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# The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value: The Vilnius case

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**Abstract**

Some of the problems associated with assessing the retrofit effectiveness of apartment buildings in urban areas are considered. The retrofit of houses should be followed by the amelioration of their surroundings. The priority order of districts to be renovated depends on the condition of the buildings in a district and on strategic urban development programmes. In order to determine the profitability of investments in housing retrofit, a number of retrofit scenarios should be developed. The authors of this paper offer a new approach to determining the retrofit effectiveness of houses based both on expected energy savings and the increase in market value of renovated buildings. In line with the proposed approach, retrofit scenarios for apartment buildings in Vilnius were developed, i.e. retrofit investment packages for various districts were prepared and arranged in the priority order for their application according to the method of geographical analysis suggested by the authors.


*Keywords:* Large-panel buildings; Energy savings; Increase in market value; Method of geographical analysis; Investment packages; Retrofit scenarios; Vilnius case

## 1. Introduction

Most European countries have succeeded in reducing energy consumption of new dwellings by more than 50% without increasing their building cost, and therefore, energy efficiency has achieved great acceptance among building owners [3]. These buildings represent about 20% of the building stock but consume only 5% of energy. Concentration on improving the energetically poor building stock has great potential. The lack of interest in housing retrofit can be explained by the fact that economic interest in a building expires after 30 years.

When the problems involved in housing retrofit, especially the solutions aimed at energy conservation, are considered, the increased market value of renovated buildings is not always taken into account. The experience has shown that reconstruction of local heating units as well as the renovation and regulation of heating systems are effective measures of saving energy. However, insulation of walls, replacement of windows, renovation of roofs, etc., which also help save energy, are not so economically effective because of large investments needed (they are usually repaid only in more than 20 years) [17]. The benefits of retrofit are often considered in terms of reduced thermal energy costs. However, retrofitting also improves the condition of all building elements as well as prolonging the lifetime of a building. It makes possible a considerable reduction in building maintenance costs and investments in the repair and replacement of worn-out elements, which would be inevitable in the future. By ignoring these significant factors, the above approach makes it difficult to prove the need for a more extensive renovation intended to improve the condition, energy conservation, and architectural and aesthetic appearance of a building (when trying to get the required loan). The order of priorities in implementing retrofit scenarios of apartment buildings in particular urban neighborhoods is determined by strategic urban development programs and the current condition of the buildings and the environment in a district.

## 2. The criteria used in rating retrofit scenarios

The critical criterion when examining and proposing any of the alternative management schemes is the sustainable

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development of society [13]. Coherent and efficient retrofit scenarios are commonly based on a building's state of degradation and its obsolescence. An advanced method, based on multicriteria analysis, also helps design effective retrofit scenarios [5]. Before a decision is made to proceed with any project of building retrofit, a brief but reliable report is needed describing the current state of the building and estimating the cost of building operations to be performed [4]. The developed methodology and software apply to specific refurbishment work and cost assessment of building renovation needs with respect to energy conservation and improvement of the indoor environment.

Several methods were proposed for rating buildings or retrofit scenarios based on criteria including thermal energy consumption for heating, availability of cooling and other appliances, retrofit impact on the environment, indoor climate, and costs [21].

The potential for energy conservation in apartment buildings was investigated following the EPIQR methodology and several scenarios were evaluated for various apartment buildings [1]. Energy savings in each building were accounted for in order to identify the most effective scenarios.

According to [30], design and realization of effective building retrofit scenario requires an exhaustive study of all solutions involving planimetric and volumetric changes, the elimination of the deteriorated and obsolete elements of a building, the improvement of its architectural and aesthetic appearance and indoor amenities, etc. The effectiveness of the building retrofit under consideration depends on many factors, including costs, annual fuel savings, when the retrofit is completed, the tentative payback period, harm to human health caused by the materials used, aesthetics, maintenance, functionality, comfort, sound reduction, longevity of structures, etc.

In general, housing renovation policy aims to:

1. Reduce energy consumption by 50%, and thus to improve the environmental value.
2. Increase the market value of dwellings.
3. Improve the condition of buildings and prolong their lifetime (for about 30–40 years) as well as preserve housing resources.
4. Raise the level of comfort in apartment blocks.
5. Avoid maintenance expenses and investments in buildings which would otherwise be needed in the future.
6. Improve the architectural appearance of the facades of apartment houses as well as harmonize them with the environment.
7. Make residential areas more attractive to their residents; improve the residential quality of a building.
8. Attract more middle-class residents to these areas.

When apartment buildings do not meet the residents' needs, the question arises of whether they should be renovated or demolished. A consensus is growing that it is easier and less expensive to slow down building deterioration by investing in proper maintenance and, thereby, prolonging its service life before reconstruction. To compare reconstruction to renovation in mathematical terms, the following formula [20] was proposed:

$$C \geq R + M\left(\frac{1-(1+i)^{-n}}{i}\right) + \frac{C}{(1+i)^n} \tag{1}$$

where $C$ is the cost of new construction, $R$ the cost of renovation, $M$ denotes the savings in annual maintenance costs in the case of new construction, $n$ the expected prolonged service life (in years) of the renovated building, and $i$ is the interest rate per year. The right-hand side of this formula is the sum of the renovation costs plus the current value of higher maintenance cost and the discounted current value of the new construction which might be delayed by $n$ years. This basic formula has several logical flaws. Some researchers believe that the value of the existing building should also be added to the renovation cost. Others argue the opposite, namely, that reconstruction should bear as an extra cost the waste of demolishing a valuable (though old and ill-functioning) existing building, while the renovation option utilizes the existing value of the old building and just adds to it.

Deciding between renovation and demolition can be made easier by the use of criteria for assessing the value of preserving a building. Not only technical building requirements but also, above all, the economic and ecological advisability of comprehensive renovation measures as compared to demolition of a building and construction of a new one or to its fundamental redevelopment must be examined more closely [19]. Once a decision to retrofit has been made, questions must usually be answered about the extent to which retrofitting measures are necessary and the extent to which one must and/or can retrofit the building structure and its technical systems. The speed and security of the return on one's investment is becoming increasingly important for property managers and owners as a criterion for their decision, in particular with respect to the nature and extent of retrofit.

In order to achieve the goals of an optimal retrofit strategy, it is essential that any given capital investment be directed to the most cost-effective group of energy-saving measures. This can be achieved by ranking the measures in order of decreasing savings—to investment ratio (SIR), where [6]

$$\mathrm{SIR} = \frac{\text{current value of the total lifetime energy saving}}{\text{investment cost}} \tag{2}$$

If a measure has a SIR greater than 1, the predicted savings exceed the investment, and the measure can be regarded as cost-effective. The higher the SIR, the larger the return on the investment. To calculate the SIR, the current value of the total energy saved must be found. Finding this value requires the discounting of all future savings to their equivalent current value, using the following equation:

$$\mathrm{PV_c} = C\left[\frac{1-(1+r)^{-n}}{r}\right] \tag{3}$$

This gives the current value, $\mathrm{PV_c}$, for an annual saving $C$, occurring for $n$ number of years (lifetime of measure), with a real discount rate of $r$.

The implementation of some energy-saving retrofit measures is associated not only with reduced energy consumption but also with the improved condition of building elements, durability, and the value of the building [15,16]. However, investments in property should not be assessed only as static costs; instead, long-term security and stability of value as well as re-usability and profitability of the retrofitted building should be considered. It is recommended that comprehensive renovations be carried out in order to increase a building's value and to ensure long-term security of that value [19].

Renovation aimed to increase building value for users has not only technical, ecological, and economic aspects but also a social dimension that should be considered. Renovation will be made only if there is a demand and acceptance among the users. The cost of a market-oriented retrofit is not simply the market value. There exists some difference between them, known as the acceptance of the market. If economic function of a building is fulfilled, the added value can increase its acceptance among the users and so increase the demand. The increase in price depends on the cost of the retrofit scenario. From the perspective of real estate market value, an effective retrofit may be described by the following market value ratio (MVR):

$$\mathrm{MVR} = \frac{M_{\mathrm{va}} - M_{\mathrm{vb}}}{C_{\mathrm{r}}} \tag{4}$$

where $M_{\mathrm{va}}$ is the market value of the building after retrofit, $M_{\mathrm{vb}}$ the market value of the building before retrofit, $C_{\mathrm{r}}$ denotes the retrofit costs of the building [28,29]. If the package of investments in retrofit has an MVR greater than 1, the package can be regarded as cost-effective from the perspective of real estate market value.

From the perspective of value, it is hardly reasonable to develop retrofit packages, which if implemented, would make apartment values, when their average current price plus the cost of dwelling retrofit are taken into account, equal to or even higher than the prices of newly constructed apartments. The cost of investment packages depends on the difference between the market value of 1 $\mathrm{m}^2$ of new dwelling area and the average price of 1 $\mathrm{m}^2$ of old dwelling area, plus the cost of retrofit measures per 1 $\mathrm{m}^2$ of area. Therefore, the efficiency of retrofit from the market value perspective can be expressed by the market value ratio as follows:

$$\mathrm{MVR} = \frac{a(M_{\mathrm{vn}} - M_{\mathrm{vo}})}{C_{\mathrm{r}}} \tag{5}$$

where $M_{\mathrm{vn}}$ is the market value of 1 $\mathrm{m}^2$ of new dwelling area, $M_{\mathrm{vo}}$ is the market value of 1 $\mathrm{m}^2$ of old dwelling area, $\alpha$ is the average coefficient of correction, depending on a particular district where retrofit is made.

In general, when energy savings and the increase in market value are taken into account, a package $k$ of retrofit measures is effective when

$$\mathrm{SIR}_k > 1, \qquad \mathrm{MVR}_k > 1 \tag{6}$$

The following criteria in particular are relevant in the renovation/reconstruction discussion: costs (taking into account the construction of a new building, the costs of demolition, relocating tenants, renovation costs, operating costs of a new building (as compared to the renovated building)), defects and drawbacks of the building (associated with heat insulation, concrete quality, humidity, ground water, soundproofing, the condition of the living environment, ventilation, parking space), architecture of the building (aesthetics, types of layout), urban planning aspects (nature of the development in the area, availability of public transport system, engineering infrastructure) and social infrastructure (building status, tenant satisfaction). When considering renovation, the major factors, such as social infrastructure and some problems, relating to urban development, in particular, should be considered first. Not only technical building requirements, but the economic and ecological purposefulness of comprehensive renovation measures as compared to demolition and constructing a new building, must be examined more closely. The assessment of the property with the option to rebuild, as compared to the existing building value, should be made and potential profitability of various renovation possibilities should be analysed. Only then should one begin the analysis of the building itself or work to answer the questions of technical detail. If a building has an insufficiently developed social infrastructure, then, this is an argument for demolition, and vice versa. If a building has an intact social infrastructure, then, this is an argument for renovation.

A decision about renovating or demolishing a building mainly depends on its physical condition, blending in the environment, maintenance quality, the planned service life, the extent of degradation, the expected economic effect of renovation, the cost of demolishing an old building and the construction of a new one, as well as social infrastructure and the priorities of urban development. One of the retrofit effectiveness criteria is MVR, therefore it can be used at the first stage of decision-making about the renovation or demolition of a building. The cost-benefit analysis can be made for a short, middle, or long term. Renovation measures are a good investment only if they improve the residential quality of a building. Improved residential quality means more than simply reducing energy consumption; renovation to increase value must do more than achieve thermal renovation. If the building's economic function is fulfilled, the added value due to market-oriented renovation can increase its acceptance by the tenants and so increase the demand. Investment value in the single most likely scenario is equivalent to market value which would be likely to result in a hold decision and thus the scenario approach potentially provides extra insight. However, not all retrofit measures can improve residential quality. If retrofit scenario which can raise residential quality is used, but its calculated MVR is less than one, then the renovation can be effective from the perspective thermal energy saving in the long term. In terms of market value, it is not advisable to develop retrofit investment scenarios which, when implemented, would make apartment values equal to or even greater than those of newly constructed dwellings in the same area, when their average current market value and the cost of retrofit are taken into account. In this case, the renovation utilizes the existing value of the old building and just adds to it, but the value is lower than the renovation scenario cost. Renovation becomes economically inefficient, i.e. market value increment of dwelling due to renovation is lower than the cost of renovation. In this case, it is not comprehensive, substantial, and sustainable renovation. Therefore, we must distinguish between energy-efficient retrofitting and market value-efficient retrofitting of buildings. An effective decision implies energy-efficient retrofitting and market value-efficient retrofitting. When, in renovation scenario $k$ $\mathrm{MVR}_k < 1$, then, it is the market value-inefficient retrofitting scenario. The problem arises what to do with such buildings. Probably, they should be reconstructed. To make a decision, a comprehensive analysis of the state of the building, its deterioration, architecture, costs of construction of a new building, the costs of demolition, relocation of the tenants, renovation costs, operating costs of a new building as compared to the renovated building, the increased rent as well as some aspects of urban planning and social infrastructure should be made. If the amount of comprehensive, substantial, and sustainable renovation investment exceeds the investment limit, it makes more sense for building owners or other investors to demolish the old building and finance the construction of a new one with the required energy efficiency and other characteristics. However, if energy prices are likely to grow, energy-efficient retrofitting would be a more attractive investment opportunity.

Developing renovation packages for apartment houses of particular districts it is possible to determine the effectiveness of these packages (from $i$ to $j$) by calculating their values $\mathrm{SIR}_i$ up to $\mathrm{SIR}_j$ and $\mathrm{MVR}_i$ up to $\mathrm{MVR}_j$ in a single step. If at least one of the indicators $\mathrm{SIR}_k$ of the package $k$ is less than one, or $\mathrm{MVR}_k$ is less than one, or both their values are less than one, then, such a package cannot be considered cost-effective. Only the packages with $\mathrm{SIR} > 1$ and $\mathrm{MVR} > 1$ should be further analysed, and the $k_{\max}$ package, ensuring the highest energy saving and market value increase, i.e. $k_{\max} = \{\max \mathrm{PV}_{ck}; \max(M_{\mathrm{va}k} - M_{\mathrm{vb}})\}$, should be chosen, taking into account the available financial resources.

When choosing a retrofit package, a number of criteria, such as retrofit cost, thermal energy savings, the extent of building deterioration and obsolescence, indoor and outdoor environmental quality, as well as technical, economic, ecological, and social aspects should be considered. The market value of real estate reflects and is affected by the interaction of four basic forces that influence human activity: social trends, economic development, governmental control and regulations, and environmental conditions. The forces are interactive because they exert pressure on human activities and are, in turn, affected by these activities. The interaction of the social, economic, governmental, and environmental forces that affect real estate value must be studied.

The index SIR refers to energy conservation, while MVR shows the market value for the evaluation of the retrofit packages. After renovation the market value of the building increases because the quality of dwelling as well as indoor and outdoor environmental quality, comfort level and living conditions are greatly improved, while maintenance costs, etc. are decreased. These criteria are reflected to some extent in the two indices SIR and MVR. Thus, in this case, a contribution principle can be observed, implying that any dwelling improvement is worth as much as the increase of the property's market value it brought about, regardless of the cost of improvement, i.e. the actual increase of the total property value is more important than the cost of improvement. The above criteria are included in the research through the geographical analysis of districts based on SIR and MVR.

## 3. The Application of geographical analysis in decision-making on the retrofit of panel houses in residential neighborhoods

The preparatory period for the renovation of residential neighborhoods includes:

1. Carrying out preliminary research.
2. Determining the retrofit areas.
3. Determining the retrofit objectives.
4. City planning.
5. Discussing renovation problems.
6. Preparing a social development plan.
7. Planning specific construction operations.

It would be more rational to renovate apartment houses based on territorial principle, i.e. arranging the districts in the order of priority and renovating them in a complex way, renewing dwelling houses and their environment. Besides, the renovation should be economically beneficial. The limits of the neighborhood can be determined based on its physical borders as well as taking into account some economic and legislative aspects. From the economic point of view, the neighborhood is delimited depending on the uses of land, while the limits of urban zones are established by legislation. The renovation of buildings should not be separated from the improvement of environmental conditions. The latter is difficult to analyse in economic terms. It is difficult to accurately predict the cost of the works to be performed in this field. Moreover, design solutions as well as economic effects may vary to a large extent. However, if the environmental conditions are improved, the market value of the land will considerably increase and the area will become much more attractive to investors. Therefore, it is clear that the renovation of a neighborhood should not be restricted to the renewal of houses, but should be extended to the whole territory. Moreover, the renovation of apartment houses should be followed by the state-financed construction of administrative and public buildings, schools, recreational areas, parks, squares, roads, etc. Only in this case a monotonous residential area can become a functional part of the city, providing its residents with all the conditions of urbanized life. Usually, the renovation of neighborhoods is effective if it proceeds without any delays and is completed in 10–15 years. During this period the neighborhoods should become so attractive that they could keep their residents from moving out. At the beginning, some pilot projects must be implemented for getting the experience and demonstrating the results of renovation, and then the whole neighborhood can be renewed.

The renovated buildings raise the market value of the neighboring houses, and the progression principle comes into operation. Renovation should also follow ‘‘the sustainable environment’’ principle which would help the neighborhood acquire some new quality. A complex analysis of renovation should include cost analysis and the variation of apartment values depending on particular districts of the city. The specific character of the district largely determines the market value of apartments. The plans for district development and the state of the neighboring districts are also important. Districts with well developed infrastructure (workplaces, transport system, health and consumer services) have many advantages compared to the districts with poor infrastructure. The demand, offer and market value of a particular district are strongly influenced by the changes taking place in other neighborhoods, and vary to a considerable extent, depending on how attractive they are to residents [18]. Vilnius neighborhoods can be divided into several groups according to their attractiveness to residents and market value of property (apartment):

- Group 1: highly prestigious neighborhoods.
- Group 2: prestigious neighborhoods.
- Group 3: non-prestigious neighborhoods.

The first steps in renovating the apartment houses should be in line with the strategic aims of urban development stated in the strategic plan. The strategic plan of city development is worked out in several stages: first, a particular vision of a city or town is created, then, the analysis of current social and economic problems is made and, finally, the priorities of long-term urban development are established. The competitiveness of any city or town as a complex social, economic and urban entity can be described by a set of criteria. For a city to be competitive on an international scale, the values of all the criteria describing it need not be the highest. The strategy of urban development defines the main movers or starting points for further activity involving the development of other areas as well.

From the perspective of their location the strategically vital districts are those where the airport, railway and bus stations are located, as well as the central districts of the city. Therefore, they can be considered perspective and the market value of real estate can be expected to grow in these districts. The image of the above districts and their attractiveness play an important part in maintaining the competitiveness of the city. This means that apartment houses on their territory should be renovated in the first place. Some of the areas may have the environment not properly adapted to residents’ needs. The strategic plan of city development should include some measures aimed at converting industrial enterprises into commercial or housing facilities. This could increase the property value in the area. Every district (neighborhood) should be evaluated based on the list of priorities in the long-term development plan of the city.

The degradation of the apartment houses is a good reason for starting the renovation. To make the final decision, the state of the buildings in various neighborhoods should be thoroughly analysed. The order of priority for renovating the standard districts which are of the same importance for strategic city development is determined based on the age and condition of their apartment houses. The state of the houses is described in terms of the defects found, deterioration of particular building elements, the state of engineering services, thermal characteristics of enclosures and heating systems, which are usually outdated single-pipe unbalanced systems, not allowing for temperature regulation in the premises and individual metering of the consumed thermal energy. The priority for being renovated should be given to a district the houses and the environment of which are in a worse state compared to the condition of other districts.

To make a particular area more attractive, a complex approach to renovation should be used, implying that both dwelling houses and the environment should be enhanced. The renovation of districts with medium or low values of geographical location indicators can hardly be expected to considerably increase the market value of property. The latter will never reach the market value of property located in highly prestigious districts because the significance of ‘geographical location’ criterion of these districts is very high.

A district is unattractive to residents if its houses are degraded and the infrastructure, transport system and environmental conditions are poor. Besides, the level of noise, pollution and crime rate are high, etc. The investments in the renovation of neglected districts may be larger than the increase in property value after renovation, i.e. they can even be unprofitable. However, the willingness of the residents of these districts to renew their houses and their financial state as well as the financial support of renovation by municipalities should be taken into account.

The priorities of the districts in the renovation project can be established based on multicriteria analysis of their significance in the strategic plans of city development, the state of their dwelling houses and the environment, renovation costs, the expected reduction of thermal energy consumption, the market value of property in the houses of old and new construction and the expected increment of market value of the renovated houses. Whenever these indicators change, the priorities of districts for renovation also change. Determining the growth of the market value of property due to renovation, some other measures which could also increase its market value should be taken into account. These are the so-called ‘‘external’’ effects. This could be the laying of the tram route, the construction of a supermarket or bridge, etc. on the renewed territory, which would undoubtedly raise the market value of property in the area.

Geographical analysis of the districts to be renovated is carried out in the following steps:

1. The urban area is divided into three groups depending on its attractiveness to residents and market value of property. They include highly prestigious, prestigious and non-prestigious districts.
2. Depending on the renovation objectives, various retrofit investment packages are formed.

3. The effectiveness indicators $SIR_{ijk}$ and $MVR_{ijk}$ of every retrofit investment package $k$ are calculated in one step for every type of dwelling houses $i$ located in the city district $j$.
4. The retrofit investment packages $k$ with $SIR_{ijk} > 1$ or $MVR_{ijk} > 1$ are included in further analysis.
5. Multicriteria analysis based on the principles described above is performed. The significances of the criteria are determined by experts. The analysis yields the retrofit priorities of the districts considered.

The renovation of a particular district may greatly influence the market value and attractiveness of the neighboring areas and their property. Therefore, before starting the renovation of a district according to the priorities established earlier, any recent changes in market value of property or thermal energy and construction cost should be taken into account, and a new multicriteria analysis aimed at determining retrofit priorities of the districts should be performed if required.

## 4. The condition of apartment buildings in Vilnius

The audits of 349 residential buildings, performed in seven European countries to collect the data on the degradation of building elements, revealed the key factors influencing the deterioration of existing residential buildings throughout Europe [2].

About 59% of the apartment buildings in Vilnius neighborhoods are large-panel houses. Dwellings in brick and cast-in-place buildings make up 35% and 4% of all apartment houses, respectively. These buildings represent seven types of panel houses, six types of brick houses, and four types of cast-in-place buildings [11]. The main problems associated with poor maintenance and defects are practically the same for all panel houses. Similar flaws are found in brick and cast-in-place buildings. Most apartment buildings were constructed in the period of 1960–1996, and their envelopes have similar thermal characteristics. In later construction these characteristics are different because building specifications have changed.

Now, most of the apartment buildings in Vilnius do not meet new specifications for housing construction and the needs of residents. Most dwellings of each type also have flaws that make their maintenance more difficult and shorten the lifetime of the buildings.

### *4.1. The state of the envelopes and other parts of panel houses in Vilnius*

Large-panel houses are of the following series: 1-464LI-18/1 (5/30/2), 120V-06/1 (5/20/1), 1605A (5/60/3), 1-464A-14LT (5/120/8), 120V-027/1 (9/36/1), 1-464LI-53/1 (9/72/2), and 1/3905 (12/60/1) (in parentheses, the number of floors, apartments, and staircases is given). The external walls of houses belonging to the 1605 series are sandwich walls with mineral wool insulation, while the houses of the 1-464LI series have single-layer walls made of 300-mm-thick expanded-clay lightweight concrete slabs. In five-story houses the expanded-clay lightweight concrete C5/8 is used, while in taller buildings

Fig. 1. Damaged external walls of a panel house.

concrete C8/10 is applied. Theoretically, the lifetime of such walls is 125 years. Most of the wall slabs on the facades have surface cracks through which moisture and pollutants infiltrate, damaging the walls and thermal insulation [11]. Flaws in the walls are also caused by migrating moisture, which contributes to crack formation and facade failure. Water gets into external walls when it is raining or drizzling. This migrating moisture washes away various salts on the wall surface, making the walls look unattractive. Since the finishing materials of such walls have worn out, their water absorption is 30 times higher than specified. Such external walls are often damp and houses experience higher thermal losses. When not properly repaired, panel houses look unattractive, with their facades decorated with ‘‘cobwebs’’ (Fig. 1). The joints between the external panels of these houses are also cracked. Therefore, water and pollutants pass through them, damaging insulation and increasing thermal losses. Joints are designed to last for 8 years. Then, they wear out and should be replaced. In general, the extent of deterioration of the external walls of panel houses constructed before 1970 in Vilnius is about 40%.

Another problem is associated with high thermal transmittance of the windows and doors of most apartment houses as well as their poor airtightness due to aging, which increases cold air infiltration into dwellings (in cold seasons) and thermal losses due to ventilation. The lifetime specified for the wooden windows and entrance doors of panel houses was 50 years. However, cold air, wind, and pollutants could pass through them from the beginning of their service. Because of poor maintenance, these doors and windows have warped, their paint has peeled off, and the wood has rotted in some places. They look unsightly and need to be replaced. Some residents have replaced the doors and windows in their apartments. However, they have used doors and windows of various types, materials, and colors; therefore, there is a lack of harmony between building facades, and this spoils the view of the city. Moreover, even though many residents have replaced the windows in their apartments, most of the old windows still remain unchanged.

The roofs of panel houses are mostly of the same type. These are flat roofs with an internal water removal system, covered with prepared roofing paper (ruberoid in rolls). The service life specified for this kind of roof covering is 12 years; therefore, theoretically the roofs of the panel houses in Vilnius must be worn out now. The main flaws in these roofs are the leakage of water through the joints connecting them with parapets and vertical structures as well as through the roofing itself. As a result, thermal insulating materials get damp, thermal losses increase, and the wall finish is damaged, making living conditions in such dwellings unhealthy. The joints in the galvanized tin plate covering have also corroded and should be replaced. The roofing is weathered and blistered in many places. This worn-out roofing needs to be replaced, and some new thermal insulation materials should be added. The deterioration of cornices and parapets in panel houses reaches 45%.

The foundations and basement walls of panel houses are made of single-layer reinforced concrete elements which are designed for a lifetime of 125 years. Their defects are usually caused by mechanical damage of external basement wall joints and finishes. Many problems also arise in the vertical joints of external basement wall slabs that are cracked and leak water and pollutants. The latter damage external basement walls, and their joints need to be fixed because of these defects.

Many of the problems in panel houses are associated with the current state of their balconies and porches, which were designed to last for 150 years. However, they are now the most heavily worn-out elements (up to 50%). The deterioration of balconies and porches was caused by the weakening of their horizontal reinforced concrete supporting slabs exposed to rain, snow, changes of temperature, and pollution. The tin-plate covering of these slabs has also corroded. Glazing balconies and porches not only helps to save thermal energy but also protects the reinforced concrete slabs from snow and rainwater, thereby reducing the deterioration of these elements.

The entrance to a panel house usually has a canopy of reinforced concrete slab over it as well as two to three reinforced concrete steps and a landing. These elements are often in a critical state. They are hazardous to people as well as being unsightly. When panel houses are retrofitted, all entrances need to be renovated.

All panel apartment buildings constructed in the period of 1960–1993 have envelopes with similar thermal characteristics and similar heating systems. The average thermal characteristics of the envelopes of these houses and the values given in the currently used specifications [22] are presented in Table 1.

These data show that thermal insulation of the envelopes of panel houses does not meet the specifications, thereby causing high thermal losses and low temperature in the premises. The actual thermal transmittance of some of the envelopes in these houses is 1.6–5.85 times higher than the specified value.

Table 1
Specified and actual thermal characteristics of the envelopes of panel houses

| Envelope | Actual average thermal transmittance of envelope ($W/m^2$ K) | Specified value of thermal transmittance of envelope ($W/m^2$ K) |
|---|---|---|
| Roofs | 0.71–0.85 | 0.16 |
| Floor slabs over un-heated basements and cellars | 0.45–0.6 | 0.16 |
| Walls | 0.86–1.17 | 0.20 |
| Windows and doors | 2.56–2.70 | 1.60 |

The surroundings of houses make an important factor in determining how attractive a particular neighborhood is to its residents. When people choose a residential area in the city, they are mainly interested in the following issues: (1) landscaping, noise level and air quality; (2) safety and neighbors; (3) the environment; (4) transportation [18]. In recent years, most of these conditions have become worse in Vilnius apartment blocks because of poor maintenance. For example, there is a lack of parking space in the yard and cars are left on children's playgrounds, sidewalks, etc. Most of the sports grounds are in poor condition. There are also too few park benches, and they are in a state of neglect. Many sidewalks have crumbled, and road crossings have not been adapted for the handicapped. There are also very few bicycle paths in the city.

### 4.2. The microclimate in dwellings

The inner climate in dwellings depends not only on the temperature and relative humidity but also on the carbon dioxide ($CO_2$) content in the air, volume flow, air velocity, dew point, the temperature of the envelope surface and the ambient air [24]. Hygienic standards provide for an adequate level of thermal comfort in public and residential buildings by specifying such parameters as air temperature, appreciable temperature, relative humidity, air velocity, and differences in temperature between the envelope surface and inside the building [14]. The specified values of thermal comfort parameters are given in Table 2.

The microclimate of a two-bedroom apartment in a panel house on Taika St. in Justiniskes was studied [8]. The average air temperature in the room was 19.90 °C. The graph was regular and slightly curved (because wind passed through the windows). Therefore, it could be claimed that the air temperature was below the specified value and reflected outside temperature fluctuations (Fig. 2). The average volume flow in the living room was 11.45 $m^3$/h. The irregularity of the volume flow graph may be explained by draughty windows in the dwelling. The average air velocity in the room was 0.09 m/

Table 2
The values of the parameters determining thermal comfort conditions in public and residential buildings provided in specifications HN 42: 2004

| Parameters of thermal comfort | Specified values | |
|---|---|---|
| | For cold season | For warm season |
| Air temperature (°C) | 20–24 | 23–25 |
| Appreciable temperature (°C) | 19–23 | 22–24 |
| Temperature difference between the air 1.1 and 0.1 m above the floor (°C) | Not exceeding 3 | Not exceeding 3 |
| Temperature difference between the envelope and the rooms (°C) | Not exceeding 2 | Not exceeding 2 |
| Floor temperature (°C) | 19–26 | Not specified |
| Relative humidity (%) | 40–60 | 40–60 |
| Air velocity (m/s) | Not exceeding 0.15 | Not exceeding 0.25 |

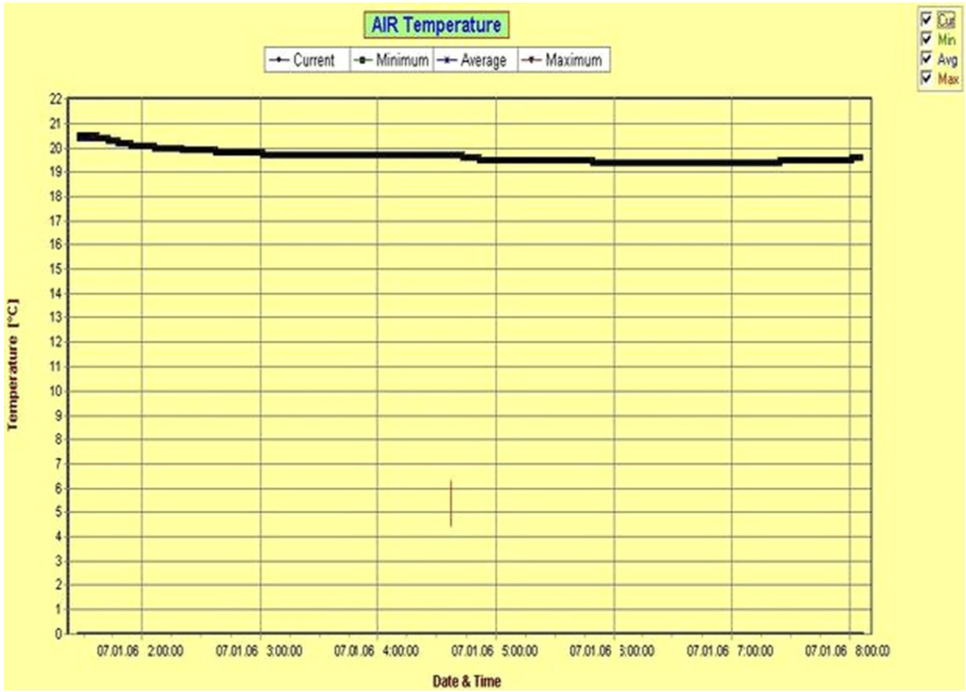


Fig. 2. Air temperature diagram showing the microclimate in a panel-house two-bedroom apartment in Justiniskes, on Taika St., in Vilnius.

s. The graph was irregular, therefore, it could be claimed that the dwelling was draughty. The average relative humidity in this room was 24.65%. The chart was regular and reflected natural relative humidity fluctuations outside the building. The relative humidity registered in the dwelling was lower than the value specified in the hygienic standards for residential houses. Thus, more powerful air conditioning or a source of moisture is needed. The average dew point temperature in this room was 0.85 °C (while outside air temperature was 9 °C, the temperature in the dwelling was 19.90 °C, and relative humidity—24.65%). The changes in the diagram of dew point temperature reflect the changes in the diagrams of temperature and relative humidity.

It is hard to find detailed data on the microclimate parameters associated with human health and working and leisure conditions in Lithuanian panel houses. However, high $CO_2$ content, moldy walls, and large difference between the temperatures of the envelope and the air in the dwelling, etc. observed in panel houses show that these parameters do not meet the specifications. The Housing and Health Research Project, carried out in 2002 by the World Health Organization (WHO), identified some key problems associated with a negative effect of the conditions in panel houses of Vilnius on human health. Dwellings have a high noise level, insufficient heating, and low air quality [7].

About 60% of Vilnius residents were not satisfied with the air temperature in their apartments in winter. More than 80% of houses do not have their own thermostats. About 75% (over 129 thousand) of apartments in Vilnius depend on centralized district heating (the municipal heat-supply systems). Houses are provided with elevator-type heating units (with their heating systems not separated from the central city system). Now, autonomous automated heating units are being installed in panel houses. Heating systems in panel houses are mostly represented by single-pipe upfeed heating. The apartments are provided with hot-water heating cast-iron or steel radiators. Heat distribution in heating risers is often not balanced. The consumption of thermal energy is determined for the whole building, and the billing is made by dividing the cost of the consumed energy by the number of apartments according to their floor space. Since residents cannot regulate heating in their dwellings and calculate the amount of thermal energy consumed in their apartments individually, they are not particularly interested in saving energy.

Another serious problem mentioned by 68.1% of respondents in Vilnius is noise. The main source of noise pollution is car traffic in the streets and in the yards of the houses. Poorly insulated windows, walls, and envelopes of houses also considerably worsen the situation. Leaking windows cause air pollution within the dwellings. About 50% of residents are not satisfied with the air quality in panel houses. Pollution and very dry air in the dwellings are the main problems. In most cases, the air quality cannot be controlled and is low.

In many panel houses, the slab joints are leaky, causing the walls to grow damp or even freeze in winter. This situation leads to higher thermal transmittance and, consequently, heat loss, as well as making the microclimate in the dwellings even less comfortable and healthy for people.

## 5. A retrofit concept for panel houses

Large-panel houses in Vilnius are in a state of disrepair and do not meet current housing needs. If not renovated, these houses may cause social problems because middle-class families can move elsewhere. Therefore, renovation is necessary, and it should be a comprehensive process because retrofitting a single house can reduce maintenance costs for residents but can hardly change the quality of life. By retrofitting the whole neighborhood or a group of houses, better results can be obtained in quality, aesthetics, and in solving social problems.

The residential districts of Vilnius are mostly built up with panel houses of the same type. However, they possess some peculiar features because of their unique environment and due to various city-planning concepts of the architects. When neighborhoods are renovated, efforts should be made to preserve and enhance their individual characteristics, environment, and design of their buildings. It is also important to develop two or three typical retrofit alternatives for each series of panel buildings. This would be cost-effective because it would help avoid the development of a new project, allowing the same elements and finishing materials to be used and a uniform architectural appearance and style to be preserved.

Several facade-finishing alternatives for insulating houses from the outside are possible. These are the use of painted stucco, facade plates, structural clay products, and tin-plate facade finishes. The insulation of the roof and new roofing should also be included in a retrofit project. If a mansard roof is built, the renovated house looks better architecturally, and the additional apartments can be sold to partially cover the retrofit expenses of the residents.

Houses, spaces, and neighborhoods may be diversified by using different colors, building extensions, mansard roofs, etc. A comprehensive approach to facade painting, i.e. preparing different painting projects for different groups of houses and neighborhoods, can help preserve the individual character of residential areas built up with panel houses.

Changing the inner layout of panel houses is hardly possible because the spacing between the external and internal bearing walls is small. Retrofit projects should provide for renovation of staircases, entrance doors, the canopies over them and balconies, which can become attractive elements of the renovated apartment houses.

Outdoor amenities, i.e. pedestrian and bicycle paths, parking lots, children's playgrounds, sports grounds, benches, litterbins, street lamps, etc., should also be renovated and rebuilt because the quality of housing largely depends on them.

### 5.1. Retrofit packages for panel houses

One of the main objectives of the housing strategy approved by the Government of the Republic of Lithuania is the efficient use of available housing resources, their maintenance, renovation and update, as well as the efficient use of energy resources and substantial improvement of the condition of existing houses and efforts to maintain and increase their value [12]. The scope of renovation is determined by its goal and the state of a building assessed from technical and functional perspectives [23]. The problems and drawbacks described above emphasize the need for renovating apartment buildings and outdoor amenities in Vilnius. For this purpose, the following measures should be taken:

- Laying new waterproof roofing.
- Adding more roof insulation.
- Replacing a flat roof with a mansard roof with new apartments in the space obtained.
- Repairing the balconies that are in a critical state.
- Replacing windows.
- Replacing entrance doors.
- Installing windows on the balconies.
- Fixing wall slab joints.
- Insulating flank walls.
- Insulating all the walls of a building.
- Renovating the heating unit, making it an independent automated system of heating and hot water supply.
- Balancing the heating system by installing balanced valves above the heating system risers.
- Installing gauges and individual thermostats in the apartments.
- Reconstructing the heating system by installing a collector.
- Replacing sewage pipes.
- Renovating the electrical equipment on staircases and in other shared spaces.
- Providing and renovating outdoor amenities.

To assess the preliminary investment packages and their profitability, four retrofit alternatives (based on small, medium, large and basic investment projects) were developed, and calculations were made for various types of panel houses. The main features of the investment packages for renovating apartment buildings of the series 1-464LI-18/1 are presented in Tables 3 and 4.

A package of small investments is aimed at repairing, reconstructing, or replacing systems and elements which are in critical or poor condition (Table 3). This package is attractive because of the relatively small investments, although the thermal characteristics of the building envelope can be only slightly improved (in reference to doors and windows only). The same applies to the architectural and aesthetic characteristics, which are also improved through the replacement of windows. There is also a drawback in the old system of regulation of thermal energy consumption, consisting in determining the energy consumed by the entire building and dividing it by the number of apartments according to their floor space. This system does not allow residents to individually regulate the temperature in their apartments.

Medium-size investment packages are more oriented to saving energy and, therefore, give relatively high returns (Table 3). The individual regulation of heating devices and thermal energy consumption encourages residents to save energy, with the savings depending on how much heat is used. The renovation of essential outdoor amenities is also planned. However, the implementation of this investment project does not result in great changes in the architectural appearance and aesthetics of panel houses. Walls (except for flank walls) do not meet current specifications and standards. Providing radiators

Table 3
Small and medium retrofit investment packages for a panel house of the series 1-464LI-18/1

| No. | Retrofit measure | Investments, USD | | Savings, USD | | Payback (in years) |
|---|---|---|---|---|---|---|
| | | Total | 1 $m^2$ | Total | 1 $m^2$ | |
| Small investment package | | | | | | |
| 1 | Laying a new roof covering | 8,007 | 4.55 | – | – | – |
| 2 | Repairing balconies in a critical state | 7,014 | 4.21 | – | – | – |
| 3 | Replacing windows | 73,486 | 42.78 | 2650 | 1.54 | 27.73 |
| 4 | Replacing entrance doors | 3,065 | 1.75 | 96 | 0.07 | 31.92 |
| 5 | Fixing slab joints | 3,811 | 2.11 | – | – | – |
| 6 | Reconstructing the heating unit | 11,924 | 7.01 | 1469 | 0.84 | 8.12 |
| 7 | Balancing the heating system | 2,525 | 1.40 | 1041 | 0.59 | 2.42 |
| | Total for construction work | 109,832 | 63.81 | 5256 | 3.04 | 20.90 |
| 8 | Design and engineering services | 8,787 | 5.26 | – | – | – |
| 9 | Client's reserve | 10,652 | 7.01 | – | – | – |
| | Total | 129,271 | 76.08 | 5256 | 3.04 | 24.59 |
| Medium investment package | | | | | | |
| 1 | Insulating the roof and laying new roofing | 19,572 | 11.75 | 1051 | 0.59 | 18.62 |
| 2 | Repairing balconies in a critical state | 7,014 | 4.20 | – | – | – |
| 3 | Replacing staircases and apartment windows | 73,486 | 42.78 | 2650 | 1.54 | 27.73 |
| 4 | Replacing entrance doors | 3,065 | 1.75 | 96 | 0.07 | 32.04 |
| 5 | Insulating flank facades | 9,941 | 5.61 | 500 | 0.28 | 19.88 |
| 6 | Reconstructing the heating unit | 11,924 | 7.01 | 1469 | 0.83 | 8.12 |
| 7 | Balancing the heating system | 2,525 | 1.40 | 1041 | 0.59 | 2.42 |
| 8 | Installing individual thermostats | 10,609 | 6.31 | 2251 | 1.29 | 4.71 |
| 9 | Providing and renovating outdoor amenities | 24,193 | 14.02 | – | – | – |
| | Total for construction work | 162,329 | 94.83 | 9058 | 5.19 | 17.92 |
| 10 | Design and engineering services | 12,986 | 7.36 | – | – | – |
| 11 | Client's reserve | 17,531 | 10.17 | – | – | – |
| | Total | 192,846 | 112.36 | 9058 | 5.19 | 21.29 |

with thermostats and devices to measure thermal energy consumption, when a single-pipe heating system is used, has some drawbacks as follows:

- Regulation of the temperature in the dwelling may lower the heating temperature in the apartments located on the left and right sides of a building.
- Measuring devices in a particular apartment do not record the total amount of thermal energy consumed, with the energy consumed by the house being proportionally divided among the apartments according to the readings on their gauges.
- If the heating system in one apartment fails or is being repaired, the heating of the other apartments is interrupted.
- The residents of individual apartments cannot use their heating systems before the heating season starts.

A package of large investments is aimed at achieving the highest-quality standard for a house in which the envelope meets the requirements of minimum heat losses, and the heating system is most efficient (with the accurate measurement of thermal energy consumed and the freedom to start or finish heating of the dwelling at any time and not to stop heating the entire building in the case of repair or failure of any system in an individual apartment) (Table 4). In fact, the overall economic efficiency of such buildings is equal to that of newly constructed houses. However, the investments are large (331.40 USD/$m^2$) and hardly affordable for most tenants. These packages are most suitable for prestigious districts because, when a mansard roof is built and, therefore, additional apartments are created, some of the investments can be returned by selling these new premises.

A basic investment package aims to ensure that the building envelope meets standard specifications for heat losses, mechanical strength and durability of structures as well as the requirements for an efficient heating system and individual control of thermal energy consumption (Table 4). This retrofit investment package also provides for minimal outdoor amenities.

These calculations show that the investments in 1 $m^2$ of floor space of various types of panel houses are similar for the same types of investment packages (Fig. 3). The cost of implementing small investment packages ranges from 62 to 78 USD/$m^2$, with an average of 70 USD/$m^2$, while the cost of a medium-size investment package is about 100 USD/$m^2$ (ranging from 89 to 111 USD/$m^2$). The cost of implementing packages of large investments is about 286 USD/$m^2$ (ranging from 240 to 332 USD/$m^2$). The cost of a basic investment package is approximately 168 USD/$m^2$ (ranging from 150 to 186 USD/$m^2$).

Since one of the retrofit objectives is to increase the economic efficiency of dwellings, a comparative analysis of retrofit scenarios from an energy-saving perspective was made (Fig. 4). The largest energy savings were obtained by

Table 4
Large and basic retrofit investment packages for a panel house of the series 1-464LI-18/1

| No. | Retrofit measure | Investments, USD | | Savings, USD | | Payback (in years) |
|---|---|---|---|---|---|---|
| | | Total | 1 $m^2$ | Total | 1 $m^2$ | |
| Large investment package | | | | | | |
| 1 | Constructing a mansard roof with dwellings inside | 147,675 | 85.57 | 1,336 | 0.78 | 110.54 |
| 2 | Repairing balconies and installing windows in them | 36,475 | 21.03 | 869 | 0.50 | 41.92 |
| 3 | Replacing apartment and staircase windows | 73,487 | 42.78 | 2,650 | 1.54 | 27.73 |
| 4 | Replacing entrance doors | 3,065 | 1.76 | 96 | 0.07 | 31.92 |
| 5 | Insulating facades | 64,217 | 37.18 | 3,235 | 1.85 | 19.85 |
| 6 | Reconstructing the heating unit | 11,925 | 7.01 | 1,469 | 0.83 | 8.12 |
| 7 | Reconstructing the heating system collector | 89,435 | 51.90 | 3,294 | 1.90 | 27.15 |
| 8 | Replacing the piping | 24,798 | 14.37 | – | – | – |
| 9 | Replacing the electrical equipment | 5,236 | 3.16 | – | – | – |
| 10 | Providing and renovating outdoor amenities | 24,193 | 14.02 | – | – | – |
| | Total for construction work | 480,506 | 278.78 | 12,949 | 7.47 | 37.11 |
| 11 | Design and engineering services | 38,440 | 22.45 | – | – | – |
| 12 | Client's reserve | 51,895 | 30.17 | – | – | – |
| | Total | 570,841 | 331.40 | 12,949 | 7.47 | 44.10 |
| Basic: investment package | | | | | | |
| 1 | Insulating the roof and laying new roofing | 19,572 | 11.23 | 1,051 | 0.59 | 18.62 |
| 2 | Repairing balconies and installing windows in them | 36,475 | 21.03 | 866 | 0.49 | 42.12 |
| 3 | Replacing apartment and staircase windows | 73,487 | 42.78 | 2,650 | 1.53 | 27.73 |
| 4 | Replacing entrance doors | 3,065 | 1.76 | 96 | 0.07 | 31.92 |
| 5 | Insulating facades | 64,217 | 37.18 | 3,235 | 1.85 | 19.85 |
| 6 | Reconstructing the heating unit | 11,925 | 7.01 | 1,469 | 0.84 | 8.12 |
| 7 | Reconstructing the heating system | 2,525 | 1.40 | 1,041 | 0.59 | 2.42 |
| 8 | Installing thermostats | 10,609 | 6.31 | 2,251 | 1.30 | 4.71 |
| 9 | Providing and renovating outdoor amenities | 24,193 | 14.02 | – | – | – |
| | Total construction work | 246,068 | 142.72 | 12,659 | 7.26 | 19.44 |
| 10 | Design and engineering services | 19,686 | 11.58 | – | – | – |
| 11 | Client's reserve | 26,575 | 15.42 | – | – | – |
| | Total | 292,329 | 169.72 | 12,659 | 7.26 | 23.09 |

implementing large packages of investments and basic investment packages. Actually, the savings obtained by using medium, large, and basic investment packages can vary considerably because, when residents have individual thermostats in their dwellings, they can choose any temperature which seems comfortable for them and consume as much thermal energy as they can afford.

The average payback period for small, medium, large, and basic investment packages is 25, 22, 40, and 24 years, respectively. As can be seen, the medium-size investment package seems to be most attractive because its payback period is the shortest. However, the use of this package will hardly improve the aesthetics of panel houses.

In the process of decision-making, i.e. selecting effective retrofit packages, designers manually produce two or more alternative scenarios, which then will be evaluated for the final choice. To determine the optimal investment in renovation of apartment houses, several factors should be taken into account.

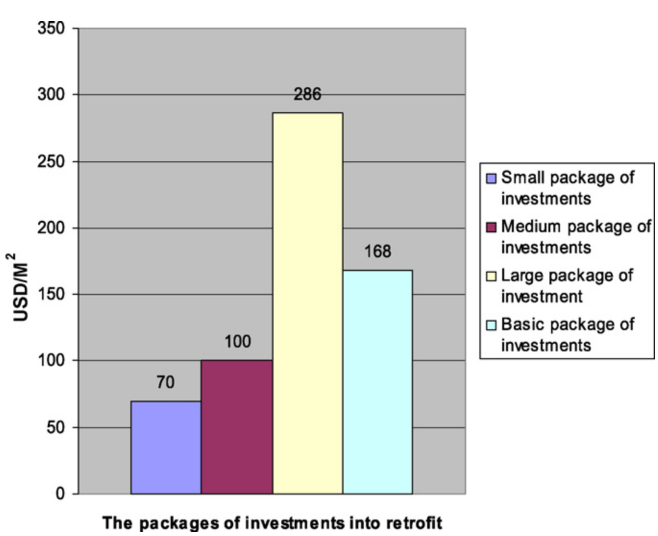


Fig. 3. Average cost of retrofit investment packages, USD/$m^2$.

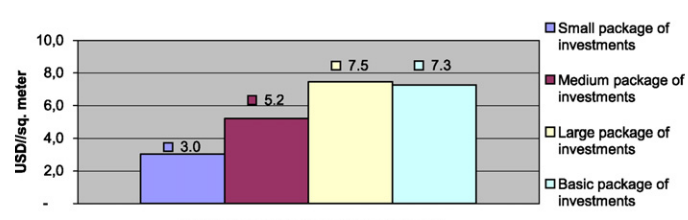


Fig. 4. Average savings resulting from the implementation of retrofit investment packages, USD/m.

It is obvious that the number of measures to be taken depends on a particular case. In general, it depends on the financial resources needed to attain the goals and objectives of renovation of dwelling houses and their environment. The analysis of the above types of retrofit packages has shown that, to increase energy efficiency and the environmental quality of a building, the investment should be from 150 to 332 USD/$m^2$ (of the apartment floor space). The large investment package was elaborated, taking into account the maximum allowable costs of the project. The retrofit scenarios were developed that could be recommended in the case of certain financial constraints, taking into consideration municipalities' subsidies and the financial position of residents.

To assess energy-efficiency and market value-efficiency of retrofitting, the investment analysis was made of four progressively energy-efficient retrofit packages. The packages were made up so that the small investment package was the least energy-efficient. Energy-efficiency of other projects was higher, with the large investment package, providing for creating new apartments by constructing a mansard roof being the most energy-efficient. According to the criterion of energy efficiency, the basic investment package was nearly equal to the large investment package. The packages were combinations of particular retrofit components, intended for gradual upgrading of heating systems and building insulation. They were also progressively applied to different components of the building envelope and renovation of outdoor amenities. In renovating panel houses, energy-saving measures related to the renovation of the building heating system and the envelope (i.e. insulation of external walls, windows, and roof structures) should be given the priority because of their long-term effect. Typical retrofit measures have been selected for packages, aiming to increase energy efficiency and quality of dwelling houses.

The generation of retrofit scenarios as well as their evaluation and selection of optimal scenarios can be automated by applying various decision-making tools and expert systems. This would allow us to automatically evaluate a large amount of retrofit scenarios in order to find the most rational alternative. The calculation of investments based on this method would help to increase the profitability of renovation projects, due to increased energy-efficiency and market value of the renovated apartment buildings.

### *5.2. The selection of effective retrofit scenarios for panel houses in residential neighborhoods in Vilnius*

One of the main objectives of the programme of strategic Vilnius development in 2002–2011 is to support housing construction and renovation of apartment buildings in Vilnius neighborhoods that are becoming less attractive for residents by encouraging investments in their renovation and the development of common-type retrofit projects and energy-saving programs [25]. The priority order of houses and neighborhoods to be renovated depends on the strategic development plans for Vilnius as well as the degree of deterioration of the existing houses and their environment. The renovation of houses should be accompanied by the renovation or creation of outdoor amenities. The programme of Vilnius development in 2002–2011 emphasizes the importance of developing the center of the city, the area on the right bank of the Neris river and other places often visited by tourists. These areas must be made more attractive to visitors in order to make Vilnius competitive on an international scale. The goals of the strategic plan for Vilnius development impose some restrictions on determining retrofit priorities for neighborhoods. A zoning principle has to be followed, the order of neighborhood's renovation has to be established, and, finally, a comprehensive program for renovating residential buildings and their surroundings has to be carried out. These measures can greatly increase the attractiveness of these areas as well as their market value. As a result, more private investments can be drawn to these districts.

Based on geographical analysis, the territory of Vilnius was subdivided into three groups of districts according to their attractiveness to residents and the market value of property as follows: highly prestigious, prestigious and non-prestigious areas. Retrofit investment packages were prepared for four apartment houses. Retrofit effectiveness ratios $SIR_{ijk}$ and $MVR_{ijk}$ were calculated in one step for every type of dwelling house $i$ located in district $j$ and every renovation investment package $k$. Then, only the investment packages $k$ having $SIR_{ijk}$ and $MVR_{ijk} > 1$ were left for further analysis. Based on such criteria as the significance of districts for strategic development plans of the city, the current state of buildings and the environment, cost of renovation, thermal energy saving, market value of apartments of new and old construction and the expected rise in the market value of property, the MCDM method COPRAS was applied to determine the priority order of Vilnius neighborhoods to be renovated according to particular scenarios [26,27]. This method assumes the direct and proportional dependence of the significance and degree of utility of the options studied on a set of criteria adequately describing the alternatives and on the values and weights of these criteria. The significance, priority order, and degree of utility of the alternatives are determined in five stages [9,10]:

1. Generating the weighted normalized decision-making matrix $D$.
2. Calculating the sums of the weighted normalized criteria describing the $j$th alternative.
3. Determining the significances $Q_j$ of the alternatives compared and describing the advantages $S_{+j}$ and disadvantages $S_{-j}$ of the alternatives.
4. Calculating the utility degree $N_j$ of the alternatives $a_j$.
5. Determining the priority order of the alternatives.

The geographical analysis performed yielded the following priority order of renovating Vilnius neighborhoods and their houses:

1. Zirmunai, Antakalnis.
2. Naujininkai, Vilkpede, Naujamiestis.
3. Virsuliskes, Karoliniskes, Lazdynai.
4. Snipiskes.

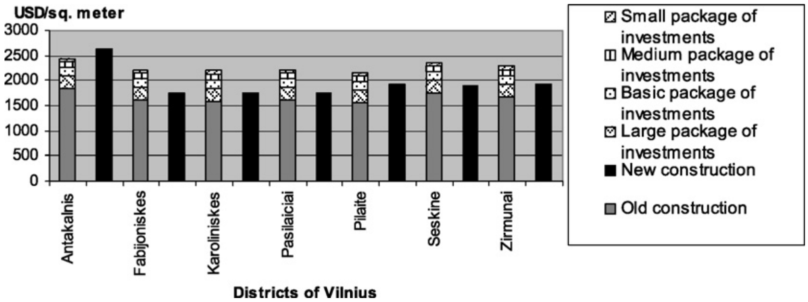


Fig. 5. Average market values of 1 $m^2$ of one-bedroom newly built and old apartment floor space plus the cost of retrofit investment packages in various Vilnius districts.

5. Seskine, Verkiai.
6. Justiniskes, Fabijoniskes, Pasilaiciai.
7. Pilaite.
8. Paneriai.
9. Grigiskes, Naujoji Vilnia.

A mathematical-statistical analysis allowed us to determine the average market value of 1 $m^2$ of floor space in apartments of old and new construction. In terms of market value, it is not advisable to develop retrofit investment scenarios which, when implemented, would make apartment values equal to or even higher than those of newly constructed houses in the same area, taking into account their average current market value and the cost of retrofit (Fig. 5).

The SIR and MVR were calculated in one step for various retrofit packages, various panel houses and districts. When the values of SIR and MVR were calculated for retrofit scenarios of various types of panel houses in Vilnius, three groups of districts to be renovated were determined (Fig. 6):

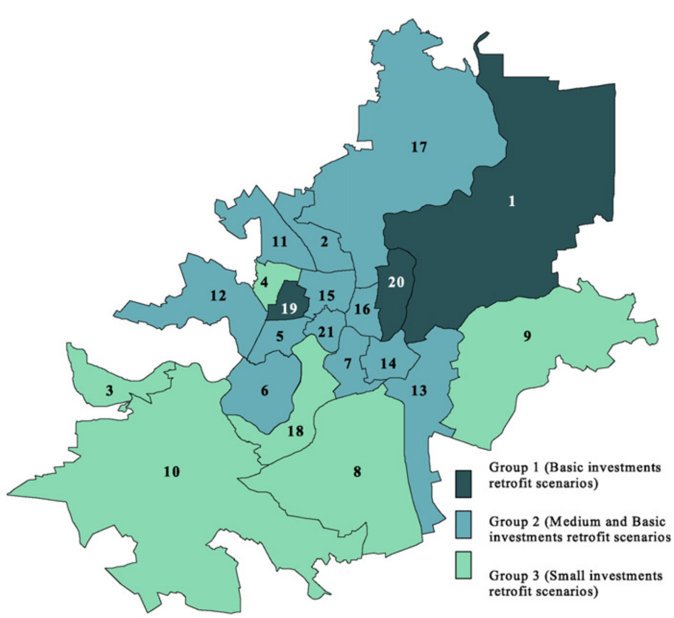


Fig. 6. Retrofit scenarios for panel houses in various Vilnius districts—1: Antakalnis, 2: Fabijoniskes, 3: Grigiskes, 4: Justiniskes, 5: Karoliniskes, 6: Lazdynai, 7: Naujamiestis, 8: Naujininkai, 9: Naujoji Vilnia, 10: Paneriai, 11: Pasilaiciai, 12: Pilaite, 13: Rasos, 14: Senamiestis, 15: Seskine, 16: Snipiskes, 17: Verkiai, 18: Vilkpede, 19: Virsuliskes, 20: Zirmunai, 21: Zverynas.

1. Group 1, including highly prestigious districts (Antakalnis, Zirmunai, Virsuliskes), where basic investment retrofit scenarios could be energy and market value-effective.
2. Group 2, including prestigious districts (Fabijoniskes, Karoliniskes, Pasilaiciai, Pilaite, etc.). Medium and basic investment retrofit scenarios could be proposed for these districts.
3. Group 3, including non-prestigious districts (Paneriai, Vilkpede, etc.). Small investment retrofit scenarios could be energy-effective in these neighborhoods.

The SIR and MVR calculations show that the value of SIR depends on the type of investment package, the type of house and the energy saved, while MVR depends on the type of investment package, the type of house and the neighborhood where the houses are located (Fig. 7). SIR is the highest for small and medium retrofit investment packages. For basic investment packages, its value ranges from 0.925 to 1.05. These figures show that, in terms of energy saving, the investments can pay off. However, the value of the ratio SIR is reduced to 0.752 for large investment packages.

The calculations have shown that in renovating the districts of Antakalnis, Zirmunai, and Virsuliskes large investment package can be effective in terms of market value of property, i.e. MVR $> 1$. However, if thermal energy saving is considered, SIR $< 1$. Finally, basic investment retrofit scenarios, with SIR $> 1$ and MVR $> 1$, were chosen for these districts.

Assessing the expected benefits of retrofit scenarios, it can be stated that hostel-type buildings of 30 (and more) years of service life, found in various Vilnius districts, are the worst in this respect. Their state is often critical because of poor quality of building work, deterioration and poor maintenance. This primarily applies to balconies and canopies over the entrance doors. The roofs are often leaky, while the windows and entrance doors are completely worn out. The heating, water and electricity supply systems and equipment are also deteriorated. This increases the accident and failure rate. The hazard of fire is also high in such buildings. Thermal characteristics of enclosures in these buildings, like in all houses built before 1993–1996, do not meet the specifications. The lay-out is obsolete and has the following drawbacks: corridor system with the shared kitchen and WC, insufficient living space, not satisfying the needs of the tenants, etc. Large investments (300–380 USD/$m^2$) are needed to improve the aesthetics and physical

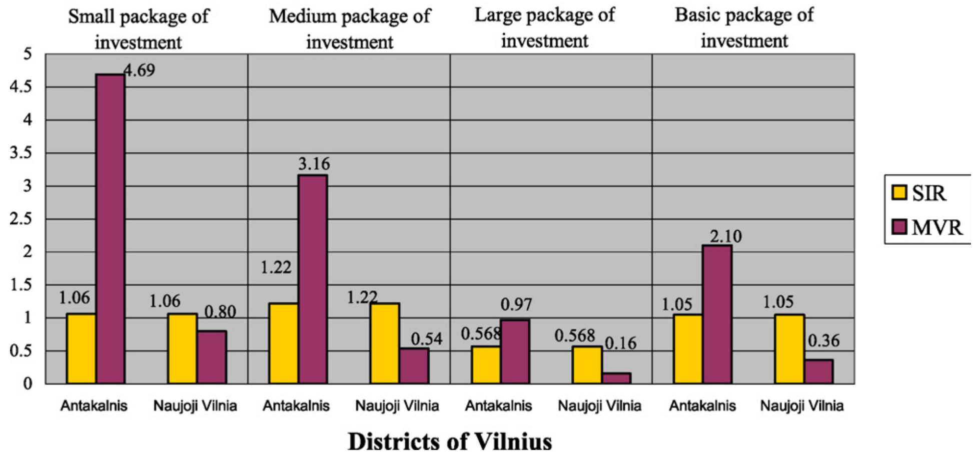


Fig. 7. Retrofit effectiveness for the panel house 1605A (5 stories, 60 apartments, 3 staircases) based on SIR and MVR ratios.

Fig. 8. A panel house in Vilnius, Zirmunai St. 3, before and after retrofitting based on a package of basic investments.

state of the buildings as well as to reconstruct the deteriorated structures and make the houses energy-efficient and ecological. It is hardly possible to change the lay-out of the apartments in these houses. The calculated retrofit effectiveness indicators MVR are much lower than one, therefore, the increase of the market property value can hardly be expected in this case. The owners or tenants of the apartments are mostly people of low-income group who can hardly pay the bills for services. They are usually not willing to join the owners' associations, therefore, their participation in renovation project implementation is rather questionable. Thus, comprehensive renovation of these apartment buildings is not economically effective and, therefore, cannot be recommended. It is more rational to demolish these houses and to construct some new administrative, residential or commercial buildings in this area (especially, taking into account the need for new schools, hospitals, recreation and shopping centres in the city).

In 1996, a pilot project initiated by the Government of Lithuania and the World Bank was launched to save energy in dwellings. This project allows the residents of apartment buildings who have established owners' associations to obtain loans under favourable conditions to make their homes more energy-efficient. In 2004, a retrofit project for a panel apartment house (of the series 1605A) was begun in Zirmunai in order to demonstrate the benefits of comprehensive renovation, embracing not only the building itself but also its surroundings (Fig. 8). In this project, a basic investment package was used.

The choice of a particular retrofit scenario and investment package may change if the renovation program is announced in a district. In this case, the price of apartments will rise in this area, and, consequently, the MVR value will also change. The value of SIR will change because of the rise in construction and energy costs. Therefore, before starting the renovation of a district, the effectiveness of the selected retrofit scenario should be analyzed.

## 6. Conclusion

When various retrofit scenarios for apartment buildings are evaluated, the solutions are usually based on the expected reduction in energy consumption. However, it should be mentioned that retrofit considerably improves the state of building structures as well as prolonging the lifetime of a building. The building's market value, which can be determined by applying MVR, is also raised. Therefore, the effectiveness of retrofitting an apartment building should be evaluated from various perspectives, with both energy conservation and an increase in market value taken into account. In order to make investments in building retrofit profitable, several retrofit scenarios should be developed and assessed from various perspectives. The choice of a particular retrofit scenario depends on strategic urban development programs as well as the condition of panel houses and their environment, renovation costs, saving of heat energy and the expected increment of market value of the renovated apartments. Retrofit scenarios should be based on a comprehensive approach, providing for the renovation of buildings and their surroundings. The SIR and MVR ratios may be applied to evaluating the effectiveness of retrofit scenarios.

The research made has shown that most of the apartment buildings in Vilnius do not meet the needs of their residents as well as current building specifications, and, therefore, they should be renovated. The values of thermal characteristics of panel apartment houses make only about a quarter of their specified values. The geographical analysis suggested in this paper was used to develop retrofit scenarios for large-panel buildings in Vilnius. Three retrofit scenarios based on small, medium, and basic investment packages were proposed for apartment houses in Vilnius neighborhoods and the priority order of their application was determined.

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