REFURBISHMENT
OF MULTI-FLAT RESIDENTIAL BUILDINGS
IN LITHUANIA
Preface

This thesis is a result of a nine month graduation work for the Building Technology track at the faculty of Architecture and the Built Environment in Delft Technical University.

The main focus of this thesis is to study the process of the refurbishment of multi-flat residential buildings in Lithuania and propose improvements using technical knowledge gained during two years of Master program in TU Delft. Such a subject was chosen because the refurbishment process these days is very common in Lithuania, my home country. The main aim was to find technical ways to increase its efficiency as long as attract building owners to actively participate in it.

I would like to thank my mentors Thaleia Konstantinou and Andy van den Dobbelsteen for their guidance and support. I should also mention Professor Aart Hordijk from the Real Estate and Housing Department who consulted me regarding Real Estate aspects discussed in this thesis. Also I am much obliged to my Lithuanian friends Lina and Ju-dita, who actively helped me to find information and connect me with Lithuanian refurbishment industry. I should also mention the municipality of Vilnius city in the person of Guoda Ropaite for willingness to collaborate and support.

Irina Martjanova
Delft, 2015
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1 Introduction

The resources of fossil fuel are decreasing and soon won’t be able to satisfy our energy needs. Therefore it is very important not only to look for the new renewable energy resources, but also try to minimize energy consumption. Most of the buildings that are now in use have already exceed their service period and don’t meet modern standards. Therefore, refurbishment of old buildings has huge potential in terms of energy savings and CO2 reduction. Moreover, refurbishment can improve inappropriate comfort level and poor living quality of such buildings.

Energy Efficiency Directive (EED) that was adopted in October 2012 has a requirement for EU member states to develop long term renovation strategies for the national building stocks (Staniaszek 2013). According to Buildings Performance Institute Europe (BPIE), the residential building stock of EU countries accounts to 75% and more than 80% of residential buildings were built before 1990 (Economidou 2011). That means, that residential sector has major potential to increase energy efficiency.

Following EED requirements, Lithuanian government adopted energy efficiency strategies that have to be followed till 2020 with further insights for 2030. One of the main strategies in the household sector is the modernization of the existing multi-flat residential buildings. In terms of Lithuania, refurbishment of multi-flat residential buildings is very important. More than 80% of residential buildings were built before 1990. About 60% of population reside in multi-flat residential buildings constructed in period 1960-1991. Majority of these buildings are in a very poor state and experience heat losses and have low comfort standards. Multi-flat residential buildings that have E, F and G energy efficiency certification have to be modernized by 2020 (The Seimas of the Republic of Lithuania 2014). Modernization of multi-flat residential buildings is believed to safe up to 30-40% heat compared to 2009 level and decrease of CO2 emissions by 4% compared to 2008 (The Seimas of the Republic of Lithuania 2010).
1.1 Problem statement

Despite all the benefits that refurbishment of multi-flat residential buildings offers, refurbishment process in Lithuania itself is very slow and it is clear that set goals wouldn’t be achieved in the set period of time. BPIE performed a survey and made a classification of barriers that slow down the refurbishment process in EU countries (Fig. 1.1).

In terms of Lithuania the main barrier of the refurbishment process is financial. The Housing strategy of Lithuania that was approved in 2004 states, that: “The average income of the population is only 32% of the average of EU countries. The average price of an apartment in an average apartment building is 8 times higher than the average annual income of the household, and the average price of a single family house – even 20 times. This ratio in the EU member states is not higher than 4-5 times (The Government of the Republic of Lithuania 2004).” Due to low incomes, people are not willing to pay for the refurbishment which results in shallow renovation. With such an approach the energy efficiency level of renovated buildings reaches maximum C class and according to European Insulation Manufacturers Association (EURIMA) survey such a refurbishment do not provide desired level of CO2 reduction (Thomas Boermans 2012). Moreover, according to research performed by BPIE, baseline and shallow refurbishment strategies have minimal net savings regarding investment and cost savings difference (Fig. 1.2). Another problem is that present refurbishment strategies focuses only on energy efficiency by means of extra insulation addition, while improvement of living quality and comfort are not taken into account. In the interview with Vilnius Gediminas Technical University professor Josifas Parasonis, he stated that performed researches concluded that construction state of panel buildings in Lithuania is good. According to him, the main problem is that they are morally obsolete and do not meet modern living standards. Last, but not least, according to him, due to financial refurbishment aspect, refurbishment is done in phases, which results in technical mistakes and extended refurbishment period.

As long as refurbishment is evaluated only from economical perspective, it is really hard to convince users about the necessity of the refurbishment. Moreover, because of financial reasons, refurbishment is done quickly and does not aim to achieve higher refurbishment standards and most likely energy efficiency and CO2 emission reduction goals set by the Government of the Republic of Lithuania will not be achieved. Therefore other refurbishment approach is needed to stimulate the desire of users and building owners to pay for the refurbishment. Refurbishment does not have to be seen only as energy efficiency measure, but also as a way to increase comfort and improved living quality of inhabitants. In addition, the way to minimize the financial burden of the refurbishment has to be found.

1.2 Research goal

The main aim of the research is to provide refurbishment design strategy that will have the potential to convince users to make positive decisions about the refurbishment of multi-flat residential buildings in Lithuania. As the main concern and the barrier for the refurbishment of multi-flat residential buildings is financial aspect it is necessary to propose a refurbishment strategy that will improve the quality of the refurbishment and introduce more benefits of the refurbishment outcomes without increasing the refurbishment costs significantly.

In order to do it the financial aspect of the refurbishment does not have to be the main decision making stimulator, therefore the research has to answer if the financial problem, which is crucial in refurbishment process, can be solved by optimizing the refurbishment processes and its outcome and considering not only financial, but also social refurbishment aspect by introducing different kind of living quality.

It is also necessary to define what the optimum value for money of the refurbishment of the multi-flat residential building is. The conclusions can influence the approach towards the refurbishment strategies.
1.3 Research question

It is clear that present approach towards the refurbishment of the multi-flat residential buildings in Lithuania has to be modernized and other benefits have to be introduced in order to fasten the process. On the other hand, the paying capability of the population has to be taken into account. Considering these aspects, the thesis is going to answer the following question:

What design strategies introduce the additional value of the refurbishment and stimulate the decision making of users to invest in the refurbishment of the multi-flat residential building?

In order to provide complex and deep research, following sub questions are introduced:

1. What are non-energy efficiency benefits of the refurbishment or how can energy efficiency improvements support multiply refurbishment objectives?
2. Is it possible to achieve higher energy efficiency and living standards applying technologies that use renewable energy sources?
3. What factors influence the final value of the building after the refurbishment?
4. Is it possible to apply the same strategy on the different buildings with the same typology and get sufficient outcome?
5. What strategies can be efficient in order to minimize costs of deep refurbishment?

1.4 Methodology

In order to answer the research question different study methods will be used. That means that purpose of the thesis paper will be focused not only on understanding of underlying reasons and motivations, but this research will also lead to a certain design solutions that will be compared and the best refurbishment design strategy will be further developed in detail. Therefore, thesis structure will consist of three main parts: research, design and conclusions. In this chapter all the parts are described step by step, more detailed relation and interactions between them can be seen from the methodology scheme (Fig.1.3).

Research part

Part 1: Literature review

This part of the thesis will mainly focus on the general information available in different literature sources and focus on understanding of the refurbishment potential not only from energy efficiency perspective, but also will try to answer the question of how refurbishment can improve living quality of users and introduce other benefits.

Part 2: Data collection

This part will be performed using both qualitative and quantitative research methods. It will provide detailed research on the current situation in Lithuania based on interviews of experts, real estate agencies and users opinion. Research on what design strategies are used for the refurbishment in Lithuania and compare it to other countries with similar environmental conditions. Data and figures about refurbishment will be studied to define the further design strategies.

Design part

Step 3: Design strategies:

Three design approaches will be proposed for the chosen building. For each of the design steps the improvement of energy efficiency and refurbishment costs have to be determined.

1. Basic refurbishment: measure strategy: strategy that uses basic measures to improve energy efficiency and do not focus on new technologies and renewable energy sources. Basically, this strategy will represent refurbishment that is done in Lithuania in most of the cases: installation of new windows, replacement of doors, roof and external wall insulation. Energy efficiency up to 30% and minimal refurbishment costs.

2. Deep refurbishment: measure strategy: strategy that focuses on deep refurbishment, applies new technologies of/and uses renewable energy sources. This strategy should influence not only energy efficiency of the building, but also add the new architectural value of the refurbishment design by introducing new volumes or elements to the building. Energy efficiency more than 60%.

3. Deep refurbishment strategy with integration of sustainable energy sources and energy saving technologies: deep refurbishment design strategy together with technologies, such as PV cells, solar thermal collectors, heat pump, heat recovery system, etc. Important aspect for this strategy is integration of renewable energy sources, clever heat distribution and heat recovery systems. Strategy is aiming to achieve high energy efficiency and living quality levels. Energy efficiency more than 60%.

Step 4: Design application for a case study building

In order to answer the research questions, the case study building has to be chosen. Because many different types of multi-flat residential buildings are present in Lithuania, it is important to define boundary conditions.

In order to compare these 3 designs, computational models and hand calculations will be made regarding their energy efficiency parameters and cost savings. The outcome of the analysis will be compared and suggestions on the improvements of each of the strategy will be proposed. Based on the conclusions, one design strategy will be further investigated. In this stage of the research it is important to provide different refurbishment process possibilities and see if financial burden of certain strategy can be minimized.

Step 5: Design proposal

The outcomes of the comparison of the 3 design strategies will disclose certain problems and conclusions which will influence the refurbishment solutions. Final design proposal will be made based on the one of the three strategies by comparing calculations and taking into account all the advantages and disadvantages of each of the strategies. If needed some changes/ improvements will be made.

Conclusions

Step 6: Conclusions

In this chapter results of the research will be presented and final conclusions will be drawn based on findings and the work done. The answer to the research question and sub questions will be provided. Further proposals for the research will be made.

Step 7: Reflection on the work done

In this step the total approach will be discussed, regarding succeeds and faced difficulties. The total work performed will be analysed and conclusions will be made.
2 Theoretical background

2.1 Refurbishment-definitions of terms

Improvement of an existing residential building stock is a very complex process, therefore different terms are used to describe intervention processes depend on different aspects. For example the building works regarding the scale of application can divided into 5 categories: XXL: town/district; XL: block/complex; M: building; S: part of building/storey; XS: dwelling/room; Other way of classification can be the degree of work that has to be done. It can range from deep or total intervention to a partial one. Also the purpose of measures can differ and may be aesthetical, technical or functional (Lenz, Fischer et al. 2009). Therefore it is necessary to agree regarding the meaning of the terms that are going to be used in this paper.

Despite all the complexity of the topic in the “Refurbishment Manual: Maintenance, Conversions, Extensions” (Lenz, Fisher et al. 2009) it very detailed classifies the existing terms that refer to certain measures on the existing building and provide definitions for them. He highlights that usually more than one term can be used as certain measures overlap or are being applied in the same time. Terminology used in this report will use these definitions as reference.

Reconstruction: This is the rebuilding of a structure that no longer exists, i.e. strictly speaking it is new building work.

Restoration: This means finishing an incomplete structure.

Deconstruction: This is intended to cure the urban problems of vacant properties through the targeted demolition of individual buildings, blocks or districts, i.e. control the process of negative growth.

Demolition: Besides deconstruction on a large scale, individual buildings are often demolished in order to erect a new structure on the same site.

Renovation/maintenance: It maintains the value and the function of the existing building through competent “upkeep”.

Repairs/maintenance: Maintenance in this case is limited to the replacement or repair of defective building components.

Refurbishment: In contrast to maintenance, refurbishment measures also include intact but, for example, outdated components or surfaces. The difference between refurbishment and conversion, however, is that refurbishment does not involve any major changes to the loadbearing structure or interior layout.

Partial refurbishment: Involves only one component or one part of the building, e.g. the facade, the ground floor or the east wing.

Total refurbishment: Demolition measures during total refurbishment projects are very extensive. The demolition returns the building more or less to its loadbearing carcass. The primary structure remains essentially unaltered.

Conversion: Conversions always affect the structure of a building.
Gutting/Rebuilding with partial retention: Gutting comes close to providing a new building. Quite frequently the project involves retaining the facades of an existing building—resulting from a disputed understanding of the conservation of historic buildings—dismantling and rebuilding the interior completely.

Modernisation: Modernization can add up to partial refurbishment, e.g. upgrading the thermal insulation or replacing windows, but also conversion work, e.g. the subsequent addition of balconies. It serves to improve the lettable floor space by increasing the level of comfort or decreasing the running costs.

Decontamination: This is proper elimination of pollutants and hazardous substances from the buildings and their correct disposal.

Extension/Additions: An extension is a new structure that is directly connected with the use of the existing building.

Fitting-out: This is all the works carried out after erecting the structural carcass plus roof structure and roof covering. Typical measure is converting the roof space into one or more habitable rooms.

Change of Use: This is a measure that concerns obvious changes such as converting an apartment block into offices or minor changes with the same usage group.

Improvement of an existing residential building stock is a very complex process, therefore different terms are used to describe intervention processes depend on different aspects. For example the building works regarding the scale of application can divided into 5 categories: XXL: town/district; XL: block/complex; M: building; S: part of building/storey; XS: dwelling/room. Other way of classification can be the degree of work that has to be done. It can range from deep or total intervention to a partial one. Also the purpose of measures can differ and may be aesthetical, technical or functional (Lenz, Fisch et al. 2009). Therefore it is necessary to agree regarding the meaning of the terms that are going to be used in this paper.

Despite all the complexity of the topic in the “Refurbishment Manual: Maintenance, Conversions, Extensions” Lenz, Fisher et al. very detailed classifies the existing terms that refer to certain measures on the existing building and provide definitions for them. He highlights that usually more than one term can be used as certain measures overlap or are being applied in the same time. Terminology used in this report will use these definitions as reference.

2.2 Impacts and benefits of the refurbishment process

Residential building refurbishment in European Union mainly focuses on energy efficiency. The main and most obvious benefit from energy efficiency measures applicable in the refurbishment process are energy savings. However this is obvious, that energy efficiency improvements can also introduce much more multiple benefits across a wide range of sectors (Ryan and Campbell 2012). In his article, Ryan proposes a classification of multiple benefits of energy efficiency that lie beyond energy savings. He divides all the benefits in 4 groups according to the scale of their impact: international, national, sectorial and individual (Fig.2.1). According to her, despite the fact that energy saving benefits for the society are obvious it is hard to calculate them. She states that: “Estimating the wider benefits of energy efficiency improvements can also assist with putting a value on the return on investment in energy efficiency”.

Mikučionienė (Mikučionienė, Rogoža et al. 2014) analyses the sustainable impacts of the refurbishment of residential buildings. She proposes classification of 5 different impacts of the sustainable refurbishment: energy efficiency, environmental impact, economic rationality, comfort and life cycle. In the classification each of impact is explained regarding its goal and function (Fig.2.2). Energy efficiency impact of the refurbishment aims to maximize primary energy savings and minimize energy consumption.

Environmental impact results in the reduction of CO2 emissions. Economical aspect of the refurbishment according to such a classification has many more goals: increase price of the building, net present value, energy saving costs and minimize payback time and investment costs. Comfort impact influences living standards and norms of climate control, while impact on the lifecycle extends lifetime span of the building.

Another benefit of the refurbishment project is the fact that it helps to completely or partially avoid demolition. Demolition costs are high and complex, especially regarding the existing environment. Demolition works produce waste and consume energy meanwhile causing noise disturbance for neighbour area. Therefore, it can be concluded, that refurbishment brings additional financial and ecological values by avoiding demolition of the buildings (Budanova 2011).

<table>
<thead>
<tr>
<th>Level</th>
<th>Benefit</th>
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<tbody>
<tr>
<td>International</td>
<td>Greenhouse gas emissions</td>
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<tr>
<td></td>
<td>Moderated energy prices</td>
</tr>
<tr>
<td></td>
<td>Natural resource management</td>
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<tr>
<td></td>
<td>Development goals</td>
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<tr>
<td>National</td>
<td>Job creation</td>
</tr>
<tr>
<td></td>
<td>Reduced energy-related public expenditures</td>
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<tr>
<td></td>
<td>Energy security</td>
</tr>
<tr>
<td></td>
<td>Macroeconomic effects</td>
</tr>
<tr>
<td>Sectorial</td>
<td>Industrial productivity and competitiveness</td>
</tr>
<tr>
<td></td>
<td>Energy provider and infrastructure benefits</td>
</tr>
<tr>
<td></td>
<td>Increased asset values</td>
</tr>
<tr>
<td>Individual</td>
<td>Health and wellbeing</td>
</tr>
<tr>
<td></td>
<td>Poverty alleviation</td>
</tr>
<tr>
<td></td>
<td>Increased disposable income</td>
</tr>
</tbody>
</table>

Figure 2.1 Example multiple benefits at different levels of the economy from Insulation of a building (adopted from (Ryan and Campbell 2012))
Refurbishment of multi-flat residential buildings in Lithuania

Figure 2.2 Diagram of criteria for general sustainability, including criteria, attributes and functions of attribute optimization (adapted from Mikučionienė, Rogoža et al. 2014)
3 Refurbishment in Lithuania

3.1 General data

Lithuania is situated in the North East Europe and is the largest country of three Baltic states, with an area of 65,300 km². An estimated population of Lithuania is around 3 million according to statistical data of 2013. Vilnius is the capital and largest city. Other major cities are Kaunas, Klaipeda, Siauliai, Panevezys and Alytus. After the WWII Lithuania was former state of the Soviet Union until 1990. On 1 May 2004, Lithuania joined the EU and agreed to follow EU policies (Fig. 3.1, 3.2).

According to Koeppen climate classification (Wikipedia 2015), Lithuania has humid continental climate. Temperatures in winter are normally below 0°C. Average winter temperature is around -3°C, however it can sometimes reach -20°C or more. Average temperature in summer is around 16°C and in winter -3°C. The average annual precipitation is 800 mm on the coast, 900 mm in the middle part and 600 mm in the eastern part of the country (Table 3.1) (Weatherbase 2015). Sun exposure depends on the region. Highest sun exposure is in the West and less sun exposure is noticeable in the East part of the country (Table 3.2).
Refurbishment of multi-flat residential buildings in Lithuania

3. Refurbishment goals and potentials

3.2.1 Energy Efficiency Strategy

The target of Lithuania is to achieve annual savings of 1.5% of the total final energy consumption, in the period through 2020. Achieving of this goal will result in reduction of CO$_2$ emission by 23% (compared to 2008 level). Thus the main priority of Lithuania in the refurbishment process of multi-flat residential buildings is the increase of energy efficiency and reduction of CO$_2$ emissions (National Energy Strategy 2010).

Energy efficiency

According to the National Energy Independence Strategy of Lithuania from 2010, the major energy improvements can be seen in residential and transport sectors. National Energy Independence Strategy initiates the heat consumption reduction in residential buildings by 30-40% till 2020 and up to 70% by 2050 (compared to 2009 level). The strategy to increase energy efficiency includes the insulation and modernization of residential buildings, which can help to save up to 220 Kilotonne of Oil Equivalent energy annually from heating (Fig. 3.3).

Reduction of CO$_2$ emissions

The improvement of energy efficiency of residential sector will influence not only energy savings, but also the decrease of CO$_2$ emissions will make it more sustainable. As a result of efficiency gains the reduction of CO$_2$ emission by 5% of total gas emissions of Lithuania in 2010 can be reached. This percentage stands for the prevention of 1.1 million tons of CO$_2$ emission (National Energy Strategy 2010).

Energy efficiency benefits of the refurbishment in Lithuania for European Union

Guertler and Smith (Guertler and Smith 2005) in their article on how to make buildings more energy efficient conclude, that the highest energy saving and CO$_2$ reduction potential is in countries such as Czech Republic, Hungary, Slovakia, Slovenia (39%) and countries such as Estonia, Latvia, Lithuania, Poland (34%) (Fig. 3.5). However, taking into account energy cost and price, and CO$_2$ savings, the perspectives changes depending on the goals of EU. If the priority is to reduce CO$_2$ emission, than the resources have to be allocated towards countries in Eastern Europe. However in terms of contribution towards energy security of EU, the resources have to be allocated towards countries of West and Central Europe. Despite such a conclusion, refurbishment of residential building stock in Lithuania can achieve heat consumption reduction up to 40% till 2020 and up to 70% in a long term perspective. Such reduction is very important in terms of sustainable future (Fig. 3.4). Moreover other aspects of the refurbishment such as living quality were not taken into account in this research.
3.2.2 Housing strategy

Lithuanian housing strategy was approved in 2004. The implementation period for the strategy is until 2020. The strategy states that: “The technical-economic feasibility study on the condition of the residential panel buildings show that it is economically expedient to renovate and modernise them. No economic conditions to modernise the existing residential areas by mass demolition of multi-apartment buildings exist (Lithuanian housing strategy 2004).” That statement highlights the importance of the refurbishment. One of the main priority goals mentioned in the approved strategy concerns the problem of the modernization of residential buildings. The document states that the buildings that were constructed before 1992 are in a very poor state, especially regarding thermal insulation, as it does not meet requirements (thermal resistant standards of the buildings were introduced after 1992). The energy consumption of residential sector is 1.8 times bigger than the energy consumption of other EU states with similar climate conditions. Furthermore it emphasizes the fact that most of residential buildings have been maintained poorly and are physically worn. As a result they cannot longer satisfy the needs of their residents and their market value has been declining.

Strategies mentioned in the Housing strategy of 2004 for the refurbishment of residential sector are:
1. Renovate and insulate roof structures
2. Change or replace windows and entrance doors
3. Remove joint defects of panel walls
4. Increase the thermal resistance of external walls
5. Reduce heat energy costs per unit of useful floor space up to 30%
6. Building Energy Performance Certification

As it is seen from the list, the main directive is energy efficiency of the refurbished building. However, the use of renewable energy sources is not mentioned. The strategy was approved in 2004 and since then renewable energy sources became less expensive and more affordable. Moreover, comfort of the users is also not taken into account. Considering the research question, the strategy proposals should go beyond strategies mentioned in the Housing strategy.

3.3 Building energy efficiency classification

Energy Performance of Buildings Directive (EPBD) (Directive 2002/91/EC) is the main energy performance policy instrument to improve the energy performance of buildings in European Union. In order to achieve energy efficiency and CO2 emission goals, EPBD specifies requirements regarding nearly zero-energy buildings ‘ZEBs’ (Jan Groezinger, Thomas Boermans et al. 2014). Article 9(1) of the EPBD requires Member States to ensure that:
(a) by 31 December 2020, all new buildings are nearly zero-energy buildings;
(b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.

However, despite the EPBD policy and goals, according to Market study for a voluntary common European Union certification scheme for the energy performance of non-residential buildings (Radersmaekers 2014): “The residential market for green sustainable schemes in Europe is immature, due to a lack of incentives for home owners to certify their homes (e.g. high costs, lack of comparable data, and lack of knowledge).” Users mainly rely on the mandatory Energy Performance Certificates (EPCs) required by the EPBD.

In the Netherlands, to determine an energy efficiency class Energy index (EI) is used. It is calculated by formula (Kennisinstituut voor de Installatiesector 2006):

\[
EI = 155 \times Ag + 106 \times Averities + 9560
\]

Where:
- \(Q_{tot}\) - Total energy consumption of the building under standard [MJ]
- \(A_g\) - Area [m²]
- \(A_{net\text{-}m2}\) - The sum of the areas of external divisions weighted according to the degree of the expected heat loss through transmission, [m²]

In Lithuania the main demand for energy certification is for the built permissions for new buildings or for the buildings undergoing major refurbishment, because they need specific energy calculations, rather than environmental certification. Energy certification is performed by means of energy audit. In terms of the refurbishment of residential sector, applying energy efficiency certification insures the quality of the refurbishment measures.

The calculation and estimation of energy performance of a building is described in Technical Regulation of Construction (STR) STR 2.01.09:2005: Energy Performance of buildings. Certification of energy performance. Energy performance is asset considering the value of the qualifying indicator C calculated as follows:

\[
C = \begin{cases} 
\frac{Q_{sum}}{Q_{N,\text{sum}}} & \text{if } Q_{sum} \leq 1 \\
1 + \frac{Q_{sum}}{Q_{R,\text{sum}}} & \text{if } Q_{sum} > 1 
\end{cases}
\]

In other cases
\[
C = 1 + \frac{Q_{sum} - Q_{N,\text{sum}}}{Q_{R,\text{sum}} - Q_{N,\text{sum}}}
\]

Where:
- \(Q_{sum}\) (kWh/(m²·year)) is estimated energy
- \(Q_{N,\text{sum}}\) (kWh/(m²·year)) reference sum

A building shall be marked under a certain energy performance class considering the value of the qualifying indicator C as shown in the table. Value of variables that are necessary to calculate energy performance of a building vary depending on the function of the building and are determined from the tables given in the STR 2.01.09:2005.
3.4 Financial refurbishment instruments

It is stated in the National Energy Independence Strategy from 2012 that in order to achieve set goals in large energy efficiency improvement of residential buildings, the amount of 5–8 billion LTL will have to be invested. It is supposed that needed money for building refurbishment will be received from EU funds, government and home owners. The estimated payback period is 10 years (The Seimas of the Republic of Lithuania 2010).

Comparing such financial refurbishment instruments to the ones applied in other countries of EU, it is clear that financial support instruments of the refurbishment in Lithuania are very weak. Support of the grants and subsidies is very low and covers only half of the refurbishment costs (Fig. 3.6). That means that the other half of the refurbishment costs lies on the owners of the buildings, however the average income of the population is only 32% of the average of EU countries.

Therefore conclusions can be made that financial aspect of the refurbishment is very important and refurbishment design strategies and solutions have to take it into account.

3.5 Technical standards and regulations

Technical standards and regulations are presented in the Building Technical Regulations of the Republic of Lithuania. The main energy performance requirements for new buildings are described in the Building Technical Regulation STR 2.01.09:2005 “Energy Performance of Buildings; Certification of Energy Performance of Buildings together with the requirements for the energy performance certification, that were mentioned in chapter 3.3.

Requirements for new building

STR 2.01.09:2005: The energy performance class of new buildings (or building parts) must not be lower than energy performance class C. This requirement is mandatory for all new buildings, for which the design parameters (references) were defined after the Regulation came into force, on the 4th of January 2006 (Table 3.4).

<table>
<thead>
<tr>
<th>Building element</th>
<th>Normative U-value, W/(m²·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofs</td>
<td>UN 0.16K</td>
</tr>
<tr>
<td>Ceiling in contat with outdoor air</td>
<td>UN 0.25K</td>
</tr>
<tr>
<td>Building elements in contact with ground</td>
<td>UN 0.20K</td>
</tr>
<tr>
<td>Ceiling over unheated basement and crawls</td>
<td>UN 1.6K</td>
</tr>
<tr>
<td>External walls</td>
<td>UN 0.20K</td>
</tr>
<tr>
<td>Windows and transparent building elements</td>
<td>UN 1.6K</td>
</tr>
<tr>
<td>Doors and gates</td>
<td>UN 1.6K1)</td>
</tr>
<tr>
<td>Linear thermalbridges</td>
<td>UN 0.18K</td>
</tr>
</tbody>
</table>

1) If the total are of windows and other transparent building elements exceed 25% of the total external wall area, the U-value of transparent elements should not exceed 1.3 W/(m²·K);
2) \( k = 20/\left( \theta_i - \theta_e \right) \) – temperature correction factor, where \( \theta_i \) - indoor air temperature, °C, \( \theta_e \) - outdoor air temperature or design temperature of adjacent space, °C. Temperature of unheated space is determined separately. If indoor air temperature \( \theta_i = 20°C \), and outdoor air \( \theta_e = 0°C \), then \( k = 1 \);

Microclimate parameters for residential buildings are specified in the Lithuanian healthy standard HN 42:2009 “Microclimate of Public and Residential Buildings”, STR 2.09.02:2005: “Heating, Ventilation and Air Cooling” and STR 2.02.01:2004: “Residential Buildings” It states that air temperatures in the rooms and air supplies of residential buildings should be as described in Table 3.5, 3.6.

<table>
<thead>
<tr>
<th>Microclimate parameters</th>
<th>Warm period</th>
<th>Cold period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature, °C</td>
<td>18–22</td>
<td>18–28</td>
</tr>
<tr>
<td>Temperature difference at the 0,1 m and 1,1 m height from the floor should be no more than °C</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Relative air humidity %</td>
<td>35–60</td>
<td>35–65</td>
</tr>
<tr>
<td>Air speed, m/s</td>
<td>0,05–0,15</td>
<td>0,15–0,25</td>
</tr>
</tbody>
</table>

Table 3.4 Requirements for new buildings STR 2.01.09:2005

Table 3.5 Basic microclimate parameters for residential buildings HN 42:2009

---

In STR 2.01.09:2005 it is stated, that building energy efficiency is assessed only by calculation of the building energy consumption according to the method presented in the obligatory Annex. The character of the tenant’s behaviour and the state of the building envelope is not taken into consideration in recent normative document (Vytautas Stankevičius, Jurate Karbauskaitė et al. 2005).

Most of the existing multi-flat residential buildings perform very badly in terms of energy efficiency. According to the data from “Long term modernization strategy of national residential building stock” 2014, buildings built before 1992 do not reach the energy efficiency class higher than E (Table 3.3).
Refurbishment of multi-flat residential buildings in Lithuania

3. Refurbishment in Lithuania

3.6 Residential building stock

In Lithuania there are 557,700 buildings with total floor area of 162.4 mln m². Percentage of residential buildings is 86.5 % and refers to the 67.4 % of total floor area. Number of the registered residential buildings reaches 482,200 with total floor area of 109.4 mln m² (Longterm modernization strategy of national building stock 2014).

The percentage of single family and multi-flat residential buildings is almost equal. This is due to the fact that multi-flat residential buildings are mostly common in major cities and in the rest of the country low rise architecture prevails. According to BPIE survey “Europe’s buildings under the microscope, 2011”, Lithuania is one of a few countries with such a distribution, however despite this fact it outnumbers the other Baltic States by the number of multi-flat residential buildings (Economidou 2011).

Multi-flat residential buildings in Lithuania can be classified into 5 main groups regarding: 1 Construction years; 2 Construction material; 3 Energy consumption; 4 Ownership; 5 Number of floors;

### 3.6.1 Construction year

As in most of EU countries, in Lithuania the majority of constructed multi-flat residential buildings took place after the WWII. Most of residential buildings in Lithuania are older than 30 years. 66 % of the population lives in multi-apartment buildings built before 1993. In this period around 35,000 buildings were constructed by technical standards and therefore buildings do not meet requirements and norms of the present. In most of the sources construction years in Lithuania are divided into 4 or 5 groups: before 1940, 1940-1960, 1961-1992, 1993-present or 1993-2001 and 2001-present (Table 3.7).

**Table 3.7 Multi-flat residential buildings (>=3 apartment) by the construction year (Daugabieju Namu Atnaujinimo Programa 2011)**

<table>
<thead>
<tr>
<th>Construction year</th>
<th>Number of buildings</th>
<th>Useful floor area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Units</td>
<td>Percentage %</td>
</tr>
<tr>
<td></td>
<td>m²</td>
<td>m² percentage</td>
</tr>
<tr>
<td>&lt;1940</td>
<td>10362</td>
<td>28</td>
</tr>
<tr>
<td>1941-1960</td>
<td>3740</td>
<td>10</td>
</tr>
<tr>
<td>1961-1992</td>
<td>21090</td>
<td>5.6</td>
</tr>
<tr>
<td>&gt;1993</td>
<td>2075</td>
<td>5.5</td>
</tr>
<tr>
<td>Total</td>
<td>37,267</td>
<td>100</td>
</tr>
</tbody>
</table>

### 3.6.2 Construction type

The materials used in construction of multi-flat residential buildings in Lithuania can be divided into four main groups: masonry, prefabricated reinforced concrete, beton monolite and timber (Table 3.8).

There is certain connection between material type and construction years. In the period of 1900-1940 the main building materials were timber and bricks. Between 1940-1961 only masonry buildings were present. The period between 1960-1992 is significant because of the mass multi-flat residential building production, where the main building materials were prefabricated reinforced concrete panels and in during the end - beton monolite. During this period the urbanization level and population growth increased drastically. Controversy, period after 1991 is characterized by stagnation of the multi-flat residential building sector (Daugabieju Namu Atnaujinimo Modernizavimo Programa 2011).
Refurbishment of multi-flat residential buildings in Lithuania

### Table 3.8 Number of buildings according to the material (adapted from Daugiabucio Namų Atnaujinimo (Modernizavimo) Programa 2011)

<table>
<thead>
<tr>
<th>Material type</th>
<th>Number of buildings</th>
<th>Percentage</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry: Longitudinal load-bearing walls</td>
<td>24331</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Transverse load-bearing walls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefabricated reinforced concrete panels: Grid:</td>
<td>5502</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2.6m x 2.6m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2 m x 3.2 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.6m x 3.2m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monolite</td>
<td>312</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Timber or other construction</td>
<td>7121</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.6.3 Energy consumption

Energy efficiency strategies of Lithuania have already been described in chapter 3.2, however in order to define which buildings need to have priority in receiving subsidies and grants from the government for the refurbishment, multi-flat residential buildings were split in 4 groups regarding their energy consumption indicators (Fig. 3.8) (Gudzinskas et al. 2011).

First group: multi-flat residential buildings which energy consumption indicators are very low. These are usually newly built, high quality buildings. The monthly energy consumption of this group is up to 9 kWh/m²; This group represents 4.6% of total multi-flat residential building stock in Lithuania.

Second group: multi-flat residential buildings which energy consumption rates is low or average. Representatives of this group are recently built multi-flat residential buildings. The monthly energy consumption of this group is up to 19 kWh/m²; This group represents 17.3% of total multi-flat residential building stock in Lithuania.

Third group: multi-flat residential buildings which energy consumption rates are high, mainly not refurbished, old construction buildings. The monthly energy consumption of this group is up to 27 kWh/m². This group is the largest group, representing 55.7% of total residential building stock.

Fourth group: multi-flat residential buildings which energy consumption rates are very high; These are old buildings with poor insulation. The monthly energy consumption of this group is up to 40 kWh/m². Their percentage corresponds to 22.4.

#### 3.6.4 Ownership

After the collapse of the Soviet Union, apartments in multi-flat residential buildings were privatized. As a result 97% of multi-flat residential buildings today are owned by condominium (United Nations Centre for Human Settlements (Habitat) 2001). This makes refurbishment process very complicated, because according to present regulations 50% + 1 vote is needed in order to initiate refurbishment works. According to the survey performed by BPIE and published in 2011 (Economidiou 2011), compared to other EU countries, this percentage is relatively high. Similar number of privately owned buildings is in Romania and Bulgaria. In total, the percentage of privately owned buildings occupied by their owners is more than 50% in all the cases.

Moreover, the condominium ownership of the building results in self-performed interventions, for example individual window replacement, glazing of the balconies. Such interventions have negative impact on the total look of the building.
3.6.5 Number of floors
In Lithuania the largest percentage of buildings are 5 storey buildings. However between 1985 and 1990 the construction of high-rise buildings of more than 9 floors rapidly increased (Table 3.9).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td></td>
<td>6</td>
<td>10</td>
<td>14</td>
<td>17</td>
<td>10</td>
<td>41</td>
<td>54</td>
</tr>
<tr>
<td>3-4</td>
<td></td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>11</td>
<td>15</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>79</td>
<td>71</td>
<td>55</td>
<td>54</td>
<td>50</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>6-8</td>
<td></td>
<td>3</td>
<td>5</td>
<td>17</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>&gt;9</td>
<td></td>
<td>2</td>
<td>4</td>
<td>22</td>
<td>25</td>
<td>19</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.9 Percentage of building regarding number of floors and construction year (adapted from Daugiaibuciu Namu Atnaujinimo (Modernizavimo) Programos 2011).

3.7 Users’ expectations about the refurbishment

Owner decision about the refurbishment is one if not the most important factors for the successful refurbishment design. Some research was performed in order to define what refurbishment aspects during design process have to be taken into account regarding this statement.

The Fig. 3.9 represents the results of the online survey about the opinion of users about different refurbishment aspects. Users were asked to evaluate the importance of 6 aspect with the scale from 1 to 10, where 1 is not important and 10 very important. According to the data, it is seen that the main priority are the costs of the refurbishment and the residual building’s value after refurbishment. Therefore it is clear, that people want to get the financial refund of the invested money. Interesting fact is that lifetime span of the refurbishment and its duration are not of high importance.

In the report about the multifamily building refurbishment process in Lithuania, Jurelionis and Šeduikytė (Jurelionis and Šeduikytė 2010) present the data collected during the evaluation of 5 floor prefabricated reinforced concrete multi-flat residential building from 1977 in Kaunas. The aim of the research was to evaluate microclimate of this type of building. The results of their research are presented in Fig. 3.10.

3.8 Conclusions

The Lithuanian goals towards energy efficiency are the same as for the rest of the European Union. Major energy efficiency and CO₂ emission reduction savings have to be achieved before 2050. Residential housing sector is the second largest energy consumer in Lithuania and the one with high saving potentials. However, certain actions are needed in order to be able to use this potential. As the most of the European countries, Lithuania experienced building boom after the WWII. Almost 70% of the residential buildings in Lithuania were built between 1996 and 1990. Therefore, majority of the buildings are 30-40 years old and require refurbishment.

Refurbishment process in Lithuania is quite slow and requires technological, social, financial support. Todays financial refurbishment instruments rely mainly on grants and subsidies (50%), when the other 50% lies on the shoulders of the buildings’ occupants. This fact in scope with the fact that almost all multi-flat residential buildings are in condominium ownership and more than 50% users have to agree on the refurbishment, makes the whole process very difficult.

Therefor, financial aspect of the refurbishment is one of the major barriers towards the set goals. Because of low incomes, most of the people do not want to invest in refurbishment or do it cheap and shallowly, which results in undesired outcomes. Modern strategies and regulations for refurbishment in Lithuania are mainly focused on the refurbishment process from the energy efficiency and minimization of heat consumption, however, as it is seen from the surveys, other aspects such as indoor climate quality and building’s value after refurbishment are of the high importance as well.

It is obvious, that in order to fulfill requirements of National Energy Strategy and Housing Strategy, different approach is needed in order to stimulate willingness of users to invest in the refurbishment. Because it is unlikely, that more financial instruments will appear to support refurbishment of residential housing, the new quality-focused strategies of the refurbishment are desired.
4 Reference projects

4.1 Reference project 1

Apartment Building (Low Energy Housing Retrofit 2009)
Location: Wezembeek-Oppem, Brussels, Belgium
Construction year: 1959
Refurbishment year: 2004
Heated surface: 6287 m²
Heating demand: 33 kWh/m², year
Costs: unknown
Architect: Quirynen Jacobs Architecten

Context
The apartment building is located in the de wijk Ban-Eik district of Wezembeek-Oppem, which is near Brussel, Belgium. The district includes 150 private houses and 320 apartments that are divided into 4 highrise apartment blocks. Back in 1959, when this district was built, the aim of high and low-rise combination ensured high residential density and still many green spaces. In 90's the district turned into the problem area, because buildings have not met comfort standards, technical facilities needed an upgrade. The rents in this area were low and could attract only lower class people. After the refurbishment of private houses, it was planned to demolish high-rise apartment blocks and build new ones. However, because of new master plan for the area, which allowed new building height to be only up to 3 storeys, such a decision would reduce the number of housing units. Moreover, structure of the apartment blocks was in a good state. Thus, the decision was made to refurbish the apartment buildings (Fig.4.1).

Refurbishment
The aim and strategy of the refurbishment was to increase living quality of the area and apartment buildings themselves (Fig. 4.2,4.3). Following interventions were planned: modification of building, insulation of building shell, improvement of building’s acoustics, elimination of thermal bridges, attention to airtightness of building, winter gardens, improved double glazing, mechanical ventilation with heat recovery, solar collectors (vacuum tube), photovoltaic cells, central management system, water-saving appliances; refurbishment projects are very extensive. The demolition returns the building more or less to its loadbearing carcass. The primary structure remains essentially unaltered.
Modification of building

The number of the apartments was reduced from 81 to 61. The storage spaces on the ground floor were moved to the first floor. First floor served as an architectural separation between the base and the structure of the building. This allowed new housing spaces with private terraces on a ground floor for better social control and interaction with low-rise buildings around (Fig. 4.4).

The existing layout for floors 2-10 was modified in order to allow daylight and natural ventilation. New layout included six apartments on each floor, which were accessible by three new staircases and had daylight from two opposite sites. Each of the apartments was provided with a terrace. The terraces were placed behind a new glass facade. In winter these terraces function as a winter garden, and in summer just as balcony. A new floor on top of the building was arranged to provide space for the technical equipment, as well as two sub-stations for GSM operators (Fig. 4.5).

Figure 21. Floor layout after refurbishment (Low Energy Housing Retrofit 2009)

Structure

The existing column based structure of this building was in a good state and remained untouched. Therefore, the increase of building’s height was undesired. Regarding this aspect, only one technical floor was built on top of the existing roof. The floor was constructed from insulating cellular concrete blocks, lined with insulation and fiber-cement siding.

To the south-west façade new 0.6m wide, self-supported concrete-steel structure was added, which allowed to extend apartments and design terraces. A new wooden volume on the ground that protrudes on the northeast facade was constructed of masonry, finished with a wood siding.

Materials

Windows: Wooden frame with improved double glazing. The U-value of the whole window is 1.52 W / m²K, the U value of the glazing 1.1 W / m²K.

To avoid thermal bridges, the building was insulated from outside. Behind different cladding types same type of insulation material (mineral wool) was used (Fig. 4.6, 4.7). The insulation was placed uninterrupted between different types of siding. All structural elements, such as beams and columns, were coated and insulated. The floors between apartments and ground were injected with polyurethane insulation (Fig. 4.8). In order to avoid thermal bridges between old and new structures, rigid insulation boards were used (Table 3.10).

Table 4.1 Layers of roof, wall and ceiling after refurbishment, adapted from (Low Energy Housing Retrofit 2009)

<table>
<thead>
<tr>
<th>Roof</th>
<th>Walls</th>
<th>Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofing</td>
<td>1cm Aerated concrete</td>
<td>0.5cm Cladding</td>
</tr>
<tr>
<td>Mineral wool insulation</td>
<td>12cm Cavity</td>
<td>3cm Chape</td>
</tr>
<tr>
<td>Layer of PE film</td>
<td>4cm Mineral wool insulation</td>
<td>15cm Sound insulation</td>
</tr>
<tr>
<td>Concrete slab (existing)</td>
<td>15cm Concrete</td>
<td>18cm Polyurethane insulation and PE film</td>
</tr>
<tr>
<td>Gypsum finishing (existing)</td>
<td>1cm Gypsum finishing</td>
<td>3cm Reinforced concrete</td>
</tr>
<tr>
<td>Mineral wool insulation</td>
<td>8 cm</td>
<td></td>
</tr>
<tr>
<td>Gypsum finishing</td>
<td>2 cm</td>
<td></td>
</tr>
</tbody>
</table>

U = 0,28 W/m²K 33cm U = 0,23 W/m²K 39,5cm U = 0,26 W/m²K 37 cm

Figure 4.4 Ground floor after refurbishment (Low Energy Housing Retrofit 2009)  
Figure 4.5 Floor layout after refurbishment (Low Energy Housing Retrofit 2009)

Figure 4.6 Connection detail between apartments’ floor and wintergarden (Low Energy Housing Retrofit 2009)

Figure 4.7 Connection detail of new facade cladding (Low Energy Housing Retrofit 2009)

Figure 4.8 Construction work: attachment of new insulation layer (Low Energy Housing Retrofit 2009)
Technical installations

Ventilation
The ventilation system was incorporated in the central core block of the apartments so that the inlet and the outlet of the air can be arranged without compromising in floor height. The extraction of the air in the apartments is in "wet" areas (bathroom, kitchen and storage), while the supply of fresh air in the sleeping and living areas. The whole ventilation system is provided with a heat recovery unit (Fig. 4.9).

Heating
The district heating system was changed completely, because of the poor state of the old one (heat losses through the pipes, leaks, high operating costs, etc.) There is a common heating system provided at the level of the building. Radiators at low temperature (70 ° -50 °) were installed in the apartments for additional space's heating.

Warm water
The hot water in the building is generated in 2 ways: via condensing gas boilers and solar vacuum collectors. The 30m2 vacuum solar collectors were installed on the roof. The area was limited by GSM stations and terraces on the same roof. The disadvantage of such a system is that it requires space for the buffer tanks. In total 1000l buffer tanks were installed for heating and 3000l buffer tanks for preheating (Fig. 4.10).

Electricity
Together with vacuum solar collectors, 15 m2 of PV panels with capacity of 1.9kWp were installed (Fig. 4.11). Such an amount of PV cells cannot satisfy all needs, therefore the rest needed electricity is taken from the central grid. The lighting system is equipped with two kinds of sensors: radiation detection and motion detectors. Radiation detectors regulate the brightness of the light and motion detectors switch the light when movement is detected. These measures help to reduce light to a large extent.

4.2 Reference project 2

Apartment Building Leeuw van Vlaanderen
Location: Amsterdam, Netherlands
Construction year: 1958
Refurbishment year: 2005
Heated surface: unknown
Heating demand: unknown
Costs: € 12.436.115
Architect: J.P. Kloos

Context
This housing block is situated in Amsterdam next to the highway A10 (Fig. 4.12). To refurbish this building was decided, because demolition in this location was not allowed due to pollution and noise regulations. This example represents the very drastic refurbishment measures, because major refurbishment works were done, such as: complete façade replacement, installation of an elevator, addition of two extra floors and construction of a new galleries (Fig.4.13,4.14).

Refurbishment
Sound insulation
Modification of building
Double skin façade as thermal envelope

Modification of building
The whole façade of the building was removed and a new one was placed. From the side of the building which was next to the highway, at a distance of 2 meters a new glass façade was laced and connected to the concrete structure of the building. In such a way, this faced could perform not only as a wind and rain protection, but also as a sound barrier between noisy highway and apartments. In-between the facades a gallery with the entrances to the apartments was designed.

The opposite faced of the building was replaced with the stone look like cladding in order to improve aesthetical impression of the surroundings.

On the top of the building two extra floors are added. Due to increased number of floors, new elevators are installed to allow easy access to the extension. Instead of storage spaces on the ground floor, additional living spaces are designed, to increase activity and social control on a ground level (Fig. 4.15).
Structure
The refurbished building is 180 meters long and only 13 m wide. Building’s structure is concrete. Initially, the building was 4 storey high. The structure was strong enough to carry additional 2 floors, however to ensure enough strength to withstand extra vertical loads, 150 extra piles were added to the foundation. The height of the apartment was 2.9m, which allowed installation of technical facilities and additional sound insulation to reach desired indoor comfort.

Materials
The materials used in this project differs depending on the façade. For the façade next to the highway, laminated glass 10/10/2 was used (Rc = 2.5 m2K / W). The glass panels spans from floor to ceiling and only horizontal edges are visible from the outside. Glass connections were secured with rubber profiles to avoid glass falling on the highway in case of emergency (Fig. 4.16). Façade inside the gallery is made out of wood and the opposite façade is made out of stone strip sand a profiling of different windows. Because the traditional stone cladding would be too heavy for the structure, the system of steel frame elements of C and U-rails and aluminium sheet piling covered with stone plates of 20 mm thickness was used.
Extra floors on the top of the building are constructed out of steel frame. Bottom part of the top extension is made 60cm higher, because the existing roof could not handle the extra weight and be used as a floor. In the space between new and existing structure, pipes and ducts were installed.

Technical installations
The main aim of the project was to reduce noise pollution, therefore energy efficiency aspect was not taken into account and there is not enough information available about the technical equipment that was installed.

Ventilation
To ensure fire safety, the installation of a push ventilation was required. Such a system activates when smoke is detected and removes it from the escape routes keeping them safe. The same systems are use in closed parkings and tunnels. In non-emergency cases, the air is mechanically taken from the surroundigs and brought to the gallery (Fig 4.17).
4.3 Conclusions

These projects were chosen for the reference, because refurbishment strategies in both of them are very drastic and aim to increase living standards of the inhabitants rather than achieve energy efficiency. Both of analysed projects were built around 1960's and required refurbishment because of low living quality and bad performance. It was planned to demolish both of these projects, however due to different reasons demolition was impossible.

In both of analysed projects the layout of the floors were modified. In case of reference project 1, because of the structural performance, the addition on top of the building were not possible. In case of reference project 2, two additional floors were constructed. In both of these cases, ground floor function has changed, instead of storage spaces new apartments were designed.

The major difference is that in reference project 1 many technical innovations, such as solar thermal collectors and PV cells were used in order to provide building with hot water and electricity supplies. Unfortunately, there is no information regarding the efficiency of these measures and approximated payback period.

In the reference project 2 no installations were used, except of ventilation system for emergency cases. The main goal was to achieve proper acoustical comfort level.

The degree of invasion is also different for both cases. In reference project 1, the façade was covered with additional insulation level, while in reference project 2 the entire façade was removed and replaced with the new ones.

To conclude, both of the projects achieved higher living standards using different tactics. The refurbishment of ground floor spaces is very important, because this is where the building and the environment connects. The analysis of the existing structure is important to define what kind of additions are possible in every specific case. Moreover, it is necessary to define to what degree the intervention is needed, because, as it is can be seen from the reference projects, both drastic and quite moderate measures are possible.
5 Case study building

5.1 Boundary conditions

Based on the research done regarding the residential building stock in Lithuania, following boundary conditions were made in order to choose the case study building for further design and implementation of suggested strategies.

Location: Vilnius city (Fig. 5.1). Vilnius city was chosen, because this is the biggest city and the capital of Lithuania, with the higher potential in the refurbishment of the residential building stock because of its variety and bigger market opportunities. Moreover, the population of Vilnius was increasing rapidly during the past years and in some districts the demand for the housing is higher than the offer (Fig. 5.2).

District: According to the survey regarding the opinion of the residents of the capital on which district of Vilnius city needs refurbishment, Naujininkai and Koroliniskes districts score the most (Fig. 5.2). On the other hand, regarding the data on the lack of housing offers, districts like Fabijoniskes, Zverynas, Virsuliskes and Pilai are at the top (Fig. 5.3). That means these districts are cherished by local people and they value them well. Taking into account this information, the location of the building was narrowed down to the following districts: Naujininkai (1), Karoliniskes (2), Pilai (3), Virsuliskes (4), Fabijoniskes (5) (Fig. 5.1). Zverynas district was left out, because this is the district with wooden construction single or double flat residential buildings.


Outer wall material type: prefabricated reinforced concrete panels;

Energy consumption: Residential building with very bad or bad energy consumption characteristics;

Number of floors: 5-12

Other aspects: preferably building of mass type production, so the proposed strategy can be applicable to large number of buildings.
5.2 General information

According to the set boundary conditions, the building of a type JUST-5-001 on Tuju st. 15 in Virsuliskes district was selected. The main criteria for such a selection were the energy performance of this type of the multi-flat residential buildings, which is relatively bad and the total number of 428 buildings of that type only in Vilnius city. They are represented in almost districts in different configurations (Fig. 5.4, 5.5). That means that the design solution can be applicable to many more buildings and therefore more relevant in order to reach sustainability goals of the refurbishment.
5.3 Site

Virsuliskes is a district in the West of Vilnius city (Fig. 5.1). Total area of the district is 2.5 km². The population reaches 14733 people, 6403 men and 8330 women. District became part of the Vilnius city in 1969. The formation of the new district was finished in 1976. It was designed as a single residential complex by architects Birutė Kasperavičienė and Juozas Zinkevičius. From 1977 people started to move into newly build multi-flat residential buildings. Because it was initially designed as a residential area, there are mainly multi-flat residential buildings and couple of park zones. The biggest park zone is Luzio Parkas in the north of the district (Fig. 5.6). At the moment this is middle class living area. All of the buildings are in their original state with small changes mainly regarding window frames and balcony glazing.

In 2007 two modern highrise residential buildings were built. In the future there are plans to further develop highrise construction and create more highrise residential buildings and a business center (Fig. 5.6).

The prevailing wind directions differ depending on the season (Fig. 5.8). The strongest winds occur in Winter. Prevailing direction is W and SW. In Spring wind is less strong, however there is no prevailing direction. During Summer less strong winds occur mainly from NW direction. In Autumn there is less wind, but it is stronger and comes from S.
Refurbishment of multi-flat residential buildings in Lithuania

5.4 Building

Location: Tuju st. 15, Virsuliskes
Built in: 1978
Function: Residential building
Storeys: 5 storeys, 30 apartments
Height: 13.8m, 5 floors
Living area: 1720.45 m²
Heated area: 1881.65 m² (Because of the staircases)
Basement area: 388.76 m²
Façade area: 158.58 m²
Plinth area: 284.39 m² (Under the ground level: 132.00)
Roof area: 493.92 m²
Energy Label: E-D

The building is situated on a hill in the middle quarter of the Virsuliskes district (Fig. 39) and is surrounded by forest areas from south and east, highway from the West and shopping mall and cemetery in the North. This is simplest configuration of the JUST-5-001 typology buildings and therefore proposed strategies can be easily modified and applied for more complex configurations (Fig. 5.9-5.11).

The building share common courtyard with children playground with other 5 neighbour buildings and has small parking area in the front (Fig. 5.7).

The orientation of the building is North-East/South-West with balconies facing the South-West side with courtyard and playground. The entrances to the building are on the North-East side facing parking lot (Fig. 5.7, 5.12).

The building is an example of the condominium ownership, which means that in order to make decision about the refurbishment, 50%+1 vote are needed.
5.5 Building’s spatial configuration

The ground floor of the building is lifted 1.1m above the ground. The building spatial configuration consists of two separate blocks with separate staircase each. Staircase provide access to the basement of the building and 15 apartments (3 on each floor).

The layout of all 5 storeys is the same and there are three different types of the apartment (Table 5.1). Every apartment has separate kitchen, bathroom and toilet. Apartments of Type 1 and 3 have two-side window orientation and apartment Type 2 only one side. The plan layouts are shown in Figures 5.13-5.15.

<table>
<thead>
<tr>
<th>Apartment</th>
<th>Number of rooms</th>
<th>Living area (m²)</th>
<th>Number of Balconies</th>
<th>Window orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>4</td>
<td>84</td>
<td>2</td>
<td>S/W-N/E</td>
</tr>
<tr>
<td>Type 2</td>
<td>2</td>
<td>51</td>
<td>1</td>
<td>S/W</td>
</tr>
<tr>
<td>Type 3</td>
<td>2</td>
<td>51</td>
<td>1</td>
<td>S/W-N/E</td>
</tr>
</tbody>
</table>

Table 5.1 Apartment types

Figure 5.13 First floor plan

Figure 5.14 3d visualisation of the one block

Figure 5.15 Apartment types
5.6 Construction

The structure of the building consists of prefabricated reinforced concrete load-bearing panels with a grid of 3.2m (Fig. 5.16, 5.17, 5.18).

The facade is made out of 250mm thick prefabricated load-bearing sandwich panels: 40mm concrete layer, 160mm mineral wool board, 35mm concrete layer, 15mm cement mortar finishing;

The inner load-bearing walls are made out of 120mm thick prefabricated concrete panels (Concrete type M150);

Partitions are made out of 50mm prefabricated concrete panels.

The ground floor of the basement is uninsulated cast concrete (150mm thick). Internal floors construction is made out of 100mm prefabricated concrete (Concrete type M200) covered with 25mm fiberboard, 3mm cement mortar layer. Finishing - 5mm thick linoleum.

The roof is made out of 50mm prefabricated reinforced concrete slab covered with 100mm thick semirigid mineral wool boards (7300kg/m³), air gap, another layer of 50mm prefabricated reinforced concrete slab. Top layer is armored rubberoid.

Windows are made of two single glazed frames. The glass thickness is 2.5mm and air gap between two frames 50mm.

Typical details of the construction are presented in Figures 5.19-5.24.
5958
Armored ruberoid
50mm prefabricated reinforced concrete slab
Air gap
100mm thick semirigid mineral wool boards
50mm prefabricated reinforced concrete slab

Cement mortar
Mineral wool insert
Prefabricated concrete balcony slab

Armored ruberoid
50mm prefabricated reinforced concrete slab
Air gap
100mm thick semirigid mineral wool boards
50mm prefabricated reinforced concrete slab

Concrete M150
Mineral wool insert

Fig. 5.19 M1:5 Horizontal section; Connection between inner loadbearing wall and external wall detail

120mm Loadbearing inner wall
Sealant
Concrete M150
Mineral wool insert

Fig. 5.20 M1:5 Vertical section; Balcony connection detail

120mm Loadbearing inner wall

Fig. 5.21 M1:5 Vertical section; Roof and inner loadbearing wall connection detail

40mm Concrete layer
160mm Mineral wool board Concrete layer
35mm Concrete layer
15mm Cement mortar

Fig. 5.22 M1:5 Vertical section; Top window connection detail

Double glazed frame
Single glazed frame

Fig. 5.23 M1:5 Vertical section; Bottom window connection detail

Armored ruberoid
50mm prefabricated reinforced concrete slab
Air gap
100mm thick semirigid mineral wool boards
50mm prefabricated reinforced concrete slab

Fig. 5.24 M1:5 Vertical section; Ground floor detail

Refurbishment of multi-flat residential buildings in Lithuania
5. Case study building
5.7 Services

Ventilation
The building is ventilated by means of natural ventilation. The air is naturally extracted from the kitchen and bathroom. During winter the building is ventilated because of infiltration: poor joints and cracks in the facade (Fig. 5.27).

Heating and hot water
The building is heated with hot water radiators. Radiators are placed in every room and are connected with one pipe (Fig. 5.28). Such a system is called a single pipe heating system. The energy for water heating is delivered from the central heating network (Fig. 5.29).

Hot water is supplied separately to kitchen and bathroom (Fig. 5.30).
5.8 Problems and refurbishment requirements

The main problem in prefabricated reinforced panel buildings of this type is low indoor temperatures during winter. That is caused by construction features. Due to old sealant between the panels, cracks and poor insulation, heat is not retained within the building. Even if the batteries are hot enough, it is difficult to reach proper indoor thermal comfort in winter time.

Because the roof is flat, leakage is very common in this type of building. The main problem occurs because of the joints between the prefab roof panels, that easily allow rainwater inside the building.

Mould that occurs in bathroom due to poor ventilation. The building is naturally ventilated through windows, however the vertical ventilation channels to draw air out do not provide proper ventilation.

Cracks in plinth that allow moisture inside and results in unequal building sediment. (Fig. 5.31)

Old windows have two frames. Inner frame has double glazing and the outer frame is single glazed (Fig. 5.32). Despite the triple glazing, most of the windows were replaced with the better performance PVC windows. However this process resulted in hectic look of the facade(Fig. 5.33,5.34).

No insulation between unheated basement and ground floor reduces thermal comfort of the ground floor apartments and increased heat losses.
6 Real estate value

6.1 Real estate valuation methods

According to the interviews with real estate agencies in Lithuania, the price of the apartments in the refurbished buildings is 15-20% higher. However, there is no proof and these numbers are very optimistic, because different literature sources mention the increase of the value of the property by 6-7% (YAU).

The main question and goal of this report is to evaluate the building after the refurbishment, therefore it is necessary to know what the methods of the evaluation of real estate property are and what data is needed for it.

First of all, it is essential to define the difference between the price and market value. Market value represents what the property is really worth and price estimates the cost to buy it. Therefore, the market value and the price of the real estate property might differ due to many factors, such as personal relationships between seller and buyer, high personal interest, etc. A price paid might not represent the property’s market value.

Apart from market value, other kinds of value should be considered and differentiated: investment value, use value, assessed value, and insurable value (Lusht 2001). In this paper, the focus will be on changes to the market value of the refurbished multi-flat residential building.

Lusht in his book Real Estate Valuation: Principles and Applications (Lusht 2001) uses the same three approaches to estimate the real estate property value as are described in the Law about Property and Business Assessment Framework of Lithuania.

Sales comparison method
This method is based on the one-price rule, where:
\[ V = \text{Price of comparable properties} \pm \text{adjustments for difference} \]

Cost method
This method is based on the principle of substitution, where:
\[ V = \text{Cost to reproduce/replace as if New-Depreciation+Land value} \]

Income method
This method is based on the principle of anticipation, where:
\[ V = \text{Present value of anticipated income} \]

After several interviews with real estate agencies, it was defined that the most common method used for property evaluation is the sales comparison method. This method can be applied to evaluate the refurbishment process that is similar to the one used at the moment in Lithuania and therefore there might be enough data available. However, for more advanced refurbishment evaluation such a method will not be sufficient, because there are no examples of such refurbishment projects in Lithuania.

The cost method is another way of property’s valuation. The costs that can be considered in this method are: direct costs, indirect costs, and developer’s profit.

The estimation of direct costs includes material and labour, indirect costs in-
include feasibility studies, insurance, taxes, architectural and engineering fees, surveys, demolition fees, etc. The developer’s profit is estimated separately as a percentage of direct and indirect costs. The problem of this kind of method is the depreciation measurement and land value. Depreciation is difficult to measure and it is associated with the building’s age. Therefore cost approach is more suitable for new buildings. The land value is estimated based on its highest and best use as if vacant, therefore in old neighbourhoods it is hard to determine it due to a few vacant sites to use as comparable.

The income method mainly focuses on the rent properties, therefore it is hard to apply it for this research as the apartments in building are privately owned by residents and are not rented by a company.

**Hedonic model**

Another way found in the literature is evaluation of the real estate property by using the hedonic model (Monson 2009). The most common example of the hedonic pricing method is in the housing market: the price of a property is determined by the characteristics of the house (size, appearance, features, condition) as well as the characteristics of the surrounding neighbourhood (accessibility to schools and shopping, level of water and air pollution, value of other homes, etc.) The hedonic pricing model is used to estimate the extent to which each factor affects the price.

For the purpose of this thesis the combination of comparison method and hedonic model will be used. Comparison method will be used to define if there is a difference in the market value between already refurbished and non-refurbished buildings. Cost method will refer to the evaluation of the energy efficiency, where the investment costs will be compared to the savings gained by these measures. Hedonic model will be used to evaluate non energy efficient benefits of the refurbishment using regression analysis.

Both comparison method and hedonic model are based on the analysis of the market, therefore it is important to define what criteria have influence on the market value of the refurbished building.

**6.2 Factors that influence market value**

There are four forces that have impact on the real estate value (Carr, Lawson; et al. 2003): Social; Economic, Physical/Environmental; Governmental;

**Social Forces**

Social factors that has an effect on real estate value are based on trends and culture of the region. These factors include demographic, cultural and social aspects, such as growth or decline of population, family composition, aging of the population, present trends.

The population of Lithuania is a slightly declining population. The main age group are people of the working age (15-64 years old) and this group stands for almost 70% of the whole population (Population and Housing Census of the Republic of Lithuania 2011). The average age of the population is 41 years. The family size in mainly 1-2 persons, the large families of 5 and more people are very rare. The data is presented in Figure 6.1.

**Economic factors**

Economic factors that influence the real estate value are based on land value and ability to purchase and use real estate property. Any land has value that is based on the productivity and function. Ability to purchase and use depends on employment, income level, credit availability, interest rates and utility costs.

As it was already discussed in previous chapters, the ability to purchase in Lithuania is low. The average monthly salary is 670 euros/month brutto. The employment rate reaches only 50.4 % in urban areas (Population and Housing Census of the Republic of Lithuania 2011).

**Physical/Environmental**

These are forces that include location, climate conditions, transportation availability, and topography. This aspects will be analysed and discussed further in more detail.

**Governmental**

Government has the force to affect and influence taxes. Local real estate taxes affect the supply and demand of homes and land in a certain area as well as commercial properties and industrial projects. It has power to support certain aspects of building sector by special funding, support, etc.

Not all of the refurbishment measures are supported by government. That should be taken into account proposing design solutions for each of the strategies.

**Refurbishment measures supported by the government:**

**Energy efficiency:**

1: Heating and hot water system reorganization/replacement, placement of renewable energy sources, piping insulation/replacement;
2: Ventilation/recuperation system reorganization/replacement
3: Roof insulation, new roof coating, pitched roof installation (without any rooms there), staircase installation if energy efficiency elements are placed in the attic;
4: Façade insulation, including elimination of construction plinth defects;
5: Balcony or logia glazing, including strengthening of the construction and/or new glazed structure installation;
6: Outdoor door replacement, including the entrance decoration works and entrance adaptation for people with disabilities;
7: Window replacement
8: Basement ceiling insulation
9: Modernization of elevators regarding energy efficiency and accessibility by people with disabilities;

**Other measures:**

Engineering system modernization, such as: wastewater system, electrical installations, fire protection system, drinking water piping and device replacement/ reorganization, drainage organization;
6.3 Market analysis

One of the main problems regarding the apartments in post-war prefabricated panel residential buildings is that they are not only physically, but also morally outdated. Thus, market analysis is divided into two parts.

First part is the analysis of the market value of the apartments in multi-flat residential buildings similar to the case study building. The special focus is on the comparison of the apartments in the refurbished and non-refurbished buildings.

The second part is the analysis of the market value of the apartments in newly built multi-flat residential buildings to understand the present tendencies and define the strategy for the modern approach towards refurbishment.

The criteria that have influence on the market value of real estate property can be classified into four groups: physical, social, economic, political. The market analysis is mainly focused on physical criteria.

Methodology of data collection
Main physical criteria that were analysed are: location, number of rooms, physical state of the apartment, construction type, total floor area, floor, orientation, installations, construction year.

According to the studies performed by “Bustas Tau” company (Stumbrys 2006), the location has a huge impact on the value, therefore they divided all Vilnius city districts into 4 groups (Table 6.1):

<table>
<thead>
<tr>
<th>Location</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centras, Senamiestis, Užupis</td>
<td>1</td>
</tr>
<tr>
<td>Naujamiestis, Antakalnis, Žvėrynas</td>
<td>2</td>
</tr>
<tr>
<td>Viršuliškės, Karoliniškės, Lazdynai, Fabijoniškės, Justiniškės, Šeškinė, Pašilaičiai, Pilaitė, Žirmūnai, Jeruzalė, Baltupiai, Santarinkė</td>
<td>3</td>
</tr>
<tr>
<td>Žemėjie Panerai, Grigiškės, Naujoji Vilnia ir visi kiti mikrorajonai</td>
<td>4</td>
</tr>
</tbody>
</table>

The case study building is in the group 4, therefore for the analysis it was decided to use the districts from the same group to eliminate the location impact on the market value. In Viršuliškės district, where the case study project is located, are not enough newly built buildings for the comparison and there are no refurbished buildings. As a result, districts Zirmunai and Pasilaiciai were added for the market analysis because Zirmu

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Boundary condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Districnt</td>
<td>Old</td>
</tr>
<tr>
<td>Zirmunai, Pasilaiciai, Virsuliskes</td>
<td>Zirmunai, Pasilaiciai, Virsuliskes</td>
</tr>
<tr>
<td>Construction type</td>
<td>Brick, masonry, monolite</td>
</tr>
<tr>
<td>Living area</td>
<td></td>
</tr>
<tr>
<td>Floor of the apartment</td>
<td></td>
</tr>
<tr>
<td>Number of floors total</td>
<td>5-9</td>
</tr>
<tr>
<td>Number of rooms</td>
<td>2-3</td>
</tr>
<tr>
<td>Heating type</td>
<td></td>
</tr>
</tbody>
</table>
| Physical state of the apartment              | Decorated or furnished | Decorated or fur

The data for market value analysis was taken from the advertisement websites: aruo-

das.lt, ntzemelapis.lt; in total there were analysed 337 advertisements in newly built buildings and 102 advertisements for the apartments in the old buildings. (Appendix A,B). The analysis graphs that reflect the relationship between different criteria are discussed in the next sub-chapter and presented in Appendix C.
6.4 Output of the market analysis

As it is seen from the graph (Fig. 6.3) the price of the apartments in newly built residential buildings is higher than in the old ones, which is natural. However the price of the apartments in new buildings in Virsuliskes district is relatively higher than in the other two districts. That means that newly designed apartments here are valuable and have high market value.

The market analysis of the value of the apartments in the old prefabricated multi-flat residential buildings showed that the number of the apartments in the refurbished buildings is very small. Out of 102 examples only 5 were in the refurbished buildings, 1 in partially refurbished building and 3 in the buildings that are ready for the refurbishment. This can be due to the fact that the refurbishment process forces people to take loans for about 20 years. Therefore, if the decision about the refurbishment is made people are likely to stay in the apartment for longer period.

Construction type

The construction of new residential buildings is mainly brick and the construction type of analysed buildings built 1965-1980 is mainly prefabricated concrete panels.

Area

The area of the apartment do have positive impact on the market value, which is logical, because the more square meters cost more money. This is true for both new and old buildings. However, the price for square meter is not affected by the area, which means that the 1m2 in small apartment values as much as or even higher than 1 m2 in large apartment. From analysis results presented in Figure 6.4 it is also clear that apartments in newly built residential houses have much more variety in terms of total area size.

Floor

Usually the apartments on the ground floor and the top floor are less valuable on Lithuanian market, because of the safety reasons and roof leakage respectively. From the analysis it is clear that this statement is not completely true. The price range from the bottom and top apartments do not reach highest values. However in most of the cases it is comparable to the middle apartment values. The number of floors in the building do not have any effect on apartment’s value as well.

Heating type

It is hard to determine if heating type has any influence on the price, because among the analysed examples main heating source is central heating, therefore it is hard to compare it with other sources due to lack of data. This is true for both old and new buildings.

Physical state of apartment

From the pictures it is hard to define the real physical state of the apartments. From the research done it is clear that undecorated apartments are much cheaper than decorated ones. The price difference between furnished and decorated is not clearly feasible because of high variety in quality, amount, design, etc. of furniture and decoration.

Parking

is not a problem in most of the cases. Newly build residential buildings provide underground parking places for additional price and have closed parking areas nearby the building. The old type residential building solve parking problem at the expense of courtyards and part of the road space.

Orientation

From the analysed advertisements only orientation with East, West or South directions were highlighted. This orientation provides most of sunlight and is mostly cherished by people and seen as an advantage.

6.4.1 Personal conclusions and observations

In this part the conclusions made after interviewing real estate agencies, municipality and apartment owners are discussed.

Private vs Public

The problem of multi-flat residential buildings from 1960-1992 is not only their poor state in terms of energy efficiency and architectural quality, but also the fact that the space configuration do not meet modern comfortable living standards anymore. The problem between private and public is very noticeable. The greenspaces between buildings are used as car parking and building itself does not have any communal spaces, where residents of the building can spend time together.

Additional floors

According to the opinion of the Vilnius city municipality representative and VGTU professor Juozapas Parasonis, the possibility to add extra floors to the refurbished building is seen as a good opportunity to change opinion about the refurbishment and improve living standards. Extra floors can attract investors and minimize refurbishment costs for the residents. This option is very promising, but also complicated, because such measures are not supported financially by the government. Moreover additional floors need to meet new building standards and meet all existing regulations.
Balconies
According to real estate experts, large balconies and terraces should boost the property’s value, however it is difficult to say what will be the final impact on the market value.

Layout
One of the problems of old apartments is the outdated layout. From the market analysis, it was concluded, that newly built apartments have more spatial living room, usually connected with the kitchen. Rooms in the apartment are organized to avoid corridors.

In Fig. 6.5-6.6 the comparison between typical newly built apartment’s layout and the case study building’s apartment layout is presented.

As it is seen from the graph Fig.6.6 all functional spaces, except of the corridor, are bigger. The size of bathroom is twice as big as in the case study building and balcony is three times bigger.

6.5 Market analysis conclusions

According to the analysis it is hard to apply any of the models presented in Chapter 4.3.1. Comparison method is hard to apply due to lack of information available on the market. Because of the small number of the apartments in the refurbished multi-flat residential buildings available on the market, it is hard to make any comparison or conclusions. Regression analysis that is used for hedonic model showed that there is no strong relationship between set criteria and the apartment price. However, it is clear, that in order to bring closer the layout of the case study building to the newly built apartments and increase its market value, major spatial configurations are needed. The easiest way is to increase space of balconies, which will directly result in the apartment’s price because of the increased total floor area. The inner layout changes would be very beneficial as well, but much more complicated. But in order to estimate the impact of the refurbishment on the market value other approach, than those discussed above, is needed.

1. In order to evaluate proposed strategies, functional, emotional and social impact will be estimated with the help of SWOT analysis (Fig. 6.7).

2. The refurbishment investments for all three strategies will be compared with:
   - Present market value Euro/1m² (PMV) = 916 Euro/m²;
   - New building market value (NBMV) = 1340 Euro/m²;
   - The desired situation is when refurbishment investments together with present market value are lower, then the new building value.

3. Increase in the energy efficiency of the building.

   Data needed to compare three strategies:
   - Refurbishment investments Euro/1m² (RI)
   - Energy savings kWh/m
   - SWOT analysis
7 Design

7.1 Climate influence on design strategies

Based on the data taken from Climate Consultant, the most efficient design strategies for best indoor comfort for Lithuanian should aim: heating and additional humidification (71.2%), internal heat gain (20.4%), passive direct solar gain (12.3%), sun shading of windows (4.6%), passive solar direct gain (5.4%), natural ventilation cooling (2.5%). Comfort zone lies above the temperature of 20°C and humidity ratio between 0.04 and 0.012 (Fig. 7.1).

7.2 Type of intervention

Depending on the type of intervention, following refurbishment strategies exist (Konstantinou 2014):

Replace
Strategy, when old elements are removed and replaced with new ones. Facade replacement can be complete and spatial. The benefits of such a strategy are increased building performance and lifespan and new building appearance. Drawbacks are increasing refurbishment costs and disturbance of the users. Includes facade replacement with curtain wall or double skin facade.

Add-in
Strategy, when building is upgraded from inside. Benefits are preserved exterior, better thermal insulation. Drawbacks are big disturbance for users and difficult connections in order to avoid thermal bridges. Includes adding new interior layer or upgrading existing one.
Wrap-it
Strategy, when building is covered from the outside with additional layer. Positive aspects of this strategy are solution for thermal bridge problem, better thermal insulation, different appearance because of various cladding and little disturbance for users. Negative aspect is that this strategy is not possible in case of monument buildings and if there are any space limitations.
Includes adding extra insulation layer or second skin facade construction possibility.

Add-on
Strategy, when new structure is added to the existing one. The major benefit of this strategy is new facade with good performance without removing an old one. Increase of functional possibilities because of new space. However structural limitations and necessity of combination with other strategies for facade are main drawbacks.

Cover-it
Strategy, when certain parts of the building, such as atria or courtyards are fully or partially covered. This strategy creates additional space, creates thermal buffer and natural ventilation opportunities using stack effect. Drawbacks lay within limited application possibilities and dependence on function and layout of the building.

The combination of intervention options and possible refurbishment solutions is presented in Table 7.1 and Fig. 7.2.

Fig. 7.2 Different refurbishment solutions
### 7.3 Design approach

In order to answer the research question and find the best approach towards the refurbishment process and its benefits in Lithuania, three strategies are proposed.

The strategies are designed in a way to gradually increase the complexity of the refurbishment design and by introducing new technologies and additional benefits. Because the refurbishment process can be beneficial in a different way depending on the target group, the three strategies aim to focus on different parties involved and represent the extreme options.

**Strategy 1** is a "Basic strategy." It aims common refurbishment goals that exist today in Lithuania and represents the easiest and cheapest refurbishment design possible.

**Strategy 2** is a "Social strategy." This strategy mainly focuses on the residents of the building and represents the benefits that residents of the building can gain after the refurbishment process. Despite the financial problems discussed in Chapter 6 and low purchase value of the population, this strategy does not focus on the cheaper solution but rather on social aspects of the refurbishment, such as disturbance during the design process, better lifestyle, etc.

**Strategy 3** is a "Commercial strategy." This strategy aims to involve third parties into the refurbishment process. That means the benefits of this strategy are influential for the potential investors that can financially support the refurbishment and therefore minimize its burden for building's residents. This is the most complex and costly strategy.

All three strategies involve different types of intervention. In order to provide proper integrated design solutions, the impact on indoor thermal comfort has to be taken into account. According to Fig. 7.3, the heating energy demands before and after the refurbishment decrease significantly, however for well insulated buildings additional energy demands for space ventilation are needed.

---

**Table 7.1** Combination of interventions and refurbishment solutions

<table>
<thead>
<tr>
<th>Replace</th>
<th>Add in</th>
<th>Wrap it</th>
<th>Add on</th>
<th>Cover it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>Wall</td>
<td>Openings</td>
<td>Balconies/Loggia</td>
<td>Ground floor</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

---

**Fig. 7.3 Residential building energy demands**

- Historic old residential buildings
- Mass production residential buildings before 1991
- Residential buildings before 2002
- Low energy residential buildings
- Passive residential buildings

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7.4 Strategy 1: Basic

Design proposed for the first strategy focuses on the simplest solution available. This is basic strategy without any additional benefits except of better energy efficiency and indoor climate. Despite its simplicity, the materials and the energy efficiency standards are kept high and aim to achieve best results possible.

7.4.1 Type of intervention

The main strategy of such a design include interventions regarding the improvement of the insulation of the building’s envelope. This include:

Façade insulation: The new ventilated facade is designed. An additional insulation of 200mm mineral wool is added to the existing facade. The insulation is placed in the special aluminium carcass attached to the existing facade. The finishing layer is the special lightweight concrete plates that are attached with the minimum of 2.5mm air gap.

Roof insulation: Roof insulation is improved with the 100mm polystyrene layer and covered with bitumen layer.

Window replacement: Windows are replaced with Low-E triple glazed argon filled windows.

Balconies: Balconies structure stays the same, only railing is replaced. According to the original project, the balconies are unglazed, however most of users decided to glaze them themselves, which resulted in hectic building’s look. Therefore for the basic strategy the glazing of all the balconies is chosen with the same triple glazed profiles as for the windows.

Doors replacement:

Outdoor doors at the entrance to the building are replaced with new ones with better U-value.

The impact on the building itself is noticeable, however not very significant.

7.4.2 Spatial configuration

Because this strategy aims the basic refurbishment measures, it does not involve any structural or spatial changes inside the building.

The comparison between the present situation and proposed design layouts and sections can be seen in Fig. 7.4

Fig. 7.4 Render Strategy 1. Front facade

Fig. 7.5 Render Strategy 1. Rare facade
7.4.3 Climate installations

In order to improve indoor thermal comfort and reduce ventilation energy demand, climate design of heating, ventilation and hot water are proposed.

Ventilation

The existing building is naturally ventilated, however according to conclusions in Chapter 5 on present situation problems and Fig. 7.3 this is not enough. The average summer temperatures based on Table 3.1 are lower than the thermal requirement for the indoor temperature during the unheated season, which is equal to 24°C (table 3.6). Thus the main focus is to provide proper ventilation during winter. The heating season (November-April) according to Table 3.1 is -3.2°C. Because this strategy represents the simplest approach possible without any interior interventions, the air supply shafts for the mechanical ventilation air supply are design outside the building. For air extract the existing shafts are used. The fresh air enters the building at the rooftop, where the heat recovery unit is placed. The diagrams for summer and winter ventilation is provided in Fig. 7.5 and Fig. 7.6.

Heating and hot water

The diagram for heating and hot water system is presented in Fig. 7.7. Main heating system is the same as in the present situation: the heat is provided by the centralized heating network. The apartments are heated with radiators that use hot water. Additionally, space is preheated with the supply air from the mechanical ventilation system, which uses recovered heat to preheat the incoming fresh air. That helps to minimize heating loads. In order to save energy and improve indoor climate, regulation valves are placed on the radiators inside the apartments for the manual control of heating inside the rooms. Also for this strategy it is considered that the piping insulation is replaced with the new one that meets requirements and the heating system is improved with the efficient hydraulic equipment.

7.4.4 Other aspect of the refurbishment

Costs

Because this strategy involves the simplest solutions available, the refurbishment costs are considered to be as low as possible, therefore only measures supported by the government are used. (Measures supported by government are presented in Chapter 6.2. The approximate refurbishment costs estimation will be calculated further.)

Impact on residents

All proposed measures involve only outside works, therefore the disturbance of residents is as low as possible.

Additional benefits

There are no additional benefits, except of better energy performance and architectural upgrade of the facade.
7.5 Strategy 2: Social

This design focuses on deeper refurbishment strategy than the previous one. Design proposed for the second strategy focuses on the additional benefits for the residents of the building. This mainly concerns the improvement of the lifestyle and indoor air climate. The financial aspect for this strategy is not of the main importance, however measures used are mainly the ones supported by the government.

7.5.1 Type of intervention

The main strategy of such a design include interventions regarding the improvement of the insulation of the building's envelope and provide new private and communal spaces within the building. This include:

Façade insulation: The new ventilated facade is designed. An additional insulation of 200mm mineral wool is added to the existing facade. The insulation is placed in the special aluminium carcass attached to the existing facade. The finishing layer is the special lightweight concrete plates that are attached with the minimum of 2.5mm air gap. On the wall between the inside and the loggia, the insulation layer is minimized to 100mm, because loggias serve as a buffer zone.

Roof insulation: Roof insulation is improved with the 100mm polystyrene layer and covered with bitumen layer. Moreover, on top of the roof the greenhouse is constructed. Such a solution not only improve thermal insulation of the building, but also has direct environmental and social benefits that will be discussed further.

Window replacement: Windows on the South-West facade that face loggias are increased to the floor. Windows are replaced with Low-E triple glazed argon filled windows.

Balconies: Old balconies are remove and replaced with big loggias. The loggias are fully glazed. The upper part (above 1.1m) is transparent and the lower part is opaque.

Doors replacement: Outdoor doors at the entrance to the building are replaced with new ones with better U-value.

Together with the envelope insulation improvements, this strategy involve extensions of the living floor area at the expanses of balconies, which become glazed loggias. Therefore impact on the building itself is noticeable. Moreover, in order to provide additional community space, the greenhouse is designed on the top of the roof.

7.5.2 Spatial configuration

This strategy aims to meet the needs of the resident's of the building. The changes in special configuration involve the new big loggias instead of small balconies that can be also use as an extension for kitchen area. Additional community space is designed on the rooftop by means of the greenhouse construction.

The comparison between the present situation and proposed design layouts and sections can be seen in Fig. 7.9.
7.5.3 Climate installations
In order to improve indoor thermal comfort and reduce ventilation energy demand, climate design of heating, ventilation and hot water are proposed.

Ventilation
As it was already discussed in the design proposal for the previous strategy, the proper ventilation of the indoor space during winter is very important. This type of strategy allows small interior interventions, therefore mechanical ventilation system is designed. The existing shafts are improved and used for mechanical air extract. The fresh air enters the building through the pipes placed in the ground. Because the average annual temperature is 6.2 °C (Table 3.1) this allows to preheat the air from -3.2 °C to 6.2 °C in order to reduce energy demand. The heat recovery system is used. The glazed loggias serve as a buffer zone and also have impact on the reduction of energy demand. The diagrams for summer and winter ventilation is provided in Fig. 7.10 and Fig. 7.11.

Heating and hot water
The diagram for heating and hot water system is presented in Fig. 7.12. Main heating system is the same as in the present situation: the heat is provided by the centralized heating network. The apartments are heated with radiators that use hot water. Additionally, space is preheated with the supply air from the mechanical ventilation system, which uses recovered heat to preheat the incoming fresh air. That helps to minimize heating loads. In order to save energy and improve indoor climate, regulation valves are placed on the radiators inside the apartments for the manual control of heating inside the rooms. Also for this strategy it is considered that the piping insulation is replaced with the new one that meets requirements and the heating system is improved with the efficient hydraulic equipment. Energy required for hot water supply is minimized by use of energy from the greenhouse to preheat the water.

7.5.4 Other aspect of the refurbishment
Costs
Because this strategy involves the more advanced refurbishment solutions compared to the first strategy, the refurbishment costs are higher. The main financial burden is his construction of the greenhouse and climate system improvements. However, taking into account that the greenhouse construction is on the list of the measures supported by the government (pitched roof installation, except of design of spaces suitable for living (Chapter 6.2), the overall costs can be minimized. The approximate refurbishment costs estimation will be calculated further.

Impact on residents
The aim of this strategy is to meet the needs of the residents, therefore all measures applied consider the fact that residents stay in the apartment or can be relocated for a very short period of time, and therefore no significant interior changes are possible. However, because of the construction of new loggias, new mechanical ventilation system and greenhouse, the disturbance level is quite high. The construction of the greenhouse provides the new community space, solving the problem of private versus common spaces, which was discussed in Chapter 6. This measure will definitely have impact on the lifestyle of the residents. Also the newly constructed loggias increase the useful area of the apartment, therefore it influences the market value of the apartment. Moreover, new loggias have enough space to place larger furniture, and therefore can be used more efficient.

Additional benefits
Construction of the greenhouse will have the positive environmental impact on urban scale. The greenhouse can be also used as a common garden for fresh vegetable production for the residents of the building.
Refurbishment of multi-flat residential buildings in Lithuania

Fig. 7.12 Comparison of present situation and proposed design

Section. Present situation  Section. Strategy 2 design

Layout.
Present situation

- Balcony
- Living room
- Bathroom/toilet
- Bedroom
- Corridor
- Kitchen
- Storage

Balcony
Living room
Bathroom/toilet
Bedroom
Corridor
Kitchen
Storage

Fig. 7.13 Ventilation. Summer

-2000
3.2
0
6.2
0
20.6
0
24
0

Fig. 7.14 Ventilation. Winter

20.6
0
6.2
0
20
0
24
0

Fig. 7.15 Heating and hot water
7.6 Strategy 3: Commercial

Design for 3 strategy targets the potential investors of the refurbishment. Two additional floors are added to the building. They are partly supported by existing structure and partly by newly created structure. The additional floors should meet new building standards and have energy efficient level A or higher.

7.6.1 Type of intervention
The main strategy of such a design include interventions regarding the improvement of the insulation of the building’s envelope and use of modern technologies to minimize energy consumption.

Façade insulation: The new ventilated façade is designed. An additional insulation of 200mm mineral wool is added to the existing façade. The insulation is placed in the special aluminium carcass attached to the existing façade. The finishing layer is the special lightweight concrete plates that are attached with the minimum of 2.5mm air gap. On the wall between the inside and the loggia, the insulation layer is minimized to 100mm, because loggias serve as a buffer zone.

Roof: On top of the roof two additional floors are constructed, therefore old roof construction is improved, but is no longer exposed to the outside.

Window replacement: Windows on the South-West façade that face loggias are increased to the floor. Window from the kitchen is replaced with the fully glazed door. All windows are replaced with Low-E triple glazed argon filled windows.

Balconies: Old balconies are remove and replaced with big loggias. The loggias are fully glazed. The upper part (above 1.1m) is transparent and the lower part is opaque. Compared to the Strategy 2, loggias run along all the length of the South-West facade.

Doors replacement: New entrance are constructed instead of the old ones. More detailed it will be discussed further.

Together with the envelope insulation improvements, this strategy involves two additional floors on top of the building and extensions of the living floor area at the expanses of balconies, which become glazed loggias and are used as a kitchen area extensions. Therefore impact on the building itself is very significant. Two additional floors serve as a space for new apartment design in order to attract investors, who can pay for the refurbishment and use the additional space for future rent.

7.6.2 Spatial configuration
This strategy involves major spatial changes. First of all the old staircase is removed and replaced with the new one and the elevator. Elevator is necessary because of the Lithuanian building regulations, where it is stated that residential buildings with 4 and more floors have to be equipped with elevators.

Loggias are designed on both facades of the building. Moreover, the living room area is placed on the North-East facade and is combined with the kitchen, in order to provide the layout of the apartment that meets modern tendencies. This allows to combine and increase total area of the toilet and the bathroom. These measures allow to reduce the size of the corridor and convert it into useful space.
The comparison between the present situation and proposed design layouts and sections can be seen in Fig. 7.14.

### 7.6.3 Climate installations

In order to improve indoor thermal comfort and reduce ventilation energy demand, climate design of heating, ventilation and hot water are proposed.

**Ventilation**

As it was already discussed in the design proposal for the previous strategy, the proper ventilation of the indoor space during winter is very important. This type of strategy allows small interior interventions, therefore mechanical ventilation system is designed. The existing shafts are improved and used for mechanical air extract. The fresh air enters the building through the pipes placed in the ground. Because the average annual temperature is 6.2°C (Table 3.1) this allows to preheat the air from -3.2°C to 6.2°C in order to reduce energy demand. The heat recovery system is used. The glazed loggias serve as a buffer zone and also have impact on the reduction of energy demand. The diagrams for summer and winter ventilation is provided in Fig. 7.15 and Fig. 7.16.

**Heating and hot water**

The diagram for heating and hot water system is presented in Fig. 7.17. Main heating system is the same as in the present situation: the heat is provided by the centralized heating network. The apartments are heated with radiators that use hot water. Additionally, space is preheated with the supply air from the mechanical ventilation system, which uses recovered heat to preheat the incoming fresh air. That helps to minimize heating loads. In order to save energy and improve indoor climate, regulation valves are placed on the radiators inside the apartments for the manual control of heating inside the rooms. Also for this strategy it is considered that the piping insulation is replaced with the new one that meets requirements and the heating system is improved with the efficient hydraulic equipment. Energy required for hot water supply is minimized by use of geothermal heating and thermal solar collectors.

### 7.6.4 Other aspect of the refurbishment

Costs for this strategy are very high mainly because of the additional floors design. On the other hand, because of the possibility to rent the newly built apartment in the future, the payback of this strategy is also higher than in the previous strategies. Moreover, it can attract investors, therefore financial burden on the residence can be much lower.

**Impact on residents**

The aim of this strategy is to meet attract potential investors. In order to meet this target, the construction of additional floors is proposed. This fact has a huge impact on the building, because the old staircases have to be demolished and replaced with new ones. That means, that the residents of the building have to be relocated for the period of the refurbishment process. That means that the disturbance layer is very high.

**Additional benefits**

Because of the requirements for the elevators, the building becomes accessible for disabled people, which increases its attractiveness for potential buyers of the apartments. Moreover, additional floors has a huge impact on the architectural appearance of the building that can be used to increase the interest in such refurbishment projects and improve the lifestyle of the whole district.
7.6.5 Design for the top floor apartments

For two additional floors the loft apartments are proposed. These type of the apartment is very popular in Lithuania. However regarding the market analysis and its outputs discussed in Chapter 6, the lofts are designed to meet requirements of the 2 member families. The exception is only the corner lofts that represent the very luxurious option.

The new apartments are designed according to the regulations and requirement for all new residential buildings.
8 Calculations

Heating and hot water load will be calculated for the top corner apartment Type 1 (Fig 8.1). For all three strategies and existing situation. This apartment was chosen as the worst case scenario. Moreover, it has the most impact after the application of all three strategies, therefore it will be easy to compare the benefits.

8.1 Heating load calculation

In order to compare and evaluate three different strategies the delivered energy has to be defined. Delivered energy or final energy is the energy supplied to the consumers, to be converted into useful energy (Konstantinou, 2014). Therefore efficiency of heating systems of all three strategies will be taken into account:

\[
H_{\text{input}} = \frac{H_{\text{out}}}{\eta_1 \times \eta_2 \times \eta_3 \times \eta_4}
\]

where:

- \(H_{\text{input}}\) - delivered energy, (kWh);
- \(H_{\text{out}}\) - useful energy, (kWh);
- \(\eta_1\) – efficiency coefficient of heating control devices;
- \(\eta_2\) – efficiency coefficient of heating source;
- \(\eta_3\) – efficiency coefficient of thermal insulation of distribution system;
- \(\eta_4\) – efficiency coefficient of heating system’s hydraulic equipment;

Efficient coefficients are provided in the Appendix 6 of the STR 2.09.04:2008: “Heating system. Energy demand for heating”.

In order to find \(H_{\text{out}}\) the energy load for heating and hot water loads will have to be defined. The heating load will be calculated using heat balance equation:

\[
Q_s + Q_i = Q_T + Q_v
\]

where:

- \(Q_s\) - Solar heat gain, (W);
- \(Q_i\) - Internal heat gain, (W);
- \(Q_T\) - Conductive heat loss, (W);
- \(Q_v\) - Ventilation heat loss or gain, (W);

In order to find \(H_{\text{out}}\) the energy load for heating and hot water loads will have to be defined. The heating load will be calculated using heat balance equation:
Heat balance equation provides the data about the heat gains and losses due to different reasons and sources (Fig.8.2). In order to convert heat into useful energy, the method of degree-days is used. A degree-day is a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperature. One degree-day means that the temperature conditions outside the building were equivalent to being below a defined threshold comfort temperature inside the building. Thus heat has to be provided inside the building to maintain thermal comfort.

\[ H = Q 	imes 24 	imes D / 1000, \]  
(8.3)

- \( H \) - Energy consumption, (kWh);
- \( Q \) - Heat/cooling gain/losses, (W);
- \( D \) - number of days in the period for which energy consumption has to be defined (degree-days);

The heating season in Lithuania runs from November till April and therefore \( D \) is equal to 225 days.

### 8.1 Solar heat gain

Solar heat gain is the total amount of energy input induced by incoming solar radiation that heats indoor air and thermal mass in the building.

\[ Q_s = G R 	imes g 	imes A_g l \times SF, \]  
(8.4)

- \( Q_s \) - Solar heat gains, (W);
- \( G R \) - the average daily total solar radiation heat flux density for the corresponding month of the year with the respect to the orientation surface, (W/m\(^2\));
- \( g \) - window solar transmission coefficient;
- \( A_g l \) - surface area of transparent components, (m\(^2\));
- \( SF \) – correction coefficient due to shading;

\[ SF = 0.9 \times F_n, \]  
(8.5)

- \( F_n \) - shading factor due to neighbour buildings and objects, if no data \( F_n = 0.8; \)
- \( F_t \) - shading factor due to shading devices;

### 8.2 Internal heat gain

Internal heat gain is the total amount of internal energy gains. This includes heat emitted from human bodies, electrical devices, artificial lighting and heating and activity and is calculated as follows:

\[ Q_i = Q_p + Q_{e,l} + Q_o + Q_h, \]  
(8.6)

- \( Q_i \) - internal heat gains, (W);
- \( Q_p \) - heat gained from people, (W);
- \( Q_{e,l} \) - Heat gained from electrical-mechanical equipment and lighting, (W);
- \( Q_o \) - Heat gain due to activity type, (W);
- \( Q_h \) - Heat load for space heating, (W);

\[ Q_p = n \times M, \]  
(8.7)

- \( n \) = number of occupants;
- \( M \) = sensible heat gain from one person, (W/p);

\[ Q_{e,l} = q_e \times A, \]  
(8.8)

- \( q_e \) - Heat gain from electrical-mechanical equipment and lighting coefficient based on the function of the space, (W/m\(^2\));
- \( A \) - heated space floor area, (m\(^2\));

\[ Q_o = q_o \times A, \]  
(8.9)

- \( q_o \) - Heat gain due to activity type coefficient based on the function of the space, (W/m\(^2\));
- \( A \) - heated space floor area, (m\(^2\));

### 8.3 Conductive heat loss

Conductive heat loss is energy lost by transmission of heat through the building envelope.

\[ Q_T = A \times U \times (T_i - T_{out}), \]  
(8.10)

- \( Q_T \) - conductive heat loss, (W);
- \( A \) - exposed surface area, (m\(^2\));
- \( U \) - overall heat transmission coefficient, (W/m\(^2\)K);
- \( T_i \) - inside air temperature, (°C);
- \( T_{out} \) - outside air temperature, (°C);

\[ U = 1 / (R_1 + R_2 + R_3 + ... + R_n), \]  
(8.11)

- \( R \) - thermal resistivity, (m\(^2\)K/W);
- \( R = x / k, \)  
(8.12)

- \( x \) - thickness of material, (m);
- \( k \) - thermal conductivity of material, (W/mK);

### 8.4 Ventilation heat loss

Ventilation heat loss or gain is caused by supply of fresh air, by removal of stale indoor air to remove smells, CO2 and other contaminants, infiltration of cold air or exfiltration of warm indoor air through cracks in the building envelope, mixing of air of different temperature zones, and mechanical ventilation.

Ventilation heat losses are calculated according to STR 2.09.04:2008: “System heating-load. Energy demand for heating.”:

\[ Q_v = Q_m + Q_{nv} + Q_{in}, \]  
(8.13)

- \( Q_m \) - heat load due to mechanical ventilation, (W);
- \( Q_{nv} \) - heat load due to natural ventilation, (W);
- \( Q_{in} \) - heat load due to infiltration, (W);

**Mechanical ventilation heat loss**

\[ Q_m = H_n \times (T_i - T_{out}) \times t_{wv} / 168, \]  
(8.14)

- \( H_n \) - specific heat losses due to mechanical ventilation, (W/K);
- \( T_i \) - inside air temperature, (°C);
- \( T_{out} \) - outside air temperature, (°C);
\( t_wv \) - ventilation system weekly duration, (h); 
168 - hours per week (24x7);

\[
H_m = c_p \times \rho \times q_m \times (1-\eta) = 0.3348 \times q_m \times (1-\eta);
\]  
\[(8.15)\]

\( c_p \) - specific heat capacity of air 0.279, (Wh/kg K); 
\( \rho \) - density of air 1.2, (kg/m³); 
\( q_m \) – air volume flow due to mechanical ventilation, (m³/h); 
\( \eta \) - heat recovery system coefficient of performance;

**Natural ventilation heat loss**

\[
Q_{nv} = H_{nv} \times (T_i - T_{out}), \text{ where:}
\]
\[(8.16)\]

\( H_{nv} \) - specific heat losses due to natural ventilation, (W/K); 
\( T_i \) - inside air temperature, (°C); 
\( T_{out} \) - outside air temperature, (°C);

\[
H_{nv} = c_p \times \rho \times q_{nv}, \text{ where:}
\]
\[(8.17)\]

\( c_p \) - specific heat capacity of air 0.279, (Wh/kg K); 
\( \rho \) - density of air 1.2, (kg/m³) 
\( q_{nv} \) – air volume flow due to natural ventilation, (m³/h)

\[
q_{nv} = (n_{nv} - n_{in}) \times A \times h \times D_{kc} \times (1 + D_{kb}) \times (1 + k_g), \text{ where:}
\]
\[(8.18)\]

\( n_{nv} \) - air flow rate due to natural ventilation,(1/h); 
\( n_{in} \) - air flow rate due to infiltration,(1/h); 
\( A \) - heated space floor area, (m²); 
\( h \) - heated space height, (m); 
\( D_{kc} \) - correction coefficient for corner apartments; 
\( D_{kb} \) - correction coefficient for ventilation system type; 
\( k_g \) - correction coefficient for apartment place in the building (8.19);

\( k_g = |N/2-N_i+1| \times 0.005/VN, \text{ where:}
\]
\[(8.19)\]

\( N \) - total number of floors; 
\( N_i \) - floor of the apartment;

**Infiltration heat loss**

Infiltration/exfiltration heat loss or gain is the unintentional or accidental introduction of outside air into/out of a building, typically through cracks in the building envelope and through use of doors.

\[
Q_{in} = H_{in} \times (T_i - T_{out}), \text{ where:}
\]
\[(8.20)\]

\( H_{in} = c_p \times \rho \times q_{in}, \text{ where:}
\]
\[(8.21)\]

\( c_p \) - specific heat capacity of air 0.279, (Wh/kg K); 
\( \rho \) - density of air 1.2, (kg/m³); 
\( q_{in} \) – air volume flow due to infiltration, (m³/h);

\[
q_{in} = n_{in} \times A \times h \times D_{kc} \times (1 + D_{kb}) \times (1 + k_g);
\]  
\[(8.22)\]

\( n_{in} \) - air flow rate due to infiltration, (1/h)*; 
\( A \) - heated space floor area, (m²); 
\( h \) - heated space height, (m); 
\( D_{kc} \) - correction coefficient for corner apartments; 
\( D_{kb} \) - correction coefficient for ventilation system type; 
\( k_g \) - correction coefficient for apartment place in the building (8.19);

**8.2 Hot water energy consumption**

According to the data provided by Lithuanian heat delivery association, 1 person needs approximately 70kWh/month for hot water heating. It is assumed to be a family of 5 people living in the selected apartment.

\[
H_{water} = H_{water/person/month} \times n_p \times n_{month}, \text{ where:}
\]
\[(8.23)\]

\( H_{water} \) - hot water load, (W); 
\( H_{water/person/month} \) - heat load for hot water per person per month, (W/pxmonth); 
\( n_{p} \) - number of person; 
\( n_{month} \) - number of months;

\[
H_{water} = 70 \times 5 \times 12 = 4200 \text{ kWh}
\]

\[
H_{water} = 54 \text{ kWh/m}^2
\]

The delivered energy needed for the hot water production is calculated according to 8.1 formula for each of the strategies, depending on the efficiency of heating systems.

***For windows and doors U value is adapted from lt.allconstructions.com***
8.3 Heating and hot water load: Present situation

The dimensions of the top apartment used for further calculations are presented in the Table 8.1 and 8.2.

<table>
<thead>
<tr>
<th>Room</th>
<th>Area</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>18.85</td>
<td>50.895</td>
</tr>
<tr>
<td>Bedroom1</td>
<td>13.73</td>
<td>37.071</td>
</tr>
<tr>
<td>Bedroom2</td>
<td>12.6</td>
<td>34.02</td>
</tr>
<tr>
<td>Bedroom3</td>
<td>14.04</td>
<td>37.908</td>
</tr>
<tr>
<td>Kitchen</td>
<td>6.9</td>
<td>18.63</td>
</tr>
<tr>
<td>Bathroom</td>
<td>2.04</td>
<td>5.508</td>
</tr>
<tr>
<td>Toilet</td>
<td>1.03</td>
<td>2.781</td>
</tr>
<tr>
<td>Corridor</td>
<td>6.25</td>
<td>16.875</td>
</tr>
<tr>
<td>Storage</td>
<td>2.36</td>
<td>6.372</td>
</tr>
<tr>
<td>Balcony1</td>
<td>3.07</td>
<td>8.289</td>
</tr>
<tr>
<td>Balcony2</td>
<td>3.07</td>
<td>8.289</td>
</tr>
<tr>
<td>Total</td>
<td>84</td>
<td>226.64</td>
</tr>
<tr>
<td>Heated</td>
<td>77.8</td>
<td>210.06</td>
</tr>
</tbody>
</table>

Table 8.1 Different space’s areas and volume

8.3.1 Heat loss

Conductive heat loss

In order to estimate conductive heat loss, the overall heat transmission coefficient U has to be defined for the all exposed surfaces based on formula 8.10-8.11.

According to "Heat consumption guideline" published by Lithuanian heating network association (Gudzinskas 2011), the U values for multi-flat residential buildings, that were built between 1959 and 1992, was 0.9-1.3 W/m²K. 8.10. For prefabricated reinforced concrete multi flat residential buildings it is 1.3 W/m²K for external walls and 0.9 W/m²K for roofs. For other components U data for calculations is presented in Table 8.3.

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Thickness x</th>
<th>Thermal conductivity k</th>
<th>R value (x/k)</th>
<th>8.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mineral wool board</td>
<td>0.1</td>
<td>0.045</td>
<td>2.222</td>
<td></td>
</tr>
<tr>
<td>Partitions</td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>Concrete</td>
<td>0.12</td>
<td>2.5</td>
<td>0.048</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.3 Data for U value calculations

U walls = 1.3 W/m²K
U partition = 1/0.048 = 20.833 W/m²K
U window = 2.4 W/m²K **
U door = 2.4 W/m²K **
U roof = 0.9 W/m²K
U floor = 1/(0.02 + 2.222 + 0.02) = 0.442 W/m²K

** For windows and doors U value is adapted from KTU Architecture and Building Institute research results

Conductive heat losses are calculated for every component according to the formula 8.10. The wall and partition height is 2.7m. For the area of walls W2 and W3 the windows and doors areas are deducted. For heat loss through the roof the correction coefficient is used because of 15% extra radiation to space. The inside temperature is 20 °C based on data from Table 6 (Chapter 3). The outside temperature is the average temperature of the heating season in Lithuania, which is 6 months strating from November to April and is calculated as the average of the average low temperatures of these months, presented in Table 1.1 (Chapter 3).
### Conductive heat loss

<table>
<thead>
<tr>
<th>Conductive heat loss Q</th>
<th>Area</th>
<th>U value</th>
<th>Tᵢ</th>
<th>Tᵢ-</th>
<th>Correction coefficient¹</th>
<th>Q = A<em>U</em>(Tᵢ - Tᵢ-)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qₑ₁</td>
<td>28.485</td>
<td>1.3</td>
<td>20</td>
<td>-3.12</td>
<td>1586.0448</td>
<td></td>
</tr>
<tr>
<td>Qₑ₂</td>
<td>10.549</td>
<td>1.3</td>
<td>20</td>
<td>-3.12</td>
<td>269.209696</td>
<td></td>
</tr>
<tr>
<td>Qₑ₃</td>
<td>18.327</td>
<td>1.3</td>
<td>20</td>
<td>-3.12</td>
<td>467.714736</td>
<td></td>
</tr>
<tr>
<td>Qₑ₄</td>
<td>12.8</td>
<td>20.833</td>
<td>20</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qₑ₅</td>
<td>8.64</td>
<td>20.833</td>
<td>20</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qₑ₆</td>
<td>15.552</td>
<td>20.833</td>
<td>20</td>
<td>16</td>
<td>1296</td>
<td></td>
</tr>
<tr>
<td>Qₑ₇ NE</td>
<td>5.693</td>
<td>2.4</td>
<td>20</td>
<td>-3.12</td>
<td>316.9895808</td>
<td></td>
</tr>
<tr>
<td>Qₑ₈ NE</td>
<td>1.9</td>
<td>2.4</td>
<td>20</td>
<td>-3.12</td>
<td>105.765008</td>
<td></td>
</tr>
<tr>
<td>Qₑ₉ SW</td>
<td>3.799</td>
<td>2.4</td>
<td>20</td>
<td>-3.12</td>
<td>211.5350016</td>
<td></td>
</tr>
<tr>
<td>Qₑ₁₀</td>
<td>2.932</td>
<td>2.4</td>
<td>20</td>
<td>-3.12</td>
<td>1868.1336</td>
<td></td>
</tr>
<tr>
<td>Qₑ₁₁</td>
<td>77.8</td>
<td>0.9</td>
<td>20</td>
<td>-3.12</td>
<td>1.15 1868.1336</td>
<td></td>
</tr>
<tr>
<td>Qₑ₁₂</td>
<td>77.8</td>
<td>0.442</td>
<td>20</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

1 STR 2.01.09.03  
2 STR 2.09.04.2008

### Natural ventilation heat loss

- **Formula**: \( Q_{nv} = \sum q_{nv} \times A \times h \)  
- **Steps**:
  1. **Calculation of**\( q_{nv} \)**:  
     - \( q_{nv} = (0.9-0.3) \times 77.8 \times 2.7 \times 1.2 \times (1+0.1) \times (1+0.003) = 166.87 \text{ m}^3/\text{h} \)  
  2. **Heat loss due to natural ventilation**:  
     - **For NE**:  
       - \( q_{nv} = 0.3 \times 77.8 \times 2.7 \times 1.2 \times (1+0.1) \times (1+0.003) = 166.87 \text{ m}^3/\text{h} \)  
     - **For SW**:  
       - \( q_{nv} = 0.3 \times 77.8 \times 2.7 \times 1.2 \times (1+0.1) \times (1+0.003) = 166.87 \text{ m}^3/\text{h} \)  

### Infiltration heat loss

In order to calculate the heat loss due to infiltration by formula 8.20, \( H_{in} \) and \( q_{in} \) has to be found. All the values needed to perform these calculations are presented in Table 8.6. \( K_l \) is calculated according to the formula 8.19. Inside and outside temperatures are the same as in heat loss due to natural ventilation calculations.

### Solar heat gain

- **Formula**:  
  - **For NE**:  
    - \( q_{in} = 0.3 \times 77.8 \times 2.7 \times 1.2 \times (1+0.1) \times (1+0.003) = 166.87 \text{ m}^3/\text{h} \)  
  - **For SW**:  
    - \( q_{in} = 0.3 \times 77.8 \times 2.7 \times 1.2 \times (1+0.1) \times (1+0.003) = 166.87 \text{ m}^3/\text{h} \)  

**Table 8.5 Data for heat loss from natural ventilation calculations**

**Table 8.4 Data for conductive heat loss calculations**

**Table 8.7 daily total solar radiation heat flux density for the corresponding month**

The window orientation of the apartments is NE and SW, therefore the total solar radiation for the heating season is:

- **For NE**:  
  - \( GR_{ne} = 37.25 + 23.5 + 35.2 + 64.1 + 112 + 113.3 + 410.6 \text{ W/m}^2 \)  
- **For SW**:  
  - \( GR_{sw} = 25.8 + 10.6 + 12.5 + 32.7 + 70.8 + 152.7 + 225 \text{ W/m}^2 \)  

**Other data used for calculations by formula 8.4 is presented in Table ZZ2**

**Table 8.6 Data for heat loss from infiltration calculations**

**Table 8.8 Data for solar heat gain calculations**
Qₜ = (225×0.71×7.593×0.72)+(410.6x0.71x6.731x0.72)=2286.14 W

**Internal heat gain**

Data required to calculate internal heat gains is presented in Table 8.9.

<table>
<thead>
<tr>
<th>Multi-flat residential buildings</th>
<th>Heat gain from people Qᵢ</th>
<th>Heat gains due to occupancy Qᵢ</th>
<th>Heat gains due to electrical equipment Qₑᵢ</th>
<th>1ST 20.06.04.2008 [Appendix 4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 W/m²</td>
<td>1.8</td>
<td>2.4</td>
<td></td>
<td>Table 8.9 Data for internal heat gain calculations</td>
</tr>
</tbody>
</table>

Based on formulas 8.6-8.9

Qₚ = 5*70=350 W

Qₑᵢ=2.4*78=187.2 W

Qₒᵢ= 1.8* 78=140.4 W

Qₜ=350+187.2+140.4=677.6 W

**8.3.3 Heating load and required energy estimation**

As it was described before, to estimate heating load the heat balance equation (8.2) is used.

\[
Q_s = Q_i - Q_p - Q_o - Q_e - Q_{inf,exf}
\]

\[
Q_s = Q_i + Q_p + Q_o + Q_e = 2286 + 677.6 + 570.94 + 648.06 = 4690.27 W
\]

\[
H_{out} = 4690.27 \times 24 \times 225 / 1000 = 25327.5 \text{ kWh}
\]

\[
H_{out} = 25327.5 / 77.8 = 325.55 \text{ kWh/m}^2
\]

According to the heating system analysis performed in Chapter 5, there is no heating control devices, therefore η₁=1;

- Heating source of existing system is central heating system, therefore according to STR 2004.04.2008 Appendix 6 η₂=1 efficiency of heating source;
- Efficiency of thermal insulation of distribution system does not meet requirements, therefore η₃ =0.9;
- There are no hydraulic equipment and therefore η₄=0.92;

\[
H_{eal}=325.55/1x1x0.9x0.92=393.2 \text{ kWh/m}^2
\]

**8.3.4 Hot water load and required energy estimation**

It was estimated that the energy needed to produce hot water for the analysed apartment is equal to 54 kWh/m², therefore:

\[
H_{water,exf}=54 \text{ kWh/m}^2
\]

\[
H_{water,exf}=54/1x1x0.9x0.92= 65.22 \text{ kWh/m}^2
\]
8.4.1 Heat loss
Conductive heat loss
In order to estimate conductive heat loss, the overall heat transmission coefficient U has to be defined for all exposed surfaces based on formula 8.10-8.11. Because building’s envelope was slightly changed compared to strategy 1, U values of components changed and were calculated according to data presented in Table 8.13.

Conductive heat losses are calculated for every component according to the formula

\[ Q_{\text{cond}} = \sum U_i A_i (T_i - T_{\text{out}}) \]

where
- \( Q_{\text{cond}} \) is the conductive heat loss (W)
- \( U_i \) is the overall heat transmission coefficient (W/m²·K)
- \( A_i \) is the area of the component (m²)
- \( T_i \) is the inside temperature (°C)
- \( T_{\text{out}} \) is the outside temperature (°C)

The overall heat transmission coefficient U is calculated as

\[ U = \frac{1}{R_{\text{tot}} + R_1 + R_2 + \ldots + R_n} \]

where \( R_{\text{tot}} \) is the total thermal resistance (m²·K/W), and \( R_i \) is the thermal resistance of individual components (m²·K/W).

### Table 8.13 Data for U value calculations

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Thickness</th>
<th>Thermal conductivity k</th>
<th>R value (x/k) (8.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>Existing</td>
<td>0.25</td>
<td>W/m²·K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mineral wool</td>
<td>0.2</td>
<td>0.045</td>
<td>4.44444</td>
</tr>
<tr>
<td></td>
<td>Air gap</td>
<td>0.025</td>
<td>0.025</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cembit facade plate</td>
<td>0.06</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Floor</td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Mineral wool board</td>
<td>0.1</td>
<td>0.045</td>
<td>2.222</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td>Partitions</td>
<td>Concrete</td>
<td>0.12</td>
<td>2.5</td>
<td>0.048</td>
</tr>
<tr>
<td>Roof</td>
<td>Existing</td>
<td>0.2</td>
<td></td>
<td>1.111111</td>
</tr>
<tr>
<td></td>
<td>Polystyrene</td>
<td>0.1</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bitum</td>
<td>0.04</td>
<td>0.23</td>
<td>0.173913043</td>
</tr>
</tbody>
</table>

adapted from EN-ISO 10456:2007

\[ U_{\text{adapted}} = \left[ \frac{U_{\text{existing}} + U_{\text{new}}}{2} \right] \]

Conductive heat losses are calculated for every component according to the formula 8.10. The wall and partition height is 2.7m. For the area of walls W2 and W3 the window and door areas are deducted. Based on STR 2.09.04:2008, for the wall W2 heat losses are multiplied by correction coefficient 0.85 (heat loss correction coefficient between heating space and glazed balcony). The inside temperature is 20°C based on data from Table 6 (Chapter 3). The outside temperature is the average temperature of the heating season in Lithuania, which is 6 months starting from November to April and is calculated as the average of the average low temperatures of these months, presented in Table 1 (Chapter 3).

### Table 8.14 Data for conductive heat loss calculations

<table>
<thead>
<tr>
<th>Component</th>
<th>Area (m²)</th>
<th>U value</th>
<th>( T_i ) (°C)</th>
<th>( T_{\text{out}} ) (°C)</th>
<th>Correction coefficient</th>
<th>( Q_{\text{cond}} ) (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partitions</td>
<td>77.8</td>
<td>0.2642</td>
<td>20</td>
<td>-3.12</td>
<td>0.85</td>
<td>54.8152413</td>
</tr>
<tr>
<td>Roof</td>
<td>77.8</td>
<td>0.442</td>
<td>20</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

1 STR 2.01.09:2005

**Ventilation heat loss**

### Mechanical ventilation heat loss

For this strategy the mechanical ventilation system with heat recovery is introduced. According to formula 8.15, to calculate specific heat losses air volume flow has to be defined. It is calculated according to STR 2.09.02:2005 Appendix 1.

### Table 8.15 Data for mechanical ventilation heat loss calculations

<table>
<thead>
<tr>
<th>Apartment</th>
<th>Volume</th>
<th>Air supply</th>
<th>Air extract</th>
<th>Air extract</th>
<th>( T_i ) (°C)</th>
<th>( T_{\text{out}} ) (°C)</th>
<th>( t_{\text{in}} )</th>
<th>( t_{\text{iv}} )</th>
<th>( H_{\text{m}} )</th>
<th>( Q_{\text{m}} ) (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>18.85</td>
<td>50.895</td>
<td>1.8</td>
<td>33.93</td>
<td>32</td>
<td>20</td>
<td>0.8</td>
<td>128</td>
<td>113.36</td>
<td>35.832</td>
</tr>
<tr>
<td>Bedroom1</td>
<td>13.73</td>
<td>37.071</td>
<td>2.5</td>
<td>34.325</td>
<td>32</td>
<td>20</td>
<td>0.8</td>
<td>60</td>
<td>11.492</td>
<td>16.992</td>
</tr>
<tr>
<td>Bedroom2</td>
<td>12.6</td>
<td>34.02</td>
<td>2.5</td>
<td>31.5</td>
<td>32</td>
<td>20</td>
<td>0.8</td>
<td>60</td>
<td>10.546</td>
<td>15.593</td>
</tr>
<tr>
<td>Bedroom3</td>
<td>14.04</td>
<td>37.908</td>
<td>2.5</td>
<td>35.1</td>
<td>32</td>
<td>20</td>
<td>0.8</td>
<td>60</td>
<td>11.751</td>
<td>17.175</td>
</tr>
<tr>
<td>Kitchen</td>
<td>6.9</td>
<td>18.63</td>
<td>2.5</td>
<td>72</td>
<td>32</td>
<td>20</td>
<td>0.8</td>
<td>50</td>
<td>24.106</td>
<td>29.702</td>
</tr>
<tr>
<td>Bathroom</td>
<td>2.04</td>
<td>5.508</td>
<td>2.5</td>
<td>54</td>
<td>32</td>
<td>20</td>
<td>0.8</td>
<td>21</td>
<td>16.079</td>
<td>10.712</td>
</tr>
<tr>
<td>Toilet</td>
<td>1.03</td>
<td>2.781</td>
<td>36</td>
<td>36</td>
<td>32</td>
<td>20</td>
<td>0.8</td>
<td>14</td>
<td>12.053</td>
<td>4.158</td>
</tr>
<tr>
<td>Corridor</td>
<td>6.35</td>
<td>16.875</td>
<td>30</td>
<td>30</td>
<td>32</td>
<td>14</td>
<td>0.8</td>
<td>1</td>
<td>10.044</td>
<td>0.176</td>
</tr>
<tr>
<td>Storage</td>
<td>2.36</td>
<td>6.372</td>
<td>30</td>
<td>30</td>
<td>32</td>
<td>14</td>
<td>0.8</td>
<td>1</td>
<td>10.044</td>
<td>0.176</td>
</tr>
<tr>
<td>Balcony1</td>
<td>3.07</td>
<td>8.289</td>
<td>30</td>
<td>30</td>
<td>32</td>
<td>14</td>
<td>0.8</td>
<td>1</td>
<td>10.044</td>
<td>0.176</td>
</tr>
<tr>
<td>Balcony2</td>
<td>3.07</td>
<td>8.289</td>
<td>30</td>
<td>30</td>
<td>32</td>
<td>14</td>
<td>0.8</td>
<td>1</td>
<td>10.044</td>
<td>0.176</td>
</tr>
</tbody>
</table>

\[ Q_{\text{m}} = 218.58 \text{ W} \]
Natural ventilation heat loss
Natural ventilation heat loss was calculated in the same way as for present situation
The only changes are the correction coefficient for ventilation system type (Dkb) and
the air flow rate due to natural ventilation coefficient (nnv), because of insulation im-
provement and different ventilation system type as described in the Appendix 5 of STR

\[
q_{nv} = (0.5-0.3) \times 77.8 \times 2.7 \times 1.2 \times (1+0.1) \times (1+0.003) = 45.5091 \text{ m}^3/\text{h}
\]

\[
H_{nv} = 0.279 \times 1.2 \times 111.24 = 353.485 \text{ W}
\]

8.4.2 Heat gain
Solar heat gain
The only changes in solar heat gain calculations for the Strategy 1 is the different win-
dow solar transmission coefficient, because instead of old windows, new triple glazed
windows are placed. Inputs for the calculations are presented in Table 8.18.

\[
Q_s = (225 \times 0.39 \times 7.593 \times 0.72) + (410.6 \times 0.39 \times 6.731 \times 0.72) = 1255.76 \text{ W}
\]

8.4.3 Heating load and required energy estimation
As it was described before, to estimate heating load the heat balance equation (8.2) is
used.

\[
Q_h = Q_s + Q_i + Q_T + Q_m + Q_{n,exf} + Q_{inf}
\]

\[
Q_h = 2323.29 + 218.58 + 353.485 + 218.58 + 353.485 + 530.228 = 1492.226 \text{ W}
\]

\[
H_{out} = 1492.226 \times 24 \times 225 / 1000 = 8058.22 \text{ kWh}
\]

\[
H_{out} = 8058.22 / 77.8 = 103.57 \text{ kWh/m}^2
\]

Because of improvements of heating system installations are made, the system efficien-
cy coefficient are changed according to 2.09.04:2008 Appendix 6:

\[
\eta_1 = 0.98 \text{ Because individual thermal regulation devices are palced in the apartments.}
\]

\[
\eta_2 = 1.1, \text{ becuase heat recovery system is used}
\]

\[
\eta_3 = 0.97, \text{ becuase system insulation meets requirements;}
\]

\[
\eta_4 = 0.99 \text{ becuase the hidraulic equipment of hgh efficiency is used;}
\]

\[
H_{heat} = 103.57 / 0.98 \times 1.1 \times 0.97 \times 0.99 = 110.057 \text{ kWh/m}^2
\]

8.4.4 Hot water load and required energy estimation
It was estimated that the energy needed to produe hot water for the analysed apart-
ment is equal to 54kWh/m2, therefore:

\[
H_{water \text{ out}} = 54 \text{ kWh/m}^2
\]

\[
H_{water \text{ in}} = 54 / 0.98 \times 1.0 \times 0.97 \times 0.99 = 65.22 \text{ kWh/m}^2
\]
8.5 Heating and hot water load: Strategy 2

<table>
<thead>
<tr>
<th>Room</th>
<th>Area m²</th>
<th>Volume m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>18.85</td>
<td>50.895</td>
</tr>
<tr>
<td>Bedroom1</td>
<td>13.73</td>
<td>37.071</td>
</tr>
<tr>
<td>Bedroom2</td>
<td>12.6</td>
<td>34.02</td>
</tr>
<tr>
<td>Bedroom3</td>
<td>14.04</td>
<td>37.908</td>
</tr>
<tr>
<td>Kitchen</td>
<td>6.9</td>
<td>18.63</td>
</tr>
<tr>
<td>Bathroom</td>
<td>2.04</td>
<td>5.508</td>
</tr>
<tr>
<td>Toilet</td>
<td>1.03</td>
<td>2.781</td>
</tr>
<tr>
<td>Corridor</td>
<td>6.25</td>
<td>16.875</td>
</tr>
<tr>
<td>Storage</td>
<td>2.36</td>
<td>6.372</td>
</tr>
<tr>
<td>Balcony1</td>
<td>7.08</td>
<td>8.289</td>
</tr>
<tr>
<td>Balcony2</td>
<td>7.08</td>
<td>8.289</td>
</tr>
<tr>
<td>Total</td>
<td>93.5</td>
<td>226.64</td>
</tr>
<tr>
<td>Heated</td>
<td>77.8</td>
<td>210.06</td>
</tr>
</tbody>
</table>

Table 8.20 Different space’s areas and volume

<table>
<thead>
<tr>
<th>Room</th>
<th>Area m²</th>
<th>Volume m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>18.85</td>
<td>50.895</td>
</tr>
<tr>
<td>Bedroom1</td>
<td>13.73</td>
<td>37.071</td>
</tr>
<tr>
<td>Bedroom2</td>
<td>12.6</td>
<td>34.02</td>
</tr>
<tr>
<td>Bedroom3</td>
<td>14.04</td>
<td>37.908</td>
</tr>
<tr>
<td>Kitchen</td>
<td>6.9</td>
<td>18.63</td>
</tr>
<tr>
<td>Bathroom</td>
<td>2.04</td>
<td>5.508</td>
</tr>
<tr>
<td>Toilet</td>
<td>1.03</td>
<td>2.781</td>
</tr>
<tr>
<td>Corridor</td>
<td>6.25</td>
<td>16.875</td>
</tr>
<tr>
<td>Storage</td>
<td>2.36</td>
<td>6.372</td>
</tr>
<tr>
<td>Balcony1</td>
<td>7.08</td>
<td>8.289</td>
</tr>
<tr>
<td>Balcony2</td>
<td>7.08</td>
<td>8.289</td>
</tr>
<tr>
<td>Total</td>
<td>93.5</td>
<td>226.64</td>
</tr>
<tr>
<td>Heated</td>
<td>77.8</td>
<td>210.06</td>
</tr>
</tbody>
</table>

Table 8.21 Different surface’s areas

Table 8.22 Data for U value calculations

8.5.1 Heat loss
Conductive heat loss

In order to estimate conductive heat loss, the overall heat transmission coefficient $U$ has to be defined for all exposed surfaces based on formula 8.10-8.11. Because building’s envelope was insulated and external windows and doors were replaced with new ones, $U$ values of components changed and were calculated according to data presented in Table 8.22.

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Thickness $x$ m</th>
<th>Thermal conductivity $k$ W/mK</th>
<th>$R$ value $(x/k)$ (8.1) m²K/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 1</td>
<td>Existing</td>
<td>0.25</td>
<td>0.77</td>
<td>4.44444</td>
</tr>
<tr>
<td></td>
<td>Mineral wool</td>
<td>0.2</td>
<td>0.045</td>
<td>2.22222</td>
</tr>
<tr>
<td></td>
<td>Air gap</td>
<td>0.025</td>
<td>0.025</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cembrit facade plate</td>
<td>0.06</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Wall 2</td>
<td>Existing</td>
<td>0.25</td>
<td>0.77</td>
<td>2.22222</td>
</tr>
<tr>
<td></td>
<td>Mineral wool</td>
<td>0.1</td>
<td>0.045</td>
<td>2.22222</td>
</tr>
<tr>
<td></td>
<td>Air gap</td>
<td>0.025</td>
<td>0.025</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cembrit facade plate</td>
<td>0.06</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Floor</td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Mineral wool board</td>
<td>0.1</td>
<td>0.045</td>
<td>2.22222</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td>Partitions</td>
<td>Concrete</td>
<td>0.12</td>
<td>2.5</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>0.2</td>
<td>1.11111111</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polystyrene</td>
<td>0.1</td>
<td>0.04</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Bitum</td>
<td>0.04</td>
<td>0.23</td>
<td>1.073913043</td>
</tr>
</tbody>
</table>

$U_{wall1} = \frac{1}{0.77 + 4.444 + 1 + 0.15} = 0.157 \text{ W/mK}$

$U_{wall2} = \frac{1}{0.77 + 2.222 + 1 + 0.15} = 0.241 \text{ W/mK}$

$U_{ground} = \frac{1}{0.02 + 2.222 + 0.02} = 0.442 \text{ W/mK}$

$U_{f1} = \frac{1}{1.11 + 3.333 + 0.1739} = 0.2642 \text{ W/mK}$

$U_{part1} = \frac{1}{0.04} = 25 \text{ W/mK}$

$U_{part2} = \frac{0.9}{0.3} = 3.0 \text{ W/mK}$

Conductive heat losses are calculated for every component according to the formula 8.10. The wall and partition height is 2.7m. For the area of walls W2 and W3 the window and door areas are deducted. Based on STR 2.09.04:2008, for the wall W2 heat losses are multiplied by correction coefficient 0.85 (heat loss correction coefficient between heating space and glazed balcony). The inside temperature is 20°C based on data from Table 6 (Chapter 3). The outside temperature is the average temperature of the heating season in Lithuania, which is 6 months starting from November to April and is calculated as the average of the average low temperatures of these months, presented in Table 1 (Chapter 3).
### Ventilation heat loss

**Mechanical ventilation heat loss**

For this strategy the mechanical ventilation system with heat recovery is introduced. Moreover, air supply via ground piping is designed in order to preheat air using winter. Air supply temperature is changed to 6.2°C, which is equal to the annual temperature in Lithuania. (Table 1) According to formula 8.15, to calculate specific heat losses air volume flow is calculated according to STR 2.09.02:2005 Appendix 1. The efficiency of heat recovery is 0.7, therefore \( (1-\eta) = 0.3 \). This means that only 30% of preheated air is lost in the system. For each of the space inside the apartment the duration of the ventilation system per week was estimated. All data used for calculations is presented in (Table 8.24).

### Natural ventilation heat loss

Natural ventilation heat loss is the same as in previous strategy, therefore \( Q_{nv} = 353.485 \text{ W} \)

### Infiltration heat loss

Natural ventilation heat loss is the same as in previous strategy, therefore \( Q_{nv} = 530.228 \text{ W} \)

### 8.5.2 Heat gain

**Solar heat gain**

Solar heat gains change because of the increased glazed area of the SW facade.

### Internal heat gain

Internal heat gains are the same as in the present situation calculations, therefore \( Q_{int} = 677.6 \text{ W} \)

### 8.5.3 Heating load and required energy estimation

As it was described before, to estimate heating load the heat balance equation (8.2) is used:

\[
Q_{in} = Q_{s} + Q_{w} + Q_{infil} + Q_{mir} + Q_{gain} - Q_{out} - Q_{loss}
\]

where:
- \( Q_{s} \) is the supply heat
- \( Q_{w} \) is the waste heat
- \( Q_{infil} \) is the infiltration heat losses
- \( Q_{mir} \) is the mirror heat losses
- \( Q_{gain} \) is the heat gains
- \( Q_{out} \) is the output heat
- \( Q_{loss} \) is the heat losses

### System efficiency coefficients

System efficiency coefficients are the same, therefore final energy requirement is:

\[
H_{fin} = \frac{Q_{out}}{\eta_{fin}}
\]

### 8.5.4 Hot water load and required energy estimation

It was estimated that the energy needed to produce hot water for the analysed apartment is equal to 54kWh/m², therefore:

\[
H_{water} = \frac{54 \text{ kWh}}{m²}
\]
8.6 Heating and hot water load: Strategy 3

### Table 8.27 Different space’s areas and volume

<table>
<thead>
<tr>
<th>Room</th>
<th>Area (m²)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>18.85</td>
<td>50.895</td>
</tr>
<tr>
<td>Bedroom1</td>
<td>13.73</td>
<td>37.071</td>
</tr>
<tr>
<td>Bedroom2</td>
<td>12.6</td>
<td>34.02</td>
</tr>
<tr>
<td>Bedroom3</td>
<td>14.04</td>
<td>37.908</td>
</tr>
<tr>
<td>Kitchen niche</td>
<td>5.56</td>
<td>15.012</td>
</tr>
<tr>
<td>Bathroom and toilet</td>
<td>6.4</td>
<td>17.28</td>
</tr>
<tr>
<td>Corridor</td>
<td>4.02</td>
<td>10.854</td>
</tr>
<tr>
<td>Storage</td>
<td>2.36</td>
<td>6.372</td>
</tr>
<tr>
<td>Balcony1</td>
<td>7.08</td>
<td>19.116</td>
</tr>
<tr>
<td>Balcony2</td>
<td>7.08</td>
<td>19.116</td>
</tr>
<tr>
<td>Total</td>
<td>97.5</td>
<td>226.64</td>
</tr>
<tr>
<td>Heated</td>
<td>77.8</td>
<td>210.06</td>
</tr>
</tbody>
</table>

### Table 8.28 Different surface’s areas

<table>
<thead>
<tr>
<th>Component</th>
<th>Area (m²)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>18.85</td>
<td>50.895</td>
</tr>
<tr>
<td>Bedroom1</td>
<td>13.73</td>
<td>37.071</td>
</tr>
<tr>
<td>Bedroom2</td>
<td>12.6</td>
<td>34.02</td>
</tr>
<tr>
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<td>37.908</td>
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<tr>
<td>Kitchen niche</td>
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</tr>
<tr>
<td>Bathroom and toilet</td>
<td>6.4</td>
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<td>226.64</td>
</tr>
<tr>
<td>Heated</td>
<td>77.8</td>
<td>210.06</td>
</tr>
</tbody>
</table>

### Table 8.29 Data for U value calculations

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Thickness (m)</th>
<th>Thermal conductivity (W/mK)</th>
<th>R value (m²K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 1</td>
<td>Existing</td>
<td>0.25</td>
<td>0.77</td>
<td>0.157 W/m²K</td>
</tr>
<tr>
<td></td>
<td>Mineral wool</td>
<td>0.1</td>
<td>0.045</td>
<td>4.444444</td>
</tr>
<tr>
<td></td>
<td>Air gap</td>
<td>0.025</td>
<td>0.025</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cembrit facade plate</td>
<td>0.06</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Wall 2</td>
<td>Existing</td>
<td>0.25</td>
<td>0.77</td>
<td>0.241 W/m²K</td>
</tr>
<tr>
<td></td>
<td>Mineral wool</td>
<td>0.1</td>
<td>0.045</td>
<td>2.2222</td>
</tr>
<tr>
<td></td>
<td>Air gap</td>
<td>0.025</td>
<td>0.025</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cembrit facade plate</td>
<td>0.06</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Floor</td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Mineral wool board</td>
<td>0.1</td>
<td>0.045</td>
<td>2.222</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td>Partitions</td>
<td>Concrete</td>
<td>0.12</td>
<td>2.5</td>
<td>0.048</td>
</tr>
<tr>
<td>Roof</td>
<td>Existing</td>
<td>0.2</td>
<td>1.1111111</td>
<td>1.73913043 W/m²K</td>
</tr>
<tr>
<td></td>
<td>Polystyrene</td>
<td>0.1</td>
<td>0.04</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Bitum</td>
<td>0.04</td>
<td>0.2</td>
<td>0.173913043 W/m²K</td>
</tr>
</tbody>
</table>

**8.6.1 Heat loss**

**Conductive heat loss**

In order to estimate conductive heat loss, the overall heat transmission coefficient \( U \) has to be defined for all exposed surfaces based on formula 8.10-8.11. Because building’s envelope was insulated and external windows and doors were replaced with new ones, \( U \) values of components changed and were calculated according to data presented in Table 8.29.

**Table 8.29 Data for U value calculations**

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Thickness (m)</th>
<th>Thermal conductivity (W/mK)</th>
<th>R value (m²K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 1</td>
<td>Existing</td>
<td>0.25</td>
<td>0.77</td>
<td>0.157 W/m²K</td>
</tr>
<tr>
<td></td>
<td>Mineral wool</td>
<td>0.1</td>
<td>0.045</td>
<td>4.444444</td>
</tr>
<tr>
<td></td>
<td>Air gap</td>
<td>0.025</td>
<td>0.025</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cembrit facade plate</td>
<td>0.06</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Wall 2</td>
<td>Existing</td>
<td>0.25</td>
<td>0.77</td>
<td>0.241 W/m²K</td>
</tr>
<tr>
<td></td>
<td>Mineral wool</td>
<td>0.1</td>
<td>0.045</td>
<td>2.2222</td>
</tr>
<tr>
<td></td>
<td>Air gap</td>
<td>0.025</td>
<td>0.025</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cembrit facade plate</td>
<td>0.06</td>
<td>0.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Floor</td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Mineral wool board</td>
<td>0.1</td>
<td>0.045</td>
<td>2.222</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>0.05</td>
<td>2.5</td>
<td>0.02</td>
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<tr>
<td>Partitions</td>
<td>Concrete</td>
<td>0.12</td>
<td>2.5</td>
<td>0.048</td>
</tr>
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<td>0.2</td>
<td>1.1111111</td>
<td>1.73913043 W/m²K</td>
</tr>
<tr>
<td></td>
<td>Polystyrene</td>
<td>0.1</td>
<td>0.04</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Bitum</td>
<td>0.04</td>
<td>0.2</td>
<td>0.173913043 W/m²K</td>
</tr>
</tbody>
</table>

Conductive heat losses are calculated for every component according to the formula 8.10. The wall and partition height is 2.7m. For the area of walls W2 and W3 the window and door areas are deducted. Based on STR 2.09.04:2008, for the wall W2 heat losses are multiplied by correction coefficient 0.85 (heat loss correction coefficient between heating space and glazed balcony). The inside temperature is 20°C based on data from Table 6 (Chapter 3). The outside temperature is the average temperature of the heating season in Lithuania, which is 6 months strating from November to April and is calculated as the average of the average low temperatures of these months, presented in Table 1 (Chapter 3).
Refurbishment of multi-flat residential buildings in Lithuania

8. Calculations

8.6.2 Heat gain

Solar heat gain

Table 8.32 Data for solar heat gain calculations

<table>
<thead>
<tr>
<th>GR</th>
<th>g</th>
<th>A</th>
<th>F</th>
<th>Fc</th>
<th>SF</th>
<th>Qs</th>
</tr>
</thead>
<tbody>
<tr>
<td>225</td>
<td>0.39</td>
<td>8.634</td>
<td>0.8</td>
<td>1</td>
<td>0.72</td>
<td>545.4746388</td>
</tr>
<tr>
<td>410.6</td>
<td>0.39</td>
<td>8.8131</td>
<td>0.8</td>
<td>1</td>
<td>0.72</td>
<td>1016.119408</td>
</tr>
</tbody>
</table>

Table 8.33 All heat gains and losses

\[ Q_s = (225 \times 0.39 + 8.634 + 0.72) \times (410.6 \times 0.39 + 8.8131 + 0.72) = 1561.594 \text{ W} \]

8.6.3 Heating load and required energy estimation

As it was described before, to estimate heating load the heat balance equation (8.2) is used.

\[ Q_i = Q_{\text{in}} - Q_{\text{out}} - Q_{\text{inf,exf}} - Q_{\text{nv}} - Q_{\text{internal}} - Q_{\text{ventilation}} \]

Table 8.34 Data for mechanical ventilation heat loss calculations

<table>
<thead>
<tr>
<th>Q</th>
<th>W/m²</th>
<th>W/m²</th>
<th>W/m²</th>
<th>W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1830.571</td>
<td>126.382</td>
<td>353.485</td>
<td>530.228</td>
<td>353.485</td>
</tr>
</tbody>
</table>

Table 8.35 Data for mechanical ventilation heat gain calculations

\[ Q_{\text{ventilation}} = 1561.594 - 677.6 = 883.994 \text{ W} \]

\[ COP = H_{\text{surf}} / Q_i = 41.747 / 883.994 = 0.0478 \text{ kWh/m²} \]

Natural ventilation heat loss

Natural ventilation heat loss is the same as in previous strategy, therefore

\[ Q_{\text{ventilation}} = 353.485 \text{ W} \]

Infiltration heat loss

Natural ventilation heat loss is the same as in previous strategy, therefore

\[ Q_{\text{ventilation}} = 530.228 \text{ W} \]
8.6.4 Hot water load and required energy estimation
The efficiency of flat plate thermal solar collector for indirect active system is 0.61 (Apricus). It was estimated that the energy needed to produce hot water for the analysed apartment is equal to 54kWh/m², therefore:

\[ H_{\text{water input}} = \frac{54}{0.68} = 79.41 \text{kWh/m}^2 \]

Because the geothermal heating is used in this strategy final is:

\[ H_{\text{water input}} = \frac{79.41}{4} = 19.85 \text{kWh/m}^2 \]

The efficiency of flat plate thermal solar collector of indirect system is 0.61 (Apricus 2015).
9 Comparison

9.1 Increase in the energy efficiency of the building

The changes in the energy efficiency of the building will be compared using the results from Chapter 8.

9.1.1 Heat gains and losses

Heat gains and losses (W) are presented in Fig. 9.1 and are based on calculations from Chapter 8.

- Solar gains
- Internal gains
- Transmission losses
- Mechanical ventilation losses
- Natural ventilation losses
- Infiltration/exfiltration losses

![Fig. 9.1 Comparison of heat losses and gains](image)

![Fig. 9.2 Transmission heat loss comparison](image)
As it is seen from the Figure 9.1, in all the cases the main heat losses are due to transmission heat loss. If we look in more detailed comparison of the transmission heat losses in all the three strategies (Fig. 9.2), the insulation of the outer walls and the roof helps to improve the situation significantly. However, the heat losses through partition 3 remain very high, despite the fact that it separates the apartment from the staircase area and the temperature difference is only 40°C. Such a result can be explained very easily. In the calculations, based on the drawings in Chapter 5, it was assumed, that Partition 3 does not have any insulation and is made from 120mm concrete panel, therefore thermal conductivity is very high. That means, that partitions between apartments and staircase should be insulated.

The heat losses through the Wall 2 are the lowest, because in all three cases this wall faces the glazed balconies and outside temperature becomes higher. STR 2.09.04:2008 states, that in this case the correction coefficient of 0.85 has to be used, however for more precise results the actual temperature in the cavity of the balcony is needed.

After the improvement of the building’s envelope, the conductive heat losses decrease by more than 50%, which is represented in the calculations for Strategy 1. In case of Strategies 2 and 3, these losses slightly decrease mainly by reducing the conductive heat loss through the roof.

Natural ventilation losses also decrease because of decreased air flow rate due to infiltration. For Strategies 2 and 3 lesser natural ventilation is needed because of better mechanical ventilation system.

Mechanical ventilation heat losses are very small. In case of Strategies 2 and 3, the supply air temperature increases to 6.20°C (more detailed the climate design is explained in Chapter 7), which helps to reduce mechanical ventilation heat loss by almost half.

Internal heat gains are assumed to be the same for all three strategies.

The lowest solar heat gains are in case of Strategy 2, because the glazed area in this case is the smallest. It is necessary to highlight, that the proper balance between solar heat gains and glazing is needed. According to the Fig. 7.1, solar heat gains are very important for the design, however oversizing the glazed area may easily cause overheating and increase cooling load.

**9.1.2 Heating and hot water load comparison**

The useful and delivered energy loads for heating for all three strategies are presented in the Fig. 9.3. As it is seen from the graph, the use of geothermal heating system helps to reduce heating load significantly. The difference between Strategies 1 and 2 is very small. This is due to the fact, that heat gains from the greenhouse are not directly reflected in the calculations. As it was described in Chapter 7, the heat collected by the greenhouse is supposed to be used to preheat the hot water. The calculations are only based on the guidelines and formulas from STR 2.09.04:2008 and do not take this into account. Therefore, it can be estimated, that energy expenses for hot water will be reduced.

The useful and delivered energy loads for hot water for all three strategies are presented in the Fig. 9.3. According to the calculations, thermal solar collectors reduce the supply of hot water by 50%.

Fig. 9.3 Useful and delivered energy for heating

Fig. 9.4 Useful and delivered energy for hot water

Overall energy consumption differs significantly between the existing situation and three strategies. However certain improvements for better results can be made. Also application of renewable energy technologies has crucial reduction in energy loads for both heating and hot water supply.

**9.1.3 Energy savings**

The percentage in total energy savings for both heating and hot water, is represented in Fig. 9.5. Even in case of Strategy 1, where only basic measures were used, the savings are higher compared to statistics from Atnaujink Busta Company (Atnaujink Busta 2015), where on average the savings reach 50% and are assumed to be higher than the real savings by different field experts.
According to pricelist set by Lesto organization (Lesto 2015), the 1kWh of energy in Lithuania costs 0.129 euro.

Money spent for heating and hot water for all three strategies are calculated according to the formula 9.24.

\[
\text{Price} = H_{out} \times A \times 0.129 \text{ (Euro)},
\]

where:

- \( H_{out} \) - amount of energy required for heating and hot water, (kWh/m²)
- \( A \) - heating floor area of the apartment, (m²)
- 0.129 - price for 1kWh, (Euro)

\[
\text{Price present} = 458.39 \times 77.8 \times 0.129 = 4600.49 \text{ Euro/year}
\]

\[
\text{Price st1} = 175.28 \times 77.8 \times 0.129 = 1759.15 \text{ Euro/year}
\]

\[
\text{Price st2} = 141.24 \times 77.8 \times 0.129 = 1417.51 \text{ Euro/year}
\]

\[
\text{Price st3} = 29.85 \times 77.8 \times 0.129 = 299.58 \text{ Euro/year}
\]

9.2 Investment cost comparison

According to the market analysis discussed in Chapter 6, in order to make the market value of the refurbished apartment comparable to the one in the new building, the following equation should be reached for the desired situation:

\[
PMV + RC < NBMV,
\]

where:

- \( PMV \) - Present market value, (Euro/m²);
- \( RC \) - refurbishment costs, (Euro/m²);
- \( NBMV \) - new building market value, (Euro/m²);

PMV = 916 Euro/m²;
NBMV = 1340 Euro/m²;
916 + RC < 1340 => RC < 412 Euro/m²

Firstly, in order to compare all three strategies, the approximate costs of applied refurbishment measures are calculated by data provided in “SisteLa” catalogue R62P: Pasta atnaujinimo ir modernizavimo darbai (Buildings’ refurbishment and modernisation works) and industry websites. The “Sistema” company’s catalogue R62P provides prices for refurbishment works, including prices for labour, materials, etc. The price estimation calculations is a very rough estimation of approximate cost investments for all three strategies and is presented in Appendix D. The results are presented in Fig. 9.6.

9.2.1 Payback time

The graph 9.5 represents the refurbishment costs for 1 m². The analysed apartments total floor area before the refurbishment is 84 m². That means, that refurbishment costs for the owners of this apartment are:

\[
\text{Pricetotal} = RC \times A
\]

where:

- \( RC \) - refurbishment costs, (Euro/m²);
- \( A \) - total floor area of the apartment, (m²);

\[
\text{Pricetotal st1} = 199 \times 84 = 16716 \text{ euro}
\]

\[
\text{Pricetotal st2} = 633 \times 84 = 53172 \text{ euro}
\]

\[
\text{Pricetotal st3} = 312 \times 84 = 26208 \text{ euro}
\]

Savings in euro for three strategies are:

\[
\text{Savings} = \text{Price present} - \text{Price st(n)}, \text{ (Euro/year)};
\]

\[
\text{Savings st1} = 4600.49 - 1759.15 = 2841.34 \text{ euro}
\]

\[
\text{Savings st2} = 4600.49 - 1417.51 = 3182.98 \text{ euro}
\]

\[
\text{Savings st3} = 4600.49 - 299.58 = 4300.91 \text{ euro}
\]

Payback time is:

\[
T_{\text{payback}} = \frac{\text{Pricetotal}}{\text{Savings}} \text{ (year)};
\]

Draft calculations give and approximate comparison of feasibility of each of the strategies. According to these draft calculations, only Strategy 1 solution meets the desired situation, when refurbishment investment costs and present market value are lower, than the price of the apartment in new building. In case of Strategy 2, even without taking into account price for the construction of additional floors, the difference is very small. To make these estimations more precise, the consultancy with field experts is needed.

Draft calculations give and approximate comparison of feasibility of each of the strategies. According to these draft calculations, only Strategy 1 solution meets the desired situation, when refurbishment investment costs and present market value are lower, than the price of the apartment in new building. In case of Strategy 2, even without taking into account price for the construction of additional floors, the difference is very small. To make these estimations more precise, the consultancy with field experts is needed.
9.2.2 Increase of the market value

Besides the savings of increased energy efficiency, the increase of market value has to be taken into account. As it was discussed in Chapter 6, it is hard to estimate the real market value of the refurbished property, however the increase of price, because of increased floor area can be roughly estimated (Table 9.1).

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Total floor area (m²)</th>
<th>Increase percentage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>Strategy 1</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>93.5</td>
<td>111.24</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>97.5</td>
<td>116.07</td>
</tr>
</tbody>
</table>

Table 9.1 Increase of total floor area

9.3 SWOT analysis

All the results discussed in the previous chapters are presented in Table 9.2. The best figures in this table are highlighted. From this comparison analysis of all three strategies, it is seen, that the results regarding the third strategy are the best. This is expectable, because it includes major upgrades and interventions. On the other hand, the second strategy also has a potential regarding many aspects that can be considered during the refurbishment.

Despite the results presented in Table 9.2, it is necessary to also evaluate the possibilities of its realisations compared to other two strategies and also foresee possible threats and weaknesses, that have not been yet reflected. For this purpose SWOT analysis is proposed

9.3.1 Strategy 1

The Swot analysis for Strategy 1 is presented in Table 9.3

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheap; Better aesthetical appearance of the building; Government support; No inside works; Short payback time;</td>
<td>Low energy efficiency compared to other strategies; No additional benefits and improvement of the lifestyle;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy to apply and convince all the parties; Because of the large number of residential buildings of this type multiple project application possibilities;</td>
<td>Chances to fail in achieving CO₂ reduction goals;</td>
</tr>
</tbody>
</table>

Table 9.2 Comparison results

Table 9.3 SWOT analysis; Strategy 1

These calculations do not include the interest rate in case the loan is taken for the refurbishment.
### 9.3.2 Strategy 2

The Swot analysis for Strategy 2 is presented in Table 9.4

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community space for the residents;</td>
<td>Compared to Strategy 3, better energy performance can be achieved;</td>
</tr>
<tr>
<td>Direct benefits for owners of last floor</td>
<td>High refurbishment costs; €</td>
</tr>
<tr>
<td>apartments;</td>
<td>Long payback time;</td>
</tr>
<tr>
<td>Increased loggias areas;</td>
<td></td>
</tr>
<tr>
<td>Better aesthetical appearance of the building;</td>
<td></td>
</tr>
<tr>
<td>Better indoor comfort;</td>
<td></td>
</tr>
<tr>
<td>Government support;</td>
<td></td>
</tr>
<tr>
<td>No inside works;</td>
<td></td>
</tr>
<tr>
<td>Increased useful floor area;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of greenhouse for food production;</td>
<td>High refurbishment costs can influence the decision of home owners to apply this strategy in reality;</td>
</tr>
<tr>
<td>Use the concept as landmark of the area;</td>
<td></td>
</tr>
<tr>
<td>Because of the large number of residential</td>
<td></td>
</tr>
<tr>
<td>buildings of this type multiple project</td>
<td></td>
</tr>
<tr>
<td>application possibilities;</td>
<td></td>
</tr>
<tr>
<td>By providing the common spaces by mean of the</td>
<td></td>
</tr>
<tr>
<td>greenhouse, it is possible to change the</td>
<td></td>
</tr>
<tr>
<td>lifestyle of the residents and rise the</td>
<td></td>
</tr>
<tr>
<td>community spirit;</td>
<td></td>
</tr>
<tr>
<td>Job creation opportunities;</td>
<td></td>
</tr>
<tr>
<td>Better image of the district creation;</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.4 SWOT analysis; Strategy 2

### 9.3.3 Strategy 3

The Swot analysis for Strategy 3 is presented in Table 9.5

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant improvement of energy efficiency;</td>
<td>High costs; €</td>
</tr>
<tr>
<td>Better aesthetical appearance of the building;</td>
<td>Relocation of residents during the refurbishment;</td>
</tr>
<tr>
<td>Access for disabled people;</td>
<td>Complex refurbishment works;</td>
</tr>
<tr>
<td>Modernized layout of the apartment;</td>
<td></td>
</tr>
<tr>
<td>Better indoor comfort;</td>
<td></td>
</tr>
<tr>
<td>Increased loggias area;</td>
<td></td>
</tr>
<tr>
<td>Use of renewable energy sources;</td>
<td></td>
</tr>
<tr>
<td>Increased useful floor area;</td>
<td></td>
</tr>
<tr>
<td>Short payback time;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use the concept as landmark of the area;</td>
<td>Convince the investors to subsidize the</td>
</tr>
<tr>
<td>Because of the large number of residential</td>
<td>refurbishment process;</td>
</tr>
<tr>
<td>buildings of this type multiple project</td>
<td></td>
</tr>
<tr>
<td>application possibilities;</td>
<td></td>
</tr>
<tr>
<td>New people with higher income are attracted,</td>
<td>Failure to find a way to relocate the home</td>
</tr>
<tr>
<td>the life level has to increase.</td>
<td>owners;</td>
</tr>
<tr>
<td>Job creation opportunities;</td>
<td></td>
</tr>
<tr>
<td>If investors are attracted, possibility to</td>
<td>Existing structure of the building has to be</td>
</tr>
<tr>
<td>minimize the financial burden on users and</td>
<td>strong enough to care additional loads;</td>
</tr>
<tr>
<td>government;</td>
<td></td>
</tr>
<tr>
<td>For the investors, there is no need to invest</td>
<td></td>
</tr>
<tr>
<td>in the installations;</td>
<td></td>
</tr>
<tr>
<td>New created apartmets can be rented for higher</td>
<td></td>
</tr>
<tr>
<td>price, because of high energy efficiency of the</td>
<td></td>
</tr>
<tr>
<td>building.</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.5 SWOT analysis; Strategy 3
9.4 Conclusions

Based on made calculations, the Strategy 3 has the best performance regarding the energy efficiency and potential savings. Despite all the benefits of the Strategy 3, application it into practice is complicated and involves different threats. However, in order to achieve European Union goals and provide Zero Energy Neutral Buildings for the future generations, this strategy is the most promising. Moreover, this is the only strategy that upgrades the layout to meet modern requirements for the comfortable apartment of the present. Beside this, together with all the benefits that this strategy has, the payback time is very close to the payback time of Strategy 1, in case additional floors construction is totally subsidised by the investors. In order to stimulate the decision making of users to invest in such a refurbishment project, the benefits of Strategy 2 (user oriented strategy), such as community space on the rooftop, can be introduced to the design of Strategy 3.

On the other hand, the calculations of the energy performance of the Strategy 2 are underestimated. According to the performed calculations, the heat balance is very similar to the Strategy 1, when it was expected to have much more heat gains because of the greenhouse. According to the STR 2.01.09:2005, the correction coefficient for the heat losses through the roof if it faces the greenhouse is 0.8. Most probably this number does not reflect the real situation.

To conclude, for the final design proposal the most promising is Strategy 3, however improvements discussed in this chapter can be introduced in order to make the final proposal design more convincing.
10 Final Design

10.1 Corrections

Before the final design proposal, the suggested improvements to the proposed strategies are made. In previous calculations, following the simplified calculations, the heat from the buffer zones and the greenhouse was not properly reflected. Therefore improvements were made. In the Appendix E the calculations of the solar heat gains and buffer zone temperatures for each of the strategies are presented. It was estimated, that the temperatures in the buffer zone (glazed balcony) of Strategy 1 during winter is 5.6°C, for Strategy 2 and 3 it is equal to 19.6°C. For the Strategy 2 the heat gains from the greenhouse were also estimated. According to the calculations, the average greenhouse temperature could be 35°C, in that case, spare heat is produced that can be used for building’s purposes and therefore heat losses from Strategy 2 are reduced significantly (Fig. 10.1-10.3).

![Fig. 10.1 Improvements Strategy 1](image1)

![Fig. 10.2 Improvements Strategy 2](image2)

![Fig. 10.3 Improvements Strategy 3](image3)
As it is seen from the graph in Fig. 10.2, there are heat gains from the greenhouse that are equal to 281.45, therefore, using the formula 8.3:

\[
Q_{\text{greenhouse}} = 281.45 \text{ W}
\]

\[
H_{\text{greenhouse}} = 281.45 \times 24 \times 225/1000 = 1519.83 \text{ kWh}
\]

Based on calculations in Chapter 8.5.4, the energy demand for the hot water can be reduced to:

\[
H_{\text{water hot}} = 59.29 - 19.54 = 39.75 \text{ kWh/m}^2
\]

As it is seen, the use of greenhouse helps to reduce the heating load significantly and after the corrections made, the Strategy 2 is closer to the Strategy 3 in terms of energy efficiency. Also these Strategies became very close to almost Zero Energy Design. This decrease in energy efficiency.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>0%</td>
</tr>
<tr>
<td>Strategy 1</td>
<td>72.7%</td>
</tr>
<tr>
<td>Strategy 2</td>
<td>96.4%</td>
</tr>
<tr>
<td>Strategy 3</td>
<td>98.2%</td>
</tr>
</tbody>
</table>

Despite the significant reduction of heating load in care of Strategy 2, the payback time is still the longest, because of high refurbishment costs.

10.2 Final design

10.2.1 Improvements of Strategy 3

Final design is mainly based on the Strategy 3. As it was discussed in the conclusions of Chapter 9, the introduction of the community space by mean of the greenhouse into the Strategy 3 can be done. After the corrections were made, it also became obvious that such a step is not only good from social aspect of the design, but also for the increase in energy efficiency.

The greenhouse is designed instead of the two apartments on the additional floors (Fig. 10.5). Instead of eight loft-apartments on the additional floors in Strategy 3, the final design proposal has only six apartments. The greenhouse is situated on the South part of the building and connects to blocks that were completely isolated from each other before. This is also beneficial in case of emergency, since the second escape root becomes possible. The layouts together with the axonometric view of additional top floors are presented in Fig. 10.8-10.9. The overall impression of the improved design is reflected in renders Fig. 10.6-10.7. The rest of the interventions, spatial configuration of the building are the same as described in Chapter 7.6. (Fig. 10.10-10.11).

![Fig. 10.5 Comparison of the layout of Strategy 3 and final design proposal](image)
10. Refurbishment of multi-flat residential buildings in Lithuania

Fig. 10.6 Render Final Design. Front facade

Fig. 10.7 Render. Final Design. Rear facade

Fig. 10.8 Loft apartments - ground floor

Fig. 10.9 Loft apartments - top floor
10.2.2 Energy efficiency
There are no major changes in the climate design compared to the Strategy 3. Because the energy efficiency calculations were made for the top corner apartment as a worst case scenario, they remain the same for the improved situation. The only difference is the solar heat gain from the greenhouse that can be used for building’s purposes, for example for water heating for domestic use.

The amount of heat that can be used for this purpose is calculated based on formulas 8.4 and 8.5.

\[ Q_{\text{greenhouse}} = 18386.95 \text{ W} \]

Because of the conductive heat losses and system’s efficiency correction, it was assumed that only 50% of this heat will be used to preheat the water.

\[ Q_{\text{greenhouse}} = 9193.475 \text{ W} \]
\[ H_{\text{greenhouse}} = 9193.475 \times 24 \times 225 / 1000 = 49644.77 \text{ kWh} \]

This amount should be divided for the total floor area of the building, including the new area of the additional floors, in order to make calculations comparable with the previous energy efficiency calculations for the top apartment.

\[ H_{\text{greenhouse}} = 49644.765 / 3180 = 15.6 \text{ kWh/m}^2 \]

Based on calculations in Chapter 8.5.4, the energy demand for the hot water can be reduced to:

\[ H_{\text{water input}} = 19.85 - 15.6 = 4.25 \text{ Wh/m}^2 \]

The annual energy savings for final design are:

\[ \text{Price present} = 458.39 \times 77.8 \times 0.129 = 4600.49 \text{ Euro/year} \]
\[ \text{Price FD} = 11.33 \times 77.8 \times 0.129 = 113.71 \text{ Euro/year} \]

The refurbishment costs for final design increase due to construction of the greenhouse. Because it is hard to calculate the construction price of the new floors, it is estimated that it remains the same, despite the changes made. To represent the worst case scenario, it is assumed that because of the construction of the greenhouse, the refurbishment costs will increase.

\[ \text{Price total FD} = 366 \times 84 = 30744 \text{ euro} \]

Savings in euro applying the final design are (formula 9.4):

\[ \text{Savings FD} = 4600.49 - 113.71 = 4486.78 \text{ euro} \]

Payback time is (9.5):

\[ T_{\text{payback}} = 30744 / 4486.78 = 7 \text{ years} \]

Despite the increase in the refurbishment costs, the payback time becomes only one year longer.
10.2.3 Present situation vs new design
In this chapter the comparison of final design proposal and existing situation will be discussed to understand the improvements and benefits of the refurbishment.

**Energy efficiency**

![Graph showing energy consumption comparison](Fig. 10.15 Energy consumption)

As it is seen from the graph Fig. 10.15, the decrease in energy consumption after the refurbishment is very significant and is close to almost energy neutral.

**Functional and spatial changes**

The spatial changes were discussed in detail in Chapter 7. The comparison of these changes is presented in Fig. 10.16. Because of the existing structure major changes are not possible, however bathroom and toilet space became twice larger. Also small balconies were converted into logias and can be used for recreation. The decrease in the corridor space is very important, because the saved space can be used more efficiently. Despite the slight decrease of the kitchen area, it became less isolated and dining function is moved to the living room. The 3d renders and layouts of old and new situations can be seen in Fig. 10.10-10.11.
10.3 Conclusions

The proposed design strategy focuses not only on the envelope of the building and its energy efficiency, but also involves social, architectural and other non-energy related benefits.

The changes in the layout of the existing apartment, spacious loggias and provided public space, make this proposal more attractive to the owners of the building.

Despite all the benefits this strategy proposes, the SWOT analysis from Chapter 9 showed, that it has also most of threats and weaknesses, which include:

- need to relocate owners during the refurbishment process;
- find the ways to convince the investors to subsidize in the refurbishment;
- make sure that the existing structure can withstand additional loads.

All these aspects have to be reflected in order to answer the research question.

---

10.2.3 Building sequence

A global impression about the building sequence of the refurbishment is presented in Fig. 10.18. The sequence is explained for the rare facade, but the same sequence applies also to the front facade. The a phase represents the existing situation. In phase b the old building’s elements such as balconies and windows are removed. Also roof is being prepared for the construction of top floors. New facade elements are attached to the existing structure. Inside refurbishment works are also done during that phase. This involves old staircase demolition and placement of the new one together with elevators. In phase c the construction of the top floors together with the new structure for loggias starts. The material for top floors construction is wood, because it is easier to work with it on site and steel is chosen for structural part of the new loggias. The greenhouse and thermal solar collectors are added at the end phases of the construction.

---

Table 10.1 Refurbishment cost comparison

<table>
<thead>
<tr>
<th>Refurbishment costs</th>
<th>Payback time (year)</th>
<th>Interest rate</th>
<th>Interest rate for estimated period (euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic refurbishment</td>
<td>16716</td>
<td>5.8</td>
<td>3</td>
</tr>
<tr>
<td>Deep refurbishment</td>
<td>30744</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

1. Atudajytė Busta 2015

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Fig. 10.18 Building sequence new vs old situations

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Fig. 10.17 Private, semi-private and public space new vs old situations
11 Conclusions
The aim of this thesis was to answer the set research and sub questions discussed in Chapter 1.

11.1 Sub questions
What are non-energy efficiency benefits of the refurbishment or how can energy efficiency improvements support multiple refurbishment objectives?

Refurbishment is a complex process that has to focus not only on the improvement of the energy efficiency of the building, but also take into account other aspects of the possible improvements. As it was defined during the research and discussed in Chapter 6, the problem of multi-flat residential buildings in Lithuania from the period 1960-1992 refers not only to bad energy performance, but also outdated apartment layouts and functional zones. On average the size of functional zone of the case study building is only 2/3 the size of the same functional zone in the apartments of newly built multi-flat residential building. Kitchen’s space is isolated from the rest of the apartment and the size of the balconies does not allow to use them for recreational purposes.

The other problem is the lack of public space within the building. Outdoor community space is used as car parking. Therefore the possibility of creation of public space within the building can be seen as another non-energy efficient benefit.

According to the market analysis performed in Chapter 6, and several interviews with real estate agencies, there is no significant change in market value of the apartment in the refurbished building. It can be assumed, that one of the reasons for such an outcome is that despite all energy efficiency improvements, the apartments themselves remain old and outdated.

The proposed refurbishment strategies 2 and 3 together with the final design proposal prove that energy-efficiency measures such as creation of buffer zones and the construction of the greenhouse act not only as energy efficiency measures, but also solve functional problems and create public space for the users of the building. The construction of the greenhouse in that sense is even more beneficial. As it is seen from the SWOT analysis in Chapter 9, it can act as a catalyst for the improvements on macro scale level.

Is it possible to achieve higher energy efficiency and living standards applying technologies that use renewable energy sources?

Such technologies are expensive, but as it was concluded in the comparison analysis in Chapter 9, the Strategy 3 was the most beneficial in terms of energy performance. This was the only strategy using renewable energy sources such as geothermal heating and thermal solar collectors. According to calculations, the use these technologies for heating and hot water production reduces energy demand 4 times.

On the other hand the passive use of renewable energy sources does not have to be underestimated. Based on the design and calculations of Strategy 2, the passive use of solar heat has also proven itself to be a promising way to increase energy efficiency of the building. According to the calculations, the heat captured within the greenhouse for the final design proposal reduced energy demand for hot water by 79%.
Introduction of new technologies mainly affect the improvement of energy efficiency of the building and indoor thermal comfort of the residents. However on the larger scale, integration of modern technologies can be beneficial for the district where the building is situated. The proposed look (Fig.10.6-10.7) of the final design proposal put into reality could serve as an example and sort of an icon for the district. By explaining to the new and existing user’s potential of renewable energy sources, it is possible to change their approach towards the way the building is used and the way their lifestyle is organized.

The other important advantage of using the renewable energy sources is “energy independence.” The main energy source in Lithuania is natural gas that is bought from Russia. The calculations have proven that it is possible to reduce energy demand to almost zero, which makes users of the building less dependent on the market situation.

What factors influence the final value of the building after the refurbishment?

The evaluation of the building is a very complex process and depends on many factors. During market analysis discussed in Chapter 6, it was concluded that there is hard to find any relationship between different criteria and their influence on the property’s market value.

It is thought that the main factor is the increase in energy efficiency of the building after the refurbishment, however the price comparison of the refurbished and non-refurbished apartments in Lithuania failed to prove this statement due to lack of data available. However this research lead to the conclusion that people prefer to stay in the apartments after the refurbishment rather than sale them.

Therefore the major improvements that include the internal upgrade of the functional zones and creation of additional spaces, both private and common has to be considered. Unfortunately, there have been no examples of such projects in Lithuania, yet. It is hard to predict to which extent it will influence the market value of the refurbished building. These measures are very costly and it is unlikely, that the increase in the property’s value would be able to cover the investments and the expenses of the refurbishment.

From the investment cost comparison and the payback time estimation, it is clear that in order to be attractive such a refurbishment, the additional investors have to be found. The Strategy 3 and final design propose to attract investors by creating additional residential spaces that can be rented after the refurbishment to the new tenants and cover the refurbishment expense.

Is it possible to apply the same strategy on the different buildings with the same typology and get sufficient outcome?

One of the boundary condition for the design proposals of three strategies was that case study building has to be the representative of the mass production of the post-war period. As a case study building the multi-flat residential building type JUST-5-001 was chosen. This type of building is very common in Vilnius and other cities. Only in Vilnius city there are 428 buildings of that type. However they are presented in different configurations and layouts depending on the district within the city. For the design proposal the basic configuration for this building type was chosen.

The final design proves that it is possible to apply the same design on the other buildings of this type. The main proposed design improvements involve the upgrade of building’s envelope, increase of balconies’ space and use of the space on top of the roof. Because the basic and simplest configuration was used as a case study, the measures presented in the final design can be applied on other, more complex configurations. Small changes might be needed because of different orientation of the building. The fact that one project can be applied to many buildings will reduce the project costs significantly. Moreover, for the final design proposal it is important to attract the investors. The fact that one design can be used multiple times is a very strong argument in that case.

What strategies can be efficient in order to minimize costs of deep refurbishment?

From the performed research, using very rough calculations for the refurbishment cost estimation, it was concluded that in best case scenario the increase of the refurbishment costs is almost 60% compared to the basic refurbishment measures. Despite the fact that rough refurbishment cost estimations were used it is clear that ways to minimize financial burden have to be found.

However according to the research, difference in the payback time between basic and deep refurbishment strategies is only one year. Taking into account the present fixed interest rate for the refurbishment the financial burden becomes less problematic. Thus it can be concluded, that the proper strategy involves the robust design that can minimize energy consumption and the payback time.

Other way to make the deep refurbishment possible is by looking into different financial sources. In Chapter 3.4 the comparison of refurbishment financial instruments from different countries is presented. It the moment the refurbishment in Lithuania is partly supported by government by mean of the loan with low interest system and subsidies for certain refurbishment measures. However, compared to other countries in that graph, it is clear that this is not enough to achieve not only desired energy efficiency, but also the possibility to consider other refurbishment benefits. Therefore it is necessary to attract new investors. The proposed final design solution is to create additional floors on top of the refurbished building with high quality apartments, which can be rented to provide financial benefit for the investors and minimize financial burden on users.

11.2 Research question

What are the design strategies that introduce the additional value after the refurbishment and stimulate the decision making of users to invest in the refurbishment of the multi-flat residential building?

In order to stimulate the decision making of users to invest in the refurbishment, not only energy efficiency measures should be taken into account. The way the building is used, its functional zoning and the lifestyle of residents has to be considered. Despite the fact, that multi-flat residential building was refurbished and the energy performance increased, the spaces inside the building remained outdated. Therefore, refurbishment process should include the analysis of the modern lifestyle and the present needs of the human beings.

In order to introduce the additional value after the refurbishment, the social and economic aspects of the refurbishment process have to be considered. As it was proved with the proposed design strategies, the energy efficiency measures can be directly related to these aspects. That makes the refurbishment process much more complex than just upgrade of the envelope.
Refurbishment of multi-flat residential buildings in Lithuania

11. Conclusions

For users all the above mentioned benefits are very tempting, because the strategy involves not only envelope upgrade, but also concerns other problems. The main interference factor for the decision making are refurbishment costs and need of relocation. However both these problems can be solved by attracting investors as a third party. If they can gain benefit out of the additional floors, it is possible to minimize costs. Also usually these companies owe newly built buildings. According to the data from Inreal Real Estate Agency (Anotavicius et al. 2014), the amount of the spare unsold apartments in newly build buildings is as presented in Fig. 11.2. Therefore there is possibility to temporarily accommodate owners of the refurbished building in these properties.

However bringing such a complex solution into reality involves not only building’s owners, but also government and building companies. Another obstacle for such a solution is the need to relocate owners during the refurbishment works.

Because many parties are involved, the decision making process becomes much more complicated, however it has to be made clear, that all of the parties eventually benefit from such a strategy.

User’s convincing mechanism

For users all the above mentioned benefits are very tempting, because the strategy involves not only envelope upgrade, but also concerns other problems. The main interference factor for the decision making are refurbishment costs and need of relocation. However both these problems can be solved by attracting investors as a third party. If they can gain benefit out of the additional floors, it is possible to minimize costs. Also usually these companies owe newly built buildings. According to the data from Inreal Real Estate Agency (Anotavicius et al. 2014), the amount of the spare unsold apartments in newly build buildings is as presented in Fig. 11.2. Therefore there is possibility to temporarily accommodate owners of the refurbished building in these properties.

Government convincing mechanism

The interest of the Government in the refurbishment process is mainly due to increase of the energy efficiency of the residential building stock and CO2 emissions reductions in order to achieve goals explained in Chapter 3. According to the Energy Independence Strategy (National Energy (Energy Independence) Strategy (2010))) by 2050 the energy efficiency of residential sector has to be improved by 70% compared to 1990 level. EU long-term goals in reducing CO2 are 85-90% by 2050 and 27% of total energy consumption from renewable energy by 2030(EU climate action 2015). This goal indicates that if better energy efficiency can be achieved, the more likely EU will succeed in reaching these goals. In the research it was estimated, that the energy efficiency of Strategy 1, which is the basic one, was 72% and renewable energy sources were not used. In case of final design proposal energy efficiency increased to 98% and the climate design system using renewable energy sources were proposed. That means that with deep refurbishment it is more likely to achieve goals set in the directives.

Investor’s convincing mechanism

Finding building companies willing to invest in such a design is crucial for this strategy. The feasibility of such a proposal is the topic for further research, however some of the benefits can be already foreseen. First of all, it is the possible to make mass production design, which will reduce the project’s price naturally. Only in Vilnius city 428 houses of that type exist. However other Lithuanian cities and also neighbour countries such as Latvia, Estonia, and Poland can be considered as potential market as well. Secondly, there is no need in communication installations as they are already there. Third argument would be the fact, that if the company that is willing to invest in the refurbishment process owns the apartments on the added floors, it actually can gain benefit after the refurbishment by renting created properties. The high energy efficiency design is proposed, therefore the price for renting the apartments situated on the newly built floors can be considered to be higher than the average.

According to the survey performed by BPIE (Investing in Energy Efficiency in Europe’s Buildings 2013), which interviewed 96 EU executives in the building sector (69% real estate segment and 31% of the building construction sector): “EU private sector is in favour of effective regulation and implementation that encourages deep renovation of the building stock.” However, according to them, the main obstacles are lack of market demand for energy efficient building and poor regulatory framework.

Collaboration

In order to make the above discussed mechanisms come true, the collaboration of user’s, government and investors is needed. Government should create proper regulatory framework for the deep refurbishment and increase the awareness of users about the sustainability aspect of the refurbishment. The users themselves have to actively participate in the refurbishment process and realize that in order to fully benefit from the refurbishment, they have to make some unpleasant decisions, such as, for example, temporary relocation. The investors [construction and real estate companies] should propose their spare properties to accommodate owners of the refurbished building and subsides the deep refurbishment in return of tax reduction and renting profits (Fig. 11.3).
11.3 Further research

As a further step for this research it would be useful to interview the potential investors and see their opinion regarding the proposal. It will help to understand what regulatory framework should be created by the government and what aspects can be investigated further or improved.

Also the research on the structure of the case study building should be done in order to estimate what kind of loads it can carry and propose detailed ways of constructing the additional floors based on the data collected. In the performed research the main focus was on the design of the strategies and refurbishment opportunities that can introduce additional benefits. In given time-frame, there was no time to properly concentrate on the proper reflection of the proposed design in the details.

11.4 Reflections

The Refurbishment process in Lithuania these days is a very important process that involves almost everyone. A lot for buildings reached the point when they have to be refurbished in order to minimize energy consumption and CO₂ emissions and reach sustainability goals of the present. Therefore it is essential to understand the right way to do it. That was the main intention choosing the research topic.

Because the refurbishment is a complex process that includes many aspects, it was hard for me, but necessary to decide which aspects of the process should be taken into account. Because a lot of researches regarding the energy efficiency of the refurbishment were done before, I decided to combine technical and social aspects of the process and see what kind of technical measures and how can influence the refurbishment outcome.

The structure of the research was defined before P2 and divided into 3 parts: Research, Design and Conclusions.

Research: The aim of the research was to understand the process of the refurbishment in Lithuania and the impact of different measures. The initial intention after P2 presentation was to evaluate the changes of the market value of the property after the refurbishment and define what measures have the most impact on it. This conclusions were supposed to be used for different design strategies. However, the real estate agencies in Lithuania were not willing to collaborate and after the market analysis of the real estate properties, it was concluded that the different approach is needed. Actually, I did not expect the evaluation process of the real estate property to be so complicated, therefore the proposed planning for the graduation project was no longer representing the real one and it was hard to follow the set schedule.

Design: The tricky part of the design phase was to keep balance between technical and real estate parts. Three strategies were chosen in order to analyse different refurbishment possibilities. The strategies range was from the most simple to the very complex one. When I look back at this decision, I find it really useful. Such an approach helped me to really see the differences of different strategies in more details and evaluate the advantages and drawbacks of each of them, which resulted in clear idea regarding the final design approach from both energy efficiency and social aspects.

During the design phase of the graduation project, I realized that in order to provide good outcome, the integrated approach is needed. My first intention was to concentrate only on the facade refurbishment of the building, however during the design process, more complexity was added to the design solutions. This resulted in more complex calculations that I was not able to do with the software I planned to use in the beginning. As a result I used simplified hand calculations to evaluate every proposal. I think that was very beneficial for me as a professional, because when you do hand calculations you realize the process behind them and how different inputs are related with each other.

Conclusions: this part of the graduation project is the final destination were you find what you expected to find in the beginning or you end up with unexpected conclusions. In my case the conclusions obtained are not surprising, however the way on how to improve present situation and refurbishment process in Lithuania became very clear to me. I would like to present my work to the experts within refurbishment industry in Lithuania and see what they think about it. I think this can result in a very interesting discussion with the additional improvements of this project.

Final product: I am happy with the results of today, however I see a lot of ways to improve this graduation thesis and a lot of directions that can be further investigated from technical, economic and social points of view regarding different parties involvement.
Bibliography


Konstantinou, T. (2014). Facade refurbishment toolbox; supporting the design of residential energy upgrades, S.n.


Multi-flat Residential Buildings Renovation Criteria in Lithuanian (01-13-2015), Apklausa.lt


R26P Pastatų atnaujinimo (modernizavimo) darbai (2014), Sistela.


Appendix

Appendix A: Market analysis data on apartments’ price from period 2000-2015;
Appendix B: Market analysis data on apartments’ price from period 1965-1980;
Appendix C: Results of regression method market analysis;
Appendix D: Estimations of the refurbishment investment costs;
Appendix E: Temperature calculations of the buffer zones;
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**Appendix A**
### Appendix B

#### Refurbished

Easy to refurbish

Partly refurbished

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Appendix C
Results of regression method market analysis

Price €/m² vs Total living area

New apartments

![Plot of Fitted Model](image)

Residual Plot
Price €/m² = 1469.57 - 1.1404/Area

Old apartments

![Plot of Fitted Model](image)

Residual Plot
Price €/m² = 1111.21 - 1.24974/Area

Appendix C
Results of regression method market analysis

Price €/m² vs Total living area

New apartments

![Plot of Fitted Model](image)

Residual Plot
Price €/m² = 1469.57 - 1.1404/Area

Old apartments

![Plot of Fitted Model](image)

Residual Plot
Price €/m² = 1111.21 - 1.24974/Area
Appendix D
Estimations of the refurbishment investment costs

New apartments

Old apartments
Appendix E
Temperature calculations of the buffer zones

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<th>ST1</th>
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Air exchange rate from STR 2.09.04:2008 (Appendix 5)

g value for windows is taken from http://www.wbdg.org/resources/windows.php

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Air exchange rate for greenhouse (Sanford 2011)

g value for windows is taken from http://www.wbdg.org/resources/windows.php

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*Air exchange rate from STR 2.09.04:2008 (Appendix 5)

* g value for windows is taken from http://www.wbdg.org/resources/windows.php