Saimaa University of Applied Sciences
Technology, Lappeenranta
Double Degree Program in Civil and Construction Engineering

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Energy efficient upgrading of the envelope structures of the typical St. Petersburg apartment house

Thesis 2017

Abstract

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The purpose of the study was to develop the program of a typical Saint Petersburg multi-story house renovation, focused on increasing energy efficiency of the envelope structures. The 5-story slag-concrete residential building was chosen as an object of the study.

The calculations given in the thesis were made according to the Russian set of rules 'Thermal performance of the building' and Eurocode norms with consideration of National Building Code of Finland. This study was carried out using Doftherm software in order to simulate thermal properties of enclosing constructions of the object building. All theoretical information was gathered from sets of rules, handbooks, thermal insulation product brochures and the internet.

Three steps of renovation program were developed as the result of the study. Questions of thermal physics of the wall, floor and roof structures have been considered as the central part of the research. Along with this some economical aspects have been described and variants of the improvements implementations have been admitted. Further study is required to identify the possibilities of applying the described methods to other types of houses and to the whole city quarters and districts.

Keywords: renovation, energy efficiency, thermal resistance, enclosing structures, slag-concrete walls, energy passport, class of energy efficiency, energy saving program, recuperation of heat.

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1 Introduction

Saint Petersburg is a big, developing city with a large historical center. The main strategy of its future development is finding new ways of making the heritage of the past suitable for the citizens of the present. In the case of civil engineering this idea has found its place in renovation activities throughout the city.

The whole massive of the civil buildings in the city can be divided into four categories by the side of renovation.

Figure 1. Four different types of building in Saint Petersburg

The first part is the old buildings, constructed from the set of the city (1703) up to the times of the Revolution and World Wars – these are the mansions with massive masonry walls and wooden floors and rafters, like the Winter Palace, or the house's facades facing the Nevskiy prospect. Historical buildings are under protection of the city, moreover, they are, as the part of the whole historic part of Saint Petersburg, protected by the UNESCO organization. So, the renovation of these objects is the required process, but its realization is not only the problem of architects or city builders, but the lawyers, historians and is extremely complicated.

The second part is the relatively new buildings, built during the last two decades, which are not considered as the objective of renovation works. New development grows in all areas of the city, except the old part, as it is protected from the interaction of new facades.

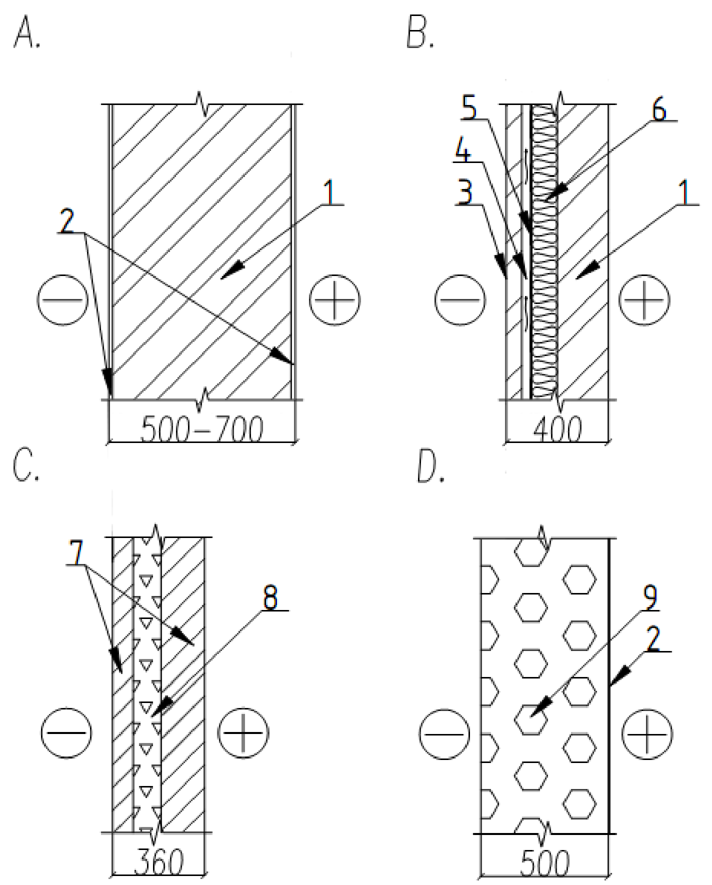


Figure 2. Wall sections of 4 types of buildings. A – massive masonry bearing wall; B – ventilated façade; C – concrete panel wall; D – slag-concrete massive wall. 1 – Brick masonry; 2 –plaster; 3 – façade brick; 4 – ventilation gap; 5 – water insulation layer; 6 – thermal insulation; 7 – concrete; 8 – lightweight concrete; 9 – slag-concrete.

The third category is the houses, which were built from the 1960s up to the end of the 20th century. The main principles of the architecture of that time were constructivism, unification, standardization and typification. The typical example of housing in that period can be the chruchyovka – these houses are usually five story panel buildings with small flats and without the elevators, so they are easy and cheap to construct. Practically in every part of Saint Petersburg these buildings can be found. Beside the construction, chrushovkas have some disadvantages: they are unconvincing, use lots of energy, have lack of heat insulation, bad looking. In fact, some of the types of the building were considered to be demolished after the five-ten year period from the time they were built. In this case demolition and new development on a vacant land parcel is more efficient than renovating existent houses.

The last category is the buildings, constructed during the period between the Revolution and the 1960s, called in common Stalinkas. These houses have been erected in eight districts of Saint Petersburg, made of bricks or blocks (or sand lime bricks), and became the most comfortable, prestigious and good looking examples of Soviet residential architecture [1]. Nowadays they are considered to be renovated, because they, from one hand, are a historic face of the non-central areas of Saint Petersburg, and on the other hand during their renovation new techniques and materials can be used, which can be experimental and even change the façade (which is forbidden in the center area). Moreover, during the renovation project new ways can be designed to increase the energy efficiency of these old houses in order to reduce the heat overuse and to make the living in these buildings more comfortable and sustainable.

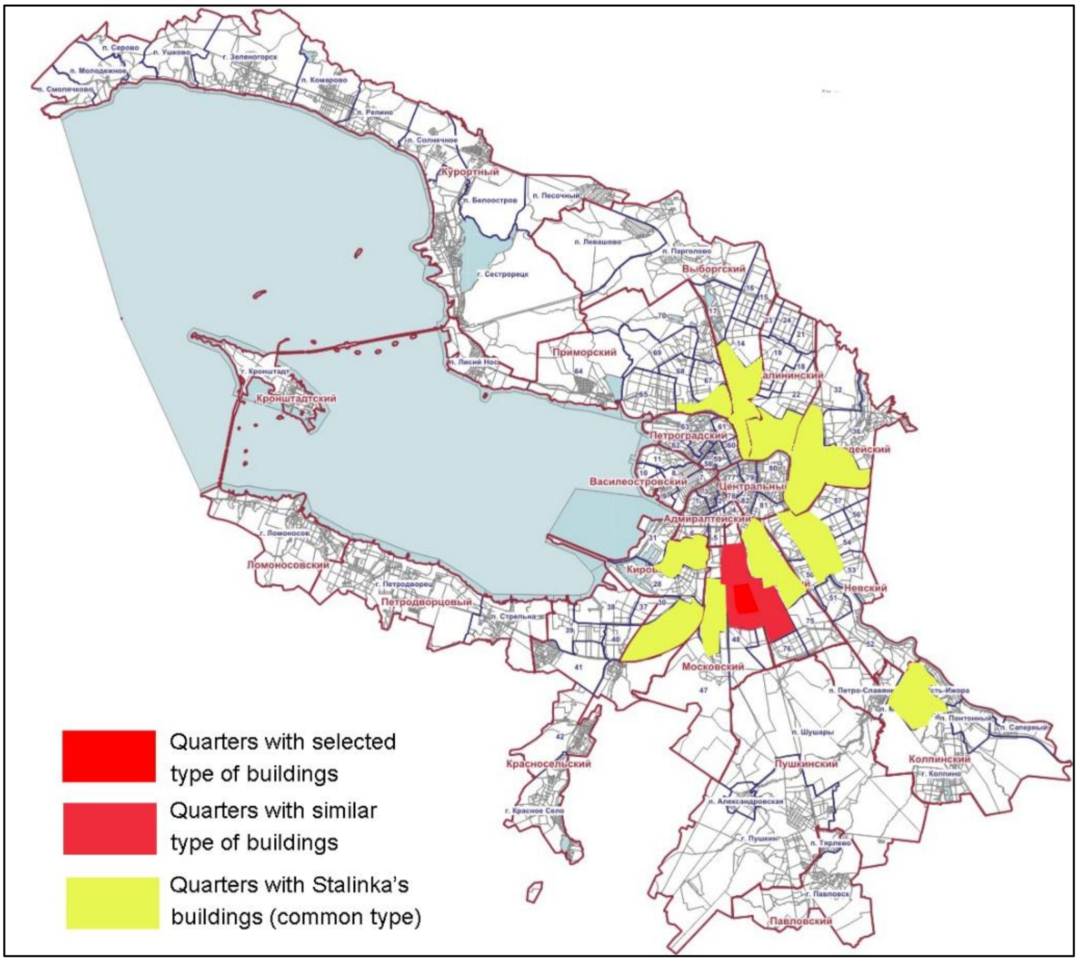


Figure 3. Spreading of the quarters built up with Stalinka's type of houses in Saint Petersburg

Residential buildings consume 40% of total power, accumulated by the Municipal Power Suppliers [2]. This is why the idea of reducing energy consumptions in residential developments during their renovation is very important.

The aim of this thesis work is to develop the complex of actions in order to improve the energy-efficient rating of the typical residential building in Saint-Petersburg, constructed in 1950s, which can be attributed to the last category (category 4).

2 Description of the research object

The first experimental houses made of blocks have been built in 1932-1934. There was the special order from the new Soviet government to create a new type of residential house, which will complete such requirements: easy to construct using existing elevation machines, easy to design using standard modules, which have to be made in the nearest fabrics to the construction site. These are the main characteristics of the industrial construction method, which was developing by the government initiative. The main reason for its developing is the tendency to construct more houses using less amount of material, labor and time – the efficiency became the main idea of new construction developments [3].

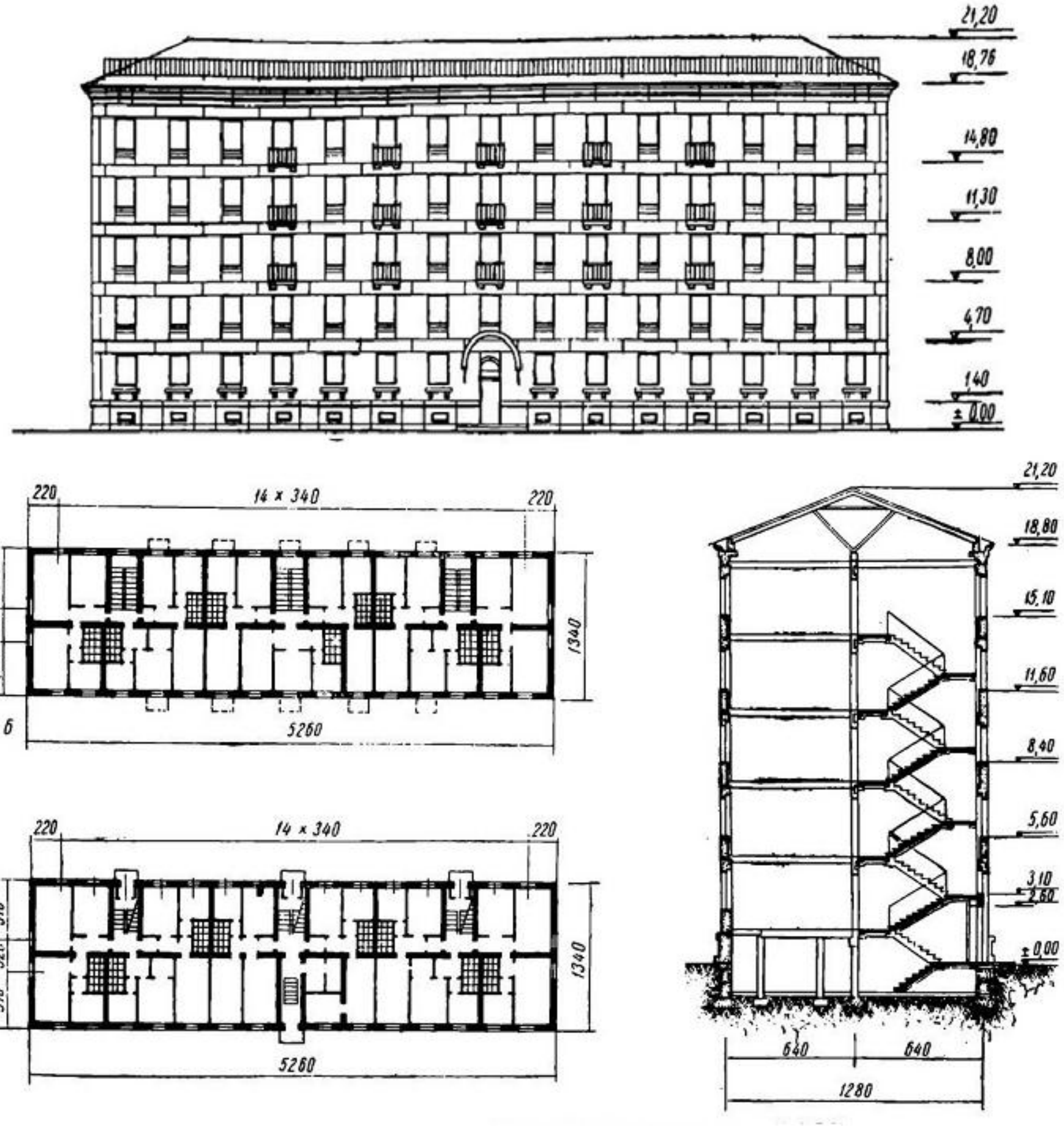


Figure 4. Façade, floor plans and section of a 1-415 house [3]

Designers replaced small bricks with bigger blocks – as a result later on in the 1960s practically all new buildings were built from large panels. It is easier, cheaper and takes less time to erupt the panel building, than the brick one.

Standard block sizes were 500 to 3000 mm in length and 860 mm in height for houses, built before 1951. The size of common brick is 250x120x65.

Usual material for blocks in Saint Petersburg was slag concrete. Coal and peat slag were used as the aggregate for the concrete. Because of industrialization it was easier to make this kind of concrete instead of spreading nowadays heavy and lightweight concrete. But, there are some disadvantages in using slag concrete blocks – they tend to crumble, and their insulation properties are not so high. This lack of thermal resistance of the material is compensated by the thickness of the walls – the thickness of the external walls was 50 cm, and internal walls – 40 cm.

Another principle, which was developed by the architects of that time was the typification principle. Instead of making an individual design for each new house, they provided a serial type residential house, which can be built in the same form in different sites. Now this concept is still common to the modern city development and is demonstrated in quarters of identical blocks of flats, as it is the cheapest and fastest way to give a living space for the largest amount of people. But, in comparison with modern panel houses, not only economical aspect of construction was considered by the architects of Stalinkas – they also concerned about the façade's presence, comfortability of the flat's arrangement and thermal insulation characteristics. This is why these houses are of interest in order to be renovated and taken care in the present.

The first series of block houses, which were designed by the main architectural department and become widespread in the Moscow district of Saint-Petersburg, are called series 1-415. The typical house of this series consists of 5-7 stores and is made of slag concrete blocks [3].

Table 1 Characteristics of the series 1-415 house [3]

Architects	I.I.Fomin, B.N.Zhuravlyov, S.B.Speranskij, L.S.Kosven, V.E.Struzman
Year	1950s
Wall	Slag concrete blocks (88 types), width = 500 mm (external), 400 mm (internal)
Base wall	Concrete blocks (gravel-sand mixture)
Floor	Concrete slabs
Base floor	Concrete slabs
Roof	Wooden rafters,
Floor high	3,30
Ventilation system	Natural ventilation (through the windows to the ventilation canals in the walls)

Heating system	Central heating

Object of this research is one of the first-built Stalinka's houses, constructed in 1958 on the Gagarina Avenue in the Moscow district of Saint Petersburg. This house represents the basic modification of a block residential house (other modification with seven floors and with first commercial floors are widely spread in this district).

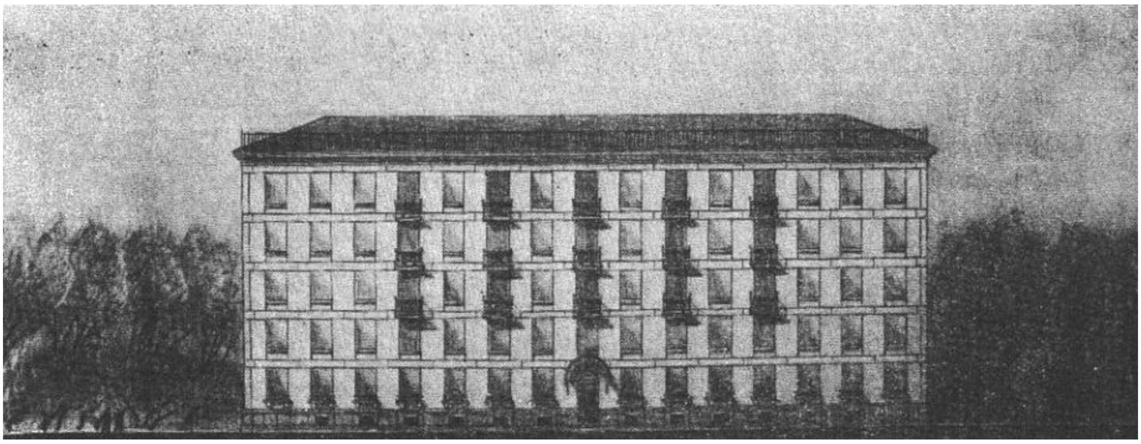


Figure 5. Image of a 1-415 house [3]

The code, which regulated the energy presence of the new residential developments in the time the series 1-415 was built, is SNiP "Norms of a construction design", written in 1954 [4].

In 2000s this house met its 50th anniversary, and it means, that it is more than half a way to the end of its exploitation period (100 years). It needs to be renovated, and during the renovation works there can be made some actions about reducing its energy consumption. In Europe there are many examples of improving old houses with new techniques and new materials, and using that experience there can be organized in an effective plan of actions, which can be suitable to the object of the research.

3 Energy analyses of the existent building

The modern Russian building regulations provide the guidance how to submit Energy Passport of building. According to calculations of energy losses and thermal resistance of the buildings' envelope, the object building can be characterized as D-class of energy efficiency. It means that the difference between the required characteristic of heat energy consumptions of heating and ventilation of the building by heating period and design characteristic is up to 50 % (and the building has not met the requirements) [5].

Another information, which can be found in the passport, is the value of energy consumption per year. The value is 618018.88 kWt·h/year, which means if the tariff value in St Petersburg is 1678.72 rub/Gcal (27 €), then per year the residents of the researched house should pay 892 079 rub (14 000 €).

Finally, the heat losses due to the unsatisfactory characteristics of the envelope structures of the building is 75284.84 kWt·h/year, and per year residents pay extra 108 669 rub (1 800 €).

Table 2. Energy passport of the object house

I. Common Information			
Date	3.2017		
Address of the object	Russia, Saint-Petersburg, Moskovskii district		
Building type	Residential, series 1-415-1		
Number of floors	5		
Number of flats	44		
Design number of residents	122		
Position in the urban development	Single-standing		
Type of construction	Prefabricated, slag-concrete large-block		
II. Design conditions			
Design characteristic	**Description**	**Unit**	**Value**
1. Design outdoor temperature	t_{ext}	°C	-8.7
2. Average outdoor temperature for the heating season	$t_{h.s}$	°C	-1.8
3. Length of the heating season	$z_{h.s}$	days/year	220
4. Degree-days of the heating season	DDHS	°C·days/year	4796
5. Design indoor temperature	t_{int}	°C	20
6. Design air temperature of the attic	t_{attic}	°C	-4
7. Design air temperature of the basement floor	t_{base}	°C	8
III. Geometry characteristics			

Design characteristic	Description	Unit	Value
8. Gross floor area	A_{fg}	m^2	4659.2
9. Living area	A_{liv}	m^2	1619.2
10. Design area	A_d	m^2	665.6
11. Heated volume	V_{heat}	m^3	10782.72
12. Façade glazing coefficient	f	-	0.2
13. Indicator of buildings' compactness	K_{comp}	-	0.35
14. Gross area of exterior enclosure structures	A_{ext}^{gross}	m^2	3764.48
facades (slag-concrete)	A_{fac1}	m^2	1800.7
facades (basement wall)	A_{fac2}	m^2	161.2
external doors	A_{door}	m^2	8
Attic floor	$A_{att.fl}$	m^2	650.08
basement floor	$A_{base.fl}$	m^2	650.08
windows (flats)	A_{win1}	m^2	441.98
windows (corridor)	A_{win2}	m^2	52.44
North oriented windows		m^2	59.8
North-East oriented windows		m^2	0
East oriented windows		m^2	187.41
South- East oriented windows		m^2	0
South oriented windows		m^2	59.8
South-West oriented windows		m^2	0
West oriented windows		m^2	187.41
North-West oriented windows		m^2	0
IV. Thermal characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
15. Equivalent thermal resistance of the enclosure structures	R_o^{unit}, $m^2 \cdot °C/Wt$		
External slag-concrete walls	R_{fac1}	3.08	0.80
External basement walls	R_{fac2}	3.08	0.69

External doors Attic floor basement floor windows (flats) windows (corridor)	R_{door} $R_{att.fl}$ $R_{base.fl}$ R_{win1} R_{win2}	0.83 4.06 4.06 0.51 0.51	0.83 1.10 1.10 0.35 0.35
V. Additional characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
16.Equivalent transmission coefficient of thermal convection	K_{tr} , Wt/(m^2·°C)		1.33
17. Air exchange rate per heating period	n_a, h^{-1}		0.30
18. Equivalent domestic heat emissions in the building	$q_{d.h}$, Wt/m^2		12
VI. Equivalent characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
22. Equivalent thermal protective characteristic of the building	k_{tot} , Wt/(m^3·°C)	0.24	0.46
23. Equivalent ventilation characteristic	k_{vent} , Wt/(m^3·°C)		0.09
24. Equivalent domestic emissions' characteristic	k_{de} , Wt/(m^3·°C)		0.08
25. Equivalent characteristic of sun thermal input to the building	k_{rad} , Wt/(m^3·°C)		0.05
VII. Coefficients			
Characteristic	**Description**	**Required value**	
26. Coefficient of heating system autoregulation	ζ	0.5	
effectivity			

27. Coefficient, which considers decrease of heat consumption due to management of heat energy distribution per flats	ξ	0	
28. Coefficient of recuperation equipment effectivity	k_{ef}	0	
29. Coefficient, which considers decrease of heat energy usage in the period, when they exceed heat losses	v	0.79	
30. Coefficient of additional heating system energy losses consideration	β_h	1.13	
VIII. Complex heat energy consumption characteristics			
Characteristic	**Description**	**Unit**	**Value**
31. Design equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period	$q_{heat}{}^{d}$	Wt/(m^3·°C)Wt/(m^2·°C)	0.50
32. Required equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period	$q_{heat}{}^{req}$	Wt/(m^3·°C)Wt/(m^2·°C)	0.36
33. Energy saving category			D
34. Have the building characteristics met requirements?			No
IX. Energy load of the building			
Characteristic	**Description**	**Unit**	**Value**
35. Equivalent heat energy consumptions for building heating per heating period	q	kWt/(m^3·year)kWt/(m^2·year)	381.68

36. Heat energy consumptions for building heating per heating period	Q_{heat}^{year}	kWt·h/year	618018.88
37. Total heat losses per heating period	Q_{tot}^{year}	kWt·h/year	693303.72

4 Energy presence improvement methods of the object

The table of methods to improve energy-saving characteristics of the building was compiled using the existing examples of resembling renovation projects in different countries with cold climate. Approximate effectivity of these methods represents the average percent of the energy, saved per year after these implementations have been established in the real renovation projects.

Table 3 Energy saving methods, considered in the renovation project

№	The improvement	Approximate max.effectivity
Enclosure structures		
1	Additional wall thermal insulation and encapsulation of the block joints	35
2	Additional thermal insulation of the basement floor	35
3	Additional thermal insulation of the attic	
4	Reducing of the flat's heating volumes (constructing suspended ceiling structures)	5
5	Replacement of the window structures	10
6	Replacement of the external door structures and structures of the attic and basement doors.	10
House systems		
1	Management and measuring systems installation to the water supply system, gas supply system, and electricity supply system and heating system.	2
2	Installation of the mechanical ventilation system with recuperation of heated air	35
3	Replacement of the light bulbs with energy saving lamps	2

5 Improvement of the enclosure structures

The building envelope of the researched house is presented by wall structures, basement wall structure, base and attic floors and roof structure.

The easiest and most widely used method to improve the thermal resistance value of the structure is to add an extra layer of efficient material to the existing structure. This can be implemented in two ways: additional thermal insulation can be placed from the living side (inside the building envelope) or from the external side of the structure.

Additional insulation inside the building can be placed only when the residents are absent in their apartments, and it usually brings the problems with moisture on the wall joints (special works have to be executed to solve these issues). Otherwise, a new layer does not affect on the façade of the building.

Additional insulation outside the building definitely affects on its façade – but if it requires renovation this type of work can be executed at one time. In addition, there is no need in resettling the residents during the works execution.

It is important to consider, that not only thermal characteristics of each part of the envelope structure need to be researched and improved if needed, but also the integrity of the whole system should be provided in order to exclude the possibility of energy losses through the joint spaces of different elements of the building.

5.1 Wall thermal insulation

External walls in the researched object have two different structures. Base floor walls are made of concrete blocks with gravel-sandy mixture. The thickness of these blocks is 700 mm. External walls are made of slag-concrete blocks with thickness 500 mm. Blocks, which have been placed under the window holes, are 400 mm thick to save space for heating radiators inside the building [5].

Such thickness is conditioned by homogeneous structure of the walls – there is no special thermal insulation layer placed inside the wall structure.

In order to calculate the thermal resistance of the wall Doftherm software was used.

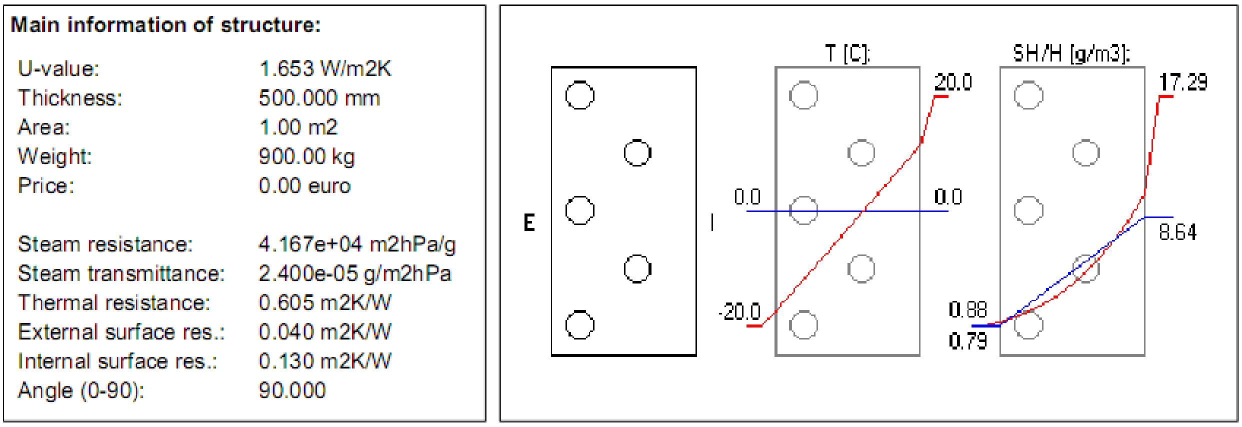


Figure 6. Thermal and humidity curves for slag-concrete wall, produced in Doftherm software

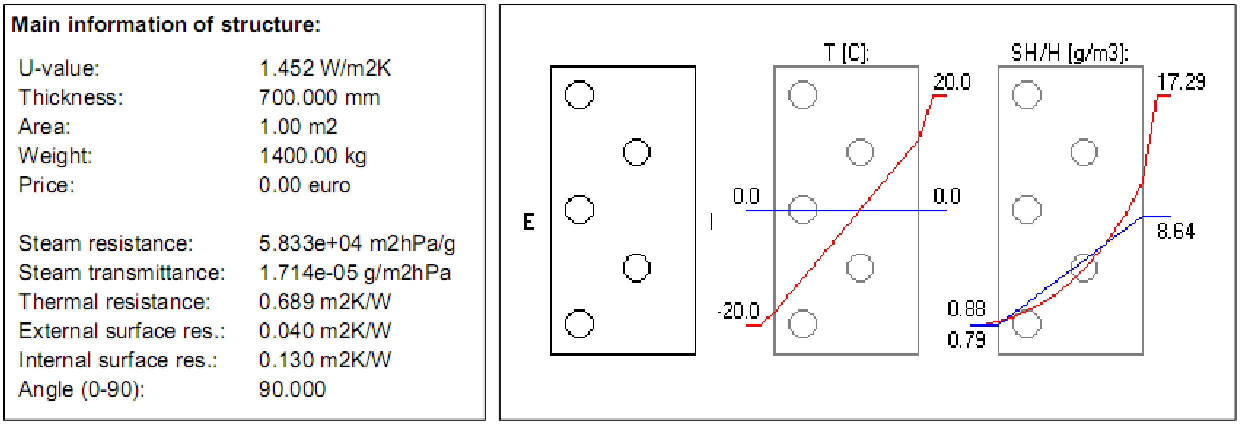


Figure 7. Thermal and humidity curves for concrete base wall, produced in Doftherm software

Slag-concrete block has got lower density value than usual medium-density concrete block (equals 1600 kg/m^2), and bigger value of thermal conductivity (equals 0,6 W/m^{2}C). Despite of this U-value of the homogeneous wall, made of slag-concrete is still bad, and equals 1,653 W/m^{2}K [6].

In Russia thermal characteristics of buildings are regulated by SP 50.1330.2012 Thermal performance of buildings. The regulated parameter for walls and floors is thermal resistance, which can be determined for the requirement area by the table 3 [5].

The requirement value of thermal resistance of the wall in Saint-Petersburg depends on the period of heating (when the outdoor temperature is under +8^{0}C). For Saint-Petersburg value of degree-day of the heating season equals:

$$DDHP = (t_{int} - t_{ext}) \cdot z_{h.s} = (20 + 1{,}8) \cdot 220 = 4796℃ \cdot days \quad (1)$$

Where

t_{int} – Temperature inside the building, equals +20^{0}C;

t_{ext} – Mean temperature of outdoor air of the heating season, equals -1,8^{0}C;

$z_{h.s}$- Length of the heating season, equals 220 days.

Using interpolation method it was determined from table 3, that requirement thermal resistance of the wall structure equals to:

$$R_{req}{}^{norm} = R_{req} m_p = 3{,}08 \cdot 0{,}63 = 1{,}94 \frac{m^2 \cdot {}^\circ C}{Wt} \quad (2)$$

Where

R_{req}- Value of requirement thermal resistance, determined by the table 3, equals $3{,}08 \frac{m^2 \cdot {}^\circ C}{Wt}$;

m_p- reducing coefficient, minimum value for walls equals 0, 63 [5].

In comparison, thermal resistance value of slag-concrete wall equals $0{,}615 \frac{m^2 \cdot {}^\circ C}{Wt}$, and thermal resistance value of medium-density concrete equals $0{,}689 \frac{m^2 \cdot {}^\circ C}{Wt}$.

Thermal resistance characteristics of the wall can be improved by using additional layers of materials. Additional insulation can be placed only on the external surface of the wall, only on the internal surface of the wall, or both on the external and internal surfaces.

Inner thermal insulation can be placed in every weather condition, even in the wintertime, on the other hand it requires to add vapor barriers to the wall structure because of water condensation. Thermal insulation layer, placed on the inside surface of the wall causes water condensation on the external surface of the insulation layer. Without vapor barrier water can cause serious damages to thermal insulation, and in fact it incapacitates thermal insulation layer. In addition to this, thermal layer inside the wall prevents heat from outside come into the building, making humidity level inside even higher [7]. This is the reason, why inside insulation is not commonly used in renovation projects. The only situation, when inside insulation is the only suitable method of thermal characteristics improvement, is in the renovation projects of buildings with facades, preserved from interaction. In this case it is restricted to put additional layers outside the bearing wall structures.

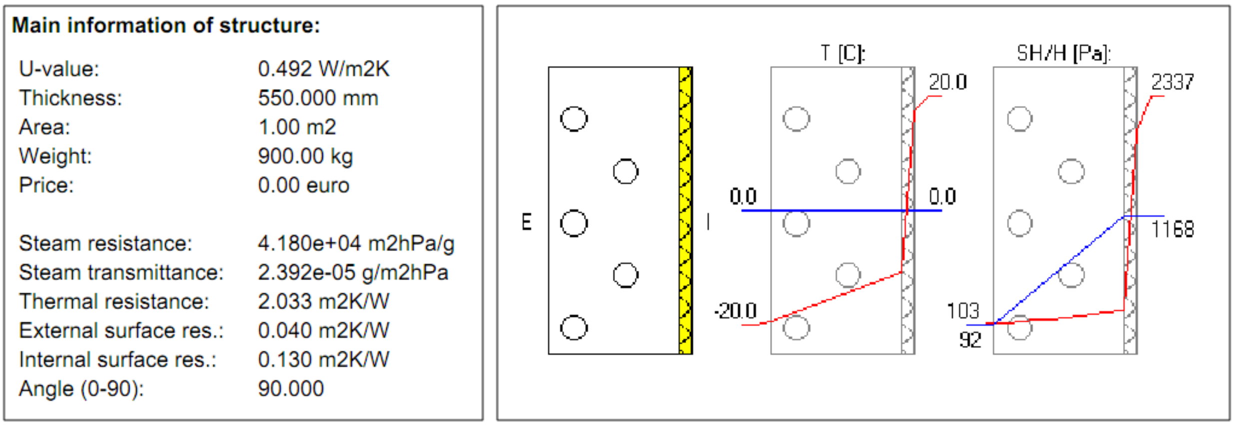
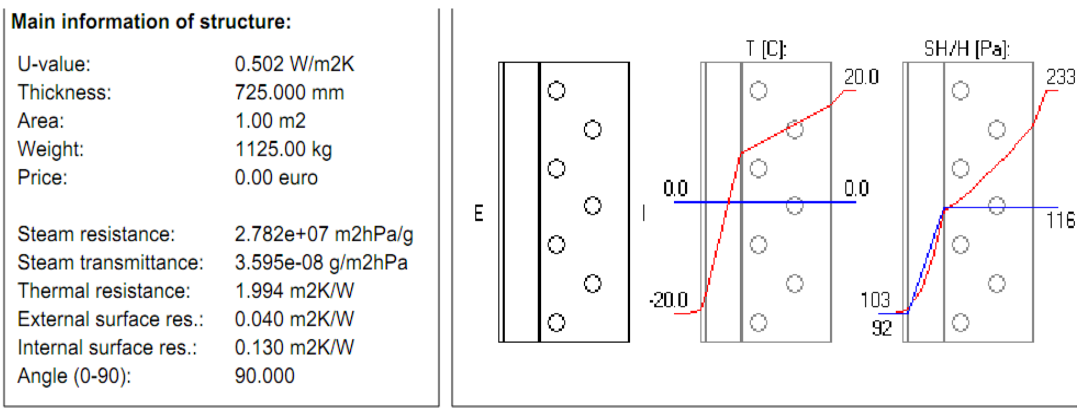


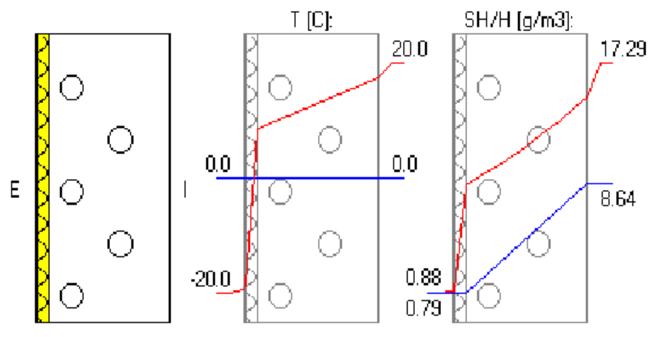
Figure 8. Thermal and humidity curves for external wall with added thermal insulation layer on the inner side of the wall, produced in Doftherm software

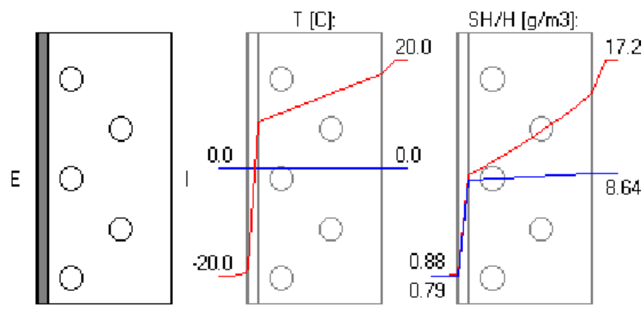
There are two main methods how to place thermal insulation outside the wall: “wet” method, using plaster layer, and “dry” method, using hinged elements. The main principle in both methods is to move dew point to the outside surface of the wall (to protect inner surface from condensate) and to increase thermal characteristics of the wall, using effective thermal insulation layers [7].

Table 4. Variants of thermal insulated wall construction

№	Layers	δ, mm	λ, $W/m^2{}^\circ C$	Advantages	Disadvantages
1					
	1. Slag-concrete	500	1,15	Polystyrene mats are cheap and widely used; This type of work can be done without interacting the house residents; Different decorative elements can be	Polystyrene is a flammable material, thus it is important to use layer of plaster 20-30 mm of thickness. Should be installed non-flammable mats around the window holes as
	2. Polystyrene mat	200	0,16		
	3. Steel mash (glued)	-	-		
	4. Cement-lime plaster	25	0,18		

<table>
<tr><td></td><td></td><td></td><td></td><td>formed using special plaster mixture and glass-fiber mesh.</td><td>a replacement (for example, mineral mats);
Requires special flexible brackets for fixation.</td></tr>
<tr><td rowspan="5">2</td><td colspan="3">**Main information of structure:**
U-value: 0.504 W/m2K
Thickness: 555.000 mm
Area: 1.00 m2
Weight: 903.00 kg
Price: 0.00 euro

Steam resistance: 4.184e+04 m2hPa/g
Steam transmittance: 2.390e-05 g/m2hPa
Thermal resistance: 1.984 m2K/W
External surface res.: 0.040 m2K/W
Internal surface res.: 0.130 m2K/W
Angle (0-90): 90.000</td><td colspan="2">
</td></tr>
<tr><td>1. Slag-concrete</td><td>500</td><td>1,15</td><td rowspan="4">Non-flammable material, does not requires thick plaster layer;
Good joints protection</td><td rowspan="4">Work can be done only in warm period;
80% of the works are hidden, requires control on each step of the works</td></tr>
<tr><td>2. ISOVER KL 37</td><td>50</td><td>0,037</td></tr>
<tr><td>3. Reinforcement mash (glued)</td><td>-</td><td>-</td></tr>
<tr><td>4. Cement-lime plaster</td><td>8</td><td>0,18</td></tr>
<tr><td rowspan="5">3</td><td colspan="3">**Main information of structure:**
U-value: 0.509 W/m2K
Thickness: 545.000 mm
Area: 1.00 m2
Weight: 903.60 kg
Price: 0.00 euro

Steam resistance: 5.973e+05 m2hPa/g
Steam transmittance: 1.674e-06 g/m2hPa
Thermal resistance: 1.966 m2K/W
External surface res.: 0.040 m2K/W
Internal surface res.: 0.130 m2K/W
Angle (0-90): 90.000</td><td colspan="2">
</td></tr>
<tr><td>1. Slag-concrete</td><td>500</td><td>1,15</td><td rowspan="4">Non-flammable material;
Can be poured into the formwork;
Cheap and widely spread insulation material</td><td rowspan="4">Requires special formwork;
Can’t be installed in the wintertime</td></tr>
<tr><td>2. Carbamide foam plastic</td><td>40</td><td>0,03</td></tr>
<tr><td>3. Reinforcement mash (anchored to the wall)</td><td>-</td><td>-</td></tr>
<tr><td>4. Cement-lime plaster</td><td>8</td><td>0,18</td></tr>
</table>

All the variants, which have been considered for the object house, are shown in Table 3. Thermal resistances of the wall structures have been calculated in Doftherm software. After adding thermal insulation layers values of walls' thermal resistances are bigger than the minimum requirement value ($R_{req}{}^{norm} = 1{,}94\frac{m^2 \cdot {}^\circ C}{Wt}$). It means, that the insulation layer thicknesses have been chosen rightly. It is important, that dew point, which occurs in the first variant of wall construction, is situated in the external insulation layer. As a result, there will be no condensate on the inner surface of the wall.

In the first variant of wall structure polystyrene mats are used as a thermal insulation layer (Penoplex). The main problem with using polystyrene is that it is a flammable material, and it should be covered with non-flammable plaster with significant thickness (20-30 mm). Polystyrene mats should be replaced with mineral mats (Rockwool) near window holes, doorways and dead walls in order not to reduce the fire-resistance characteristics of these elements [8].

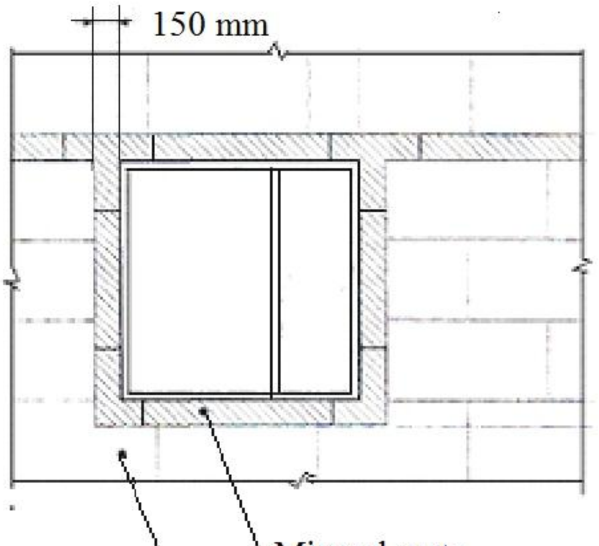


Figure 9. Installing of fire-resistant mineral mats edging around window hole [8]

The first step of thermal insulation installment is to pin insulation mat down to the existent wall structure with braces. Then mats are fixed with reinforcement meshes and pins. After this layer of primer made of cement-lime mixture 7-8 mm thick is placed over the metal parts and mats. Since the primer layer hardens another cement-lime mixture leveling layer 10 mm in thickness is applied. This layer prevents mats from atmospheric moisture and metal parts from staining. Texture layer, usually colored, is applied next. It is important to have the overall thickness of the plaster layers more than 20 mm.

Flexible braces are used during the installation of polystyrene thermal insulation because of thick coating layer. These anchors do not resist temperature deformation development and perceive only tension stresses.

In the second variant of wall structure mineral mats (ISOVER) are used as thermal insulation layer. In contrast to polystyrene, mineral mats are non-flammable, thus can be used with thin layers of coating (8-12 mm). The process of mineral mats installation is similar with written earlier, with one main difference. Since the coating layer is thin, there is no need in using flexible braces. Insulation mats are glued to the existent wall surface, and after glue harden enough (at least 24 hours) they are mechanically anchored with plastic dowels (cap diameter 60-140 mm). Then mats are covered with plaster layer 3-5 mm thick, and reinforcement glass-fiber mesh is put into the plaster before it harden. Leveling and decoration plaster are put over the premier layer in the final stage.

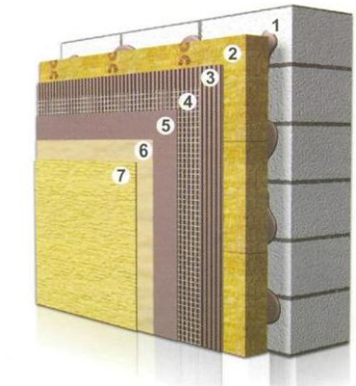


Figure 10. Fragment of the wall with thin plaster layer over the mineral mat insulation ISOVER
1 – glue for insulation mats attachment to the existent wall; 2 – insulation mat; 3 – glue layer for reinforcement attachment; 4 – reinforcement glass-fiber mesh; 5 – primer plaster layer; 6 – levelling; 7 – mineral decoration plaster.[9]

The lowest part of the insulation system should be put at least 500 mm under the earth surface. Base for the first raw of insulation mats in the researched house can be foundation wall, which is 700 mm thick and has 100 mm projection into the street [9].

In the third variant of wall insulation placement the insulation layer is represented by carbamide foam plastic. Foam plastic mixture can be poured into the non-removable formwork (then formwork is composed of volume mesh construction) or into removable formwork (then it is necessary to install glass-plastic braces or anchors). After the mixture is hardened, the surface of thermal installation should be protected from atmospheric moisture with layer of plaster, brick or mineral tiles.

The main advantage of using carbamide foam plastic is that the price of 1m^2 of that wall is 15-30% lower than the same wall with usual polystyrene mats. It is also easier to produce watertight shield of insulation using liquid insulation material, as it does not have joints between elements (mineral mats or plates should be connected closely to each other in order to provide integral insulated building envelope) [8].

5.2 Basement floor thermal insulation

All floors in the object house have the same structure – with reinforced concrete slabs as the bearing element. Precast ribbed slabs have been filled with slag layer 60 mm thick as thermal insulation and covered with wooden flooring. Basement floor has got no additional thermal insulation, thus medium air temperature in the first floor is lower than in the rest part of the building. Slabs in the basement lay straightly on the sand.

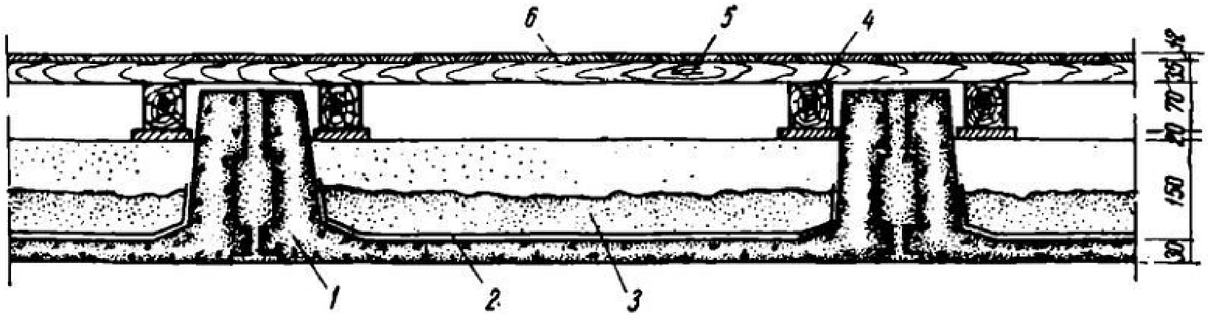


Figure 11. Structure of the floor. 1 – ribbed reinforced concrete slab; 2 – tar paper; 3 – slag layer; 4 – wooden logs; 5 - boards; 6 – parquet [3]

It was calculated in Table 2 that the required thermal resistance of basement floor is 4,06 m2·°C/Wt , and the value of the existing structure is 1,10 m2·°C/Wt. The only way to improve thermal characteristics of the basement floor is to add a thermal insulation layer to the structure. Methods of using different layers of insulation are listed in Table 5.

Table 5. Variants of thermal insulated basement floor construction

№	Layers	δ, mm	λ, $W/m^2°C$	R, $m°C/W$	Advantages	Disadvantages
1	Filling slab voids with soft thermal insulation mats					
	Existing slab structure	270	-	0.70	The height of the first store does not decrease after renovation	Works can be conducted only when residents have been resettled, Existing flooring have to be removed, End faces of slabs' ribs are not insulated – lots of cold bridges
	Soft insulation mats – mineral wool PAROC eXtra	130	0.038	3.42		
	Polyethylene vapor insulation	-	-	-		
	Existing flooring structure	48	-	-		
2	Additional hard insulation layer from the upper side of the floor					
	Existing slab structure + slag filling	270	-	1.10	End faces of slabs' ribs are insulated – few of cold bridges, Good sound insulation	The height of the first store decreases after renovation, Works can be conducted only when residents have been resettled, Existing flooring have to be removed and replaced
	Hard insulation mats PAROC WAS 35t	100	0.033	3.03		
	Polyethylene vapor insulation	-	-	-		
	Concrete screed (reinforced with steel meshes)	40	1.2	0.03		
	Flooring	10	-	-		
3	Additional hard insulation from the lower side of the floor					
	Plasterboard	12	0.2	0.06	The height of the first store does not decrease after renovation, Works can be conducted without resettlement of the residents, Existing flooring have not to be removed	Lower floor surface have to be dry in order to conduct the renovation works, Voids in mats should be done for communications and tubes, which are suspended under the basement ceiling, Insulation works requires a lot of
	Hard insulation mats PAROC WAS 35t	100	0.033	3.03		
	Polyethylene vapor insulation	-	-	-		
	Plaster	10	0.9	0.01		
	Existing floor structure	300	-	1.10		

						time and great accuracy from the workers
4	Additional soft insulation from the lower side of the floor					
	Plasterboard	12	0.2	0.06	The height of the first store does not decrease after renovation, Works can be conducted without resettlement, All thermal bridges can be eliminated, Voids for communications and tubes, which are suspended under the basement ceiling can be done easily	Lower floor surface have to be dry in order to conduct the renovation works, Insulation works requires a lot of time and they should be done by special crew with additional equipment
	mineral wool PAROC BLT6	130	0.041	3,17		
	Polyethylene vapor insulation	-	-	-		
	Plaster	10	0.9	0.01		
	Existing floor structure	300	-	1.10		

The main disadvantage of insulating from top of floor structure is that the residents of the first floor should move out for a time – it would be hard to organize during a real renovation project realization. On the other hand this type of insulating is cheaper and the process of installation is much easier, than from the bottom of the floor. In this case the insulation works require more time and the qualification of the workers should be very high. All suspended elements should be fixed to dry existent structure with great accuracy in order to have long period of durability [8].

5.3 Attic thermal insulation

Attic floor has the same structure, as the other floors in the house, so all the methods, described in the previous chapter can be implemented to the attic floor. The only difference is that it will be necessary to move out the residents from the last floor for a time in order to do insulation works from the heated side of the floor structure.

Also it is possible to consider the special type of insulation placement on the attic floor: PAROC mineral wool can be blown inside the attic volume. This variant was considered in Table 6.

Table 6. Variants of thermal insulated attic floor construction

№	Layers	δ, mm	λ, $W/m^2°C$	R, $m°C/W$	Advantages	Disadvantages
1	Blown mineral wool in the attic volume					
	Existing floor structure	300	-	1.10	The height of the last store does not decrease after renovation, Works can be conducted without resettlement, All thermal bridges can be eliminated easily	Requires special equipment and qualified crew
	mineral wool PAROC BLT6 (frame)	100	0.041	2.43		
	mineral wool PAROC BLT6 (homogeneous layer)	100	0.041	2.43		
2	Additional mineral wool insulation layer from the upper side of the floor					
	Existing floor structure	300	-	1.10	The height of the last store does not decrease after renovation, Works can be conducted without resettlement, Easy installation process	Harder to cover thermal bridges, then with blown material, thus use of additional insulation mats to place in the joints
	mineral wool mat PAROC eXtra (frame)	100	0.036	2.78		
	mineral wool mat PAROC eXtra (homogeneous layer)	100	0.036	2.78		

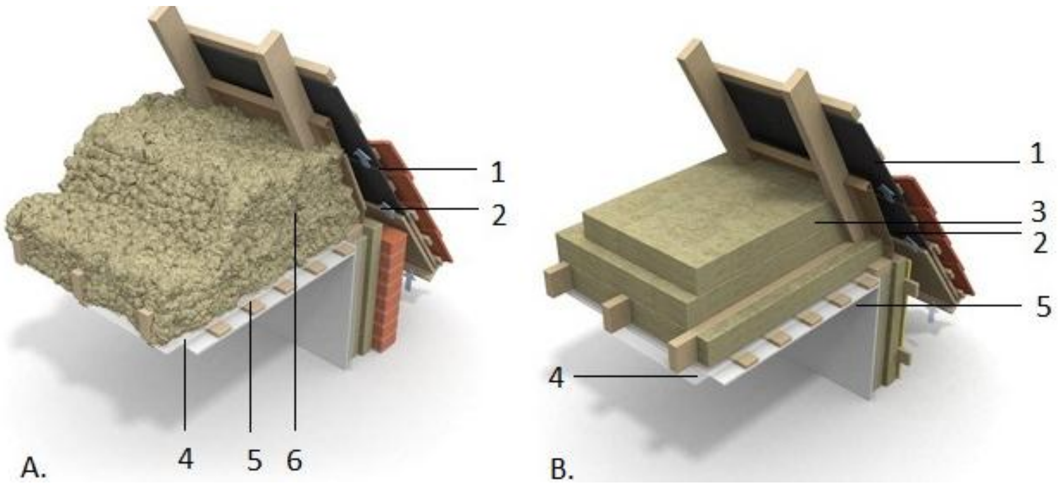


Figure 12. Thermal insulation layers in the attic floor (example for small residential house). A.PAROC BLT blown insulation layer B. PAROC eXtra insulation layer 1 – roof structure; 2 – wind diverter; 3 – PAROC eXtra mat; 4 – vapor barrier; 5 – inner surface; 6 – PAROC BLT blown layer [10]

Variants, in which thermal insulation layer is added from the living volume of the building have not been considered because of reducing the living space of the last floor. Also the installation of insulation layer from the ceiling of the last floor requires better qualification from the workers and is harder to conduct. Thus it is more efficient to put insulation in the attic volume.

5.4 Windows replacement

Windows are the most vulnerable parts of the enclosing structure of every building. Heat losses through the old windows are the biggest ones.

There are two kinds of existent windows in the researched house: wooden with two glasses (but there is no hermetic volume between glass sheets), which are the original ones, and plastic with double glazing. The second type is good enough, as its thermal characteristics are high. U-value of these windows is about 2.86$m℃/W$. The original windows have much lower characteristics' values: U-value of these structures is more than 3 $m℃/W$.

The window structure consists of two parts: the translucent element, usually one, two or three layers of glass, and the joint element, which belt the glass panels and let the whole structure of the window works as one. This encircle element also protects the inner volume between two sheets of glass from moisture going through the window. Usually this volume is filled with special inert gas, the thermal conductivity of which is low. It can be filled with xenon, krypton, and argon, in the old windows for this purpose dry air was used. The relation between thermal conductivity coefficient, the gas, used in the window structure and the distance between glass sheets is presented on diagram 1. [11]

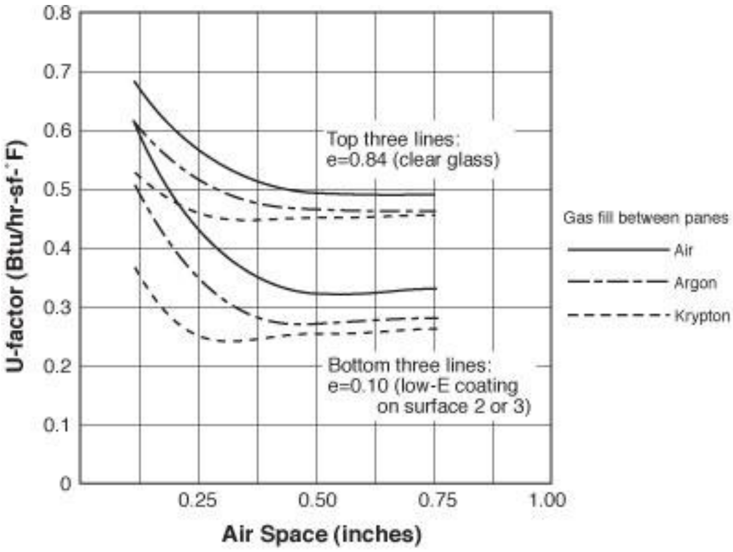


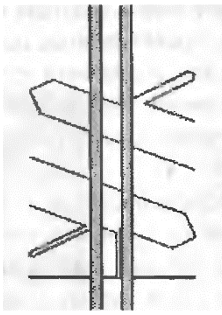
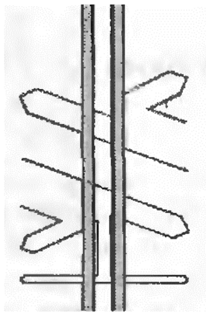
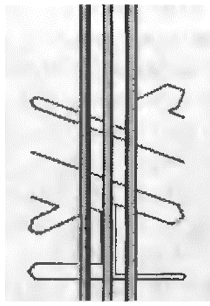
Figure 13. U-factor as a function of air-space thickness and emittance. [11]

There was shown less than 0.5% leakage per year in a well-fabricated unit, or a 10% loss in the total gas over a twenty-year period. Keeping the gas within the glazing unit depends mostly upon the quality of the design, materials, and, most important, assembly of the glazing unit seals. [11]

In the renovation project two main types of new glazing were considered: insulated glass unit and triple glazing unit, which are the most energy efficient and widely spread variants in the modern market. The comparison of these variants is presented in Table 7.

Table 7. Comparison of the Existing window structure, Insulated glass unit and Triple glazing unit. [8]

	Existing glass unit	Insulated glass unit	Triple glazing unit
Thermal energy flow through the glazing	80%	50%	30%
Reflection from outside	10%	30%	29%
Reflection from inside	20%	50%	70%
Secondary heat transfer outside	5%	12%	29%
Secondary heat transfer inside	5%	12%	9%
Light transmittance	82%	76%	64%

Heat transfer coefficient, U W/m^2K	3,0	1,1	0,5
Coefficient of energy permeability, g	77%	58%	50%
Filling between the glass sheets	air	Argon, inner side of the closest to the room glass is covered with thin metallized covering	Krypton
Image			

Covering the inner side of glass with a thin metal layer helps to combine high light transmittance and energy permeability values with optimal values of heat transfer coefficient. Low-emission covering reflects heat energy flow from the room. For this purpose usually metals like gold, silver, copper or aluminum are used. They have neutral color and reduce thermal radiation ability of the glass surface (silver covering is the most efficient, as it loses the heat 8 times slower, than usual glass surface).

Window frame can also be fabricated in different ways, which reflects on the window structure thermal transmittance properties. Frame is the thermal bridge element, thus it should be made and installed properly. Usually it is made of plastic (U = 1, 8-2, 2 W/m2K), Wood (U = 1, 2-1, 7 W/m2K) or Steel (U > 3, 0 W/m2K). Wooden frames are the best, if we are talking about thermal resistance value, and the steel frames are the worst. But the maintenance of the wooden frames is the most expensive, as they require to be polished and painted once during 3-5 years period. According to this, the plastic frames are the most affordable and efficient material to be used in the multi-storey house. Plastic window frames are made of multi-chamber profile PVC. [8]

Dependence between the U-value of the window structure, the size of the window, the type of glazing and the window frame material is presented in Table 8.

Table 8. U-values of the window structures, depending on glazing area, type of glazing unit and window frame material. [8]

U-value of glazing, W/m^2K	Area of the window, m^2	Percentage of glazing, %	Window frame material	U-value of frame, W/m^2K	Percentage of framing area, %	U-value of window structure, W/m^2K	Thermal resistance of window structure, R m^2K/W
1,1	0,5	48	Plastic	2,0	52	1,69	0,59
			Wood	1,5		1,43	0,70
			Wood + thermal insulation	0,8		1,06	0,94
	1,5	71	Plastic	2,0	29	1,49	0,67
			Wood	1,5		1,34	0,75
			Wood + thermal insulation	0,8		1,14	0,88
	3,0	76	Plastic	2,0	24	1,42	0,70
			Wood	1,5		1,30	0,77
			Wood + thermal insulation	0,8		1,13	0,88
0,5	0,5	48	Plastic	2,0	52	1,50	0,67
			Wood	1,5		1,24	0,81
			Wood + thermal insulation	0,8		0,87	1,15
	1,5	71	Plastic	2,0	29	1,18	0,85
			Wood	1,5		1,03	0,97
			Wood + thermal insulation	0,8		0,83	1,20
	3,0	76	Plastic	2,0	24	1,01	0,99
			Wood	1,5		0,89	1,12
			Wood + thermal insulation	0,8		0,72	1,39

As it was calculated before, the required value of thermal resistance of the window structure is $r_{req} = 0{,}51 \frac{m^2 \cdot °C}{Wt}$. From Table 8 it can be observed, that each variant of window structure, listed in the table, has the value of thermal resistance bigger than required.

The area of the window is 2,87 m^2. Using interpolation method the thermal resistance values for two types of windows were calculated, which can be installed during the renovation process. These values are presented in Table 9.

Table 9. Thermal characteristics of two window structure variants

Type of glazing	Material of frame	Area of the window, m^2	Percentage of glazing, %	Percentage of framing, %	U-value of window structure, W/m^2K	Thermal resistance of window structure, R m^2K/W
Insulated glass unit	Plastic	2,87	75,57	24,43	1,426	0,701
Triple glazing unit					1,025	0,975

6 Improvements of the house systems

House systems are represented by heating, gas, hot and cold water and electricity supply systems. There is natural ventilation in the researched object. Electricity, gas, water and heat are provided by central supplying grids, there are no additional energy resources in the building.

6.1 Electrical system

Monitoring of energy consumptions is one of the most effective and the cheapest ways to save energy and to control its use.

According to the federal law 23.11.2009 №261-FZ “About energy saving and increasing of energy efficiency…” all electrical resources have to be accounted for consumptions with use of special accounting meters. It means, that it is mandatory to have meters installed in order to monitor electrical, gas, water and heat consumptions.[12]

There are two main groups of meters, which can be installed in the researched house: one-tariff and multi-tariff. Multi-tariff meters provide two or three types of tariff accounting for different parts of the day. In the peak hours, when the voltage, producing by power supplier is the highest, the price of 1 kW/hour of energy is the highest also – and in the night time, when the demand on electricity from the consumers is low, the price is usually twice cheap. This type of meters help consumers to control their consumptions and expenses.

Electricity consumption for lighting is the part of expenses which can be reduced significantly. Modern energy-efficient lightbulbs can serve as a good substitute to old Incandescent bulbs. Modern types of lighting devices are presented in Table 10.

Table 10. Different types of lighting devices

Lamp type	Average life time, hours	Efficiency (Lm/Wt)	Decrease of light flow I the end of life time	Temperature of exploitation, °C	Maintenance during first 5 years of use
Incandescent	1000	4-6	40-60%	-50…+70	Bulb replacement
Fluorescent	8000	26-29	40-50%	+10…+40	Bulb replacement
Luminescent	8000	18-22	15-30%	-20…+40	Bulb replacement
Metal halide	8000	24-36	15-20%	-20…+40	Bulb replacement
LED	60000	95-123	20-30%	-60…+60	Process cleaning
Induction LVD	100000	80-110	10-15%	-42…+50	Process cleaning

Lamps in the corridor and in stairs should be replaced in order to save electrical consumptions. Moreover, modern lighting devices have a significantly long life time, and thus it excludes the need to change them for 5-8 years of continuous use. It is also important to mention, that LED and LVD lamps are harmless after their possible break, but luminescent lamp should be utilized in a special way. These lamps require special conditions in order to store them also.

6.2 Ventilation system

The researched house has natural ventilation system – for ventilation purposes each window has an opening window leaf. Influx of fresh air occurs in the bedrooms, living rooms and kitchens. Some internal structural concrete blocks have ventilation channels, which go to the roof and provide air extraction from the kitchens and the toilets. This ventilation system does not require any special devices and does not consume energy, but a lot of heat goes out of the building with heated warm air. In practice use of natural ventilation can nullify all the efforts to make the building energy efficient, thus it is mandatory that every passive house should be provided with a mechanical ventilation system. About 50% of all heat losses goes with air exchange, while using mechanical ventilation this value can be reduced up to 30 %. [8]

If we consider that after the renovation works the object house has a sealed enclosing structure, there should be a new ventilation system designed. In this house the normal rate of air exchange should be no less than 3 /hour (in houses with mechanical combined extract and input ventilation this rate should be no less than 1,5 /hour) [5].

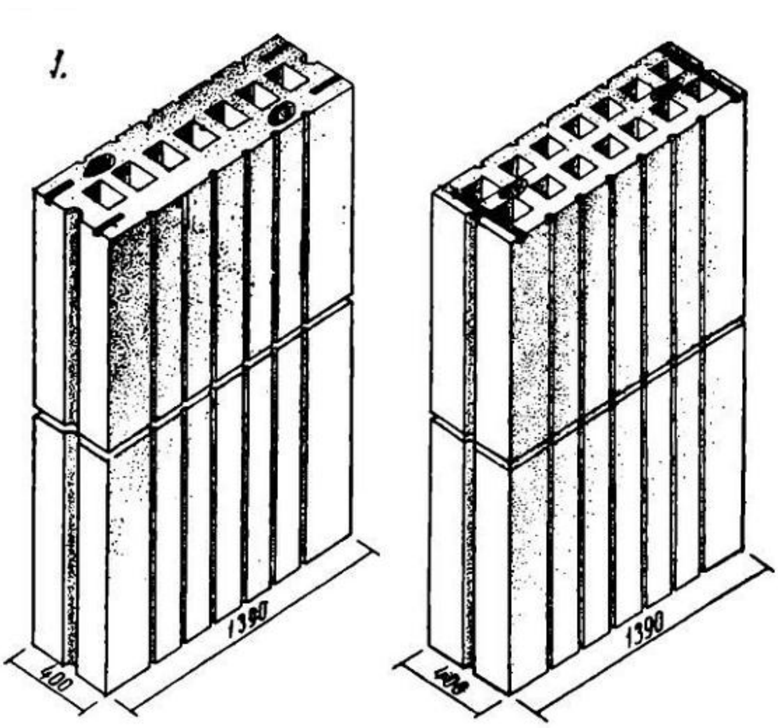


Figure 14. Concrete blocks with ventilation chambers in the existing object [3]

There are three variants how to provide normal rate for air exchange in a sealed building:

1. “Volley aeration” – when windows are opened for 10-15 minutes in order to provide fresh air input into the building. Rarely used in practice.

2. Extract ventilation. Mechanical extract of the heated air is provided in bathrooms, toilets and kitchens, while input of fresh air is provided by air vents in the enclosing structures of the building.
3. Mechanical combined extract and input ventilation with recuperation of heat. Extracted warm air used in order to heat input cold air, all air movements are controlled by mechanical systems.

Different types of natural aeration are presented in Table 11.

Table 11. Types of natural aeration in different kinds of buildings [8]

Type of building	Type of air vent	rate of air exchange, /hour	Time to replace air in the room with input air, min
Leaky shell of the house	-	2,0	-
Sealed shell of the house	Sealed windows and doors	0,1-0,3	-
	Regulated air vent	0,2-0,8	75-300
	Opened window leaf	0,8-2,5	24-75
	Opened window leaf (end-to-end airing)	2-4	15-30
	Wide open window	9-15	4-7
	Wide open window (end-to-end airing)	>20	Up to 3

Usual extract ventilation consists of input air valves, installed in enclosing structures in living rooms and bedrooms; silencers, which absorb noise from the system; fens, which extract exhausted air from toilets and kitchens with pipes and ducts in the walls; exhaust pipes, through which exhausted air leaves the building. Fens should have the switches in every flat in order to regulate the work of ventilation system independently from each flat.

Recuperation of heat can be provided in combined extract and input ventilation. Heated exhausted air can share thermal energy with input clean air. Clean air goes through central air collector (usually a pipe outside the building) to heat exchanger, and then, heated, goes to the living spaces. Exhausted air goes to heat exchanger through the ducts from kitchens and toilets, and after that through exhaust pipes it leaves the building.

This system can be also improved with implementation of ground heat exchanger. In this case input air goes through the plastic pipe 35-50 m length on the level of 1, 50 m under the ground surface. In the wintertime input air will be warmed up to 6-8 degrees because of ground heat. In the summertime, on the other hand, input air will be cooled up to 8-12 degrees. [8]

There are ready-to-install LTO-packages, which are common to European countries, but not familiar in Russia, the installation of which can reduce the requests for heating by 40%. But the main problem with LTO-packages is that recuperation systems can cause the need of decreasing heating energy by energy suppliers – but in Russia there is no such option to combine two different types of heating systems. It is not efficient to install such systems without changing the whole heating system, but due to the fact, that there is only one heat distributer in the researched building area, it is impossible during the usual renovation project.

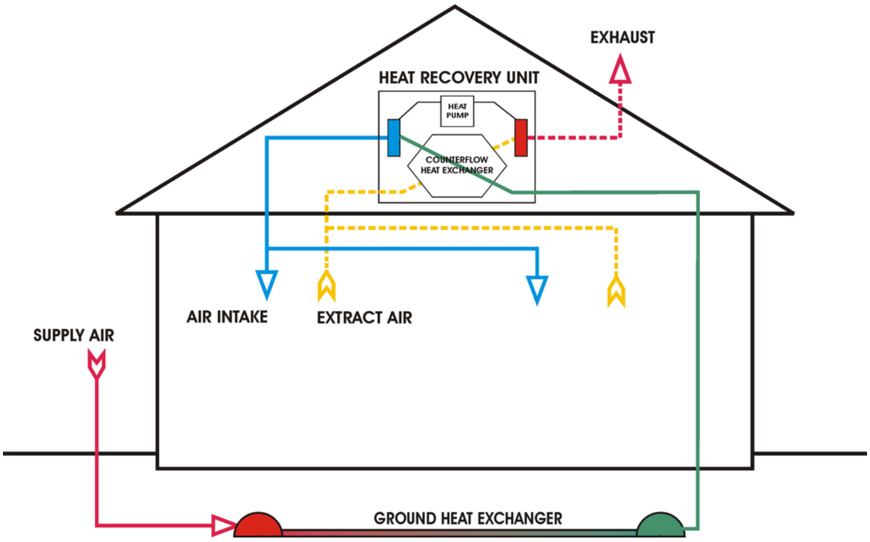


Figure 15. Heat recovery ventilation with ground heat exchanger. [13]

Otherwise, mechanical ventilation systems can be designed only by professional team of HVAC-engineers and architects because of their complexity. Their installment is a very hard and expensive work, and can be effectively implemented only after the shell of the building is sealed. The approximate cost calculation of mechanical exhaust and mechanical combined ventilation systems was held in Appendix 1.

7 Summary renovating programs

All variants of improvements, which have been considered in chapter 6 and chapter 7 have been analyzed according to their possible contribution to the energy performance characteristic of the object building and economic efficiency of their implementation.

As a result there three main programs of renovation have been chosen, which vary on the level of objects' summary energy efficiency.

Table 12. Description of the energy saving renovation programs

<table>
<tr><th colspan="3">Name</th><th>Implemented improvements</th><th>Approximal minimal cost, €</th><th>Design equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period, q_{heat}^{d}</th><th>Total heat losses per heating period Q_{tot}^{year}</th><th>Energy saving category</th></tr>
<tr><td rowspan="7"></td><td rowspan="6"></td><td rowspan="3">Program A</td><td>1. Gas supply system meters, water supply systems meters, heat supply system meters and electricity supply system meters (multi-tariff)</td><td>5500</td><td rowspan="3">0.41 kWt/(m^3·year)</td><td rowspan="3">612639.41 kWt·h /year</td><td rowspan="3">C- (normal)</td></tr>
<tr><td>2.Replacement of the windows (new insulated glass units in plastic frames)</td><td>24000</td></tr>
<tr><td>3.Replacement of the lightning devices with new LED lamps</td><td>360</td></tr>
<tr><td colspan="1" rowspan="3">Program B</td><td>4.Additional wall thermal insulation (with usage of carbamide foam plastic)</td><td>10030</td><td rowspan="3">0.19 kWt/(m^3·year)</td><td rowspan="3">340172.42 kWt·h /year</td><td rowspan="3">A++ (very high)</td></tr>
<tr><td>5.Additional basement floor thermal insulation (soft insulation from the lower side of the floor)</td><td>4200</td></tr>
<tr><td>6.Additional attic floor thermal insulation (blown mineral wool in the attic volume)</td><td>3600</td></tr>
<tr><td colspan="2">Program C</td><td>7.Implementation of the mechanical exhaust ventilation system</td><td>82300</td><td>0.16 kWt/(m^3·year)</td><td>299689.23 kWt·h /year</td><td>A++ (very high)</td></tr>
</table>

First program A of renovation can be considered as the preparation to the future improvements of the buildings' enclosure structure. From table 12 it is clear that methods, used during program A implementation do not give immediate positive results, the result building after this kind of renovation will be categorized as class C- of energy efficiency, which is the lowest value of "normal" building category. Otherwise, the installation of house systems' meters can show to the residents of the house future perspectives of saving energy. Energy passport of the object, renovated according to the program A is presented in Appendix 2.

The building, renovated according to the program B, can be categorized as energy efficient with very high level of energy saving. This example can show the impact of organizing the sealed shell of building to the whole concept of energy efficient building. Energy passport of the object, renovated according to the program B is presented in Appendix 3.

Program C represents the next step after putting to life the previous programs of renovation. In order to make the building not only energy efficient, but to label it a passive system, there should be a well-designed mechanical ventilation system implemented into the sealed shell of the house. This program implementation in a real project requires huge money investments and a qualified group of HVAC engineers, architects and workers. Energy passport of the object, renovated according to the program C is presented in Appendix 4.

8 Conclusion

There are many variants how to improve energy efficient presence of the object during the planned renovation project. The main idea is that after 50-80 years since the construction of a building not only physical deterioration should be eliminated, but the building should correspond to the changed energy saving regulations. This issue is more important even during the renovation project of architectural valuable buildings – buildings, which have an opportunity to become the part of the new city view.

Three stages of typical house renovation show that the renovation process can be executed during a long period of time. The main impact on energy saving can be brought by implementing additional thermal insulation to the existing enclosing structure. It is also the most common practice. But it requires to overlook all energy supplying systems in order to make a passive house from the regular one. This is the most expensive and hard to establish part of each renovation program. In Russia it is hard to manage energy consumptions in the old multi-storey residential houses because it is impossible to regulate temperature inside the house. Usual radiators have no special regulators, and even if the house will be improved with a recuperation system and mechanical ventilation system, the same amount of heat will be distributed to the house, and the residents will still be paying the same bills. This is why the program C of renovation should be conducted only after this scheme of energy distribution will be modernized. Otherwise, programs A and B can be conducted even now, and as it is shown in Table 12, a house, renovated according to program B can be considered energy efficient. This will bring not only economic benefits for the residents, but will make the future process of the quarter's compaction easier to implement. This fact should also be considered, as the population of St Petersburg grows rapidly, and future developments of the existing quarters have been already considered. Making the historic houses energy efficient means making them competitive to the modern requirements and thus protecting from extinction.

Figures

Tables

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Appendix 1.

Cost calculations of the improvement methods, described in the chapters 5 and 6

№	Name of the method	Price of 1 m^2 of a structure	Price of a whole structure	Additional costs
Wall thermal insulation methods				
1	Wall thermal insulation with usage of polystyrene mat	7,65 €	13800 €	Installation, elevator for montage
2	Wall thermal insulation with usage of ISOVER KL 37	8,04 €	14500 €	Installation, elevator for montage
3	Wall thermal insulation with usage of carbamide foam plastic	5,56 €	10030 €	Installation, elevator for montage, framework assembly and installation
Basement floor insulation methods				
1.	Filling slab voids with soft thermal insulation mats	7,09 €	5000 €	Installation, floor covering replacement, resettlement of residents
2.	Additional hard insulation layer from the upper side of the floor	12,87 €	9070 €	Installation, concrete works, resettlement of residents
3.	Additional hard insulation from the lower side of the floor	11,96 €	8430 €	Installation
4.	Additional soft insulation from the lower side of the floor	5,92 €	4170 €	Installation, rent of special equipment
Attic floor insulation methods				
1.	Blown mineral wool in the attic volume	5.05 €	3560 €	Installation, rent of special equipment
2.	Additional mineral wool insulation layer from the upper side of the floor	6,84 €	4820 €	Installation
Window structures for replacement				
1.	Insulated glass unit	141,17 €	24000 €	Installation
2.	Triple glazing unit	180,18 €	30700 €	Installation
Replacement of the lightning devices (in the common areas)				
1.	Luminescent lightbulbs	7 € for 1 lamp	210 €	-
2.	LED lamps	12 € for 1 lamp	360 €	-
Mechanical ventilation system installation (approximate calculations)				
1.	Exhaust ventilation system	-	82300 €	Designing, installation of the equipment, maintenance
2.	Combine ventilation system with heat recuperation	-	180800 €	Designing, installation, maintenance

Appendix 2.

Energy passport for the object building, renovated with conditions of program A

Renovation program A			
I. Common Information			
Date	3.2017		
Address of the object	Russia, Saint-Petersburg, Moskovskii district		
Building type	Residential, series 1-415-1		
Number of floors	5		
Number of flats	44		
Design number of residents	122		
Position in the urban development	Single-standing		
Type of construction	Prefabricated, large-block		
II. Design conditions			
Design characteristic	**Description**	**Unit**	**Value**
1. Design outdoor temperature	t_{ext}	°C	-8.7
2. Average outdoor temperature for the heating season	$t_{h.s}$	°C	-1.8
3. Length of the heating season	$z_{h.s}$	days/year	220
4. Degree-days of the heating season	DDHS	°C·days/year	4796
5. Design indoor temperature	t_{int}	°C	20
6. Design air temperature of the attic	t_{attic}	°C	-4
7. Design air temperature of the basement floor	t_{base}	°C	8
III. Geometry characteristics			
Design characteristic	**Description**	**Unit**	**Value**
8. Gross floor area	A_{fg}	m^2	4659.2

9. Living area	A_{liv}	m^2	1619.2
10. Design area	A_d	m^2	665.6
11. Heated volume	V_{heat}	m^3	10782.72
12. Façade glasing coeficient	f	-	0.2
13. Indicator of buildings' compactness	K_{comp}	-	0.35
14. Gross area of external enclosure structures	A_{ext}^{gross}	m^2	3764.48
facades (slag-concrete)	A_{fac1}	m^2	1800.7
facades (basement wall)	A_{fac2}	m^2	161.2
external doors	A_{door}	m^2	8
Attic floor	$A_{att.fl}$	m^2	650.08
basement floor	$A_{base.fl}$	m^2	650.08
windows (flats)	A_{win1}	m^2	441.98
windows (corridore)	A_{win2}	m^2	52.44
North oriented windows		m^2	59.8
North-East oriented windows		m^2	0
East oriented windows		m^2	187.41
South- East oriented windows		m^2	0
South oriented windows		m^2	59.8
South-West oriented windows		m^2	0
West oriented windows		m^2	187.41
North-West oriented windows		m^2	0
IV. Thermal characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**

15. Equivalent thermal resistance of the enclosure structures	R_o^{unit} , $m^2 \cdot °C/Wt$		
External slag-concrete walls	R_{fac1}	3.08	0.80
External basement walls	R_{fac2}	3.08	0.69
External doors	R_{door}	0.83	0.83
Attic floor	$R_{att.fl}$	4.06	1.10
basement floor	$R_{base.fl}$	4.06	1.10
windows - Insulated glass units(flats)	R_{win1}	0.51	0.70
windows - Insulated glass units(corridor)	R_{win2}	0.51	0.70
V. Additional characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
16.Equivalent transmission coefficient of thermal convection	K_{tr} , $Wt/(m^2 \cdot °C)$		1.15
17. Air exchange rate per heating period	n_a, h^{-1}		0.30
18. Equivalent domestic heat emissions in the building	$q_{d.h}$, Wt/m^2		12
VI.Equivalent characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
22. Equivalent thermal protective characteristic of the building	k_{tot} , $Wt/(m^3 \cdot °C)$	0.24	0.40
23. Equivalent ventilation characterisic	k_{vent} , $Wt/(m^3 \cdot °C)$		0.09
24. Equivalent domestic emissions' characteristic	k_{de} , $Wt/(m^3 \cdot °C)$		0.08

25. *Equivalent characteristic of sun thermal input to the building*	k_{rad} , Wt/(m^3·°C)		0.04
VII. Coefficients			
Characteristic	**Description**	**Required value**	
26. *Coefficient of heating system autoregulation effectivity*	ζ	0.85	
27. *Coefficient, which considers decrease of heat consumption due to management of heat energy distribution per flats*	ξ	0.1	
28. Coefficient of recuperation equipment effectivity	k_{ef}	0	
29. Coefficient, which considers decrease of heat energy usage in the period, when they exceed heat losses	v	0.79	
30. Coefficient of additional heating system energy losses consideration	β_h	1.13	
VIII. Complex heat energy consumption characteristics			
Characteristic	**Description**	**Unit**	**Value**
31. *Design equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period*	$q_{heat}{}^{d}$	Wt/(m^3·°C)Wt/(m^2·°C)	0.41
32. Required equivalent characteristic of heat energy consumptions of heating and ventilation of the	$q_{heat}{}^{req}$	Wt/(m^3·°C)Wt/(m^2·°C)	0.36

building by heating period			
33. *Energy saving category*			C-
34. Have the building characteristics met requirements?			No
IX. Energy load of the building			
Characteristic	**Description**	**Unit**	**Value**
35. Equivalent heat energy consumptions for building heating per heating period	q	kWt/(m^3·year)kWt/(m^2·year)	313.76
36. Heat energy consumptions for building heating per heating period	Q_{heat}^{year}	kWt·h/year	508037.90
37. Total heat losses per heating period	Q_{tot}^{year}	kWt·h/year	612639.41

Appendix 3.

Energy passport for the object building, renovated with conditions of program B

Renovation program B			
I. Common Information			
Date	3.2017		
Address of the object	Russia, Saint-Petersburg, Moskovskii district		
Building type	Residential, series 1-415-1		
Number of floors	5		
Number of flats	44		
Design number of residents	122		
Position in the urban development	Single-standing		
Type of construction	Prefabricated, large-block		
II. Design conditions			
Design characteristic	**Description**	**Unit**	**Value**
1. Design outdoor temperature	t_{ext}	°C	-8.7
2. Average outdoor temperature for the heating season	$t_{h.s}$	°C	-1.8
3. Length of the heating season	$z_{h.s}$	days/year	220
4. Degree-days of the heating season	DDHS	°C·days/year	4796
5. Design indoor temperature	t_{int}	°C	20
6. Design air temperature of the attic	t_{attic}	°C	-4
7. Design air temperature of the basement floor	t_{base}	°C	8
III. Geometry characteristics			

Design characteristic	Description	Unit	Value
8. Gross floor area	A_{fg}	m^2	4659.2
9. Living area	A_{liv}	m^2	1619.2
10. Design area	A_d	m^2	665.6
11. Heated volume	V_{heat}	m^3	10782.72
12. Façade glasing coeficient	f	-	0.2
13. Indicator of buildings' compactness	K_{comp}	-	0.35
14. Gross area of external enclosure structures	A_{ext}^{gross}	m^2	3764.48
facades (slag-concrete)	A_{fac1}	m^2	1800.7
facades (basement wall)	A_{fac2}	m^2	161.2
external doors	A_{door}	m^2	8
Attic floor	$A_{att.fl}$	m^2	650.08
basement floor	$A_{base.fl}$	m^2	650.08
windows (flats)	A_{win1}	m^2	441.98
windows (corridore)	A_{win2}	m^2	52.44
North oriented windows		m^2	59.8
North-East oriented windows		m^2	0
East oriented windows		m^2	187.41
South- East oriented windows		m^2	0
South oriented windows		m^2	59.8
South-West oriented windows		m^2	0
West oriented windows		m^2	187.41

North-West oriented windows		m^2	0
IV. Thermal characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
15. Equivalent thermal resistance of the enclosure structures	R_o^{unit}, $m^2\cdot°C/Wt$		
External slag-concrete walls with carbamide foam plastic thermal insulation	R_{fac1}	3.08	1.97
External basement walls with carbamide foam plastic thermal insulation	R_{fac2}	3.08	1.94
External doors	R_{door}	0.83	0.83
Attic floor with blown mineral wool thermal insulation	$R_{att.fl}$	4.06	5.96
basement floor with soft insulation from the lower side of the floor	$R_{base.fl}$	4.06	4.34
windows - Insulated glass units(flats)	R_{win1}	0.51	0.70
windows - Insulated glass units(corridor)	R_{win2}	0.51	0.70
V. Additional characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
16.Equivalent transmission coefficient of thermal convection	K_{tr}, $Wt/(m^2\cdot°C)$		0.52
17. Air exchange rate per heating period	n_a, h^{-1}		0.30

18. Equivalent domestic heat emissions in the building	$q_{d.h}$, Wt/m^2		12
VI.Equivalent characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
22. Equivalent thermal protective characteristic of the building	k_{tot} , Wt/(m^3·°C)	0.24	0.18
23. Equivalent ventilation characterisic	k_{vent} , Wt/(m^3·°C)		0.09
24. Equivalent domestic emissions' characteristic	k_{de} , Wt/(m^3·°C)		0.08
25. *Equivalent characteristic of sun thermal input to the building*	k_{rad} , Wt/(m^3·°C)		0.04
VII. Coefficients			
Characteristic	**Description**	**Required value**	
26. *Coefficient of heating system autoregulation effectivity*	ζ	0.85	
27. *Coefficient, which considers decrease of heat consumption due to management of heat energy distribution per flats*	ξ	0.1	
28. Coefficient of recuperation equipment effectivity	k_{ef}	0	
29. Coefficient, which considers decrease of heat energy usage in the period, when they exceed heat losses	v	0.79	

30. Coefficient of additional heating system energy losses consideration	β_h	1.13	
VIII. Complex heat energy consumption characteristics			
Characteristic	**Description**	**Unit**	**Value**
31. *Design equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period*	q_{heat}^{d}	Wt/(m^3·°C)Wt/(m^2·°C)	0.19
32. Required equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period	q_{heat}^{req}	Wt/(m^3·°C)Wt/(m^2·°C)	0.36
33. *Energy saving category*			A++
34. Have the building characteristics met requirements?			Yes
IX. Energy load of the building			
Characteristic	**Description**	**Unit**	**Value**
35. Equivalent heat energy consumptions for building heating per heating period	q	kWt/(m^3·year)kWt/(m^2·year)	145.49
36. Heat energy consumptions for building heating per heating period	Q_{heat}^{year}	kWt·h/year	235570.91
37. Total heat losses per heating period	Q_{tot}^{year}	kWt·h/year	340172.42

Appendix 4.

Energy passport for the object building, renovated with conditions of program C

Renovation program C			
I. Common Information			
Date	3.2017		
Address of the object	Russia, Saint-Petersburg, Moskovskii district		
Building type	Residential, series 1-415-1		
Number of floors	5		
Number of flats	44		
Design number of residents	122		
Position in the urban development	Single-standing		
Type of construction	Prefabricated, large-block		
II. Design conditions			
Design characteristic	**Description**	**Unit**	**Value**
1. Design outdoor temperature	t_{ext}	°C	-8.7
2. Average outdoor temperature for the heating season	$t_{h.s}$	°C	-1.8
3. Length of the heating season	$z_{h.s}$	days/year	220
4. Degree-days of the heating season	DDHS	°C·days/year	4796
5. Design indoor temperature	t_{int}	°C	20
6. Design air temperature of the attic	t_{attic}	°C	-4

7. Design air temperature of the basement floor	t_{base}	°C	8
III. Geometry characteristics			
Design characteristic	**Description**	**Unit**	**Value**
8. Gross floor area	A_{fg}	m^2	4659.2
9. Living area	A_{liv}	m^2	1619.2
10. Design area	A_d	m^2	665.6
11. Heated volume	V_{heat}	m^3	10782.72
12. Façade glasing coeficient	f	-	0.2
13. Indicator of buildings' compactness	K_{comp}	-	0.35
14. Gross area of external enclosure structures	A_{ext}^{gross}	m^2	3764.48
facades (slag-concrete)	A_{fac1}	m^2	1800.7
facades (basement wall)	A_{fac2}	m^2	161.2
external doors	A_{door}	m^2	8
Attic floor	$A_{att.fl}$	m^2	650.08
basement floor	$A_{base.fl}$	m^2	650.08
windows (flats)	A_{win1}	m^2	441.98
windows (corridore)	A_{win2}	m^2	52.44
North oriented windows		m^2	59.8
North-East oriented windows		m^2	0
East oriented windows		m^2	187.41

South- East oriented windows		m^2	0
South oriented windows		m^2	59.8
South-West oriented windows		m^2	0
West oriented windows		m^2	187.41
North-West oriented windows		m^2	0
IV. Thermal characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
15. Equivalent thermal resistance of the enclosure structures	R_o^{unit} , $m^2{\cdot}°C/Wt$		
External slag-concrete walls with carbamide foam plastic thermal insulation	R_{fac1}	3.08	1.97
External basement walls with carbamide foam plastic thermal insulation	R_{fac2}	3.08	1.94
External doors	R_{door}	0.83	0.83
Attic floor with blown mineral wool thermal insulation	$R_{att.fl}$	4.06	5.96
basement floor with soft insulation from the lower side of the floor	$R_{base.fl}$	4.06	4.34
windows - Insulated glass units(flats)	R_{win1}	0.51	0.70

windows - Insulated glass units(corridor)	R_{win2}	0.51	0.70
V. Additional characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
16.Equivalent transmission coefficient of thermal convection	K_{tr} , Wt/(m^2·°C)		0.52
17. *Air exchange rate per heating period*	n_a, h^{-1}		0.22
18. Equivalent domestic heat emissions in the building	$q_{d.h}$, Wt/m^2		12
VI.Equivalent characteristics			
Characteristic	**Description, Unit**	**Required value**	**Design Value**
22. Equivalent thermal protective characteristic of the building	k_{tot} , Wt/(m^3·°C)	0.24	0.18
23. *Equivalent ventilation characterisic*	k_{vent} , Wt/(m^3·°C)		0.06
24. Equivalent domestic emissions' characteristic	k_{de} , Wt/(m^3·°C)		0.08
25. *Equivalent characteristic of sun thermal input to the building*	k_{rad} , Wt/(m^3·°C)		0.04
VII. Coefficients			
Characteristic	**Description**	**Required value**	
26. *Coefficient of heating system*	ζ	0.85	

autoregulation effectivity			
27. *Coefficient, which considers decrease of heat consumption due to management of heat energy distribution per flats*	ξ	0.1	
28. *Coefficient of recuperation equipment effectivity*	k_{ef}	0.1	
29. Coefficient, which considers decrease of heat energy usage in the period, when they exceed heat losses	v	0.79	
30. Coefficient of additional heating system energy losses consideration	$β_h$	1.13	
VIII. Complex heat energy consumption characteristics			
Characteristic	**Description**	**Unit**	**Value**
31. *Design equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period*	$q_{heat}{}^{d}$	Wt/(m^3·°C)Wt/(m^2·°C)	0.16
32. Required equivalent characteristic of heat energy consumptions of heating and ventilation of the building by heating period	$q_{heat}{}^{req}$	Wt/(m^3·°C)Wt/(m^2·°C)	0.36

33. *Energy saving category*			A++
34. Have the building characteristics met requirements?			Yes
IX. Energy load of the building			
Characteristic	**Description**	**Unit**	**Value**
35. Equivalent heat energy consumptions for building heating per heating period	q	kWt/(m^3·year)kWt/(m^2·year)	120.48
36. Heat energy consumptions for building heating per heating period	Q_{heat}^{year}	kWt·h/year	195087.72
37. Total heat losses per heating period	Q_{tot}^{year}	kWt·h/year	299689.23