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# COST ANALYSES OF ENERGY-EFFICIENT RENOVATIONS OF A MOSCOW RESIDENTIAL DISTRICT

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## ABSTRACT

This paper estimates the costs of adapting three different holistic energy renovation concepts both in the buildings and at the corresponding residential district in Moscow. The results represent a baseline for the decision makers when planning implementations of holistic energy renovations in Russian residential districts.

In the buildings, the estimated costs included both mandatory less energy efficient repairs and suggested energy efficiency improvements. At the building level, the costs of different renovation packages varied between €125/m$^2$ and €200/m$^2$ depending on the selected renovation package. The estimated district renovation costs include both the renovation costs of the buildings and the costs of improving district energy and water infrastructure. At the district level, the costs of the main cases per inhabitant varied between €3,360 and €5,200.

The net present values for different building and district level renovation packages for a 20-year period were also calculated using different interest rates and annual energy price growth rates. The results suggest that renovation of a district may be more feasible than renovation of individual buildings.

## KEYWORDS

Cost analyses, building renovations, district renovations, energy efficiency, Russia, case study

## 1. INTRODUCTION AND LITERATURE REVIEW

For economies in transition such as Russia, the technical greenhouse gas (GHG) reduction potential for the building stock in 2030 ranges between 26 and 47% of the national baseline (Ürge-Vorsatz & Novikova, 2008). About 60% of Russia's multi-family apartment buildings are in need of major capital repair (IFC & EBRD, 2012). This also offers an opportunity to reduce the environmental load of energy used in buildings and thus improve the sustainability of existing cities and neighbourhoods.

Retrofit should comply with the sustainable development requirements (Raslanas et al., 2011). Often, a main component of the sustainable retrofit decision is to reduce costs and increase the return on the retrofit investment. However, in certain situations where existing buildings are in disrepair and in need of major retrofit to enhance their service lives, building owners should not necessarily choose sustainable retrofit projects based on the return on investment alone (Menassa & Baer, 2014). Gorgolewski et al. (1996) point out that economic indices show only comparative energy benefits, and acknowledge that in practice other non-energy considerations may well prove to be the deciding factor in determining the nature of the refurbishment to be undertaken. Anyway, it is vital to estimate the costs and benefits of different renovation solutions before making any decisions.

In Russia, the multi-family apartment buildings are typically heated with district heating (The International CHP/DHC Collaborative, 2009). Due to the technical structure of the district heating used in Russia (Eliseev, 2011), the heating cannot usually be controlled in the buildings. Then, improving the energy-efficiency solely in buildings seldom reduces the heating energy production and the resulting primary energy consumption. So, in order to support the sustainable development in Russian residential districts whole districts, instead of just single buildings, should be renovated holistically including renovations of the related infrastructure.

Previous recent studies (Paiho et al., 2013 & Paiho et al., 2014a) show remarkable energy saving potentials of a Moscow Soviet-era residential district by adapting different holistic energy renovation concepts both in the buildings and at the district level and taking into account the whole energy chain from production to consumption and thus considering not only building scale renovations, but also improvements on the energy supply systems. In the buildings, the concepts focused on measures reducing heating and electricity demand, reducing water use, and improving ventilation. At the district level, the focus was in improving the related energy and water infrastructure as well as introducing energy production from renewable sources in the most advanced concepts. In addition, Paiho et al. (2014a) analyse the emissions of different energy production scenarios. Even though the examinations were made as case studies to one pilot area, their results can be generalized to other similar residential areas existing in Moscow as well as in other locations and countries including Soviet-era residential buildings.

This paper continuous the work even further by assessing the feasibility of the different building and district energy renovation concepts in the same pilot area in monetary terms and testing the profitability of the renovation solutions over a 20 year period. We also test if it is possible to provide some baseline cost data, which does not exist at the moment, for the decision makers in charge of the potential implementation of such holistic district renovations.

## 1.1. Literature review

Even research from the 1990s indicates the need for energy-efficiency improvements of the Russian housing (Martinot, 1998; Opitz et al., 1997). Still, several recent references (UNDP, 2010; UNDP & GEF, 2010; Masokin, 2007; Filippov, 2007; Bashmakov et al., 2008, the World Bank & IFC, 2008; Garbuzova & Madlener, 2011) show considerable potential for improving energy-efficiency in Russian residential buildings and the related infrastructure in districts. However, there are only a few scientific papers related to energy renovations of Russian residential districts (Paiho et al., 2013; Paiho et al., 2014a). Even less work is reported about the economic analyses of the energy-efficiency measures or energy renovations of Russian residential districts. Some partly relevant literature is available from Soviet-era residential buildings from other countries. In the following, this literature related to cost analyses made about renovating Soviet-era apartment buildings is shortly reviewed and reference data and information given for assessing the results of this study in a relevant context.

In a general level, Bashmakov (2007) assesses that technologies already applied in Russia may cost-effectively halve its energy consumption. Bashmakov (2009) estimates energy-efficiency potentials and costs of various energy supply and consumption sectors in Russia. Incremental capital costs of implementing the energy efficiency potential were assessed at the following values: in power generation at about $US 106 billion; in district heating renovation at $US 27 billion; in pipeline transportation at $US 23–30 billion; and in buildings at $US

25–50 billion. These numbers show the significant modernization markets even if the exact values may differ.

One of the few recent economic investigations for the capital repair of Russian residential buildings, conducted in 2011 (IUE, 2011), suggests three different packages for capital repairs, which are different in terms of investment costs and estimated savings. All the packages include both basic improvements, such as repairing or replacing worn-out building parts, systems (including elevators) and devices, and energy-efficiency improvements, such as thermal insulation, space heating controls and consumption meters; interestingly, seemingly no improvement in ventilation systems are proposed. However, for example Biekša et al. (2011) claim that insufficient attention to the problem of ventilation could lead to large-scale and long-term health problems, and suggest obligatory installation of (mechanical) ventilation system for renovations. The investment costs of the packages estimated by IUE (2011) varied between €38 and €168/m$^2$ (considering RUR40 = €1) and the achieved maximum savings were 27% for the heating consumption, 11% for the electricity consumption, 18% for the gas consumption and 22% for the water consumption.

Kredex (2008) reports reconstruction of a Soviet-era apartment building in Tallinn, Estonia. The project included renovation of the roof, replacing windows, renewal of balconies, insulation of outer walls, renewal of the heating system, implementing electricity meters, and installing a metering and calculations system for sharing the heating costs between residents. The total costs were €128/m$^2$. The reported savings from the energy audit before the renovation was around 50%, while measurement results after showed around 40%. Other benefits from the reconstruction were building aesthetics and comfort, since the inhabitants could adjust the heating according to their needs.

Zavadskas et al. (2008) assess the financial profit from several renovation scenarios of Soviet-era buildings in Vilnius. Renovating buildings does not only result in the benefit of reduced energy demand, but also improves the state of building structures and prolongs the expected lifetime of the building, thus increasing its market value. The need to generate several investment cases in order to determine a profitable solution for the renovation of a building is also highlighted. Even though neighbourhoods are considered, only improvements to buildings are analysed. In addition, none of the suggested retrofit investment packages include renovation of ventilation systems.

Biekša et al. (2011) discuss about the multi-apartment renovation process in Lithuania. As a part of a case study of a group of residential buildings in Birštonas determination of the economic feasibility of the renovation process was done. Project payback time equalled to 16 years.

Raslanas et al. (2011) highlight the need to define retrofit scenarios for Soviet-era residential areas in Lithuania based on relevant strategies including the retrofit measures, their priority and their potential effect. However, the authors do not suggest the scenarios nor analyse any effects.

Ferrante (2014) presents alternative ways of investigating, planning, creating and managing sustainable urban environments, also by exploring the possibility to use energy retrofitting options as a social form of integration. The performed technical–economical evaluation demonstrates that energy efficiency in residential urban complex can be considered as an extraordinary opportunity to restore environmental, social and urban quality. The study was done in the Mediterranean context but the main ideas can be applied elsewhere too. Ferrante (2014) also discusses involvement of business investors, public bodies and local communities in the common efforts of decreasing of energy consumption in urban environments.

In order to introduce private investors, propose suitable business and financing models for renovating Russian residential buildings and districts, there is a need for baseline cost estimates and economic analysis. The literature review shows that the energy saving potential in residential districts built with Soviet-era buildings is huge, the same is true for amount of investments required, and this suggests there must be a significant market potential for businesses. At the same time, while there is little information available on renovation of Soviet-era buildings and almost no studies of district-level renovations. In addition, the costs and energy saving estimates for Soviet-era buildings from available literature usually do not include scenarios with mechanical ventilation systems, which are capable of ensuring good indoor air quality throughout whole year and enable heat recovery. This paper aims to contribute to existing knowledge by estimating investment costs of several renovation packages consisting of improvements in both buildings and district technical infrastructure, calculating net present values, as well as performing an analysis of sensitivity to such parameters as discount rate and energy price growth rate.

# 2. BACKGROUND

Paiho et al. (2013) present three different renovation concepts for apartment buildings in a Moscow residential district and estimate their energy saving potentials. Paiho et al. (2014a) continue the analyses further by introducing three corresponding district level energy renovation concepts and analysing the annual energy demands and emissions of different energy production scenarios.

In this section, the housing district and the selected renovation concepts used are briefly introduced. More detailed descriptions can be found from Paiho et al. (2013) & Paiho et al. (2014a). These were used as a base line in the cost analyses presented in this paper.

## 2.1. The housing district selected

A typical residential district was selected for analysis. The district selected mostly represents the 4th Microrayon of Zelenograd, Moscow (longitude 37° east and latitude 55° north). Zelenograd is located about 35 km to the north-west from Moscow City centre. The district dimensions are approximately 1 km × 0.5 km. It represents a typical residential district of Moscow and the Moscow region with high-rise apartment buildings constructed for the most part in the 1960s and 1970s. The district is heated with district heating. Renovation of such buildings and districts may be needed in the near future.

## 2.2. Considered building and district renovation concepts

Selection of the renovation concepts started with an analysis of the current state, which was based on a review of the available literature and on original design U-values. The latter makes the analysis of the current state, and consequently the savings, rather conservative.

Three alternative renovation concepts were selected for the analyses both at the building and at the district level and named Basic, Improved and Advanced. The renovation cases were adjusted in such a way that each of them results in an improvement on a previous one when it comes to total annual energy consumption. The building level cases had different values for the following characteristics: the U-values of building structures (outer wall, base floor, roof, windows and doors), ventilation, air tightness factor, lighting (indoor), electricity and water consumption. The building level improvements included in the previously done (Paiho et al., 2013 & Paiho et al., 2014a) energy and emission analyses are listed in Table 1.

**Table 1. Building level renovation concepts. If not otherwise stated the improved and advanced concepts always include the solutions mentioned in the previous renovation.**

| Technology/ system | Current status | Basic renovation | Improved renovation | Advanced renovation |
|---|---|---|---|---|
| Structures: U-values (W/m$^2$K) | | | | |
| - outer walls | 1.1 | 0.5 | 0.32 | 0.15 |
| - base floor | 1.1 | - | - | - |
| - roof | 1.1 | 0.25 | 0.24 | 0.15 |
| - windows and doors | 2.9 | 1.85 | 1.5 | 1.0 |
| Ventilation | Natural | Restoration of existing natural ventilation.<br>Air inlet valves to ensure sufficient air exchange | Enhanced mechanical exhaust | Mechanical ventilation (supply and exhaust air) with annual heat recovery efficiency 60 % |
| Air tightness factor n50 (1/h) | 6.5 | 4.0 | 2.0 | < 2.0 |
| Heating and hot water systems | Centralized control, no radiator temperature based control.<br>Four-pipe system (centralized substations) | Replacement of radiators and pipes, pipe insulation, simple automated temperature regulators in buildings | Building heating substations and water heating (two-pipe system), thermostatic valves on radiators | |
| Electrical appliances and lighting | | Energy efficient household appliances and lighting of public spaces | Energy efficient pumps and fans in new systems | Elevators – recovery breaking.<br>Presence control of lighting in public spaces |
| Water supply systems (Consumption in l/day/occupant) | Old pipes and water appliances, building-level metering (272 / of which hot water 126) | Replacement of pipes, fixtures and appliances (160) | Installation of water saving fixtures and appliances.<br>Remote meter reading (120) | Household-specific metering (100) |

The basic renovation refers to minimum mandatory repairs as well as easy-to-do retrofit measures, making use of inexpensive products, available on the market, with modest energy properties. The improved renovation improves the thermal insulation of buildings to a level comparable with or higher than current Moscow requirements for new buildings and introduces exhaust mechanical ventilation, which ensures sufficient air exchange rate in apartments. The advanced renovation suggests use of even more progressive solutions, which were considered realistic.

At the district level, different energy renovation scenarios were analysed in terms of energy demand and emissions (Paiho et al., 2014a). Each of the proposed Current, Basic, Improved and Advanced districts contained buildings with a corresponding level of renovation and additionally the improvements suggested in Table 2. The focus was on buildings and infrastructure and thus transportation or other services resulting in further energy demand were not accounted in the district analyses. It should be noted that the measures for space heating system adjustment in buildings are also included in Table 2.

**Table 2. District level renovation concepts compared to the current status. If not otherwise stated the improved and advanced solutions always include the solutions mentioned in the previous renovation.**

| Technology/ system | Current status | Basic renovation | Improved renovation | Advanced renovation |
|---|---|---|---|---|
| Energy production | Energy produced by large-scale plants, mainly using natural gas | Increasing energy-efficiency of generation processes | Reduction of emissions (e.g. change of fuel, or flue gas treatment). | Replacing fossil fuels with renewable energy sources (fuel cells, photovoltaic panels, heat pumps, etc.) and/or increasing plants' efficiency, e.g. increasing the share of CHP plants |
| District heating network (Heat losses, substations, flow/energy/ adjustment/ control) | Poor control<br>High distribution losses | Replacement of distribution pipes (thus reducing distribution losses of district heating)<br>Adding building-level substations and flow control valves | | Heat generation plant is capable of adjusting production according to the variable heat energy demand. Heating network able to buy excess heat production from buildings, so-called heat trading (Nystedt et. al 2006) (for example excess solar heat production) |
| Electricity distribution | Electricity distribution networks design does not allow to feed locally produced electricity to the grid, one-way flow. In some cases networks operate close to their limits, low power factor possible, old equipment (e.g. transformers). | Replacement of old equipment and cables, power factor and harmonics compensation where necessary | | The basic scenario & review of automation systems to allow for connection of distributed generation.<br>Smart meters (in case of demand response and local controllable energy generation) |
| Lighting (outdoor) | | Energy-efficient street lighting | Street lighting designed to avoid light pollution | Smart outdoor lighting (sensor driven), street lighting electrified with solar PV's |
| Water purification and distribution, waste water collection and treatment | Drinking water not safe.<br>High leakage rate in water and sewer networks.<br>Improvement of sewage treatment efficiency where needed | Improved water purification technology.<br>Refurbishment of water and sewer networks | | Smart water network<br>Block scale purification and treatment (to ensure safe local potable water and waste-water treatment) |

# 3. PRINCIPLES OF THE ECONOMIC ANALYSES

## 3.1. Principles from the literature

There are various methods for economic analyses (Remer & Nieto, 1995). In the following, some are briefly presented focusing on the ones which have been used when analysing renovations of Soviet-era apartment buildings (Bashmakov, 2009; Zavadskas et al., 2008; Martinatis et al., 2004; Biekša et al., 2011). In addition, some others are mentioned in order to give a bit wider view even if it is not within the scope of this paper to evaluate cost calculation methods in general.

Bashmakov (2009) use three definitions of energy efficiency potential when studying the extent of possible energy savings across various sectors, including residential buildings, of Russian economy: *technical (technological) potential*, *economic potential* and *market potential*. Cost curves for energy efficiency improvements were developed using the incremental cost approach to identify the cost-effective part of the potential.

Zavadskas et al. (2008) use a market value ratio (MVR), meaning the difference in the market value of the building before and after retrofitting divided by the retrofit cost, to assess the market value of a building. An investment ratio (SIR), which is the present value of energy saved over the lifetime divided by the investment, was used for assessing the cost effectiveness of the energy-saving measures. A retrofit case was considered cost-effective once both the MVR and SIR ratios were positive.

Martinatis et al. (2004) also introduce a “twofold benefit” of building’s renovation — the energy saving and the rehabilitation of the buildings elements physical condition. The formulas determining the profitability of renovation measures made in different parts of a building are proposed. Biekša et al. (2011) further explore the “twofold benefit” methodology and suggest that only the share of financial liability attributed to energy saving should be covered from energy savings, while the rest – from building “purely” renovation funds, accumulated by owners.

Dall’O’ et al. (2012) used a simple payback method in financial evaluation of building envelope improvements in selected Italian municipalities. The information on building surfaces, available for retrofit interventions, was collected to form an energy cadastre. Using the estimated existing and post-retrofitting U-values of windows, roofs and façades, potential energy savings through envelope improvements were identified.

The Buildings Performance Institute Europe (BPIE, 2010) introduced a general methodology for comparing different packages of energy measures to be implemented on reference buildings in terms of economic optimum. The BPIE recommends the use of 31 CEN standards for calculations of energy performance combined with economic evaluation procedure of the European Standard EN 15459. The results of calculations could then be compared to environmental targets and other circumstantial requirements. Through iteration of the results and requirement, the economic optimum can be shifted to support either mid- or long-term targets.

Jacob (2006) empirically quantifies the marginal costs of building energy efficiency investments (i.e. additional insulation, improved window systems, ventilation and heating systems and architectural concepts). The approach is more targeted to illustratively compare costs of individual refurbishment actions, such as different façade insulation thicknesses, rather than for analysing costs of preselected holistic renovation packages. Besides marginal costs of energy efficiency measures and architectural concepts, Jacob (2006) presents economic value of co-benefits (comfort, reduced noise, better indoor air), and claims the co-benefits are of the same order of magnitude as energy-related benefits. Their cost-benefit analysis takes into consideration the future reduction of investment costs through experience curve approach. Our work intentionally didn’t focus on quantifying the co-benefits, as the objective was to look at financial viability of an investment first of all from the point of view of a private third-party, (e.g., an ESCO).

Galvin & Sunikka-Blank (2012) introduce a method for incorporating a factor for fuel price elasticity into models for assessing the net present value (NPV) and payback time of thermal retrofits of existing homes. In a case study, the inclusion of price elasticity is found to lower the net present value, lengthen the payback time and suggest less $CO_2$ savings than estimated. The paper includes only one approach for dealing with uncertainty in calculating NPV and other approaches such as the ones suggested by Hanafizadeh & Latif (2011) should be studied before drawing wider conclusions. In addition, a recent study by Štreimikienė (2014) highlights that demand for energy is generally quite price-inelastic. While price elasticity is important on free fuel markets, in the context of regulated residential tariffs for both district heating and electricity (Korppoo & Korobova, 2012; Kuleshov et al., 2012), as is the case in Russia, it does not play a similar role.

Kumbaroğlu & Madlener (2012) present a techno-economic evaluation method for the energy retrofit of buildings, geared toward finding the economically optimal set of retrofit measures. The case study results indicate that energy price changes significantly affect the profitability of retrofit investments, and that high price volatility creates a substantial value of waiting, making it more rational to postpone the investment. Postponing of an investment may indeed be reasonable in some cases. Due to the free privatization of the housing stock after the Soviet collapse, Russia has become a country of poor owners who cannot afford property maintenance and taxation (Shomina & Heywood, 2013). Thus, in Russia there is significantly more uncertainty associated with estimated initial investments rather than uncertainty of future development of energy prices.

### 3.2. The approach used

In this study, we chose to consider economic attractiveness of investing into additional improvements compared to the basic capital repairs that will in any case be implemented in buildings. The suggested straightforward approach eliminates the need to consider division of an investment into energy-efficiency and structural renewal (the twofold method), since the latter is assumed to be covered by basic capital repairs, no matter whether these are entirely subsidized or paid by residents.

The cost analyses were made with the following process. At first, the costs of renovating the II-18 type building were calculated. These costs were then divided by the total gross floor area of the type building (getting costs per the gross floor area for the type building). Then, the costs for upgrading the district energy and water infrastructure for the II-18 type building were calculated. These costs were also divided by the total gross floor area of the type building. Summarizing these two values (the total costs for renovating one type building and the total costs for upgrading the surrounding infrastructure for one type building), the district wide costs for the II-18 type building were achieved (per the total building gross floor area). Finally, the total district level costs in rubles were achieved by multiplying the previous value with the total gross floor area in the district. The district level cost per inhabitant was calculated by dividing this total district level cost by the number of inhabitants (total population) in the area. This whole process was done for all the cases.

After the cost calculations, the annual heating, electricity and water savings were calculated compared to the calculated current status (as the calculated consumption with the suggested measures minus the calculated consumption with the existing solutions). Then, using the tariffs for the year 2013, tariff savings for each of these components were achieved. The total tariff savings are the summary of these separate tariff savings.

Since the Soviet-era residential apartment buildings are in urgent need of capital repairs (IFC & EBRD, 2012) the baseline used included restoration of buildings to their initial conditions (referring to the mandatory non-energy related repairs) and restorations of buildings using nowadays materials available on the market, which properties have improved over the past 40 years. This baseline is referred to as “the basic renovation”.

The simple payback time was calculated for the renovation solutions going beyond the basic baseline renovation using the following formula:

$$payback\ time = \frac{additional\ investment}{additional\ annual\ savings} \qquad (1)$$

In addition to the previously mentioned calculations and as a last step in the analysis, it was decided to make a further analysis by accounting the net present values for the expected future growth of energy prices since it was noticed that the simple payback times are very long. Net present value (NPV) is one of the most typical techniques used for economic analyses (Remer & Nieto, 1995), for example used by Ferrante (2014), Kurnitski et al. (2011), Kurnitski et al. (2014), Ristimäki et al. (2013), Rysanek & Choudhary (2013), Tommerup & Svendsen (2006), Verbeeck & Hens (2005) & Winkler et al. (2002). The NPV is also suggested by the Energy Performance of Buildings Directive (EPBD) recast of the European Commission as a method for an economic assessment (BPIE, 2010). The net present value of a renovation package is the difference between the present costs of a baseline package and of the considered renovation package. Formula 2 was used to calculate the present cost (PC) of a renovation package over a time period of N years (as being the sum of the investment and the discounted future consumption costs):

$$PC = I + \sum_r \sum_{t=0}^{N-1} \left(\frac{1+g_r}{1+d}\right)^t \times C_r \times P_r \qquad (2)$$

where I – initial investment; $C_r$, $P_r$ – annual consumption and initial price of resource r (electricity, heating, water); $g_r$ – average growth rate of a resource price over future period t [%/100]; d – discounting rate [%/100]. Then the NPV was calculated as follows:

$$NPV = PC_{base\ case} - PC_{package} \qquad (3)$$

## 4. COST ANALYSES

Some renovation solutions could result in multiple benefits, for example, the introduction of heat recovery ventilation which, while consuming additional electricity, results in considerable saving of heating energy, provides better indoor air quality and even enables centralized cooling. The benefit of using multiple energy conservation measures is not the sum of the benefits of using each individual measure due to the interactive nature among different building subsystems and different energy conservation measures (Ma et al., 2012). As the example of recovery ventilation demonstrates, the interdependencies may exist between types of energy resources, in particular between electricity and heating energy. In addition, consumption of water may also be associated with certain energy consumption (e.g., pumping or hot water heating). Therefore, rather than analysing individual measures, it is reasonable to create renovation packages first and only then proceed with evaluation of their economic attractiveness.

The package, corresponding to the “to-be-implemented-in-any-case” basic capital repair was selected as a baseline, and baseline investment and level of resource consumption were determined. Consequently, the value of additional savings obtained as a result of implementing a more advanced renovation was compared to the associated increase of investment. In the case where implementation of more progressive renovation is profitable, there is a chance that a suitable business arrangement could be found.

A similar procedure was followed to identify the most appropriate renovation of districts, represented by groups of typical buildings and associated district infrastructure, to see whether renovation of an entire district may be more economical. No special corrections were made to consider economies of scale, mass procurement, etc.

Table 3 shows the building and district properties used in the calculations. The cost estimations for each building renovation case were based on data from former renovation projects and other available cost data in 2013 collected from various sources in Russia and mainly in Moscow. For some measures, data was not available for the year 2103. For these a couple of years older data was used. The exact price data and sources for the numerous separate products, systems, repairs and installations can be found in Paiho et al. (2014b). These costs were further projected onto the district renovation cases to which costs from infrastructure renovation and energy system were added. So, the building and district renovation concepts were modified to real renovation packages including actual products and systems.

**Table 3. The building and district properties used for cost estimations.**

| **Building (II-18) properties** | | **District properties** | |
|---|---|---|---|
| Total gross floor area | 4,911 $m^2$ | Total gross living area | 327,581 $m^2$ |
| Roof area | 410 $m^2$ | Total roof area | 31,230 $m^2$ |
| Total façade area | 3,060 $m^2$ | Total population | 13,813 |
| Area of apartment windows | 670 $m^2$ | Total surface area of solar photovoltaic | 15,615 $m^2$ |
| Other glazing | 28 $m^2$ | Total surface area of solar collectors | 8,012 $m^2$ |
| Area of walls | 2,355 $m^2$ | | |
| Building length/ width/height | 28/14.5/36 m | | |
| Number of floors | 12 | | |
| Number of residents | 207 | | |

### 4.1. Building level case

The **basic renovation** served as a reference case, where an attempt was made to restore building elements to their original condition, but some additional improvements took place. For example, installation of rather inexpensive space heating system controllers was considered necessary. Another example is installation of relatively inexpensive but modern windows, since the original designs were considered not to be acceptable by residents and even unavailable on the market. The basic renovation package does not meet current Russian construction requirements for new buildings, because only minor wall insulation was envisaged.

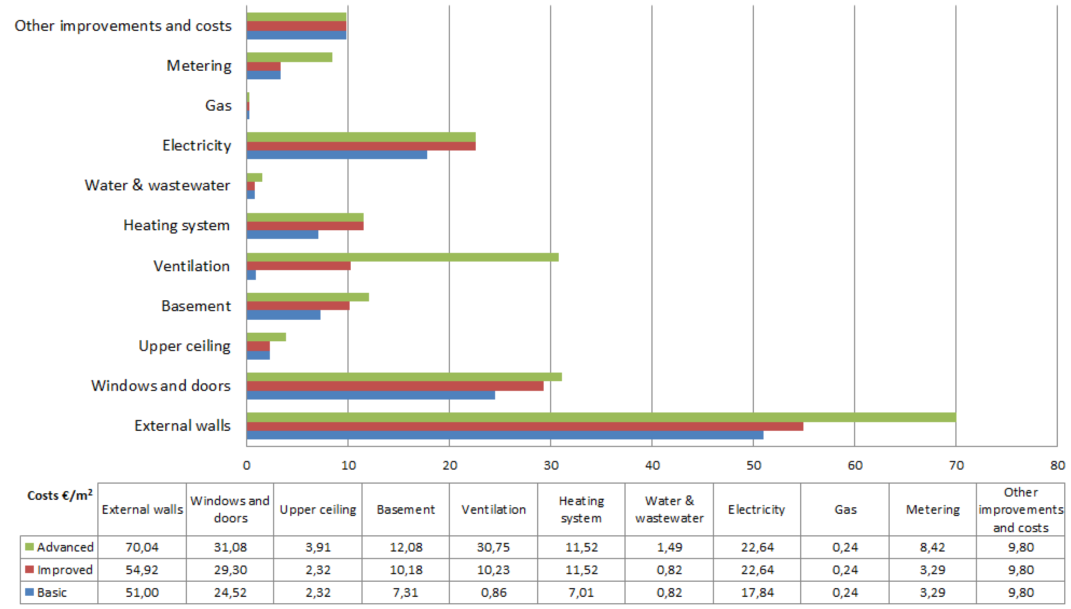
The two other renovation packages, closely matching the more progressive solutions outlined in Table 1, were named accordingly – Improved and Advanced. Thus, all the three cases envisaged improvement measures for external walls/facades, doors and windows, roof, basement, ventilation system, heating system, water and sewage systems, internal networks of electricity and gas, consumption meters, and other improvements.

The **Basic renovation package** contains only the measures involving the restoration of building structures and systems, as well as improvements in thermal insulation in relatively easily accessible areas. The existing ductwork of the natural ventilation system is cleaned and restored where needed. Some improvements were made, even though these were not required, because it would be more feasible to implement them at this stage in combination with other measures than to implement them later separately. For example, renewal of the electricity network in combination with heating and water pipe system reparation could be cheaper since parts of the structures are open.

The **Improved renovation package** includes improvement of thermal insulation of walls to meet the current requirements for new buildings, installation of better performing windows, introduction of mechanical exhaust ventilation and building-level heat substations. It was assumed that the residents purchase water and energy-efficient appliances and fixtures for their own apartments in both the Improved and Advanced models. These investment costs were not included in the cost analysis in this study.

The **Advanced renovation package** includes further improvement of thermal insulation to reasonably high levels, although not the highest possible. Use of thermal insulating façade modules with embedded air supply ducts was envisaged. One of the considerable cost components of this package is a mechanical ventilation system with heat recovery from the exhaust air. This solution does not, however, only reduce heating energy demand but also improves the air quality in the apartments. The improvement in air quality was not considered in the cost calculations.

The set of measures included in the renovation packages was selected so that the expected energy savings were realized. The categorized measures and their costs per square meter of gross floor area can be seen in Figure 1. Paiho et al. (2013) calculated that currently the annual heating energy consumption for the II-18 type building is 219 kWh/m$^2$,a and the annual electricity consumption 47 kWh/m$^2$,a, correspondingly. The earlier calculated energy consumptions and energy savings (Paiho et al. 2013 & Paiho et al. 2014a) and the total costs per gross floor area of the different renovation measures are shown in Table 4.



| Costs €/m² | External walls | Windows and doors | Upper ceiling | Basement | Ventilation | Heating system | Water & wastewater | Electricity | Gas | Metering | Other improvements and costs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 🟩 Advanced | 70,04 | 31,08 | 3,91 | 12,08 | 30,75 | 11,52 | 1,49 | 22,64 | 0,24 | 8,42 | 9,80 |
| 🟥 Improved | 54,92 | 29,30 | 2,32 | 10,18 | 10,23 | 11,52 | 0,82 | 22,64 | 0,24 | 3,29 | 9,80 |
| 🟦 Basic | 51,00 | 24,52 | 2,32 | 7,31 | 0,86 | 7,01 | 0,82 | 17,84 | 0,24 | 3,29 | 9,80 |

**Figure 1. The categorized measures included in the renovation packages of the II-18 type building and their costs per square meter of gross floor area [€/m$^2$]. Prices were calculated in rubles and converted to euros assuming an exchange rate of 40 RUR/€.**

**Table 4. The estimated annual energy consumptions per gross floor area (kWh/m$^2$,a), the corresponding energy savings (%) and the total costs of different renovation packages per gross floor area (€/m$^2$).**

| | **Basic renovation package** | | **Improved renovation package** | | **Advanced renovation package** | |
|---|---|---|---|---|---|---|
| | Heating | Electricity | Heating | Electricity | Heating | Electricity |
| Annual energy consumption (kWh/m$^2$,a) | 134 | 37 | 104 | 35 | 71 | 39 |
| Energy savings (%) | 39 | 21 | 53 | 26 | 68 | 18 |
| Total costs (€/m$^2$) | 125 | | 155 | | 200 | |

## 4.2. District level cases

The district renovation concepts were aligned with the building renovation packages, and the costs of building renovations were included in the costs of improving district energy and water infrastructure. The projection of building renovation costs to district level was based on specific costs per square meter of gross floor area of buildings. Following the analysis of the existing infrastructure in the pilot district, it was decided to utilize a nodal representation, meaning that a node is a location where local distribution infrastructure is connected to main utility networks, the lengths of distribution legs is the same for electricity, heating, water and sewage lines and there are five such legs per node. In practice, this means that one district heating substation or one electricity distribution substation supplied energy to five apartment buildings. In addition, an estimated length of main/trunk utility lines, connecting the nodes with a district connection point located on the edge of the residential area, was allocated to each node. This allowed for distribution of a certain amount of district infrastructure to apartment buildings to make a further estimate of the costs of district infrastructure renovation attributed to one building and compares the costs and effects of building and district renovation cases. The distribution of infrastructure is presented in Table 5. The specific district level costs for each renovation case were thereafter aggregated by extending them onto the total amount of residential gross floor area in the district.

**Table 5. Costs of upgrading the surrounding infrastructure for the II-18 building.**

| Measure | Quantity | Unit | Cost per unit (+ installation cost) (€) | Total cost of measure (€) |
|---|---|---|---|---|
| District heating distribution pipe replacement | 40.00 | meter | 237.5 | 9,500 |
| District heating main pipe replacement | 30.00 | meter | 487.5 | 14,625 |
| District heating substation | 0.17 | Pcs. | 237,500.0 | 39,583 |
| Light bulbs for street lighting | 34.51 | Pcs. | 412.5 | 14,237 |
| Water distribution pipe | 40.00 | meter | 625.0 | 25,000 |
| Water distribution main pipe | 30.00 | meter | 625.0 | 18,750 |
| Water sewage distribution main pipe | 40.00 | meter | 625.0 | 25,000 |
| Water sewage main pipe | 30.00 | meter | 625.0 | 18,750 |
| Electrical grid renewal | 40.00 | meter | 150.0 | 6,000 |
| Main grid renewal | 30.00 | meter | 150.0 | 4,500 |
| Transformer substation | 0.17 | Pcs. | 250.000.0 | 41,667 |

Light bulbs for street lighting were included in all the packages except the basic one. Apart from the Basic, Improved and Advanced cases, two additional alternatives were explored. The additional alternatives called **Advanced+** and **Advanced++ renovation packages** both represent an extension of the advanced district renovation package, and envisage that residential heating demand is provided by geothermal heat pumps, while the electricity demand is partly covered by solar photovoltaic panels (PVs). In the Advanced++ case, heating energy was produced by solar thermal collectors mounted on the roofs of buildings. The cost estimate of implementation these advanced packages was first calculated for the II-18 building and then further projected onto the whole district. At the same time, the need for renewal of the district heating infrastructure was excluded in both the Advanced+ and Advanced++ solutions since the heating energy would then be locally produced. Table 6 shows the additional costs of the on-site energy production solutions in total and floor area-specific terms for the II-18 building.

**Table 6. Renewable energy system costs of advanced district renovation solutions for the II-18 building.**

| Energy production system | Installed amount | Unit | Price (€/unit) | Total cost of system (€) | Cost per living area (€/m$^2$) |
|---|---|---|---|---|---|
| Solar PV peak capacity | 29 | kWp | 2,500 | 73,155 | 14.90 |
| Solar collector peak capacity | 84 | kWth | 800 | 67,264 | 13.70 |
| Ground source heat pump capacity | 151 | kW | 775 | 116,970 | 23.82 |

Similarly, the estimated costs of on-site energy production systems for the type building II-18 were extended to the residential district using specific costs per floor area (specific costs per floor area multiplied with the total (gross) living floor area in the district). Figure 2 shows the total district renovation costs per inhabitant of the different renovation packages including both the building renovations and the infrastructure renovations.

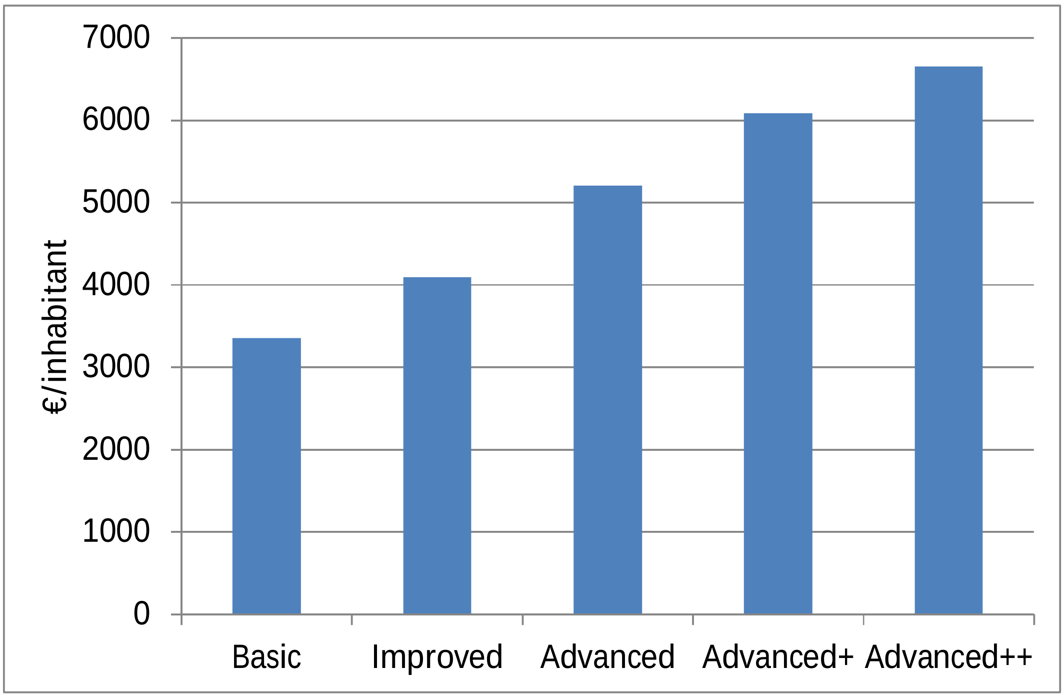
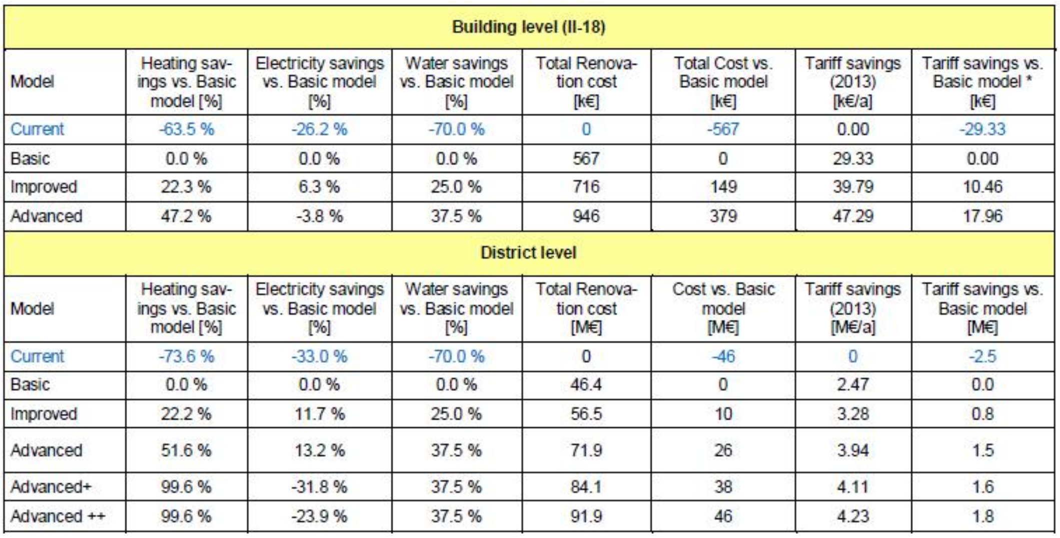


**Figure 2. The total renovation costs per inhabitant of the different renovation packages including renovations of all the apartment buildings in the area and the district energy and water infrastructure modifications.**

Table 7 shows the total renovation costs in euros both for the type building and for the case district as a whole. At the district level, the estimated specific renovation costs of all the building and district renovation packages along with resulting annual energy and water savings are summarized in the lower part of the Table 7. The prices used were for heating €36.5/MWh (1700 RUR/Gcal), for electricity €0.10/kWh (4 RUR/kWh), for water and wastewater €1.21/m$^3$ (48.55 RUR/m$^3$). The prices in euro are based on estimates in rubles that were converted using an exchange rate of 40 (€1=40 RUR).

**Table 7. The total costs and annual energy and water savings comparison of the renovation solutions both in the type building and at the district level (the later including renovation costs of all apartment buildings in the district and the renovation costs of the related energy and water infrastructure).**



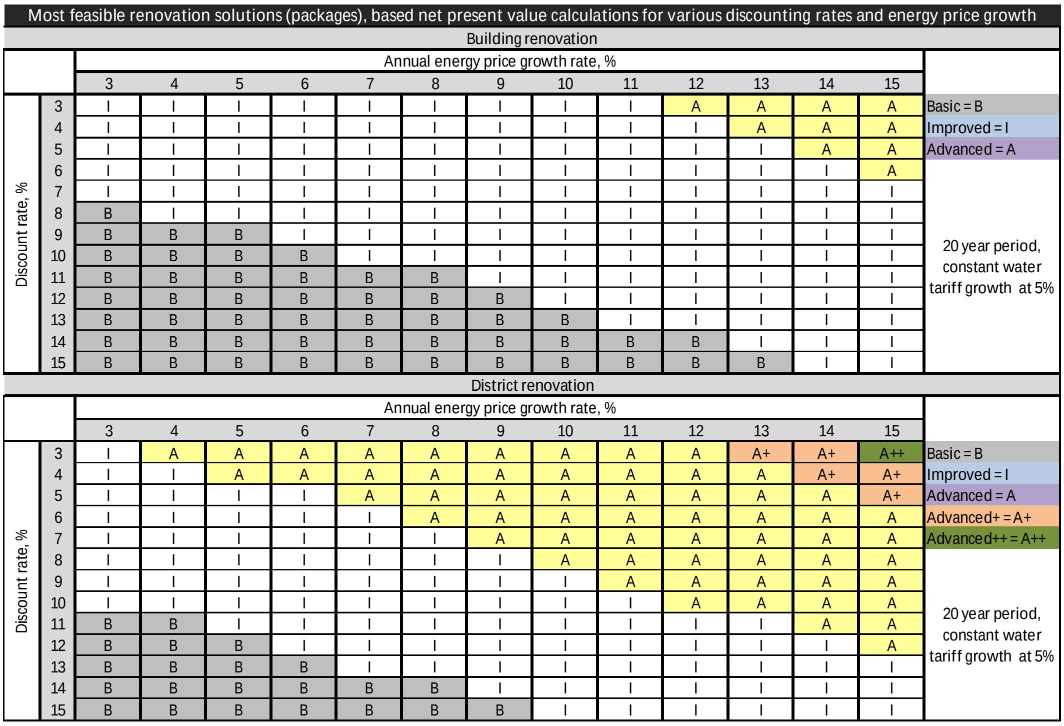
| Building level (II-18) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Model | Heating savings vs. Basic model [%] | Electricity savings vs. Basic model [%] | Water savings vs. Basic model [%] | Total Renovation cost [k€] | Total Cost vs. Basic model [k€] | Tariff savings (2013) [k€/a] | Tariff savings vs. Basic model * [k€] |
| Current | -63.5 % | -26.2 % | -70.0 % | 0 | -567 | 0.00 | -29.33 |
| Basic | 0.0 % | 0.0 % | 0.0 % | 567 | 0 | 29.33 | 0.00 |
| Improved | 22.3 % | 6.3 % | 25.0 % | 716 | 149 | 39.79 | 10.46 |
| Advanced | 47.2 % | -3.8 % | 37.5 % | 946 | 379 | 47.29 | 17.96 |
| District level | | | | | | | |
| Model | Heating savings vs. Basic model [%] | Electricity savings vs. Basic model [%] | Water savings vs. Basic model [%] | Total Renovation cost [M€] | Cost vs. Basic model [M€] | Tariff savings (2013) [M€/a] | Tariff savings vs. Basic model [M€] |
| Current | -73.6 % | -33.0 % | -70.0 % | 0 | -46 | 0 | -2.5 |
| Basic | 0.0 % | 0.0 % | 0.0 % | 46.4 | 0 | 2.47 | 0.0 |
| Improved | 22.2 % | 11.7 % | 25.0 % | 56.5 | 10 | 3.28 | 0.8 |
| Advanced | 51.6 % | 13.2 % | 37.5 % | 71.9 | 26 | 3.94 | 1.5 |
| Advanced+ | 99.6 % | -31.8 % | 37.5 % | 84.1 | 38 | 4.11 | 1.6 |
| Advanced ++ | 99.6 % | -23.9 % | 37.5 % | 91.9 | 46 | 4.23 | 1.8 |

## 4.3. Profitability of the renovation solutions

Investigation of Table 7 reveals that the simple payback time of additional investments into implementing renovations going beyond basic exceeds 12 years. With such long payback periods, the cost of capital plays a significant role, and in order to assess the long-term feasibility net present values (NPV) over the period of 20 years were calculated and a sensitivity analysis performed. As expected, the long-term viability varied significantly depending on the scenario of assumed discounting rates and rates of energy price growth. Despite the annual energy price rises in Russia have been over 10 percent in recent years, the long-term economic forecasts envisage that growth will be slowing down beyond 2020. The development of water supply and wastewater treatment tariff growth was assumed to be stable at a level of 5% annually. The results of the NPV calculations are summarized in Table 8. Since in the NPV calculations for the district renovations show that solutions going beyond the basic have the highest NPV in a larger domain of combinations of discounting rates and energy price growth rates, it perhaps becomes feasible to implement more advanced renovations in case a renovation project is to cover a residential district. Thus, the results suggest that renovation of a district may be more feasible than renovation of individual buildings.

The Advanced+ and Advanced++ solutions are unlikely to be feasible unless a rapid growth of energy prices in combination of low capital cost is assumed. At the same time, implementation of such renovations may substantially reduce emissions (Paiho et al., 2014a).

**Table 8. Renovation packages having the highest net present value over period of 20 years in various scenarios.**



Most feasible renovation solutions (packages), based net present value calculations for various discounting rates and energy price growth

Building renovation

| Discount rate, % | Annual energy price growth rate, % | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
| 3 | I | I | I | I | I | I | I | I | I | A | A | A | A | Basic = B |
| 4 | I | I | I | I | I | I | I | I | I | I | A | A | A | Improved = I |
| 5 | I | I | I | I | I | I | I | I | I | I | I | A | A | Advanced = A |
| 6 | I | I | I | I | I | I | I | I | I | I | I | I | A | |
| 7 | I | I | I | I | I | I | I | I | I | I | I | I | I | 20 year period, constant water tariff growth at 5% |
| 8 | B | I | I | I | I | I | I | I | I | I | I | I | I | |
| 9 | B | B | B | I | I | I | I | I | I | I | I | I | I | |
| 10 | B | B | B | B | I | I | I | I | I | I | I | I | I | |
| 11 | B | B | B | B | B | B | I | I | I | I | I | I | I | |
| 12 | B | B | B | B | B | B | B | I | I | I | I | I | I | |
| 13 | B | B | B | B | B | B | B | B | I | I | I | I | I | |
| 14 | B | B | B | B | B | B | B | B | B | B | I | I | I | |
| 15 | B | B | B | B | B | B | B | B | B | B | B | I | I | |

District renovation

| Discount rate, % | Annual energy price growth rate, % | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
| 3 | I | A | A | A | A | A | A | A | A | A | A+ | A+ | A++ | Basic = B |
| 4 | I | I | A | A | A | A | A | A | A | A | A | A+ | A+ | Improved = I |
| 5 | I | I | I | I | A | A | A | A | A | A | A | A | A+ | Advanced = A |
| 6 | I | I | I | I | I | A | A | A | A | A | A | A | A | Advanced+ = A+ |
| 7 | I | I | I | I | I | I | A | A | A | A | A | A | A | Advanced++ = A++ |
| 8 | I | I | I | I | I | I | I | A | A | A | A | A | A | 20 year period, constant water tariff growth at 5% |
| 9 | I | I | I | I | I | I | I | I | A | A | A | A | A | |
| 10 | I | I | I | I | I | I | I | I | I | A | A | A | A | |
| 11 | B | B | I | I | I | I | I | I | I | I | I | A | A | |
| 12 | B | B | B | I | I | I | I | I | I | I | I | I | A | |
| 13 | B | B | B | B | I | I | I | I | I | I | I | I | I | |
| 14 | B | B | B | B | B | B | I | I | I | I | I | I | I | |
| 15 | B | B | B | B | B | B | B | I | I | I | I | I | I | |

## 5. DISCUSSION AND CONCLUSIONS

The economic attractiveness of the suggested holistic energy-efficient renovation packages of multi-family apartment buildings and the related residential districts in a typical Russian neighbourhood were analysed by comparing the additional improvements to the basic capital repairs that in any case need to be implemented. This study is a forerunner and a pioneer since similar cost analyses for holistic district energy renovations including energy improvements for the whole energy chain from production to consumption have not been done for Russian or any other countries’ residential districts.

In the buildings, the cost analyses included the cost for improvements of external walls, windows and doors, upper ceiling, basement, ventilation, heating system, water and wastewater, electricity (including replacement of elevators), gas, metering, and other improvements and costs (including improving of public spaces). At the building level, the costs per gross floor area of the different renovation measures were €125/m$^2$ for the basic package, €155/m$^2$ for the improved package and €200/m$^2$ for the advanced package.

With the suggested building-level renovation packages, the estimated energy and water savings potential is remarkable compared to packages of the only other study (IUE, 2011) including concrete solutions with cost estimates. In addition, the ventilation repairs are included which would further improve the indoor conditions. Still, the estimated maximum costs were only about €30/m$^2$ higher than in IUE (2011).

Apart from energy savings, there are other benefits, the ones discussed by e.g., Næss-Schmidt et al. (2012), that may result from the renovation of apartment buildings. These benefits are not as easily measureable as energy savings, but could improve, for example, thermal comfort, health, the living standard of residents and raise overall attractiveness of local urban environment. Neither these benefits nor increasing property value for owners were considered, since these are unlikely to benefit third-party investors. At the same time, stressing the additional benefits to be enjoyed by the residents may increase acceptance and possibly even encourage minor participation by (some) apartment owners in financing.

The district renovation concepts were aligned with the building renovation packages, and the costs of building renovations were included in the costs of improving district energy and water infrastructure in the pilot district. Apart from the Basic, Improved and Advanced cases, two additional alternatives were explored. The additional alternatives, called Advanced+ and Advanced++ renovation packages, both representing an extension of the advanced district renovation package, were also calculated. In the district level, the costs per inhabitant varied between €3,360, €4,090 and €5,200 for the Basic, Improved and Advanced renovation packages, respectively. The costs of the additional alternatives per inhabitant were over €6,090.

Simple payback time (i.e., the ratio of initial investment to costs of annual savings) for the additional improvements beyond the basic renovations exceeds 12 years. In addition to the costs, also the net present values for different building and district level renovation packages for a 20-year period were calculated with different interest rates and annual energy price growth rates. The results indicate that both at the building level and the district level, with most combinations of the interest rate and annual energy price growth rate, the Improved renovation package will be the most profitable. This result is interesting for private investors to consider whether to finance more energy efficient renovations.

The non-monetary benefits that could further improve the attractiveness and value of the whole area were not evaluated in the results when estimating the profitability. In addition, such component of operational costs as maintenance was not included into the calculations due to a lack of reliable data.

Energy tariffs are subsidized in Russia (Korppoo & Korobova, 2012) and they do not follow or even cover the production costs. Thus, the actual fuel price does not have a similar effect on the tariffs as in the Western countries. Due to this reason, the fuel price elasticity was not taken into account even if it may have a considerable impact on the results as shown by Galvin & Sunikka-Blank (2012) in their case study.

Typically, neither energy production nor consumption is metered in Russia (Korppoo & Korobova, 2012; Kuleshov et al., 2012. According to the Russian Federal Law No. 261-FZ from 2009 “On Energy Saving and Energy Efficiency…” a) homeowners and owners of apartments are to install energy meters on the flat level, except heat meters and b) renovated buildings must be equipped with heat meters to the extent technologically possible. The progress with installations of metering is extremely slow and measured data on energy usage is hardly ever available. Thus, even if there can be large disparity between calculated and actual heating consumption taken this into account in the cost calculations would have been challenging in the Russian conditions. This issue could be a topic of further research when metering becomes more common.

Preparing cost estimates for renovation packages was challenging due to various factors. First of all, the prices vary depending on contractors/suppliers. Secondly, there is an uncertainty in defining the scope of basic repairs, which may vary from building to building; our assumption, based on the literature review, was that no major structural improvements were needed. Furthermore, there is an interdependency of the measures needed and the total cost of implementing several measures is likely to be lower than their individual costs if implementation takes place separately. For example, the total cost of window installations and façade thermal insulation may be lower if implemented simultaneously. Although some of the costs are based on previous cases, the costs of some, such as for example, mechanical ventilation, were assumed to be close to those implemented outside Moscow.

It should be noted that physical energy and water savings may vary somewhat year by year due to changing weather conditions, changing habits, varying stock and efficiencies of household appliances, etc. However, since there exist various other changing variables in the analyses the intention of this work was anyway rather to assess the magnitude of the costs than to generate the exact values. However, the cost estimates can be used as an initial and reference data when planning building and district renovations in Russia, convincing different stakeholders and developing financing models for such renovations. So, this paper makes a significant contribution to knowhow on the sustainable renovation market in Russia.

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