is from a centralized grid. [72.] The buildings have natural ventilation, with the exhaust ducts that come from every apartment to the unoccupied roof attic [73].

3 Methods and Materials

In order to answer the research questions, it was decided to study the case with a particular building of the series 1-528. A complex analysis of the building's condition and its potential for the renovation or reconstruction was conducted. The possible options for renovation of the building were evaluated and analyzed, and energy simulations and cost-efficiency calculations were done in order to find out the most optimal measures to improve the building's performance.

The building was chosen on the basis of the programme of reconstruction planned to be implemented in St Petersburg in the early 2000 (see chapter 2.5.2) [30]. Data of the current condition of the building was gathered from a governmental website that provides access to the technical information about buildings in St Petersburg [74]. Calculations for potential for reconstruction were made according to a special methodology of early stage design assessment of investment potential issued by a group of architects [10].

Based on the theory research about the existing methods of renovation and completed projects, three options for the renovation and reconstruction were developed for the studied building. The renovation options followed the notions developed by the researchers on a similar project, where each subsequent renovation option was made more comprehensive than the previous [50].

Energy calculations for the renovation options were performed in two programs simultaneously: DesignBuilder (DB) [75], which enables to perform energy simulations on the conceptual design stage, and Passive House Planning Package (PHPP) [76], which is convenient to use as the tool to calculate overall heating demand of the building and electricity consumption with greater detail. Cost efficiency calculations included the net present value (NPV) life-cycle cost calculations to evaluate the alternative options, and simple payback time calculations to obtain the time that is required to return the initial investment [77]. Extra calculations to establish the potential of including any other energy-efficiency measures were performed as well. The calculations aim at evaluating the possibilties of using renewable energy sources and how cost-efficient that will be for a mass renovation project.

3.1. Materials for Analysis

The choice for a particular building for case study was made based on the data given in the materials of the Regional Programme of Reconstruction of the buildings of first mass series in St Petersburg [30]. The programme provides a list of districts with a high potential for reconstruction. In each district the potential residential quarters are mentioned. One such quarter, “85”, is located in the Moskovskiy district of St Petersburg. The quarter has the biggest number of buildings of the 1-528 series. The district can be seen in figure 14.

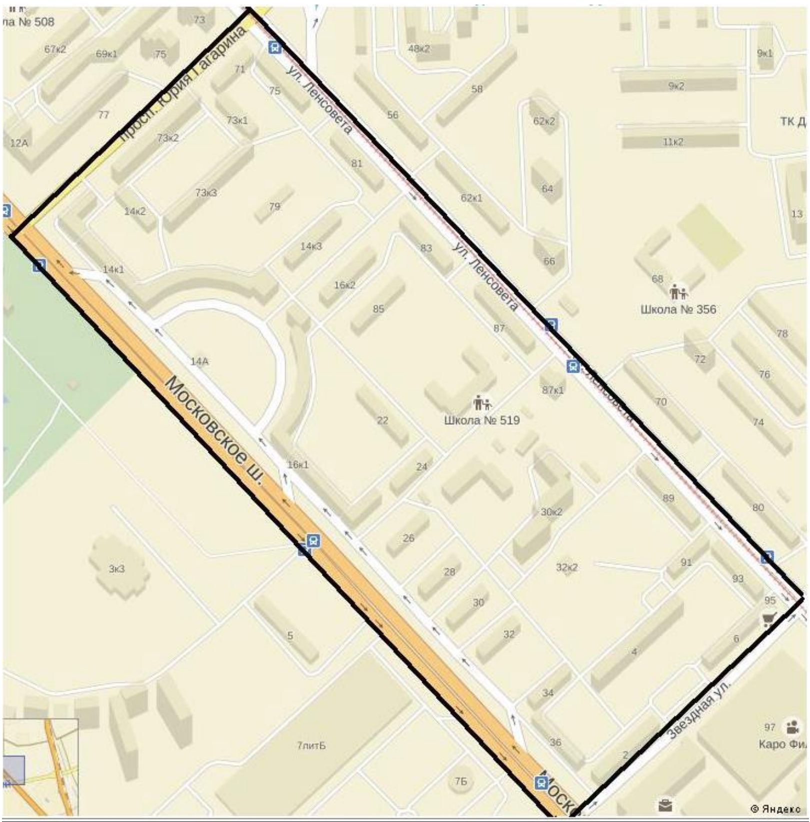

Figure 14. Quarter 85 of the Moskovskiy district in St Petersburg [78].

The quarter has a good location in the south of the city, there are good connections to the transportation system, and the existing infrastructure is in proper condition [78].

A building in this quarter was chosen according to the amount of technical data with open access, which was gathered from the city government website [74]. The information contains the general features of the building, its technical characteristic, and the energy consumption of the building. Most information could be found for the building with the address 83, Lensoveta street. This particular building was built in 1961, the series configuration of this building is 1-528-KP-3. The total area of the building is 3798.8 square metres and the total volume is 15574 cubic metres. The building has five floors, four stairwells, and 155 residents. [74.]

3.2. Condition Survey

Condition survey of the building at 83, Lensoveta street (figure 15) was carried out in order to identify the core problems that can lead to the decision for renovation. The data of the technical condition of the building provided on the city government website was used as the reference for a visual survey in order to check the compliance of the listed condition and the actual situation [74]. The condition survey included the familiarization with the existing technical survey, onsite visual inspection with photographing, conclusions and suggestions for feasibility of renovation measures. The observations of the survey can be found in appendix 2.

Figure 15. The building at Lensoveta,83.

Based on the survey, the following suggestions for renovation actions were proposed:

- Foundations need partial restoration and waterproofing.
- External walls require partial repair of the damaged brickwork (figure 16).
- Stairwells might need partial repair of the stair steps.
- Balconies require complex repair.
- Partial renovation of ceilings, floors, walls, windows in the common spaces is recommended (figure 17). The windows in the common stairwells had recently been replaced.
- Old building services engineering networks need to be replaced.

Figure 16. Detail of the external wall façade of the building at Lensoveta,83.

Overall, the building's condition is quite satisfactory. The floor slabs were in good condition, but the external elements need some basic repair. The load bearing elements could not be thoroughly examined during the survey, however, their proper condition is also not under question. The condition of the common stairwells (figure 17) located within the thermal envelope demonstrate quite satisfactory levels of indoor air quality. No traces of mold or fungus or any unpleasant smells that can usually come from the basement were observed.

Figure 17. One of the common stairwells of the building at Lensoveta,83.

The walls had probably been painted recently, and the windows had been replaced with the PVC framed windows, which could improve the air-tightness of the building. Nevertheless, the renovation activities are recommended for the whole building.

3.3 Calculated Potential for Reconstruction

The studied building's potential for reconstruction was calculated according to the special methodology of town planning and investment potential of existing housing [10]. Such calculations are done in order to help to justify the financial benefits for investors of a reconstruction project. General renovations are often costly activities. On the other hand, if basic repairs are done together with the reconstruction of a building and without relocation of residents, there could be some profit from selling the new apartments in the extended existing building. [10.]

For the calculations, the total area of the building at 83, Lensoveta street was obtained, and the average prices for the basic renovation and the new construction per square metres were estimated based on the Territorial Unit Prices for reconstruction of buildings [79]. The calculations included the options for basic renovation as well as the renovations with the construction of extra floors on the existing building. Construction of extra floors, as it was discussed in the chapter 2.2.3, can be done in three ways, however, for these calculations only two ways are considered: the attic floor and the full extra floor.

The cost of renovation for the whole building can be calculated as follows:

$$Cost\ of\ renovation\ = (\text{cost of renovation of 1 sq m})(\text{total area of the building}) \quad (1)$$

$$Cost\ of\ renovation\ for\ the\ case\ building = \text{35 000 roubles x 3798.8 sq m}$$
$$= \text{132 958 000 roubles}$$

Then, the next step was to calculate the cost of construction of an extra upper floor:

$$Cost\ of\ construction\ =$$
$$(\text{cost of construction of 1 sq m})(\text{total area of the new construction}) \quad (2)$$

$$Cost\ of\ construction = \text{55 000 roubles x 713.728 square metres} \ =$$
$$\text{39 255 040 roubles (attic floor)}$$

$$Cost\ of\ construction = 55\ 000 \text{ roubles x } 893.6 \text{ square metres } = 49\ 148\ 000 \text{ roubles (full floor)} \quad (3)$$

If an extra full floor is added to the existing building, then there is the need to include in the calculations the cost of construction of elevator shafts.

$$Cost\ of\ construction\ of\ elevator\ shafts = (\text{Cost of construction of 1 square metre})(\text{total area of the elevator shafts}) \quad (4)$$

$$Cost\ of\ construction\ of\ elevator\ shafts = 55\ 000 \text{ x } 288 = 15\ 840\ 000 \text{ roubles}$$

In this case, the total cost of reconstruction with the construction of an attic floor will be:

$$The\ total\ cost\ (with\ an\ attic\ floor) = 132\ 958\ 000 + 39\ 255\ 040 = 172\ 213\ 040 \text{ roubles} \quad (5)$$

$$The\ total\ cost\ (with\ a\ full\ floor) = 132\ 958\ 000 + 49\ 148\ 000 + 15\ 840\ 000 = 197\ 946\ 000 \text{ roubles} \quad (6)$$

The next step is the calculation of financial income from additional construction. First, the minimal market price for a square metre of new construction without profit is determined:

$$Minimal\ price\ (for\ attic\ floor) = (132\ 958\ 000 + 39\ 255\ 040) / (3798{,}8 \text{ x } 0{,}8 \text{ x } 1) = 56\ 666{,}92 \text{ roubles} \quad (7)$$

$$Minimal\ price\ (for\ full\ floor) = (132\ 958\ 000 + 49\ 148\ 000 + 15\ 840\ 000) / (3798{,}8 \text{ x } 1) = 52\ 107{,}51 \text{ roubles} \quad (8)$$

For getting a profit, the market price should be greater than the calculated values. Here, the market price is doubled for the calculation:

$$Price\ of\ housing\ (attic\ floor) = \text{713,728 square metres x 1 x 110 000 roubles} = \text{78 510 080 roubles} \quad (9)$$

Financial income is obtained:

$$Financial\ income = \text{78 510 080 roubles} - \text{39 255 040 roubles} = \text{39 255 040 roubles} \quad (10)$$

$$Price\ of\ housing\ (for\ full\ floor) = \text{893,6 square metres x 1 x 110 000 roubles} = \text{98 296 000 roubles} \quad (11)$$

$$Financial\ income = \text{98 296 000 roubles} - \text{49 148 000 roubles} = \text{49 148 000 roubles} \quad (12)$$

These calculations show that the reconstruction of the building at 83, Lensoveta street can be profitable and the financial profit from such activities can be used for any extra modernization measures, as well as actions to improve the energy efficiency of the building.

3.4. Renovation Options for Analysis

Three renovation options were modelled for the studied building based on the theory research and literature review on the existing methods of renovation and reconstruction.

The first renovation option follows the general proceedings of basic repairs of the existing buildings that are currently done in Russia [17]. This option includes only basic renovation measures and it is referred to as basic renovation in the thesis.

The second option is modelled according to the reconstruction measures that were planned for the buildings in the Regional Programme of Reconstruction of the Buildings of the First Mass Series in St Petersburg [30]. It includes the construction of an attic floor and extra thermal insulation of external walls. This option is more expensive and requires more resources. It is called the improved renovation option with attic floor in the thesis.

The third option is the most comprehensive one, it not only includes the construction of an extra upper floor and elevator shafts, but also some extra energy-efficiency measures previously discussed in chapter 2.3. This option might be the most expensive. The option is called advanced renovation in the thesis.

The three renovation scenarios were modelled in the DesignBuilder software. The conceptual design of them can be seen in figures 18-20.

Renovation measures for all three options were divided into construction parts, building services, and finishing works of the building. Basic renovation option (figure 18) includes such measures for construction parts, as partial restoration and waterproofing of foundation as well as insulating the basement, basic roof repair and insulation of the cellar, and the replacement of doors and windows (partial) with the repair of balconies.

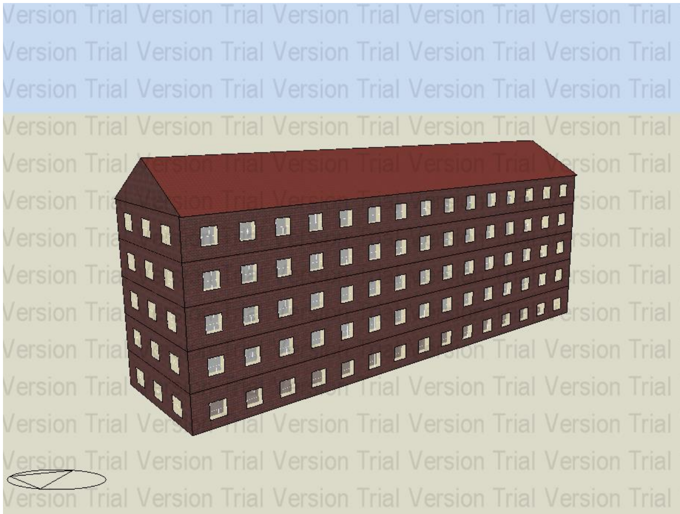

Figure 18. Basic renovation option.

As for the building services, the replacement of all utilities and equipment is recommended. These include the heating system, domestic hot water network, water and sanitary services, gas distribution, tv-radio-internet communications, electrical equipment, and lighting. Energy and water consumption meters should be installed in the apartments. Also, heating exchangers in the individual substation of the building should be installed. The finishing works include the basic façade repair with the repair of damage to the brickwork and plastering, and the interior repair of the entrances and stairwells (floors, ceilings, walls, doors, lighting).

Improved renovation option (figure 19) includes the same basic renovation measures as in the basic renovation option, but with a number of improvements. In construction, thermal insulation to the external walls is added to improve the thermal qualities of the building. The construction of an attic floor is planned for economic considerations. Mechanical exhaust ventilation is included to improve the indoor air quality of the building. The finishing works include the same activities as in the basic renovation option except that the façade repair includes the construction of a “wet” façade.

Figure 19. Improved renovation option with attic floor.

The advanced renovation option (figure 20) also includes all basic renovation measures same with the basic renovation option, but with more improvements and measures for sustainability and energy-efficiency. The construction of an extra full upper floor is planned, and for this reason the extension of elevator shafts is also recommended. In addition, storage spaces are planned for bicycles and wheelchairs in the basement. The whole building envelope should be thermally insulated for better thermal properties of the building. Mechanical supply-exhaust ventilation with heat recovery (HRV) is also included to improve the indoor air and thermal qualities of the building. The finishing works might be more comprehensive in comparison with the previous options. The façade repair includes the construction of a “ventilated” façade.

Figure 20. Advanced renovation option with extra upper floor.

The summary of the options and renovations activities is presented in table 2.

Table 2. Renovation options summary.

Renovation option/activites	Basic	Improved	Advanced
Construction			
Foundation	x	x	x
Roof	x	x	x
External walls insulation		x	x
Attic floor construction		x	
Full floor construction			x
Extension of elevator shafts			x
Doors and Windows, balconies	x	x	x
Extra storage spaces			x
Building Services			
Replacement	x	x	x
Energy meters	x	x	x
Heating exhangers	x	x	x
Mechanical exhaust ventilation		x	
Mechanical heat recovery ventilation			x
Finishing works			
Façade	x	x	x
Entrances and stairwells	x	x	x

3.5. Energy Calculations

3.5.1 Current Performance of the Building

When beginning the energy calculations, the current energy performance of the building was examined. The data provided on the city government website included the numbers for annual and specific energy consumption of the building. It was estimated that 1248.08 kWh/m^2 is used for thermal energy, and from that, 812.703 kWh/m^2 is spent on heating and ventilation only [74]. These numbers not only exceed the previous standards of energy consumption, but also substantially far from the current norms. The building can only be assigned to the lowest energy class, Energy Class E. [80.] The modernization of the building is strongly recommended. The actual energy consumption is measured based on the readings of household energy metering devices.

3.5.2 Heating Demand Calculations

Heating demand calculations of the studied building were performed using the Passive House Planning Package (PHPP) and the results of calculations were compared to the base numbers of energy consumption issued in the Federal Law on Energy Efficiency No. 261 Ф34 [43]. The tables of data are included in Appendix 1.

The first inputs were the parameters of the current condition of the building. The inputs included the climate data, building envelope composition, areas of building components, information about the building's ventilation, and some other specifications. The goal was to attempt to model the actual building performance so that the model of the existing building could be used as the reference model for any other calculations. In that case, the improvements on the heating demand number will seem more applicable to the real situation.

As a result, the reference model of the building received the number 608 kWh/m^2 of heating demand, the result of calculations is seen in table 3.

Table 3. Reference model heating demand.

Heating demand	608	kWh/(m²a)
Heating load	173	W/m²

These numbers are somehow close to the actual building performance, but assumption is made that the high energy consumption in the building can also be explained not only by the faults in the building's fabric, but also it can be caused by an inefficient heating system. Thus, the performance of the existing heating system is not considered in these calculations.

Next, the inputs were made for the option of basic renovation. All the renovation measures applied for this option were included. The inputs also included an extra insulation of the attic space with 100 mm mineral wool insulation and the same layer of insulation was also placed on the ground floor. Windows were changed from single glazing ones to double glazing, and the timber frames to PVC frames. The changes to the building elements resulted in a significant change in heating demand of the building, which can be observed from table 4 below.

Table 4. Basic renovation model heating demand.

Heating demand	337	kWh/(m²a)
Heating load	99	W/m²

As it could be seen from the table of base numbers of energy consumption (Appendix 1), such numbers are still far from the standard values. The base value for five-storied building with the given degree days of 4356 for St Petersburg [74] is about 130 kWh/m2 for heating and ventilation only.

The third model included inputs for the improved renovation option. An extra insulation of 200 mm was added to the external walls, and 250 mm layer of insulation was added to the roof structure, underground walls, and ground floor. An extra input was also made for the inclusion of mechanical exhaust ventilation, although its performance does not influence the heating demand of the building. The U-value of the external wall was reduced from 1.234 W/m2K to 0.153 W/m2K in comparison to the reference and basic renovation models. The significant improvement was also observed for the properties of the ground floor slab, where with the addition of insulation it was possible to reduce U-value number from 3.876 W/m2K in the reference model to 0.321 W/m2K in basic renovation model, and 0.134 W/m2K in the improved renovation model.

The heating demand was also lowered, as can be seen in table 5 below.

Table 5. Improved renovation model heating demand.

Heating demand	162	$kWh/(m^2a)$
Heating load	50	W/m^2

The obtained values are still quite high and differ quite much from the base numbers for 6-story buildings. The base value is about 96.832 kWh/m2 for heating and ventilation.

The fourth model was made for the advanced renovation option. The insulation layers remained with the same thickness, but the exterior wall composition was changed from the simple plastered “wet” façade in the improved model to the ventilated façade system and the thickness of mineral wool insulation changed to 250 mm. This made possible the further reduction in the U-value from 0.153 W/m2K to 0.126 W/m2K.

A significant reduction in the heating demand in the advanced option is also explained because of inclusion of some other energy-efficiency measures, such as windows with a better G-value and the addition of mechanical ventilation with heat recovery. As the result of such measures, the number of heating demand was substantially lowered, as it is shown in table 6.

Table 6. Advanced renovation model heating demand.

Heating demand	100	kWh/(m^{2}a)
Heating load	33	W/m^2

Such number of space heating demand is quite close to the base value of 96.832 kWh/m2. Based on the difference between these values, the building could obtain the Energy Class C, which is considered as “Normal”. The detailed calculations for the third renovation option can be checked in Appendix 3.

To improve the building performance, other energy efficiency measures could also be implemented to lower the primary energy number. Any other improvements to the building envelope are considered unnecessary as, for example, adding even more insulation to the structures would make them already too thick and produces an extra weight to the structures. Common practice shows that insulation with large thicknesses tend not to be very durable, and might result in other complications associated with the indoor air climate.

3.5.3 Energy Simulations

Energy simulations of all three renovation options were performed using the DesignBuilder software. First, the options were modelled and a brief conceptual design for each of them was created for functional purposes.

The inputs to every model included the building’s location and the country, activity of the building, special norms considering heating and hot water consumption, construction elements, openings, and HVAC section.

It was possible to model the construction elements of the building with greater detail. The composition of exterior wall elements and their difference can be seen in figures 21 and 22.

Figure 21. Exterior wall composition comparison between basic renovation model (on the left) and improved renovation model (on the right).

The difference between building envelope composition played a significant role in the calculations. The results from the calculations in DesignBuilder also showed the same trend of lowering the U-value of building elements in each subsequent renovation option.

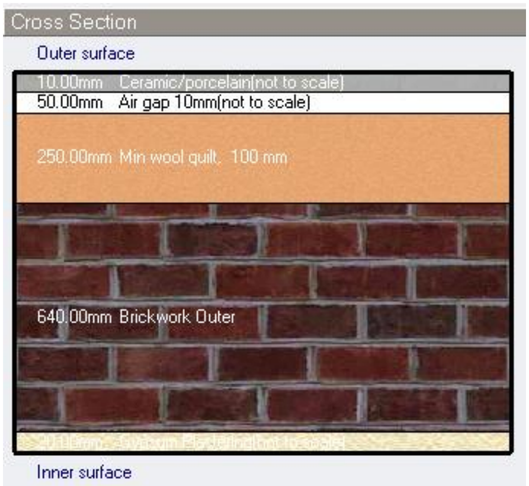

Figure 22. Exterior wall composition advanced renovation model.

The results of the energy simulations are expressed in table 7 below. From the table, the differences between the renovation options can be clearly observed. The basic renovation scenario shows an improvement in the total energy consumption compared to the reference building model. However, such number still does not reach to the minimal difference with the base value. The building in this case will be assigned the Energy Class D, which is “Low”.

Table 7. Energy simulations results.

	"Basic"	"Improved"	"Advanced"
Total Site Energy	279.99 kWh/m2	248.82 kWh/m2	237.86 kWh/m2
Total Source Energy	1003.09 kWh/m2	890.45 kWh/m2	850.84 kWh/m2

The improved renovation shows a significant reduction in energy use, this can be explained by the extra measures to thermally insulate the building envelope. As the previous calculations showed, the space heating demand is still a bit higher than the current regulations suggest. Nevertheless, the total energy consumption falls into the category Energy Class C, the “Normal”.

The advanced renovation scenario includes mechanical heat recovery ventilation as an extra energy-efficiency measure. In the previous calculations performed in PHPP it showed a significant reduction of space heating demand. In the total energy calculations, electrical energy that is used for operation of mechanical ventilation is also taken into account. Thus, the number of energy consumption of the advanced option does not substantially differ from the improved renovation model. However, the advanced option reaches the energy consumption number which is slightly lower that the base value, and for that reason it receives Energy Class C, the “Normal”.

Screenshots of the software with detailed results of the simulations can be checked in Appendix 4.

3.6 Cost Efficiency Calculations

3.6.1 Life-Cycle Cost Calculations

Cost efficiency calculations were performed for extra energy-efficient measures with a high initial investment. Net Present Value (NPV) life-cycle cost calculations were carried out for the advanced renovation option with an additional heat recovery mechanical ventilation, which was compared with the improved renovation option with mechanical exhaust only ventilation. Calculations for other renovation measures were deemed unnecessary as most of the activities will be performed during renovation and reconstruction works at any case. The life cycle calculation of the installation of mechanical ventilation can help to choose the optimal option. However, as it was mentioned earlier in thesis, the choice upon the renovation activity or a product might not be based purely on such calculations.

The data for the calculations included the costs for heating energy and electrical energy, which are city tariffs for energy [81], energy use number that are taken from PHPP calculations, initial investment based on the Territorial Unit Prices for ventilation and air conditioning, which are calculated on averages per square metres of total area of the building, maintenance, repair, and replacement costs. [82,83]

The results obtained are summarized in table 8 and the details of the calculations are found in Appendix 5.

Table 8. LCC calculations results.

Heating + ventilation	"Improved"	"Advanced"
Initial investment	10497000	15043400
Energy costs	17080112	11276678
Annual maintenance	39000	100100
Repair	40000	120000
Replacement	300000	1200000
Total LCC	26200234.43	26068608.3

The initial investment for both options included the costs for installation of heating and ventilation systems. Calculations of energy costs showed the decrease in the total costs in advanced renovation option. The annual maintenance, repair, and replacement were found to be higher in the option with mechanical heat recovery ventilation. The graphical representation of the results can be seen in figure 23.

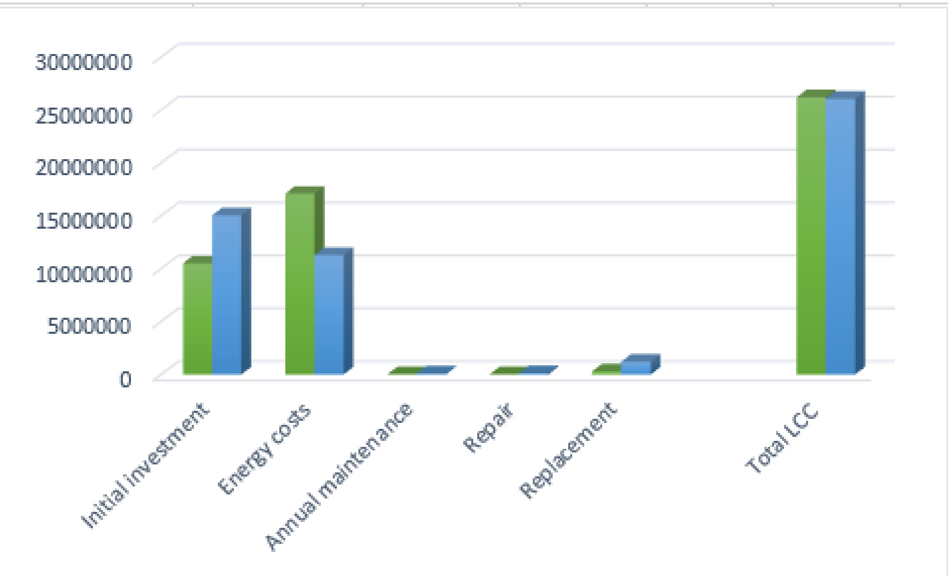

Figure 23. Graphical representation of the results.

It is interesting that the total life-cycle costs of options with different mechanical ventilation systems are almost identical. This can be explained by the difference between the energy costs: the price for electricity, 4.61 roubles per kWh, is about three times higher than for heating energy, 1.53 roubles per kWh. Such results more or less explain the unpopularity of the installation of ventilation systems with heat recovery. Besides, such systems require not only high investment, but also regular professional maintenance, which should be controlled by the house management company. All this complicates the expansion of such technology on a large scale. Nevertheless, it should be noted that the positive effects of heat recovery balanced ventilation in terms of reduction of heating loads and improving the indoor air quality should be seriously considered despite the possible complications of installation of such type of ventilation.

3.6.2 Simple Payback Time Calculations

Simple payback time calculations were performed for the heat recovery ventilation system in the advanced renovation option.

Simple payback time is calculated by dividing the initial investment by the net annual savings:

$$Simple\ payback\ time = \text{Initial investment / Net annual saving} = \ldots \text{ years} \quad (13)$$

The net annual savings in this calculation are energy savings, or the difference of the annual energy cost between the discussed options of ventilation systems. The initial investment for heat recovery ventilation system is approximated based on the Territorial Unit Prices for ventilation and air conditioning [82] as in the previous life-cycle cost calculations. The result of the calculation is as follows:

$$Simple\ payback\ period = 5\,546\,400\ /\ 223\,208 = 24.8 \text{ years} \quad (14)$$

The time that is required to return the initial investment is 24.8 years, which almost equals to the normal life-cycle of such a ventilation system.

3.6.3 Potential of Installation of Extra Energy-Efficiency Measures

Solar photovoltaic system was chosen for electricity production on site for the following calculations. The technology is not new in Russia, although it has not become a common modernization method for existing buildings [7]. One of the benefits of this technology is the possibility to produce own free electricity for household purposes, and in this study case the produced energy can be used for operation of mechanical heat recovery ventilation, which consumes quite much of electricity and for that reason its installation is often quite questionable.

Photovoltaic panels can be installed on the roof of the case building. The current building at Lensoveta, 83 has a pitched rood with a low slope, and one slope faces the southwest side. If the total roof area is 636.5 m^2, and the installation of solar panels will take approximately 85% of a space of one slope, then about 270.5 m^2 of a southern slope can be occupied by solar panels.

For the estimation, a solar panel with a power of 270 W was chosen for calculations [84]. The size of the panel is 1650 mm x 992 mm, then the total area of one panel is 1.6368 m^2, thus it will be possible to install about 165 panels on the available area. The price for these number of panels plus other equipment will equal about 2 005 740 roubles [84].

The energy saving produced by solar panels accounts for 56 378 kWh as it was calculated with the help of PHPP (appendix 6). Given the known electricity price, it is possible to calculate the time that it takes for the return on investment:

$$Simple\ payback\ period = 2\ 005\ 770 \ /\ 259\ 902.8\ =\ 7.7\ \text{years} \quad (15)$$

This period of time is almost equal to the estimation presented by the company that produces the chosen solar photovoltaic systems.

4 Discussion

The chosen building for analysis of series 1-528 is recommended for renovation and reconstruction activities based on the obtained data from calculations.

The conducted condition survey of the building showed a satisfactory condition of the house. Minor building elements might need a replacement, as well as all the engineering equipment of the building. Nevertheless, the building still has a great technical potential for any renovation or reconstruction measures.

The calculations of the financial potential of reconstruction showed a positive trend in the implementation of such project for investors. The profit from the reconstruction could be sufficient for implementation of more complex modernization of the building. In the calculated cases, the profit reached to about 40 to 50 million roubles. This sum can cover the installation of mechanical heat recovery ventilation, photovoltaic systems, and probably any other additional renovation activities.

The options proposed for renovation and reconstruction were compared and evaluated in terms of their potential to improve the building's performance and reduce the energy consumption. The basic renovation option has the minimum investment cost, however, it cannot improve the qualities of the building so that it would meet the modern standards for energy consumption. The improved renovation includes more activities that are targeted on the reduction of heating load, nevertheless, the measures for improving only thermal properties of building envelope is still not enough to comply with requirements. The advanced renovation option includes not only the measures for thermal insulation and improving air-tightness, but also the installation of mechanical heat recovery ventilation. Only with the help of the latter, it is estimated that the building can reach the modern standard for energy consumption.

The obtained results from energy calculations and cost-efficiency calculations also showed that the set of measures proposed in the advanced renovation option could lead to greater energy savings and better building performance. The use of extra layers of thermal insulation and mechanical heat recovery ventilation can boost the building's performance up to normal levels, and such building can obtain the Energy Class C according to the current legislation on energy efficient classes.

Greater energy savings can be achieved if any other energy efficiency measures are implemented. However, given the very high initial investments of many such technologies, not all of them can be successfully included in the renovation and reconstruction. Given the disparity between the energy prices for electricity and heating energy, many applications that consume a lot of electricity are considered as not very cost-efficient during their life-cycle. For this reason, their addition to the renovation projects is still not very widespread in Russia.

For the case of mechanical heat recovery ventilation, the comparison of the life-cycle costs of this type of ventilation with the conventional exhaust mechanical ventilation did not show the significant difference between the two options. It is proposed in this thesis, that the positive benefits of heat recovery ventilation in terms of reduction of heating demand and improving indoor air quality should be addressed in greater detail. However, the decision upon the technology to be used should be done according to the budget limitations as well.

In the performed analysis, the potential of inclusion of other extra energy-efficiency measures was calculated as well. The choice for the technology was made for solar photovoltaic panels. The calculations showed that there is enough of free roof space for the installation of many solar panels, and the yield of the whole system is quite significant. The payback time calculation also showed that it should take only about seven or eight years to receive the return on the investment.

Other possible energy-efficient technologies can be included in the renovation and reconstruction of the building of series 1-528, however, the initial high investments and the questionable benefits in terms of their life-cycle costs might make such projects not very profitable and quite expensive in maintenance. Thus, the most sustainable option for the renovation of such types of houses as the studied building is the renovation option that include only minimum of extra energy-efficiency measures. Furthermore, such measures should prove their cost-efficiency over their life-cycle.

5 Conclusion

In this thesis project, several research questions were investigated through the means of theory research, literature review on the topic, and an analysis part was done as a case study of a particular building in order to answer the questions.

The need and potential for renovation was proved by theoretical research on the condition of the existing buildings, and by a condition survey of the building chosen for analysis. The existing renovation and reconstruction solutions in Russia were studied and based on that knowledge, possible solutions were chosen for analysis. The solutions included also measures for energy-efficiency. Information about the current norms and standards of energy consumption helped to determine the most optimal renovation option that can meet the modern requirements. Possible economic and technical limitations were also mentioned, and during the calculations for energy and cost-efficiency some of the common obstacles became evident.

The most optimal and sustainable renovation option for the studied building of the series 1-528 is the complex reconstruction option with an addition of an extra upper floor and inclusion of only few energy efficient measures: an addition of extra thermal insulation of all building envelope and the installation of mechanical heat recovery ventilation. The inclusion of solar photovoltaic panels can be also considered. The calculations showed that, to reach the level of current energy consumption requirements, the above-mentioned measures can be sufficient. With these measures, the project becomes economically feasible as it does not include many complicated solutions, and the cost of the extra measures can be paid by the income acquired from the selling of the apartments on the new floor. Overall, the building's performance is improved, the energy consumption is significantly reduced, and the building can reach the level of energy-efficiency class C.

In conclusion, the research that was carried out proved that the renovation of buildings of the first mass series is both necessary and economically viable. The results obtained from the analysis part of this project show the great potential of reconstruction solutions to improve the condition of existing buildings. The results can be applied not only to the series with the greatest potential for reconstruction, but also to many other buildings of the first mass series. The proposed solution could be further studied and probably applied as pilot projects to some buildings to test the calculated potentials in a real-life situation.

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Energy-efficiency classes according to the Federal Law on Energy Efficiency No. 261 Ф34

Table 1 represents the base values for energy consumption of apartment buildings. The base values are given as kWh/m^2.

Table 1. Base values for energy consumption of apartment buildings.

Basic level of the specific annual consumption of energy resources in an apartment building

Name of the indicator	degree days	number of storeys 2	4	6	8	10	>12
Heat consumption for heating, ventilation, hot water and electricity	2000	215	206	203	201	199	198
	3000	228	216	212	208	205	203
	4000	256	239	234	229	225	223
	5000	284	263	256	251	245	242
	6000	312	287	278	272	265	262
	8000	370	337	326	317	308	304
	10000	426	384	370	359	348	342
Including heat energy for heating and ventilation	2000	67	56	44	42	40	39
	3000	100	83	67	63	60	58
	4000	133	111	89	84	80	78
	5000	167	139	111	106	100	97
	6000	200	167	133	127	120	117
	8000	253	211	169	160	152	148
	10000	317	264	211	201	190	185

Modified from the source: Order of the Ministry of Construction of the Russian Federation of 06.06.2016 N 399 "On the approval of the rules for determining the class of energy efficiency of apartment" [online]. Ministry of justice of the Russian Federation.

URL: https://minjust.consultant.ru/documents/20368?items=1&page=2. Accessed 20 February 2019.

Table 2 represents the division of energy classes and requirements for each of the energy class.

Table 2. Energy-efficiency classes requirements.

Table of energy-efficiency classes requirements

Energy Class	Name of the class	The deviation of the consumption of thermal energy from the base number,%	Activities
in the design and operation of new and reconstructed buildings			
A++	Very high	Lower -60	property tax relief for 3 years
A+		from -50 to -60	
A		from -40 to -50	
B+	High	from -30 to -40	
B		from -15 to -30	
C+	Normal	from -5 to -15	–
C		from +5 to -5	
C-		from +15 to +5	
in the operation of existing buildings			
D	Reduced	from +15,1 to +50	reconstruction with a corresponding economic feasibility
E	Low	more than +50	reconstruction with appropriate economic justification, or demolition

Modified from the source: Energy-efficiency class [online]. Energy Efficiency and Energy Audit LLC.

URL:https://energo-audit.com/klass-energoeffektivnosti-zdania#ekspluatiruemye-zdaniya. Accessed 27 February 2019.

Condition Survey of the building at Lensoveta street, 83

Name of the building element	Photography	Technical condition[1]	Recommendations
Foundation		Efflorescence, traces of moisture basement walls, blocks crack	Partial restoration and waterproofing
External walls		Weathered joints, weakening of brickwork, traces of wall wetting	Partial repair of the damaged brickwork. Basic façade renovation

			
Floors		Erasing the surface in running places, pot-holes up to 0.5 m2 on an area of up to 25%, in some places swell-ing of tiles, lagging of tiles on an area from 20 to 50%	Basic repairs

Stairwells		Potholes in the steps, railings damaged in places. Steps worn, chipped and cracked	Partial repair of the stair steps
Balconies		Traces of moisture on the bottom plane of the plate, cracks, corrosion of metal supporting structures (consoles, brackets, hangers)	Repair/replacement is needed

Interior finish		The paint layer is dirty in some places, damaged in some places, opaque spots on the paint layer	Partial renovation of ceilings, floors, walls, windows (windows in the common stairwells were recently changed)

[1]Modified from the source: Portal "Our St. Petersburg" [online resource]. Government of St Petersburg. URL:https://gorod.gov.spb.ru/. Accessed 6 April 2019.

Heating energy demand calculations for the "Advanced" renovation option

Table 1. Inputs for "Areas" worksheet in PHPP tool.

Building: Residential apartment block   Heatir

Group Nr.	Area group	Temp.-zone	Area	Unit
1	Treated floor area		2773.16	m²
2	North windows	A	207.90	m²
3	East windows	A	18.90	m²
4	South windows	A	202.23	m²
5	West windows	A	18.90	m²
6	Horizontal windows	A	0.00	m²
7	Exterior door	A	9.45	m²
8	Exterior wall - Ambient	A	1551.63	m²
9	Exterior wall - Ground	B	155.42	m²
10	Roof/Ceiling - Ambient	A	636.48	m²
11	Floor slab / Basement ceiling	B	0.00	m²
12	Floor slab	A	591.18	m²
13			0.00	m²
14		X	0.00	m²
15	Thermal bridges Ambient	A	0.00	m
16	Perimeter thermal bridges	P	0.00	m
17	Thermal bridges FS/BC	B	0.00	m
18	Partition wall to neighbour	I	0.00	m²
Total thermal envelope			3392.09	m²

Table 2. External wall composition.

Assembly no. 2   Building assembly description: Exterior Wall Element   Interior insulation? no

Heat transfer resistance [m²K/W]   interior R_{si}: 0.13   exterior R_{se}: 0.04

	Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Cement plaster	0.800					20
2.	Silicate brick	1.040					640
3.	Mineral wool	0.035	Aluminium frame	0.500			250
4.	Air gap	0.024					50
5.	Ceramic tile	0.750					10
6.							
7.							
8.							
	Percentage of sec. 1	95%	Percentage of sec. 2	5.0%	Percentage of sec. 3		Total 97.0 cm

U-value supplement [ ] W/(m²K)   U-Value: 0.126 W/(m²K)

Table 3. Energy balance of the building.

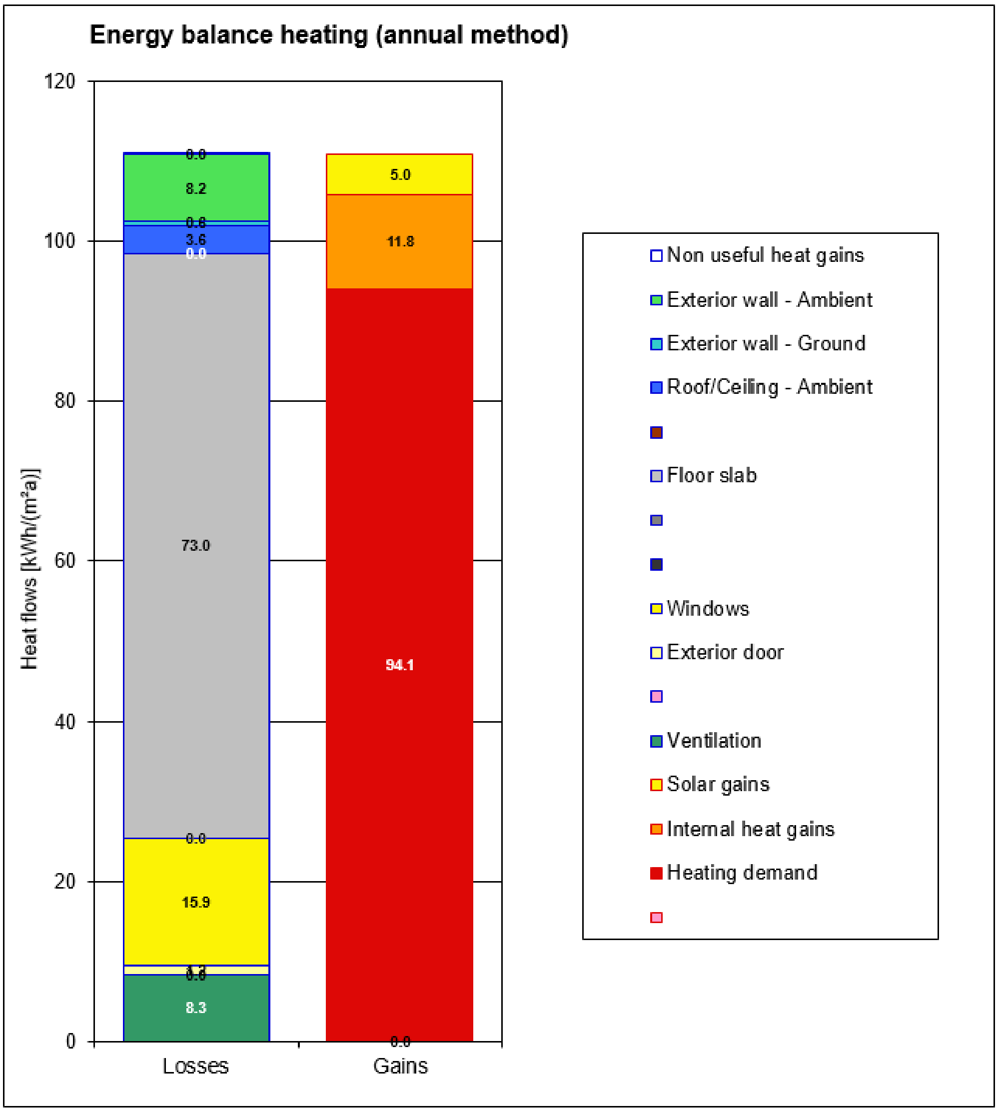


Table 4. Space heating demand of the building.

Space heating			
	Heating demand	**100**	**kWh/(m²a)**
	Heating load	**33**	**W/m²**

Energy simulations results for the “Advanced” renovation option

Table 1. Heat losses in the building.

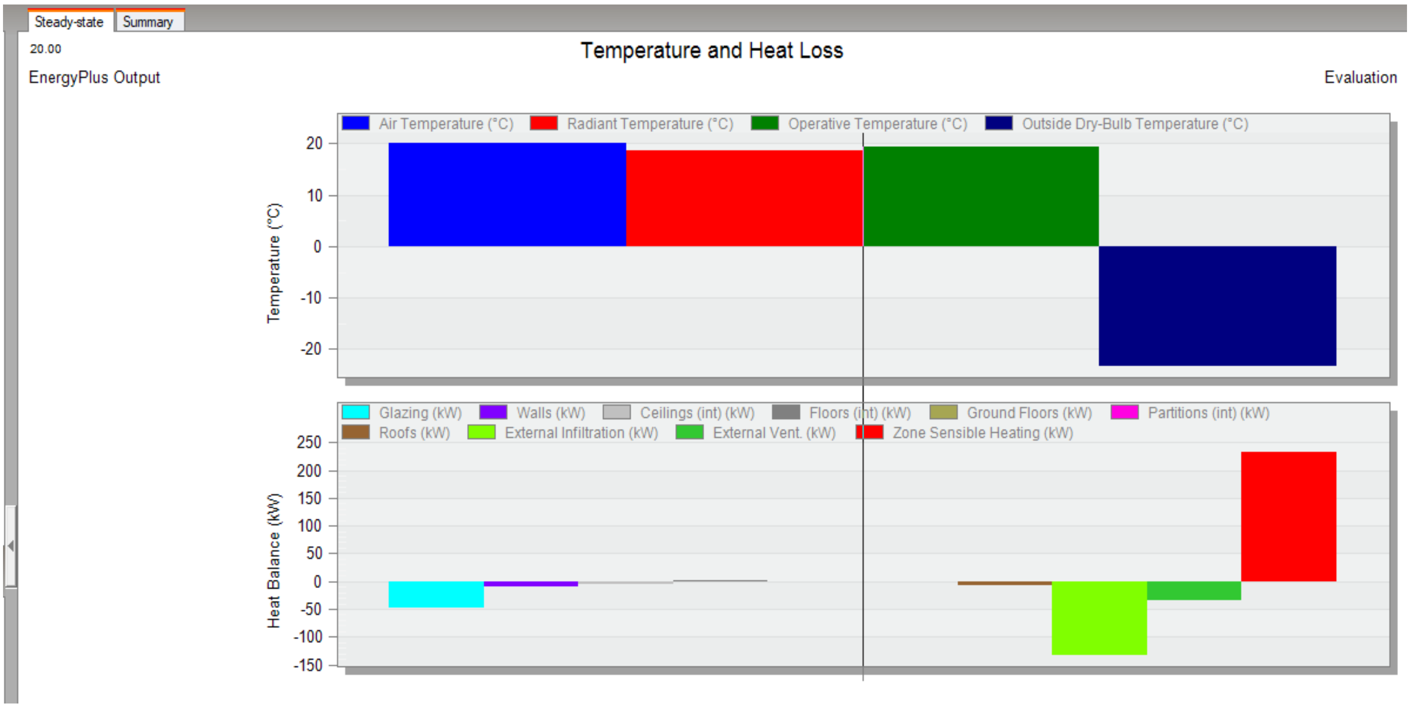


Table 2. Heating design capacity of the building.

Zone	Comfort Temperature (°C)	Steady-State Heat Loss...	Design Capacity (kW)	Design Capacity (W/m2)	Glazing Gains (...	Wall Gains (kW)	Floor Gains (kW)	Roof and Ceili...	Ventilation Gai...	Infiltration Gain...
Building 1 Total Design Heating Capacity = 291.560 (kW)										
Block 1 Total Design Heating Capacity = 43.050 (kW)										
Zone 1	19.35	34.44	**43.05**	77.7615	-4.130	-1.672	0.219	-0.083	-5.688	-23.091
Block 2 Total Design Heating Capacity = 41.090 (kW)										
Zone 1	19.35	32.87	**41.09**	74.2122	-3.913	-1.718	0.219	-0.119	-5.688	-21.653
Block 3 Total Design Heating Capacity = 41.170 (kW)										
Zone 1	19.35	32.94	**41.17**	74.3670	-3.931	-1.724	0.230	-0.162	-5.688	-21.666
Block 4 Total Design Heating Capacity = 41.340 (kW)										
Zone 1	19.33	33.07	**41.34**	74.6665	-3.943	-1.718	0.265	-0.310	-5.688	-21.679
Block 5 Total Design Heating Capacity = 41.850 (kW)										
Zone 1	19.27	33.48	**41.85**	75.5885	-3.951	-1.695	0.413	-0.868	-5.688	-21.693
Block 6 Total Design Heating Capacity = 43.830 (kW)										
Zone 1	19.04	35.07	**43.83**	79.1687	-3.953	-1.610	0.979	-3.089	-5.688	-21.706
Roof 1 Total Design Heating Capacity = 0.000 (kW)										
Zone 1	-17.06	0.00	**0.00**	0.0000	0.000	0.470	2.702	-0.993	0.000	-2.198
Block 7 Total Design Heating Capacity = 9.460 (kW)										
Zone 1	17.03	7.57	**9.46**	4352.7909	-5.470	0.055	0.007	-1.601	-0.022	-0.545
Block 8 Total Design Heating Capacity = 9.800 (kW)										
Zone 1	16.94	7.84	**9.80**	4488.3047	-5.770	0.088	0.007	-1.600	-0.022	-0.547
Block 9 Total Design Heating Capacity = 9.690 (kW)										
Zone 1	16.96	7.75	**9.69**	4508.4543	-5.705	0.085	0.007	-1.584	-0.022	-0.539
Block 10 Total Design Heating Capacity = 10.280 (kW)										
Zone 1	16.91	8.22	**10.28**	4130.1139	-6.011	0.115	0.008	-1.693	-0.026	-0.624

Table 3. Graphs of the energy simulation results.

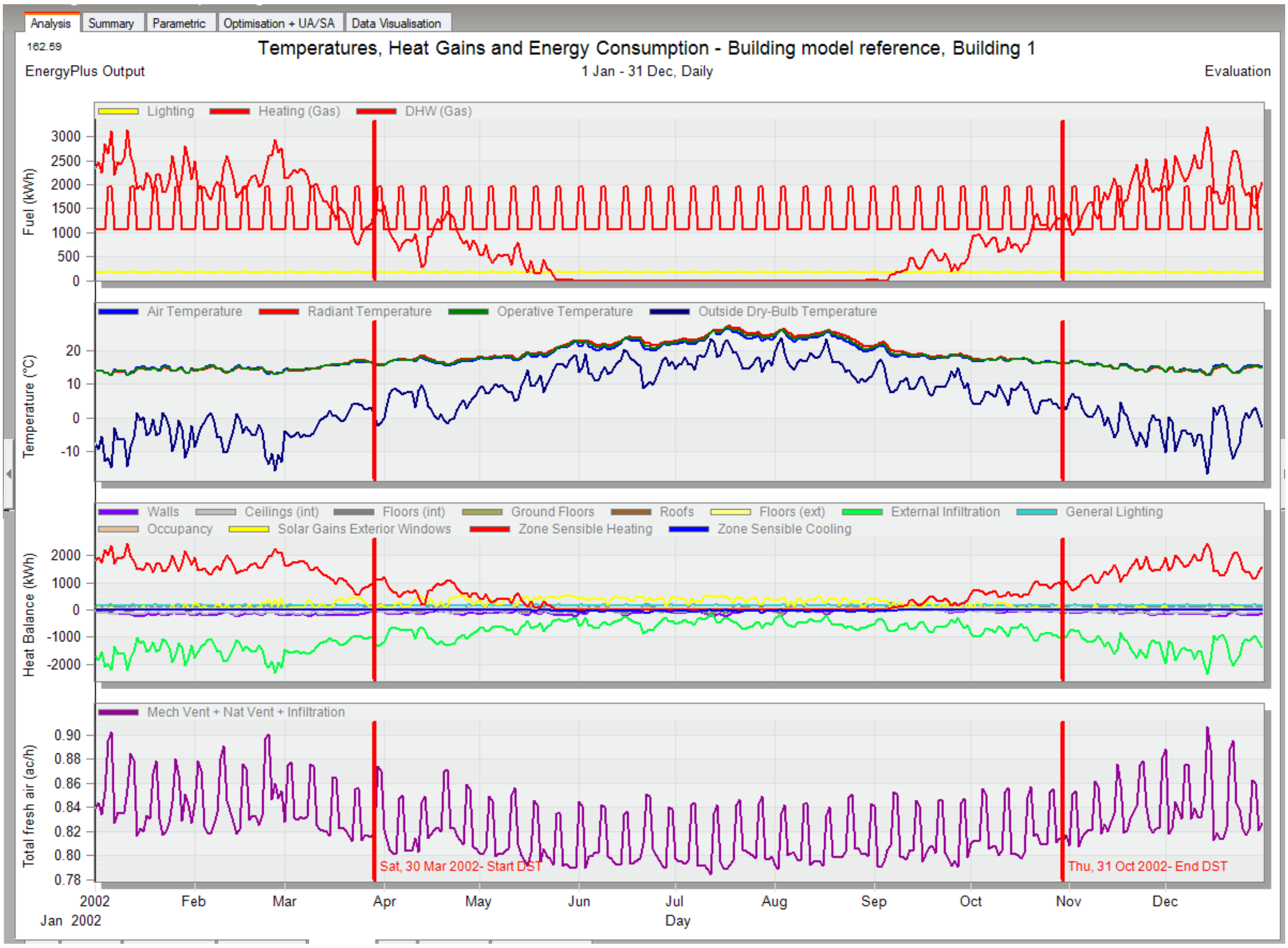


Table 4. Summary of the total energy consumption.

Analysis | Summary | Parametric | Optimisation + UA/SA | Data Visualisation

Program Version:**EnergyPlus, Version 8.9.0-40101eaafd, YMD=2019.04.23 22:45**

Tabular Output Report in Format: **HTML**

Building: **Building**

Environment: **BUILDING MODEL REFERENCE (01-01:31-12) ** SAINT-PETERSBURG - RUS IWEC Data WMO#=260630**

Simulation Timestamp: **2019-04-23 22:45:04**

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2019-04-23 22:45:04**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	773468.97	237.86	237.86
Net Site Energy	773468.97	237.86	237.86
Total Source Energy	2766803.54	850.84	850.84
Net Source Energy	2766803.54	850.84	850.84

Life-cycle cost calculations for ventilation options

Comparison calculation between the “Improved” renovation option and “Advanced” renovation option. The first includes the installation of a conventional mechanical exhaust ventilation system, the second contains the mechanical heat recovery balanced ventilation.

1st option											
Year\Title	I	E	A	M	R		I	E	A	M	R
0	10497000	656927.4	1500				15043400	433718.4	3850		
1		656927.4	1500					433718.4	3850		
2		656927.4	1500					433718.4	3850		
3		656927.4	1500					433718.4	3850		
4		656927.4	1500					433718.4	3850		
5		656927.4	1500	10000				433718.4	3850	30000	
6		656927.4	1500					433718.4	3850		
7		656927.4	1500					433718.4	3850		
8		656927.4	1500					433718.4	3850		
9		656927.4	1500					433718.4	3850		
10		656927.4	1500	10000				433718.4	3850	30000	
11		656927.4	1500					433718.4	3850		
12		656927.4	1500					433718.4	3850		
13		656927.4	1500		150000			433718.4	3850		600000
14		656927.4	1500					433718.4	3850		
15		656927.4	1500	10000				433718.4	3850	30000	
16		656927.4	1500					433718.4	3850		
17		656927.4	1500					433718.4	3850		
18		656927.4	1500		150000			433718.4	3850		600000
19		656927.4	1500					433718.4	3850		
20		656927.4	1500	10000				433718.4	3850	30000	
21		656927.4	1500					433718.4	3850		
22		656927.4	1500					433718.4	3850		
23		656927.4	1500					433718.4	3850		
24		656927.4	1500					433718.4	3850		
25		656927.4	1500					433718.4	3850		
Sum	10497000	17080112	39000	40000	300000	Sum	15043400	11276678	100100	120000	1200000
LCC total	£26,200,234.43					LCC total	£26,068,608.34				
Energy co:	DH	1.51	628539				393975.61				
	Electricity	4.61	28388.38				39742.81				
Total			656927.4				433718.42				

Calculations for additional energy-efficient measures: solar photovoltaic panels

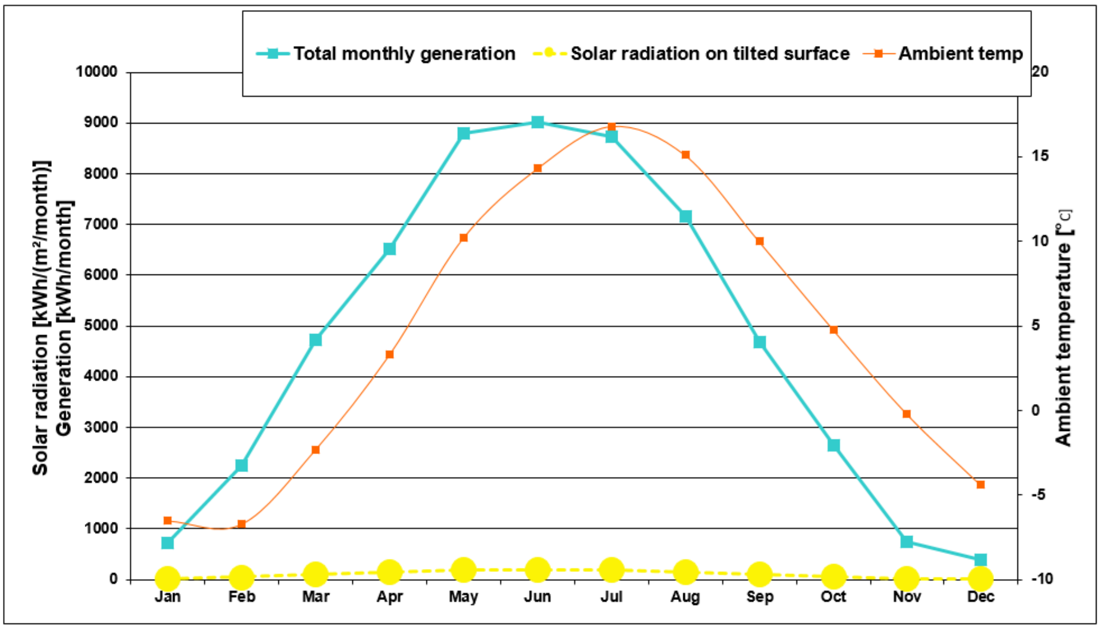
Table 1. Calculation for solar photovoltaic panels in PHPP.

Information from the module data sheet

Technology	Poly-Si		
Nominal current	I_{MPP0}	9.09	A
Nominal voltage	U_{MPP0}	38.08	V
Nominal power	P_n	346	Wp
Temperature coefficient short-circuit current	α	0.030	%/K
Temperature coefficient open-circuit voltage	β	-0.340	%/K

Further specifications

Latitude:		60.2	°
Number of modules	n_M	165	
Deviation from North		180	°
Angle of inclination from horizontal		43	°
Height of module array		1	m
Height of horizon	h_{Hori}		m
Horizontal distance	a_{Hori}		m
Additional reduction factor shading	r_{other}	97%	
Efficiency of the inverter	η_{HRV}	95%	
Annual yield of the inverter		56378	kWh
Annual losses due to shading		1744	kWh
PE value (non-renewable)		0.3	
CO_2-equivalent emission value		53.9	g/kWh



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Year	
Solar radiation on tilted surface	16	49	103	141	190	195	190	155	101	57	16	8	kWh/m²/Month	1222.3	kWh/m²/a
Ambient temp	-7	-7	-2	3	10	14	17	15	10	5	0	-4	°C	4.5	°C
Total monthly generation	731	2245	4728	6512	8789	9013	8737	7149	4691	2643	752	388	kWh/month	56378.4	kWh/a
Losses due to shading situation	23	69	146	201	272	279	270	221	145	82	23	12	kWh/month	1743.7	kWh/a

Figure 1. Screenshot of the PHPP calculation.