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Dissertation

72

Energy-efficient renovation of residential districts

Cases from the Russian market

Satu Paiho

VTT SCIENCE 72

Energy-efficient renovation of residential districts

Cases from the Russian market

Satu Paiho

Dissertation for the degree of Doctor of Science (Tech.) to be presented with due permission of the School of Engineering for public examination and criticism in Lecture Hall 216, in Building K1 at Otakaari 4, Espoo, at Aalto University, on the 12th of December 2014 at 12 noon.

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Preface

Just a year ago, I could not have imagined that I would someday decide to finalize my doctoral studies. After having done the post-graduate courses already about 20 years ago, I did not have any motivation to continue with the dissertation itself. But this research theme was interesting enough to motivate me to write the dissertation. Perhaps this process is well suited to a marathon runner. There are obvious similarities in these two matters: a long training period, an intensive finishing section, a relatively short event, a moment of satisfaction in the end, and finally setting new targets after the occasion. In addition, during the long training hours, there has been lots of time to think and restructure thoughts – and that is exactly what is needed in writing a dissertation.

The research was performed in the ModernMoscow project, funded by the Ministry of Foreign Affairs of Finland. I want to thank Mr. Petri Haapalainen from the Ministry of Employment and the Economy as being our contact on the funding side. VTT Technical Research Centre of Finland provided me with funding for one month to finalize this overview.

There were two individuals at VTT without whom I would never have started this effort: Prof. Dr., VP Abdul Samad (Sami) Kazi and Dr. Isabel Pinto Seppä. I greatly value your full trust in me over the years we have known each other. During this dissertation process, Sami as my advisor was always there for me whenever I needed some encouragement, had a moment of disbelief, or just wanted to discuss the subject. Sami also gave me extremely valuable guidance for the work. Isabel was my final motivator even to start this work, when she urged me to “wrap it up”. Her kind, warm, and emphatic support has been most helpful and important on many occasions. Sami and Isabel, there are no words to express how grateful I am. I thank you both from the bottom of my heart!

I want to express my sincerest gratitude to my supervisor, Prof. Dr. Risto Lahdelma from Aalto University School of Engineering. He openly welcomed a middle-aged lady to return to academic studies, and kindly guided me through the process. I would also like to thank Dr., Senior University Lecturer Minna Sunikka-Blank from University of Cambridge and Prof. Dr. Frede Hvelplund from Aalborg University for pre-examining this overview and Prof. Dr. Jan-Olof Dalenbäck from Chalmers University of Technology for acting as an opponent for my dissertation.

I am grateful to my co-authors, Mr. Rinat Abdurafikov, Mrs. Malin zu Castell-Rüdenhausen (former Meinander), Mrs. Åsa Hedman, Mr. Ha Hoang, Dr. Johanna Kuusisto and Ms. Mari Sepponen from VTT. Unfortunately, Mr. Ilpo Kouhia is not with us anymore to hear my acknowledgements. Without his practical experience, formulating the renovation concepts would have been much harder. I am extremely grateful to Rinat and Ha for their help during this work. Rinat always kindly explained to me the Russian way of thinking, and "how things are in Russia". His help in interpreting the Russian data was of vital importance. Ha was always willing to help with whatever new detail I discovered. Gentlemen, I see the great potential you have. Maybe someday I will be able to join you defending your dissertations.

I want to thank my mother and stepfather Irja and Pauli Hirsivaara for their love and support. I have always been able to count on you whenever I have needed help with the kids. You have also taught them many practical skills, such as berry picking, cooking, fishing, lighting the fire, and rowing. I am sure the boys will value these for the rest of their lives.

Last but not least, I want to mention my husband Juhani, and our sons Lauri and Matti. Boys, you are precious to me. I dedicate this work to you. And I'll keep on running…

Helsinki, August 2014
Satu Paiho

Academic dissertation

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List of publications

This dissertation is based on this overview and the following original publications which are referred to in the text as I–IV. The publications are reproduced with kind permission from the publishers

I Paiho, S., Hedman, Å., Abdurafikov, R., Hoang, H., Sepponen, M., Kouhia, I. & Meinander, M. 2013. Energy saving potentials of Moscow apartment buildings in residential districts. Energy and Buildings 66 (2013) 706–713. http://dx.doi.org/10.1016/j.enbuild.2013.07.084

II Paiho, S., Hoang, H., Hedman, Å., Abdurafikov, R., Sepponen, M. & Meinander, M. 2014. Energy and emission analyses of renovation scenarios of a Moscow residential district. Energy and Buildings 76 (2014) 402–413. http://dx.doi.org/10.1016/j.enbuild.2014.03.014

III Paiho, S., Abdurafikov, R. & Hoang, H. 2015. Cost analyses of energy-efficient renovations of a Moscow residential district. Sustainable Cities and Society 14 (2015), pp. 5-15. http://dx.doi.org/10.1016/j.scs.2014.07.001

IV Paiho, S., Abdurafikov, R., Hoang, H. & Kuusisto, J. 2015. An analysis of different business models for energy efficient renovation of residential districts in Russian cold regions. Sustainable Cities and Society 14 (2015), pp. 31–42. http://dx.doi.org/10.1016/j.scs.2014.07.008

Author's contributions

The author was the first and main author in all the publications. All the work done for publications was performed in the MoscowModern project, led and managed by the author. All the research was done together with the co-authors but under supervision and planning by the author. The co-authors performed the calculations and provided comments and corrections to the articles. Analyzing the results was done together. In Publication IV, the co-authors had a minor role.

Contents

Appendices

List of abbreviations

Bio	biogas
BIPV	building integrated photovoltaic
BM	business model
CHP	Combined Heat and Power
CO_2	Carbon dioxide
EE	energy-efficiency
ESCO	Energy Service Company
GSHP	ground source heat pump
MSW	municipal solid waste
Nat	natural gas
NPV	net present value
PV	photovoltaic
ref.	reference
RES	renewable energy sources
RQ	research question
SO_2	Sulfur dioxide
SPV	solar photovoltaic
STH	solar thermal heating/collector
TOPP	tropospheric ozone precursor potential
WF	wind farm
4P	Public-Private-People Partnership

1. Introduction

The energy strategy of Russia for the period up to 2030 states that Russia must improve its energy-efficiency and reduce the energy intensity of its economy to the level of countries with similar climatic conditions, such as Canada and the Scandinavian countries (Ministry of Energy of the Russian Federation, 2010). In addition, it is required that Russia's living standards must correspond to those of the developed countries. This strategy is supported by the adoption of Federal Law No. 261-FZ "On Energy Saving and Energy Efficiency…", which clearly represents a significant move toward an increase in public awareness of the importance of energy saving, and presents substantial business opportunities for companies working in various sectors of the economy (CMS, 2009).

Estimates suggest that Russia could improve its primary energy-efficiency by 45% compared with 2005 (Bashmakov et al., 2008). Full use of the potential for electrical energy savings could reduce consumption by 36%; a more efficient use of thermal energy and reduction of losses in heating networks could save up to 53% of heat use; the potential for reducing natural gas consumption was estimated at 55% of the domestic consumption level in 2005, much exceeding the annual level of Russian gas exports in 2005–2008 (UNDP, 2010). Apart from energy-efficiency, high-quality renovation of buildings could also have other benefits, such as improved quality of the indoor environment, improvement of physical performance, and increased property value (e.g., Baek & Park, 2012a; Menessa & Baer, 2014).

In Russia, there are nearly 20 million residential buildings with a total floor area of over 3 300 million m^2 (Federal Service for State Statistics, 2013). 42% of these buildings were built during 1946–1970 and 30% during 1971–1995 (Figure 1). It is estimated that more than 290 million m^2, or 11% of the Russian housing stock, needs urgent renovation and re-equipment, while 250 million m^2, or 9% should be demolished and reconstructed (United Nations, 2004). About 60% of the country's total multi-family apartment buildings are in need of extensive capital repair (IFC & EBRD, 2012). In 2009, the total costs of capital repairs of apartment buildings in Russia amounted to 137 500 million rubles (€3,140 million) (IUE, 2011).

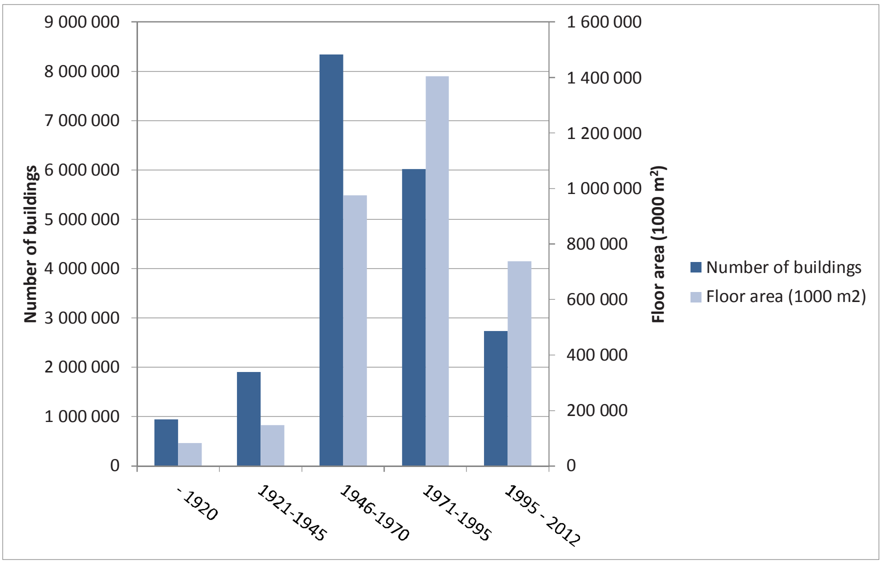

Figure 1. Russian residential buildings by the year of construction (Source: Federal Service for State Statistics, 2013).

District heating accounts for 70% of total heat supply, at least in urban areas in Russia (Masokin, 2007; Nuorkivi, 2005). Due to the technical structure of the district heating used in Russia, heating typically cannot be controlled in Russian apartment buildings (Eliseev, 2011; Nuorkivi, 2005), meaning that energy renovations of single buildings seldom lead to reduced energy production. Because heat exchangers are lacking between district heating networks and the buildings in Russia, reduced energy demands in buildings do not lead to savings in the beginning of the energy chain but may instead even lead to overheating of the building. Energy production demands will reduce only if the residential districts and their various utilities and networks are renovated holistically. The district renovations would include renovations of the buildings and all their technical systems, modernization of heating energy production and distribution systems, renovation of local electricity production and transmission systems, renewal of street lighting, renovation of water and wastewater systems, and modernization of waste management systems. This topic is not addressed in the scientific literature as discussed in Section 2.1. It is the focus of this dissertation.

2. Problem identification analysis

This chapter concentrates on the research setting. First, the relevant literature is introduced and analyzed, including arguments for renovation and demolition. On this basis, the research gaps are identified, the research questions set, and the dissertation contribution placed. Finally, the outline of the dissertation is described.

2.1 Literature review

Quite a limited amount of international scientific literature is available about the energy-efficiency of Russian residential districts. Figure 2 illustrates the issues and topics relevant to the dissertation, as they are addressed in the scientific literature. The key findings are briefly introduced in this section.

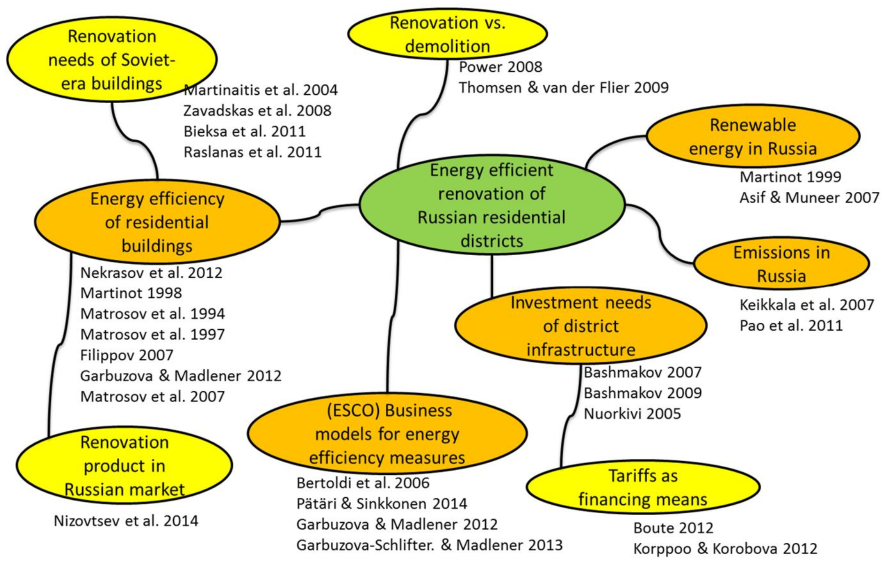

Figure 2. Issues addressed in the international scientific literature.

During the Soviet era, starting in the late 1950s, the housing problems of the Soviet Union were solved by building poorly insulated big blocks of flats and heating them with district heating solutions implemented inefficiently. These energy-wasting buildings and facilities still comprise a majority in Russian cities (Figure 3), although it was assumed that in 25 years, better dwellings and systems would replace them (Nekrasov et al., 2012).

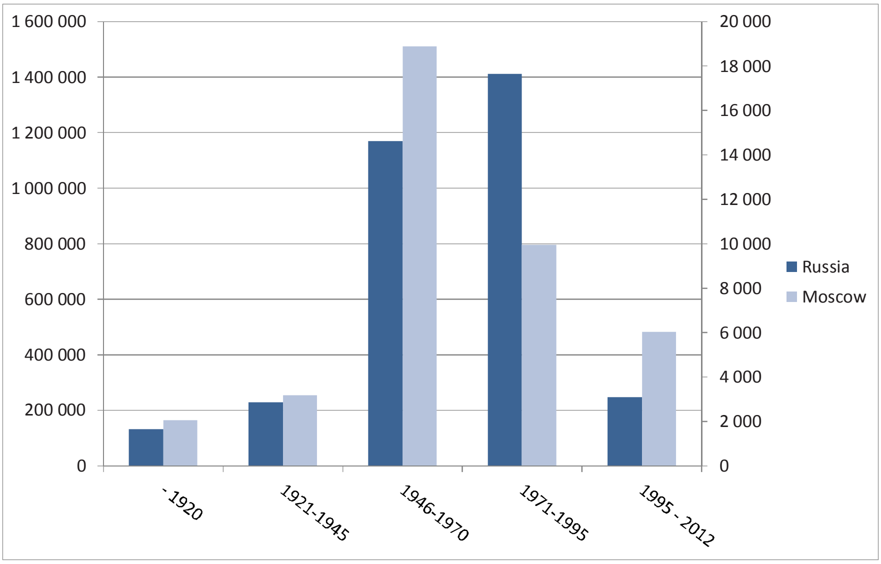

Figure 3. Number of apartment buildings by the year of construction in Russia and in Moscow (Source: Federal Service for State Statistics, 2013).

Studies on the energy consumption and energy-efficiency of Russian buildings have been made already in the 1990s, and they indicate the need for energy-efficiency improvements of Russian housing (Martinot, 1998; Matrosov et al., 1994; Matrosov et al., 1997; Opitz et al., 1997). There are quite a few recent references (Filippov, 2009; Garbuzova & Madlener, 2012; Matrosov et al., 2007), but they also discuss the considerable potential for improving energy-efficiency in Russian residential buildings and the related infrastructure in districts.

Nizovtsev et al. (2014) describe a new thermal-insulating façade system for newly constructed and renovated buildings, based on heat-insulating panels with ventilated channels. The thermal insulating façade systems based on the ventilated channel panels were installed in more than ten new and renovated buildings in Novosibirsk and Novosibirsk Region. The experience gained in installation of the new façade system in renovated buildings proved the possibility of performing efficient, good-quality installation work. Thermal imaging confirmed the high efficiency of the panels for heat insulation of reconstructed buildings.

Martinaitis et al. (2004), Zavadskas et al. (2008), Biekša et al. (2011), and Raslanas et al. (2011) highlight the renovation needs of the Soviet-era apartment buildings in Lithuania. The focus is on economic feasibility, but potential measures are also discussed. Neighborhood issues are partly introduced (Table 1), but only improvements to buildings are analyzed. In addition, the neighborhood issues addressed mainly deal with the social issues and needs to improve the surroundings, not the needs and solutions to improve the related energy and water infrastructures.

Table 1. Building and district-level renovation aims addressed by Raslanas et al. (2011).

Strategies for retrofit of apartment buildings and their environmental aims	Strategies for modernization of areas with apartment buildings must have the following key goals
• to cut energy consumption • to cut building maintenance costs • to reduce the effect of polluting factors thus boosting the value of the environment • to improve the condition of buildings and to extend their service (30–40 years) • to improve the indoor comfort • to improve the quality of buildings and to make urban areas more attractive • to increase the market value of buildings • to attract and retain the middle classes	• to improve living standards and the quality of environment • to cut energy consumption and CO_2 emissions • to maintain mixed social structure • to integrate new buildings in the existing environment in a sustainable manner • to develop an urban center of a residential area as a functioning part of the city • democratic planning • close cooperation of partners involved in modernization • lasting retrofit and facilities management

Martinot (1999) analyses the feasibility of renewable energy in Russia. In 1999, among those with the most potential were: district heating for buildings from biomass, hot water for buildings from solar thermal, and electricity and heat from geothermal. Even today, utilization of renewable energy is quite low in Russia (Asif & Muneer, 2007).

Keikkala et al. (2007) estimate the potential for reduction of fossil fuel consumption and CO_2 emissions in Murmansk Oblast. The potential for energy-efficiency, and reduced fossil fuel consumption and greenhouse gas emissions is estimated by comparison with the city of Kiruna in Northern Sweden, with a climate similar to that of North-East Russia, and with an iron ore mining company. The results are shown on municipal and industry levels. It is highlighted that the energy-efficiency improvement potential in buildings in the municipalities is 30–35%.

Pao et al. (2011) apply the co-integration technique and causality test to examine the dynamic relationships between pollutant emissions, energy use, and real output during the period between 1990 and 2007 for Russia. The results indicate that both economic growth and energy conservation policies can reduce emissions without a negative impact on economic development. Hence, in order to reduce emissions, the best environmental policy is to increase infrastructure investment to improve energy-efficiency, and to step up energy conservation policies to reduce any unnecessary use of energy.

Bashmakov (2007) estimates 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 106 000 million; in district heating renovation at $US 27 000 million; in pipeline transportation at $US 23 000–30 000 million; and in buildings at $US 25 000–50 000 million. Nuorkivi (2005) estimates that the investment needs for rehabilitating the district heating systems will be at US$ 70 000 million by the year 2030 in Russia. These numbers show the significant modernization markets, even if the exact values differ.

The Russian regional authorities can require heat companies to implement ambitious energy-efficiency improvement measures and guarantee the financial viability of these measures by adopting appropriate tariffs (Boute 2012). At the moment, heating tariffs fail to cover the costs of production, distribution, and the massive need for modernization of residential heating (Korppoo & Korobova 2012). At the federal level, short-term (heat) price increases are a very sensitive issue and a serious obstacle to the implementation of energy-efficiency and renewable energy initiatives (Boute 2012).

The ESCO (Energy Service Company) is one business model often suggested for building energy-efficiency measures. ESCOs offer energy services to final energy users, including the supply and installation of energy-efficient equipment, and/or building refurbishment, maintenance and operation, facility management, and the supply of energy including heat (Bertoldi et. al, 2006). The overall aim of an ESCO is to be a supplier of cost-effective energy-efficiency services (Pätäri & Sinkkonen, 2014). In Russia, ESCO activities are still in a nascent stage, at least when compared to a “Western-ESCO” (Garbuzova & Madlener, 2012). Garbuzova-Schlifter and Madlener (2013) point out the main problems in the Russian energy service industry: lack of government support, a high credit risk of energy-efficiency projects, lack of awareness of the energy-efficient potential, a weak legal and contract enforcement framework, and bureaucracy.

2.1.1 Renovation or demolition

It is sometimes argued whether old buildings should be renovated or demolished and new ones built to replace them. No exact demolition rates exist for Russia, but still especially “Khrushchevki” apartment buildings built in 1950s are being demolished (Figure 4). However, statistics indicate that the annual demolition rate is below 1% of the total housing stock (Federal Service for State Statistics, 2011), including housing other than just apartment buildings. Table 2 expresses arguments for both cases in the Western European context, based on the literature. From a sustainable perspective, life-cycle extension appears preferable to demolition, followed by replacement with new construction (Thomsen & van der Flier, 2009). Only the most extreme physical conditions justify such high social, economic, and environmental costs related to demolition (Power, 2008). Evaluating demolition and rebuilding against renovation in the Russian context is not within the scope of this dissertation. Thus, this dissertation does not consider the demolition and rebuilding alternative, but fully concentrates on renovation.

Table 2. Issues related to renovation and demolition with rebuilding addressed in the Western European context (Power, 2008; Thomsen and van der Flier, 2009).

Renovation	Demolition and rebuilding
• preserves the basic structure of the property • renewal gives a clear signal that the neighborhood is worth investing in • upgrading is quicker than demolition and replacement building • less disruptive to residents • involves a shorter and more continuous building process, since most of the work can happen under cover in weatherproof conditions • has a positive impact on the wider neighborhood, sending a signal that renewal and reinvestment will ensure the long-term value and stability of an area • adds value and attractiveness to the whole area • for materials and waste, the environmental impact of life-cycle extension is less than demolition and new construction	• involves the loss of homes and the cost of new replacements • causes damage to neighboring properties • even in the most unpopular areas, the majority of homes are occupied • even plans have knock-on effects on local services • ugly gaps often remain for decades • loss of social infrastructure and social capital • reduced housing capacity • slow rebuilding timescales • blighting effects in poorer neighborhoods • loss of materials • impact on landfill sites • transportation of materials to/from demolition sites • particulate pollution • shifting social problems from one place to another • not easy to establish when a dwelling has lost its basic performance

Tuesday, June 10, 2014 | REAL ESTATE | The Moscow Times • 7

A bulldozer crawling over a pile of debris during the demolition of one of Moscow's five-story apartment blocks.

Moscow Flattening Old Dwellings

By Mark Lammey
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Demolition men have flattened 1,438 of Moscow's Khrushchevki — cheaply built 1950's apartment blocks that were never meant to make it into the 21st century — in the last 15 years, as part of a foundering plan by ex-Mayor Yury Luzhkov to freshen up residential areas, the head of construction at City Hall said Monday.

In total, 114 blocks will be knocked down this year — 93 at the expense of the city budget and 21 by investors in construction — thereby wrapping up work in five of Moscow's 12 administrative districts. Moscow's construction chief Andrei Bochkaryov told Vedomosti that by the beginning of 2016, no more than 30 of the architectural relics should remain.

The demolition drive should have been wrapped up four years ago, but due to the economic crisis of 2009 and changes in housing legislation, 271 of the doomed five-story apartment blocks still stand. Bochkaryov is contrite — "Muscovites who have been promised rehousing should not have to suffer because someone has not fulfilled their duties," he said.

Suffering is the word. Khrushchevki were built at breakneck speed in the late-1950s and early 1960s — during Nikita Khrushchev's leadership — to satisfy the rapidly growing demand for housing in Moscow and throughout the Soviet Union. Usually built from scratch in as little as 45 to 50 days, they were only meant to last for 25 years, but many have stood for twice as long, turning into dilapidated eyesores.

The outdated technology used during construction rendered the apartment blocks unsuitable for renovation, and in 1999, then-Mayor Yury Luzhkov ordered 1,722 of them to be razed by 2010. The authorities stipulated that the apartment blocks could only be torn down after its residents had been rehoused.

The most productive period was between 2006 and 2007 — just before the 2008 to 2009 economic crisis decimated the Russian economy — when 680 were knocked down. By 2009 the plan was 70 percent complete, but it struggled to recover its momentum as Russia emerged from recession. Only 48 were demolished in 2010, and 31 the following year, as developers labored to cope with the responsibility of rehousing people.

Oleg Repchenko, head of the analytical center at real estate company IRN, told the paper that investors are still shaken by the crisis and don't want to take risks, whereas in 2008 they were fully confident that their construction projects would yield returns. "Few believe that the value of real estate will grow. On the contrary, many are worried that it will start to get cheaper," Repchenko said.

Amendments made to housing legislation in 2013 also stopped the wrecking balls from swinging quite as regularly, as Moscow authorities were forbidden from assigning land to developers without conducting a tender. Of the 13 companies that have been involved in the demolition project at some stage, only five have renewed their contracts with City Hall.

Remstroitrest is one of the remaining investment and construction companies to have a contract. It has been a partner of the city since 1996 and is now investing about $437 million in nine apartment blocks in Moscow's Obruchevsky district. It plans to finish the project by 2017. Those who wish to return to their old address once the new property has built are often priced out, but Remstroitrest has set aside 30 percent of the new apartments for prospective returnees to bid on at a lower price. The remaining 70 percent can be put on the market at whatever price the company sees fit.

Repchenko said that the burden of rehousing residents is another reason investors have shied away in recent times.

Part of the problem is having to deal with the residents who will be displaced by the demolition. They could flatly refuse to leave or issue demands that would make the project unprofitable for the developer, and that can drag out the length of the project. Those risks could be swallowed when the market was booming, but the slowdown changes the logic.

Moscow's old five-story apartment blocks are being phased out steadily.

Builders Trying Out 'New Technologies'

By Alexander Panin
a.panin@imedia.ru

Until the demand for cheap and affordable housing is satisfied in Russia, there will be no incentive to use modern materials or advanced technology to improve the quality of the living quarters that are being built for most consumers.

This was one of the conclusions that was reached in Moscow last week during a roundtable on the problems associated with introducing new technologies in construction.

"New technologies" refers to the broad range of solutions that improve living standards, including better lighting, ventilation, soundproofing, insulation and energy efficiency.

Russia is far from being the world's leader in using new materials and technology in construction and any attempts to change that are hindered by the need to build apartments quickly and cheaply, industry experts said.

The average resident in Russia is still squeezed into 22 square meters, which is two times less than in France or Britain, said Gonzague de Pirey, chief of operations in Russia, Ukraine and the CIS for Saint-Gobain, a Paris-based international construction group.

President Vladimir Putin has repeatedly stressed the need for more affordable housing in Russia. The upshot is that apartments made from standard concrete blocks spring up rapidly all over major cities, while governors proudly report increases in living space in their regions.

In Moscow the aim is to build 3.2 million square meters of residential space this year, according to Deputy Mayor Marat Khusnullin, who oversees construction in the city. "Our plan is to further build no less than 3 million square meters per year," Khusnullin has said.

Measuring everything in square meters is a very formal approach to housing construction that will not provide quality, just quantity, said a prominent Russian architect Mikhail Khazanov, adding that the term "innovation" may only be applied to about 1 percent of what is currently built in Russia.

"Construction businesses today aim for fast returns on investment, using cheap labor, which puts barriers on innovation. They are building as fast as possible, with no real care for quality," he said.

Moreover, most consumers do not prioritize improved ventilation, better insulation and energy efficiency when choosing their new home.

"The main criteria for choosing a house is its price and location, although consumers do want better value for money," said Yana Sozonova, deputy head of the NDV real estate company.

Customers do inquire about the kind of construction materials were used, and about the quality of ventilation and windows. "But questions as to whether there is air conditioning, for instance, are only addressed to find out if they would have to incur extra expenses, something that is not desired," she said.

Top-notch engineering systems, quality materials and safety, however, become more important as potential buyers' incomes grow, developers said.

"In our elite housing projects we use modern technology that not only ensures comfortable living conditions but also lowers utility bills for the clients," said Igor Bychenok, head of sales at Hals Development. "The use of advanced technology in construction is not widespread in the business and economy segments of real estate as it pushes up the cost of each square meter," he said.

But as technology develops further and becomes cheaper, it will be applied more widely, Bychenok said, adding that even today most construction companies try to use them at least to some extent.

This will become more common as middle class attitudes are currently changing in Russia, Saint-Gobain's de Pirey said.

"Until recently the situation here was similar to what we saw in France in the 1950s and 1960s, when there was a need for a lot of affordable housing. Now it is different, people do not want to live in low-quality apartments any more," de Pirey said.

At the same time advanced technology does not necessarily substantially increase the costs of construction. "When new materials and better solutions are planned at an early stage of the project, they on average add about 5 percent to the overall cost," he said.

If, however, changes are introduced later, the cost may spiral up to 50 percent, he added.

Figure 4. News about demolition in Moscow (Source: The Moscow Times, June 10, 2014).

2.2 Summary of the research gaps

There is only a little relevant scientific literature related to the energy consumption of Soviet-era buildings in Russian residential districts. In addition, nothing was found on the impacts of different options for energy renovations of residential buildings or districts in Russia. Furthermore, no studies were available that take into account the different emissions of energy production types when analyzing the whole energy chain from production to consumption in residential buildings.

Due to the technical structure of the district heating used in Russia, energy renovations of single buildings seldom lead to reduced energy production. Energy production demands will reduce only if the residential districts and their various utilities and networks are renovated holistically. This idea is not introduced in the scientific literature.

Some partly relevant cost studies of energy renovations of Soviet-era buildings exist, mainly in countries other than Russia, but they all have obvious limitations, and they do not take into account district-scale renovations. In addition, since the idea of holistic district renovations in Russia is new, potential business models have not been analyzed in this context.

2.3 Research questions and dissertation contribution

The overall aim of the dissertation is to provide means for the holistic district renovations improving the energy-efficiency of Russian Soviet-era residential districts. Figure 5 shows the research process used and introduces the main topics of the research questions stated in the following text.

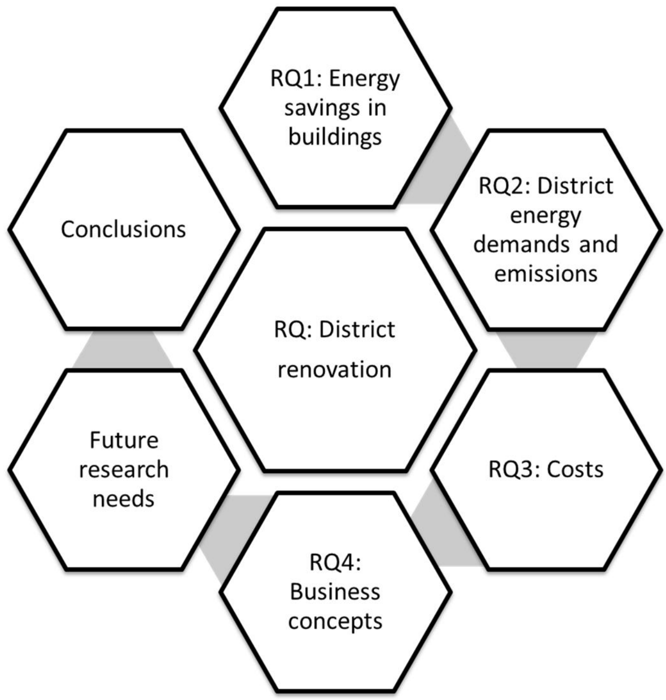


Figure 5. The research process with the main topics of the research questions.

The main research question (RQ) of the dissertation is:

- Do energy renovations make more sense at the district level rather than at a building level: how could we upscale Russian residential districts?

The supplementary research questions, each of which partly responds to the main question, are:

RQ1. What are the energy savings potentials of different energy renovation concepts in typical Russian residential buildings (I)?
RQ2. How do the different renovation concepts and alternative energy production scenarios affect the energy demands and emissions at a typical Russian residential district (II)?
RQ3. What are the costs of the different energy renovation concepts in a typical Russian residential district (III)?
RQ4. Are there suitable business models for holistic energy renovations of Russian residential districts (IV)?

The principal contribution of this dissertation is the pioneer analyses of energy-efficient holistic renovations of Soviet-era residential districts in Russia. Even the idea of district renovations is new. This dissertation contributes to the topic by means of solutions, impacts, and business aspects.

2.4 Outline of the dissertation

The remaining chapters of this dissertation are organized as follows (Figure 6).

Chapter 3 presents the methods and materials used in the dissertation. Chapter 4 describes the analyzed cases and their properties, and introduces the holistic district renovation concept with the main stakeholders involved. Chapter 5 presents the results answering the research questions. Discussions are presented in Chapter 6, and general conclusions in Chapter 7.

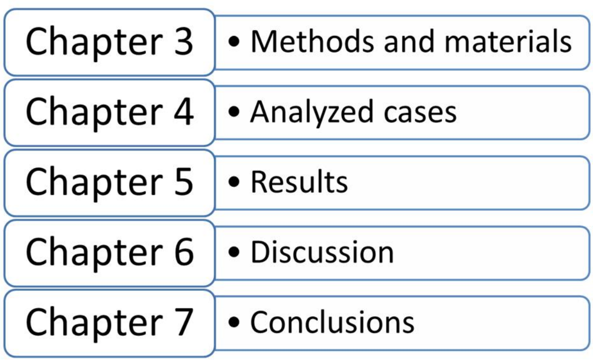


Figure 6. Main contents of the remaining chapters.

3. Methods and materials

The aim of this dissertation is to analyze energy-efficient renovation of residential districts through case studies from Russia. The research approach of this dissertation involves several different methods by which aims to find solutions, and analyze impacts and business aspects for energy-efficient renovation of Russian Soviet-era residential districts. This chapter presents selected methods and materials that were used in the dissertation. The exact mathematical formulations and lists of all references used can be found in the Publications. Figure 7 identifies the frame of the analyses. Table 3 lists the Publications and summarizes the research approaches used in them.

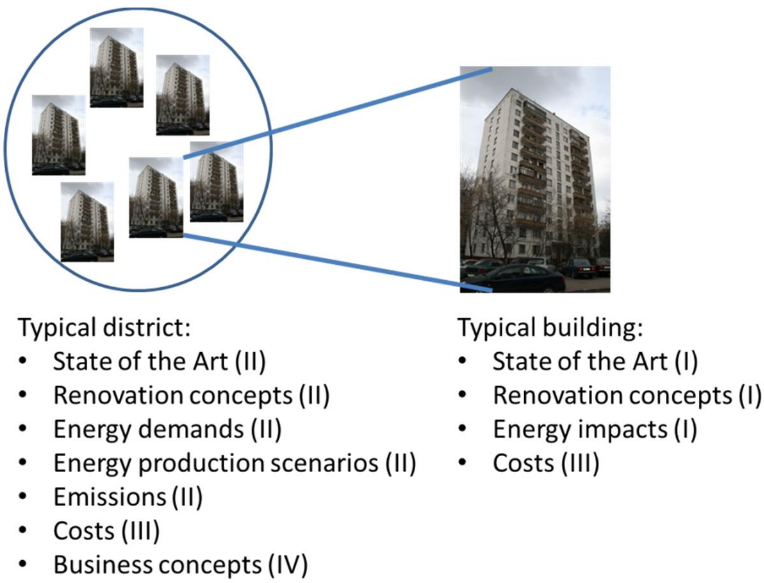


Figure 7. Frame of the materials used.

Table 3. Illustration of Publications.

	Publication	Research setting	Objective	Methods used
I	Energy saving potentials of Moscow apartment buildings in residential districts	What are the energy saving potentials of different energy renovation concepts in typical Russian residential buildings?	Estimating the present state of energy consumption of a typical Moscow apartment building and a typical district Analyzing energy consumptions of different building-level energy renovation concepts Describing non-technical barriers to energy-efficient renovations	Case study Building typology Expert analysis for defining building renovation concepts Energy calculations
II	Energy and emission analyses of renovation scenarios of a Moscow residential district	How do the different renovation concepts and alternative energy production scenarios affect the energy demands and emissions at a typical Russian residential district?	Analyzing energy demands of different energy renovation concepts at the district level Exploring emissions to air	Case study Expert analysis for defining district renovation concepts and energy production scenarios Emission calculations

III	Cost analyses of energy-efficient renovations of a Moscow residential district	What are the costs of the different energy renovation concepts in a typical Russian residential district?	Assessing the feasibility of the different building and district energy renovation concepts in monetary terms Testing the profitability of the renovation solutions over a 20-year period Providing baseline cost data for the decision-makers of holistic district renovations	Case study Cost analyses
IV	An analysis of different business models for energy efficient renovation of residential districts in Russian cold regions	Are there suitable business models for holistic energy renovations of Russian residential districts?	Analyzing if business models identified from the literature are adaptable for holistic district renovations of Russian residential districts Suggesting modifications for the business model with the most potential	Literature review Stakeholder analysis Business model canvas Expert analysis

3.1 Methods used in the case studies

Most of the results are based on case studies. This approach was selected in order to concretize the research questions. First, a typical Russian residential district was chosen. Then a typical apartment building from the typical district was chosen. Typical technical solutions both for the district and for the building were identified, following formulation of alternative renovation concepts and energy production scenarios. This section describes the methods utilized when analyzing these cases.

Figure 8 gives an overview of the approach for conducting the energy and emission analyses. As a whole, four variations of the II-18 type building were created and analyzed. These were given names according to the concept on which they were based: Current, Basic, Improved, and Advanced. These building variations were used in the energy demand analyses of their corresponding district concepts. Each district concept was further studied with different energy production scenarios, from which the resulting emission levels were examined.

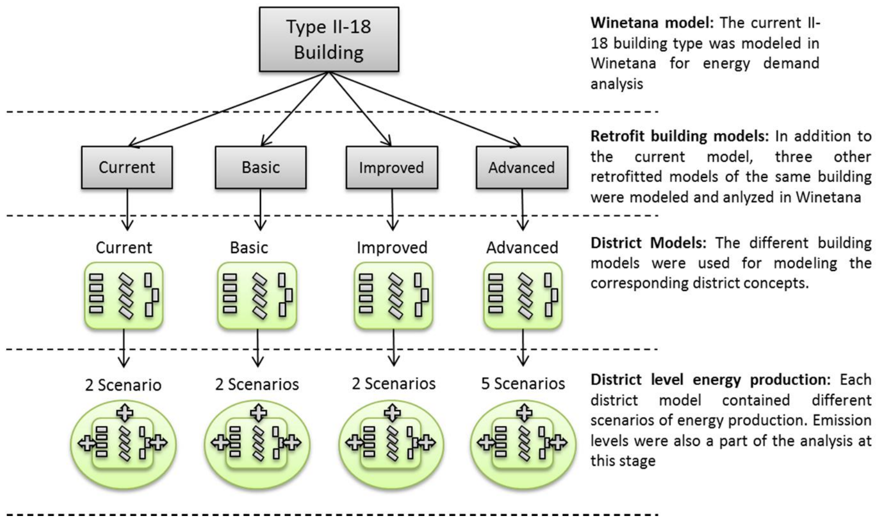


Figure 8. Overview of the process of conducting the energy and emission analyses. (WinEtana is computer software for making building energy analyses developed by VTT Technical Research Centre of Finland.)

3.1.1 Building typology

The term "building typology" refers to a systematic description of the criteria for the definition of typical buildings, as well as to the set of building types itself (Ballarini et al., 2014). A thorough typology of the Russian housing stock does not exist.

Thus, lots of data and information about Russian apartment buildings, their technical systems, energy and water infrastructure, and Russian housing in general was collected from various sources. This input data was needed for defining and analyzing the state-of-the-art in Publications I–II that was used as a reference for the further analyses. The data used about Russian housing and residential districts was gathered from several sources including literature, Russian records, databases and statistics, and site visits, and cross-checked when appropriate sources were found.

3.1.2 Defining renovation concepts and energy production scenarios

The renovation concept is here defined as a set of measures to be carried out. Three alternative energy renovation concepts, named Basic, Improved, and Advanced, reducing the environmental impacts of the buildings and the district, were developed. The basic renovation refers to minimum, low-cost, or easy-to-do renovation measures. The improved renovation solutions give better energy or eco-efficiency. In the advanced renovation, advanced solutions are also suggested.

The renovation concepts and energy production scenarios were selected based on expert experience from field studies of energy-efficient renovations in Finland. These were adjusted to Russian conditions, taken into account the existing Moscow building codes for new construction. Relevant detailed building codes, standards, and so on do not exist for renovation. The opportunity to utilize renewable energy production was also emphasized.

Before formulating the renovation concepts, several typical Russian apartment buildings and their technical spaces were visited in order to get a better view of their conditions and technical systems. The concepts were selected primarily with the view on practical implementation of building renovations as follows:

- (i) only restoration of buildings to their initial condition,
- (ii) restoration of buildings using modern materials available on the market, for which the properties have improved over the past 40 years,
- (iii) significant improvement of buildings to meet local requirements for new construction, and
- (iv) improvement of buildings going beyond the local requirements for new buildings, but being “normal” for renovation projects in Finland and Northern Europe.

3.1.3 Energy calculations

The building energy consumptions (Publication I) were calculated using the WinEtana building energy analysis tool developed by VTT Technical Research Centre of Finland. The tool calculates the building’s energy flows based on structural properties, the characteristics of heating and ventilation systems, water use and drainage, and a set of electrical household appliances assumed to be in use in the building.

The annual energy demands for the different district concepts were calculated by taking into account the energy consumption of the buildings, the energy needed for water purification, the electricity for wastewater treatment, electricity for outdoor lighting, and the heat distribution and electricity transmission losses (Publication II). For the different cases, the energy demand of buildings was calculated by multiplying the specific energy consumptions per square meter of floor area by the total floor area of the buildings in the district, and taking into account the losses. For the current status, the losses and the energies needed for water purification, wastewater treatment, and outdoor lighting were estimated based on realistic values from the literature. These values improved in each renovation concept.

Transportation and other services resulting in further energy demand were not included in the district energy analyses. Although these usually form a significant share of the total energy consumption in a district, they were ignored, since the focus was on buildings, and on energy and water infrastructures.

3.1.4 Emission calculations

The values for emissions per produced energy (kg/MWh) were retrieved from GEMIS (Global Emission Model for Integrated Systems software, 2012) and account for the life cycle of the facility by which the energy is generated. The emission values for CHP were divided into the proportions for heat and electricity generated. This was done by the partial substitution method described in Publication II, where the idea is to split the emissions into equal parts for the heat/electricity quote in relation to the efficiency of the type of energy generated.

CO_2-equivalents, SO_2-equivalents, TOPP-equivalents, and particulates were selected to represent the environmental impact of the energy production alternatives. These values were retrieved for each of the energy production technologies involved in the scenarios, and accounted for the life cycle of the production unit.

The reference emissions (Moscow ref.) were calculated using the equivalent values for the whole of Moscow multiplied by the number of inhabitants in the selected district. These average reference values indicate the emissions based on the different energy production means and their portions currently existing in Moscow.

3.1.5 Cost analyses

The economic attractiveness of investing in additional improvements (Publication III) was compared to the basic capital repairs that will, in any case, be implemented in buildings. The suggested straightforward approach eliminates the need to consider the division of an investment into energy-efficiency and structural renewal, since the latter is assumed to be covered by basic capital repairs.

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 (product catalogues, manufacturers, direct contacts to companies, public records, Russian statistics, etc.) in Russia and mainly in Moscow.

The cost estimates include both the costs of the renovation measures (products, systems, equipment, etc.) and the required secondary costs to implement them (installation, cleaning, sealing, and other labor costs).

The economic calculations were based on the use of the net present value (NPV) method, and accounted for the expected future growth of energy prices. The net present value of a renovation package is the difference between the present values of this package and a baseline package.

The package, corresponding to the "to-be-implemented-in-any-case" basic capital repair, was selected as a baseline, and the 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 in investment. 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.

The estimated district renovation costs included both the renovation costs of the buildings and 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 floor area of buildings. A nodal representation was utilized for existing infrastructure, whereby a node is a location where local distribution infrastructure is connected to the main utility networks, the lengths of distribution legs are the same for electricity, heating, water, and sewage lines, and there are five such legs per node. In addition, an estimated length of the 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.

3.2 Literature-based approach

The essence of a business model is in defining the manner by which the enterprise delivers value to its customers, entices its customers to pay for value, and converts those payments into profit (Teece, 2010). According to Osterwalder (2004), a business model is a conceptual tool that contains a set of elements and their relationships and enables the expression of a company's logic of earning money. It is a description of the value a company offers to one or several segments of customers, and the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, in order to generate profitable and sustainable revenue streams.

Potential business models for holistic energy-efficient renovations of Russian residential districts were analyzed, based on a critical review of the literature (Publication IV). Figure 9 illustrates the scientific literature used in the analysis. In addition, other relevant literature was utilized. In addition, statistics, websites, public documents, and newspaper articles were used. Besides, data was gathered through semi-structured interviews with selected Finnish and Russian experts who all had a minimum of 10 years' expertise in the Russian market. These experts were identified through personal contacts in Finland, and networking in different business occasions and expert seminars in Russia. The interviews were conducted face-to-face with 2–5 experts at the same time. They were not recorded but notes were written all the time and especially carefully about the concluding remarks. The interviews followed a flexible structure but the main frame was the following:

a) Presenting statistic data on the renovation markets in Russia
b) Describing the general idea of holistic district renovations in Russia
c) Presenting the main results from Publications I–III in order to give basic information on energy saving potentials, emissions to air and costs
d) Discussing about the different stakeholders and their roles in Russian district renovations
e) Discussing about the challenges in Russian district renovations and the potential solutions to them
f) Briefly presenting the business models identified from the literature
g) Discussing about the advantages and disadvantages of the existing business models
h) Discussing about the required changes to the ESCO model

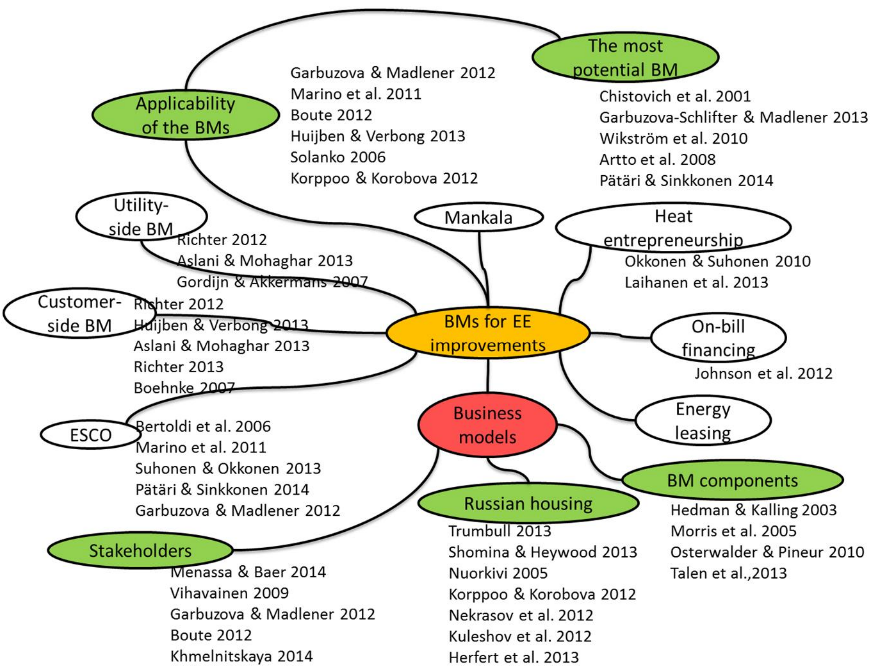


Figure 9. Scientific literature utilized in Publication IV.

3.2.1 Stakeholder analysis

Identification of the stakeholders is an important task before formulating business concepts. A stakeholder analysis clarifies which stakeholders there are, how they are connected to each other, and what benefits they could achieve through district renovations. Stakeholder analysis is a basis for evaluating the needs and expectations of stakeholders in relation to the main objectives of a construction project (Olander, 2007). Typically, the (construction) projects involve a range of actors, firms and experts with sometimes conflicting ideas and priorities (Wikström et al., 2010). There is no single, most effective approach, and usually a number of alternative approaches are combined to analyze and engage stakeholders (Yang et al., 2011).

The different building stakeholders can play an important role in determining how, why, and whether retrofit measures will be implemented, and the development of methodologies that enhance the interaction among these stakeholders (Menassa & Baer, 2014). The scope of the analysis covered the whole energy and water infrastructure, including energy production facilities, heat and electricity networks, water networks, building blocks, individual buildings, and users of the buildings who influence the energy demand profiles.

3.2.2 Structuring business model components

There are several ways to structure the components of a business model (e.g., Shafer et al., 2005; Morris et al., 2005; Hedman and Kalling, 2003). One of the most used structuring systems is the business model canvas developed by Osterwalder and Pigneur (2010). In the canvas, the key components of a business model are the following: customer segments, value proposition, channels, customer relationships, revenue streams, key resources, key activities, key partners, and cost structure. This model was used to analyze what kinds of issues a service-oriented company should consider in order to access the energy-efficient renovation market in Russia.

4. Analyzed cases

As the analyses made in the dissertation were based on case studies, the selection of representative cases was an important part of the work. Selection of the renovation concepts started with an analysis of the current state, which was based on a review of the available literature (see Section 2.1). This chapter describes the analyzed cases used in Publications I–III and the idea of the holistic district renovation used for analyzing the potential business concepts in Publication IV.

The renovation concepts and energy production scenarios were selected based on expert experience from field studies of energy-efficient renovations in Finland. These were adjusted to Russian conditions, taking into account the existing Moscow building codes for new construction. Relevant detailed building codes, standards, and so on do not exist for renovation. The opportunity to utilize renewable energy production was also emphasized. 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 demand.

4.1 Typical residential buildings and districts

At the end of 2009, the Russian housing stock included 3.2 million apartment buildings with a total floor space of 2 237 million m^2 (IUE, 2011). In the Russian Federation, most of the apartment buildings were constructed between 1960 and 1985 during the Soviet era, and as a result, the urban housing stock today consists mainly of a few standard building types (United Nations, 2004; Trumbull, 2013). Each building series represents a specific building design (Opitz et al., 1997; Raslanas et al., 2011).

In these buildings, natural ventilation dominates (Opitz et al., 1997). District heating networks supply heat to about 80% of Russian residential buildings, and about 63% of the hot water used by Russia's population (International CHP/DHC Collaborative, 2009). The apartment buildings typically do not include building-specific heat exchangers or any other means to control heating (Eliseev, 2011). Energy efficiency of these apartment buildings is typically poor.

4.1.1 Analyzed housing district

A typical residential district was selected for analyzing the building energy saving potentials (Publications I), the district energy demands and emissions (Publication II), and the related costs (Publication III). The selected district mostly represents the 4th Microrayon of Zelenograd, Moscow (longitude 37º east and latitude 55º north). Zelenograd is located about 35 km to the north-west of Moscow city center. 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 has district heating. Renovation of such buildings and districts may be needed in the near future.

The apartment buildings in the area can be divided into groups according to the building series: II-57, II-49, AK-1-8, II-18, and Mr-60, which are apartment buildings constructed between 1966 and 1972. There are also a few other newer buildings, but since these analyses concentrated on the modernization of buildings, these newer buildings were excluded from the studies. According to the initial analysis (Publication I), the most common building type, II-18, was selected for further analyses, since a comparison of the energy consumptions of the buildings showed only minor differences.

In total, there are approximately 13 800 residents in the buildings included in the calculations. The total floor area of the buildings studied is 327 600 m^2 and the total roof area is 31 200 m^2. The number of residents was estimated based on the assumption that the average occupancy rate per flat is 2.7 persons (United Nations, 2004). Table 4 gives a summary of the main building and district properties used in the analyses.

Table 4. The main building and district properties used in the analyses.

Building (II-18) properties		**District properties**	
Indoor temperature	18 ºC	Total living area	327 581 m^2
Total floor area	4 911 m^2	Total roof area	31 230 m^2
Roof area	410 m^2	Total population	13 813
Total façade area	3 060 m^2	Total surface area of solar photovoltaic	15 615 m^2
Area of apartment windows	670 m^2	Total surface area of solar collectors	8 012 m^2
Other glazing	28 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		

4.2 Building renovation concepts

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 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 a sufficient air exchange rate in apartments. The advanced renovation suggests the use of even more progressive solutions, which were considered realistic. The building-level improvements included in the energy and emission analyses are listed in Table 5. These building energy renovation concepts were utilized when analyzing the potential energy savings in buildings (Publications I) and the district-level energy demands and emissions (Publication II).

Table 5. Building 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^2K) • outer walls • base floor • roof • windows and doors	 1.1 1.1 1.1 2.9	 0.5 – 0.25 1.85	 0.32 – 0.24 1.5	 0.15 – 0.15 1.0
Ventilation	Natural	Restoration of existing natural ventilation. 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 (not building specific), no radiator temperature based control. 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 braking. 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. Remote meter reading (120)	Household-specific metering (100)

4.2.1 Building renovation packages

For the cost analyses, the concepts were modified to renovation packages, named the **Basic renovation package**, **Improved renovation package**, and **Advanced renovation package**. The packages were formulated so that they included actual products and systems available on the Russian market. The products were selected to meet the U-value and other requirements defined in Table 5. In addition, some improvements were made, even though these were not required, because it would be more feasible to implement them in combination with other measures than to implement them separately later. These also included measures for mandatory basic capital repairs with no direct energy-efficiency influence. Thus, all 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 costs of implementing these building renovation packages in a Moscow case district were analyzed in Publication III.

4.3 District renovation concepts

At the district level, 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 6. 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 6. These concepts were analyzed by means of energy and emission impacts in Publication II.

Table 6. District 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 High distribution losses, about 20–30% (International CHP/DHC Collaborative, 2009)	Replacement of distribution pipes (thus reducing distribution losses of district heating) 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 network design does not enable feeding locally produced electricity into 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 and review of automation systems to allow for connection of distributed generation. Smart meters (in case of demand response and local controllable energy generation)
Lighting (outdoor)	Old light bulbs	Energy-efficient street lighting	Street lighting designed to avoid light pollution	Smart outdoor lighting (sensor driven), street lighting electrified with solar PVs
Water purification and distribution, waste water collection and treatment	Drinking water not safe. High leakage rate in water and sewer networks. Improvement of sewage treatment efficiency where needed	Improved water purification technology. Refurbishment of water and sewer networks		Smart water network Block scale purification and treatment (to ensure safe local potable water and waste-water treatment)
Waste	Mixed waste collection, >60% municipal solid waste (MSW) landfilled (27% incinerated, 10% recycled)			Increased recycling and energy utilization: approx. 22% MSW landfilled (24% incinerated, 54% recycled)

4.3.1 Energy production scenarios

Since almost all energy produced in the Moscow area comes from natural gas (City of Moscow, 2009), the scenario of heat and energy production from natural gas-powered CHP plants (Nat) was taken as a baseline for each of the district concepts. In order to evaluate the opportunity for using renewable energy, the scenarios where natural gas is replaced with biogas (Bio) were additionally examined. Table 7 summarizes the scenarios analyzed.

For the Advanced district concept, the A3, A4, and A5 scenarios involving renewable energy were created, in addition to the natural and biogas scenarios. In the A3 and A4 scenarios, roof-mounted solar panels (PV) would generate part of the electricity demand and would cover 50% of the total roof area. The rest of the electricity would be bought from the Moscow grid in A3, and certified electricity from a wind farm (WF) in A4. All the heating needed would be provided by ground source heat pumps (GSHP) in both A3 and A4, which on the other hand would consume a considerable amount of electricity. In addition to the A4 scenario, part of the energy needed for the domestic hot water in the district is produced by solar thermal collectors mounted on the roofs of the buildings and covering 25% of the total roof area in scenario A5. This would eventually lead to fewer boreholes and less electricity needed for ground source heating.

Table 7. Analyzed energy production scenarios for the different district concepts.

	Current	Basic	Improved	Advanced
CHP natural gas	x	x	x	x
CHP biogas	x	x	x	x
A3 scenario: solar panels, ground source heat pumps, electricity from grid				x
A4 scenario: solar panels, ground source heat pumps, (certified) electricity from wind farms				x
A5 scenario: solar collectors, solar panels, ground source heat pumps, (certified) electricity from wind farms				x

4.3.2 District renovation packages

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. Corresponding to the building renovation packages, the district renovation packages were named **Basic renovation package**, **Improved renovation package**, and **Advanced renovation package**. 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 the **Advanced+** and **Advanced++ renovation packages**, both represent an extension of the advanced district renovation package. In principal, Advanced+ equals to energy production scenarios A3 and A4, and Advanced++ equals to scenario A5. As it was assumed that certified wind energy is produced in large wind farms and bought from the electricity grid, it was not included in the packages. Table 8 shows the district-scale measures included in the district renovation packages. 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. The costs of implementing these packages were analyzed in Publication III.

Table 8. District-scale measures included in district renovation packages.

District infrastructure and utility	Basic	Improved/ Advanced	Advanced+	Advanced++
District heating distribution pipe replacement	x	x	-	-
District heating main pipe replacement	x	x	-	-
District heating substation	x	x	-	-
Light bulbs for street lighting	-	x	x	x
Water distribution pipe	x	x	x	x
Water distribution main pipe	x	x	x	x
Water sewage distribution pipe	x	x	x	x
Water sewage main pipe	x	x	x	x
Electricity grid renewal	x	x	x	x
Main grid renewal	x	x	x	x
Transformer substation 10–0.4 kV	x	x	x	x
Energy systems	**Basic**	**Improved**	**Advanced+**	**Advanced++**
GSHP	-	-	x	x
SPV	-	-	x	x
STH	-	-	-	x

4.4 Holistic district renovation concept

District heating is mainly used for space heating in Russian apartment buildings. The buildings do not include heat exchangers, thermostats or any other means to control the incoming district heating flow. Due to the technical structure of the district heating used in Russia, energy renovations of single buildings seldom lead to reduced energy production. Energy production demands are reduced only if the residential districts and their various utilities and networks are renovated holistically. The district renovations would include renovations of the buildings and all their technical systems, modernization of heating energy production and distribution systems, renovation of local electricity production and transmission systems, renewal of street lighting, renovation of water and wastewater systems, and modernization of waste management systems (Table 9). Some of these systems are less-energy related but because there is an interdependency of the systems, they were included to the general district renovation concept. In addition, they can still affect the whole energy chain. For example, waste incineration is an option if waste is properly collected. Publication IV deals with analyzing potential business models for these kinds of holistic district energy renovations. The main stakeholders are introduced in Section 4.4.1, and the key aspects of the business model components in Section 4.4.2.

Table 9. Main contents of holistic district renovations.

DISTRICT RENOVATION		
Buildings • Renovating all buildings • Retrofitting building energy, water, and other technical systems • Improving ventilation • Improving insulation	**District infrastructure** • Renovating district heating distribution • Renovating electricity transmission • Renewal of street lighting • Renovating water and wastewater systems • Modernizing waste management	**Distributed energy production** • Energy production from renewable sources o Replacing district heating o Reducing electricity demand from the grid • Only in the most advanced cases

4.4.1 Main stakeholders

Menassa and Baer (2014) conducted an extensive review of the literature and identified 30 potential stakeholder requirements important for the sustainable retrofit of a building. The requirements also indicate the benefits of sustainable retrofits. Not all of the identified requirements are valid for energy renovations of residential buildings or districts. However, Table 10 shows an estimation of how the main stakeholders identified in Publication IV could perceive benefits of sustainable retrofits in Russian residential districts.

As can be seen, the role of public bodies is remarkable. In addition, the role of the inhabitants cannot be underestimated. About 76% of housing units in apartment buildings are reported to be in private ownership (IUE, 2011), and joint decision-making by inhabitants is required for major repairs. For example, varying income levels among the residents of the same building may complicate joint decision-making on building renovation. Since renovations are subsidized or centrally-(regionally)-implemented in Russia, there may be budgetary or other limitations increasing the role of the public bodies. Utilities and network operators have a poor reputation as public bodies, so they would want to improve their image in the eyes of the public but the utilities see renewable energy as competition rather than an opportunity. The financial sector is generally happy to lend more money but as part of its loan repayment may come from energy savings it could also be interested in reducing energy consumption. Banks would be interested in increasing property value only in case bank holds the property as a security guaranteeing that the debt will be returned (currently, not possible in Russia).

Table 10. Motivations of different stakeholders in Russian district renovations for sustainable retrofits according to stakeholder requirements identified by Menassa and Baer (2014).

	Inhabitant	Homeowners' association	Public bodies	Utility and network operators	Construction companies	Financial sector	Product manufacturers and system providers
Increase return on investment	*	*	*	*		X	
Achieve lower total ownership costs	X	X	X	X			
Lower project capital costs	X	X	X				
Increase property value	X	X	X			X	
Avoid costs due to opposition	X	X	X	X	X	X	X
Gain the public's trust			X	X			
Reduce chance of opposition	X	X	X	X	X	X	X
Improve esthetic quality of the site	X	X	X				
Decrease outages/interruptions	X	X	X	X			
Improve occupant comfort	X	X					
Improve occupant health	X	X	X				
Increase energy-efficiency	X	X	X	X	X		X
Reduce energy consumption	X	X	X			X	
Provide a secure energy supply	X	X	X	X			
Facilitate renewable energy			X				X
Minimize environmental impact	X		X	X			
Increase carbon neutrality							X
Meet regulatory requirements	X	X	X	X	X	X	X
Diversify investment portfolios						X	

* May invest in some cases but their true interest is to achieve lower total ownership costs

4.4.2 Key aspects of business model components

The key components of a business model are shown in Figure 10 and are briefly introduced in the following text from Osterwalder and Pigneur (2010). The main aspects of the business model components of Russian district renovations are shown in Table 11, listed based on the general business model canvas in Figure 10. They are discussed in more detail and compared to existing business models in Publication IV.

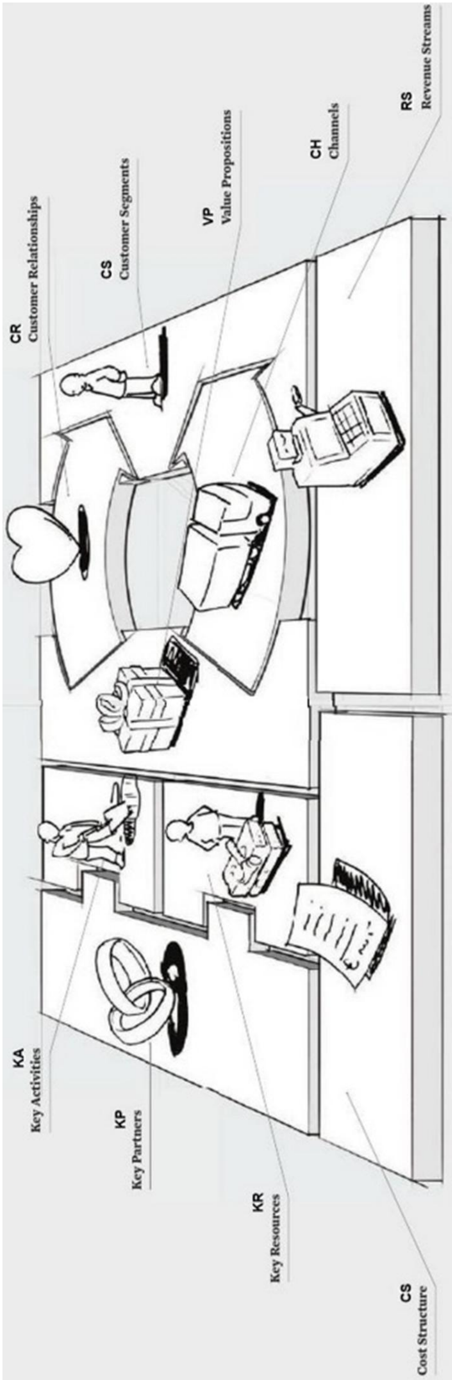


Figure 10. General business model canvas by Osterwalder and Pigneur (2010).

Customer Segments. The Customer Segments define the different groups of people or organizations that an enterprise aims to reach or serve.

Value Propositions. The Value Propositions describe the bundle of products and services that create value for a specific Customer Segment.

Channels. The Channels describe how a company communicates with and reaches its Customer Segments so as to deliver a Value Proposition.

Customer Relationships. The Customer Relationships describe the types of relationships that a company establishes with specific Customer Segments.

Revenue Streams. The Revenue Streams represent the cash that a company generates from each Customer Segment (costs must be subtracted from revenues to create earnings).

Key Resources. The Key Resources describe the most important assets that are required to make a business model work.

Key Activities. The Key Activities describe the most important things that a company must do in order to make its business model work.

Key Partnerships. The Key Partnerships describe the network of suppliers and partners that make the business model work.

Cost Structure. The Cost Structure describes all costs incurred in operating a business model.

Table 11. Main identified aspects of different business model components in Russian district renovations. In Publication IV, these are compared to the existing business models.

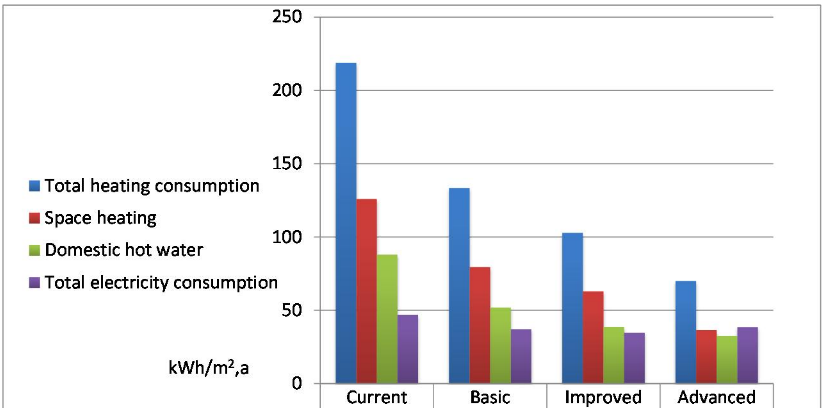
Business model component	Main aspect
Customer segments	renovated buildings and the related infrastructure, knowledgeable customers required
Value proposition	energy-efficiency in combination with other values and benefits
Channels	due to many involved stakeholders several are needed including personal contacts and actions in municipality levels
Customer relationships	trust creation is mandatory in Russia
Revenue streams	perhaps partly tied to tariffs and partly to services
Key resources	skillful labor and production capacity
Key activities	comprehensive services
Key partners	local actors including public bodies
Cost structure	value driven

5. Results

This chapter presents the main findings of the different analyses made. The focus is on answering the research questions presented in Section 2.3.

5.1 Building-level energy consumption

Publication I, which deals with the energy-saving potentials of Moscow apartment buildings in residential districts, shows that there were only small variations in the annual heating and electricity consumptions between the different apartment buildings in the case districts. Thus, the most common building type, II-18, was selected to represent the typical building in the district, and it was used in the further analyses. The annual heating consumption of the building type II-18 was 219 kWh/m^2, and the annual electricity consumption 47 kWh/m^2. These represent the building level energy demands. In the energy production site, also the losses from production to usage need to be taken into account.



	Current	Basic	Improved	Advanced
Total heating consumption	219	134	103	70
Space heating	126	79	63	37
Domestic hot water	88	52	39	33
Total electricity consumption	47	37	35	39

Figure 11. The calculated energy consumptions for the different renovation concepts and the current status of the building II-18.

Figure 11 shows the total annual heating and electricity consumptions, as well as the annual space heating consumptions and heat consumptions for domestic hot water for the different renovation concepts, compared to the current situations. In particular, the heating consumption could be reduced substantially. Even with the most moderate renovation concept (Basic), the total heating consumption would be reduced by 39%, the space heating consumption by 37% and the heat consumption for domestic hot water by 41%. With the improved concept, the corresponding reductions would be 53%, 50%, and 56%, and with the advanced concept 68%, 71%, and 63%, respectively.

The total electricity consumption would be reduced by 21% with the basic concept, by 26% with the improved concept, and by 18% with the advanced concept. The electricity consumption rises between the improved and advanced concept due to the different ventilation system.

5.2 District-level energy demands and emissions

Publication II, which deals with the district renovation concepts and energy production scenarios, describes the energy and emission analyses of the case district. The annual energy demands for the different district concepts are shown in Figure 12. Results show that the share of buildings of the total energy demand in the district is remarkable. Considerable energy savings, up to 34% of the electricity demand and up to 72% of the heating demand, could be achieved in the district considered using different district renovation concepts. Even with the basic district concept, the total annual electricity demand would be reduced by 24%, and the total annual heating demand by 42%.

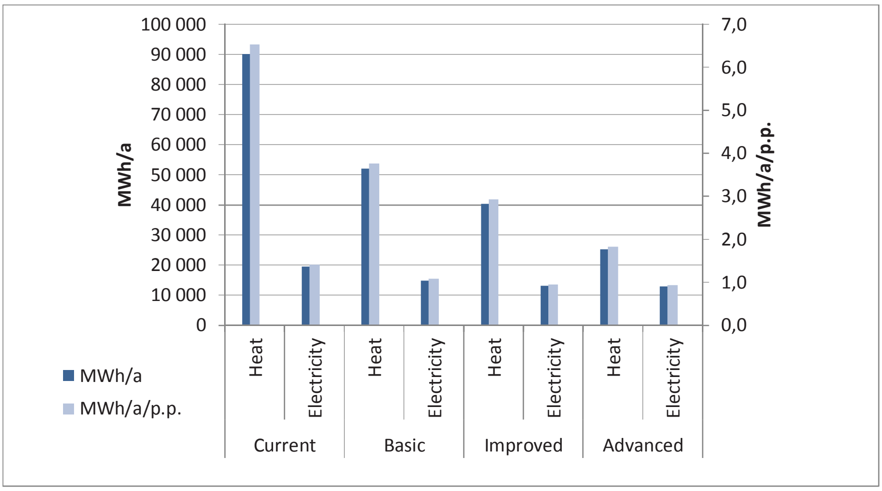


Figure 12. The annual energy demands for the different district concepts. The total demand is given on the left and the demand per inhabitant on the right.

As described in Section 4.3.1, the life-cycle emissions of different energy production scenarios were analyzed, too. The results are shown in Figures 13–16. CO_2-equivalent emissions (Figure 13) and TOPP-equivalent emissions (Figure 16) could be reduced significantly with all alternatives, compared to the Moscow reference values. For the SO_2-equivalent emissions (Figure 14) and particulates (Figure 15), changing from a natural gas CHP plant to an alternative biogas CHP plant would not be favorable. Buying electricity from the grid is not favorable and would cancel out the effect of using ground source heating pumps for reducing emissions in A3. The most advanced energy production scenarios, A4 and A5, would reduce all emissions dramatically.

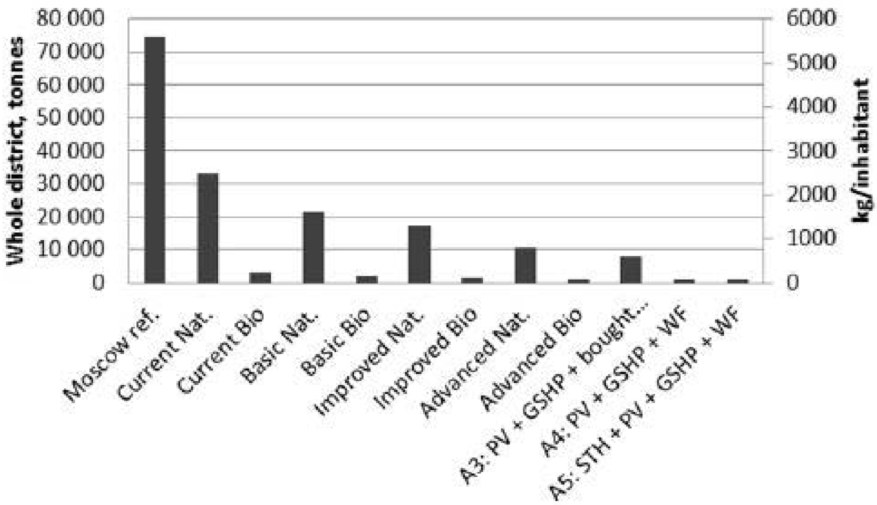


Figure 13. CO_2-equivalent emissions of the district energy production scenarios.

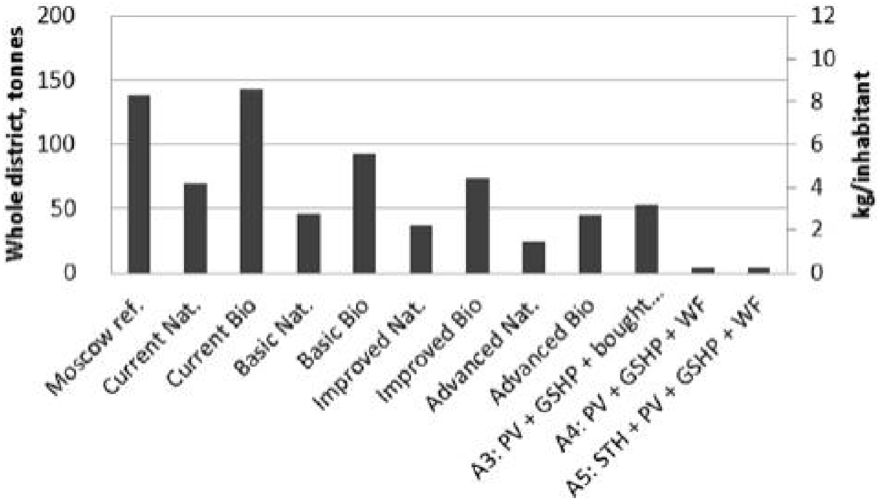


Figure 14. SO_2-equivalent emissions of the different energy production scenarios.

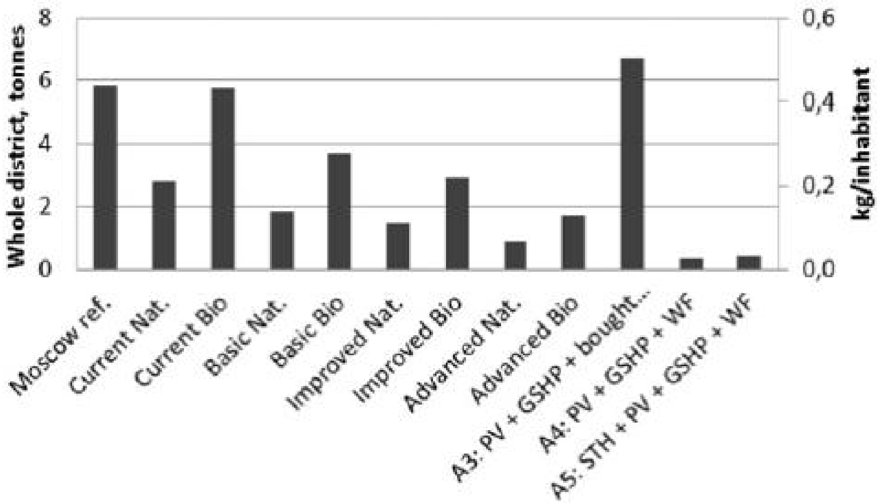


Figure 15. Particulates of the district energy production scenarios.

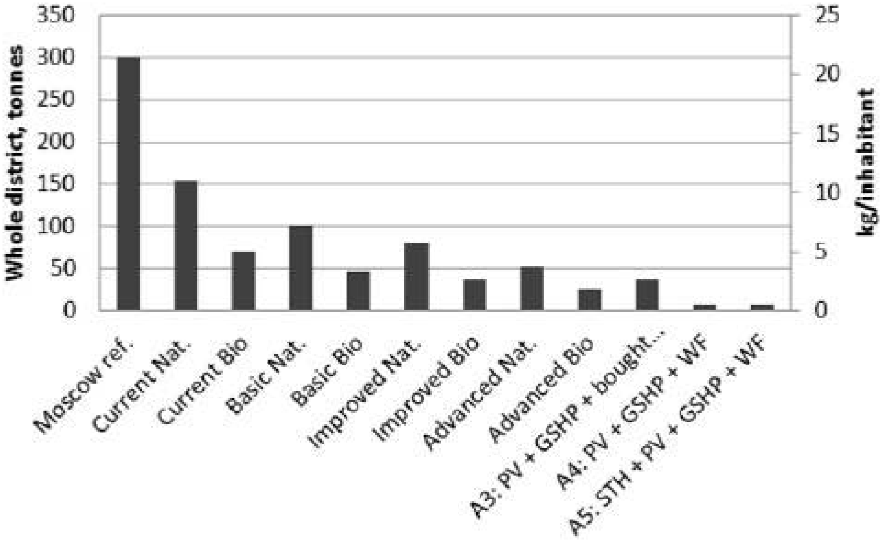


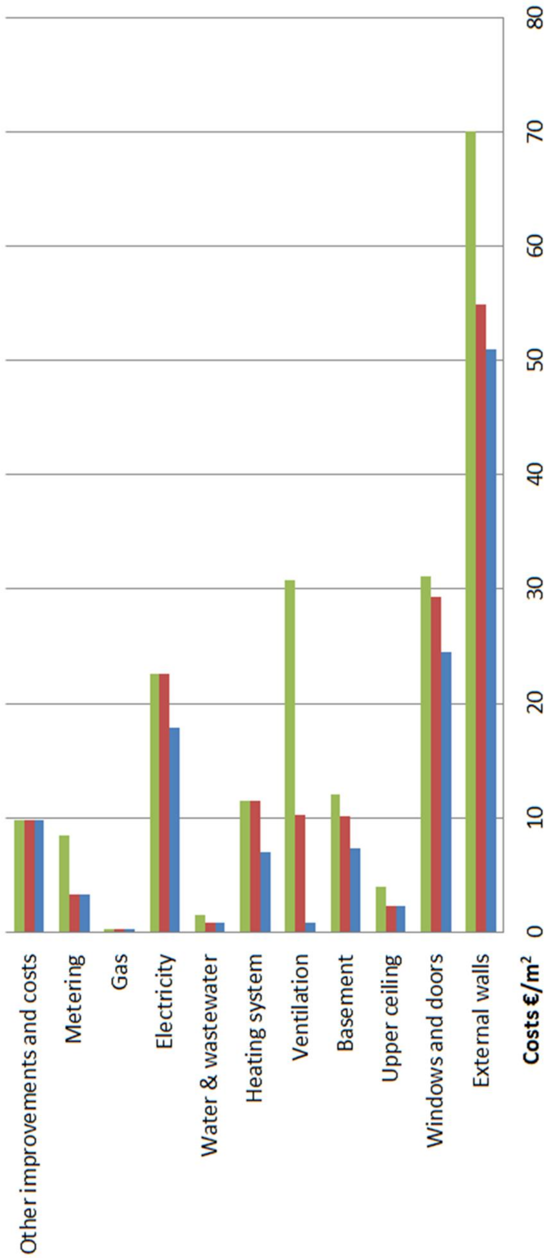
Figure 16. TOPP-equivalent emissions of the district production scenarios.

5.3 Renovation costs

This section summarizes the results from Publication III dealing with the costs of different renovation concepts. In the cost analyses, the Basic renovation package including also mandatory capital repairs served as the reference case. The building-level costs are presented in Section 5.3.1 and the district-level costs in Section 5.3.2. Section 5.3.3 deals with the cost-effectiveness of the renovation packages.

5.3.1 Building-level costs

The total investment costs per square meter of gross floor area of the categorized measures for each building renovation package can be seen in Figure 17. The total costs and the expected energy savings for each renovation package are presented in Table 12.



	External walls	Windows and doors	Upper ceiling	Basement	Ventilation	Heating system	Water & wastewater	Electricity	Gas	Metering	Other improvements and costs
Advanced	70,0	31,1	3,9	12,1	30,8	11,5	1,5	22,6	0,2	8,4	9,8
Improved	54,9	29,3	2,3	10,2	10,2	11,5	0,8	22,6	0,2	3,3	9,8
Basic	51,0	24,5	2,3	7,3	0,9	7,0	0,8	17,8	0,2	3,3	9,8

Figure 17. 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 12. The energy savings (%) and the total investment 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
Energy savings (%)	39	21	53	26	68	18
Total investment costs (€/m^2)	125		155		200	

Figure 18 shows the shares of the categorized measures of the total renovation costs for each renovation package. Renovating external walls would comprise over 35% of the total costs in each package. Changing windows and doors to more energy-efficient ones would cover 15–20%, and renovating electricity systems 11–15% of the total costs. Façade related costs (external walls, windows, and doors) would form the majority of the renovation costs.

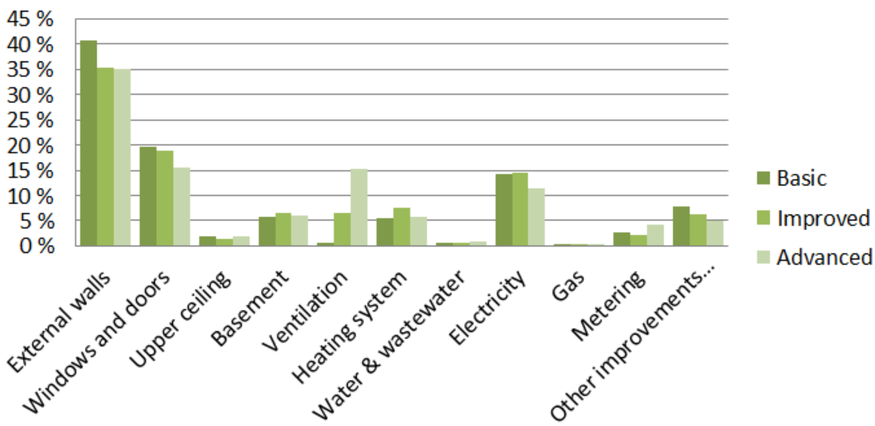


Figure 18. Shares of the categorized measures of the total building renovations costs.

5.3.2 District-level costs

The total district-scale costs include the renovation costs for both renovating the apartment buildings in the area and renovating the energy and water infrastructure in the case district. The estimated costs for the II-18 type building were extended to the residential district using specific costs per floor area. Figure 19 shows the costs for upgrading the surrounding infrastructure for the II-18 type building. The costs of district heating substations and transformer substations would be the biggest in the investment. Table 13 shows the costs of the renewable energy systems. Since solar thermal collectors can produce the energy for heating domestic hot water only during the summer time, the size of the ground source heat pump was estimated to cover the total heating demand during the coldest periods as well.

Figure 20 shows the total costs per inhabitant for renovating the whole district. The Basic renovations would cost nearly €3,500 per inhabitant, and the most advanced renovations would cost over €6,000. These figures show the magnitude of such renovations.

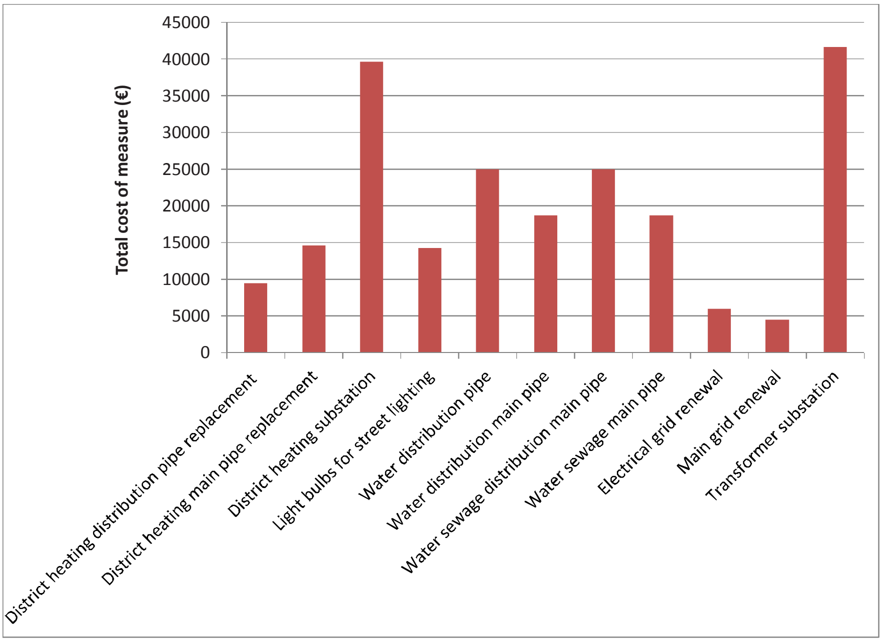


Figure 19. Costs of upgrading the surrounding infrastructure for the II-18 type building.

Table 13. 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

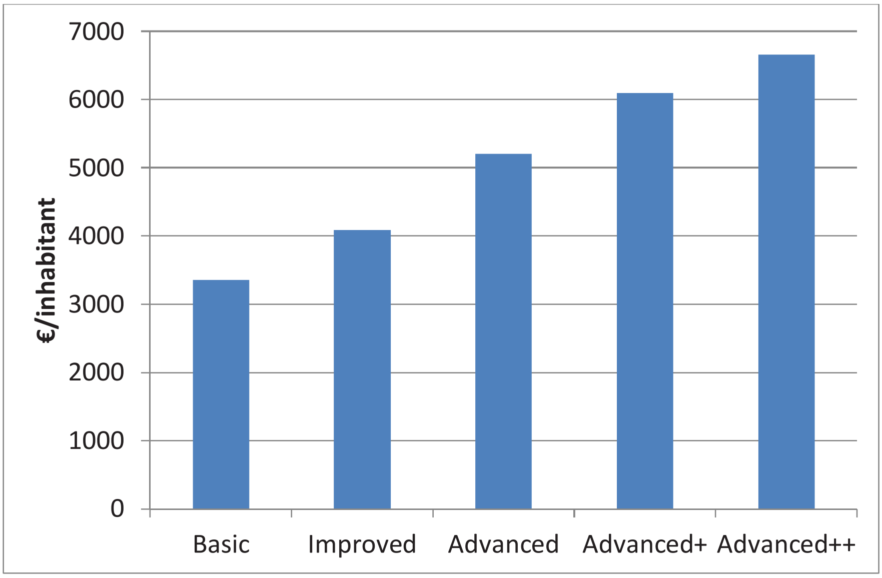


Figure 20. The total investment costs per inhabitant of the different renovation packages including both the building-level renovations and the district-level renovations.

5.3.3 Cost-effectiveness of the renovation packages

The estimated specific renovation costs (the total initial investment costs) of all the building and district renovation packages, along with the resulting annual energy and water savings, are summarized in Table 14. The prices used were €36.5/MWh (1700 RUR/Gcal) for heating, €0.10/kWh (4 RUR/kWh) for electricity, and €1.21/m^3 (48.55 RUR/m^3) for water and wastewater. The prices in euros are based on estimates in rubles that were converted using an exchange rate of 40 (€1=40 RUR).

Since it was estimated that the Basic renovation packages, both in the buildings and in the district, include mandatory renovations that need to be performed in any way, it was selected as a reference case. Thus, the values for the current state in Table 14 refer to the savings losses compared to the Basic renovation. Corresponding to the energy-saving potentials described in Sections 5.1 and 5.2, cost savings in heating are remarkable. With the most advanced renovations, the electricity cost savings are marginal compared to the current state, due to the considerable amount of electricity needed by the ground source heat pumps.

Table 14. Investment costs and energy and water savings comparison of the renovation solutions at building and district levels. The prices used were €36.5/MWh for heating, €0.10/kWh for electricity, and €1.21/m^3 for water and wastewater.

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

An examination of Table 14 reveals that the simple payback time (i.e., additional investment/additional annual savings) of additional investments in implementing renovations going beyond basic exceeds 12 years. In order to assess the long-term feasibility, net present values (NPV) over a period of 20 years were calculated and a sensitivity analysis performed. 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 15, applying the most feasible renovation package with different combinations of annual energy price growth rates and interest rates. With most combinations, the renovation packages beyond the Basic solution would be the most feasible.

Since in the NPV calculations for the district renovations show the 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.

Table 15. Renovation packages with the highest net present value over a period of 20 years in various scenarios.

Most feasible renovation solutions (packages), based on 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	
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	20 year period, constant water tariff growth at 5%
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	
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	20 year period, constant water tariff growth at 5%
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	

5.4 Analyzing business models for holistic district renovations

The potentially suitable business models identified for holistic district renovations were: the ESCO model, the customer-side renewable energy business model, the utility-side renewable business model, Mankala company, heat entrepreneurship, on-bill financing, and energy leasing. Their main features are described in Publication IV, which deals with the business models for district energy renovations in Russia.

As can be seen from Table 16, these business models are mainly meant for some large-scale energy production solution or for limited energy-efficiency improvements in buildings. None of the models as such is suitable for holistic energy-efficient renovations of Russian residential districts. If one actor takes the responsibility for all the renovation needs, the business model should also include all the construction renovations or modernizations in the district, such as building structures and systems, heating distribution networks, electrical systems, street lighting systems, water and waste water systems, and waste management systems. Which of the existing actors would take the lead is yet to be seen.

Since some ESCO activities have been realized in Russia it was assessed to be the most potential business model for district renovations. However, it would need modifications, such as more extensive offering of services and clear definitions of the visible and invisible benefits. Due to the large offering required for the holistic district renovations, perhaps only parts of district renovations could be realized through ESCO activities, such as the district infrastructure renovations.

Developing a completely new business model for the Russian district renovations may be needed but the new business model can also be sort of a “hybrid” model of the ones identified. However, all the identified models include features which could be included in the most idealistic model depending on the responsible actor involved.

Table 16. Advantages and disadvantages of different business models in Russian residential district renovations (Publication IV).

Business model	**Advantages**	**Disadvantages**
ESCO model	• One actor takes responsibility for all renovations	• "Western ESCO" not common in Russia • Current ESCO companies are small • Requires tangible guarantees of the benefits • Existing low energy tariffs limit revenues
Customer-side renewable energy business model	• Final consumers less dependent on municipal energy production	• Suitable only for energy production units serving just one building • Another model needed for other renovations • Feed-in tariffs not adopted in Russia
Utility-side renewable business model	• The same energy utility serves the whole district • Optimization and balancing of production	• Covers only modernization of district energy production
Mankala company	• Joint ownership between end users and energy companies • In a modified form could be applied to all district renovation aspects	• Complicated heavy structure
Heat entrepreneurship	• Local actors specialized in local conditions involved	• Basic model aimed solely at heat production
On-bill financing	• Local authorities can require heat companies to implement energy-efficiency measures • Simple financing mechanism	• Consumer payments for energy are subsidized • Russian laws regulate tariffs • Heat consumption is not currently metered, however heat metering installations are mandatory in renovations
Energy leasing	• No need to buy the energy production units • Russian legislation supports leasing schemes	• Not suitable for renovations of systems integrated in the district • Leasing contracts could involve long-term agreements and several stakeholders which could make it complicated to reach an agreement

6. Discussion

In this chapter, findings of this research are discussed mainly from the future research needs points of view following the research process shown in Figure 5. In addition, it was recognized that some of the challenges related to energy-efficient renovation in Russia could be mitigated with policy instruments. Section 6.1 deals with policy instruments identified from renovation-related and energy-efficiency related studies and which instruments could be suggested to stimulate the holistic district renovations in Russia. Section 6.2 deals with the limitations of this study.

The need to modernize and upgrade Russian residential districts is evident. Energy-efficiency improvements should be considered when upgrading the districts, to benefit from opportunities to reduce energy consumption and reduce environmental loads.

Soviet-era residential districts include only a few building types, and due to the similarities of the building types, adequate building analyses can be made even by using only one building type. Therefore, even though the analyses were made with one building type in a pilot area, their results can be generalized to other similar residential areas in Moscow, as well as in other parts of Russia. In addition, comparable building typologies exist extensively throughout Eastern Europe. Therefore, after updating the results to different climate conditions, similar solutions and concepts could be adopted much more widely.

Though this dissertation concentrated on renovation, a share of the Russian apartment buildings is perhaps in critical condition and needs to be demolished anyway. Such decisions will be made based partly on the evaluated physical conditions of the buildings and partly on economic assessments. For the latter, a Danish example shows that the investment cost and future market value of the buildings are then the dominant factors in decision-making (Morelli et al., 2014).

Losses in energy networks are considerable in Russia. In addition, heat exchangers are lacking between networks and buildings, as well as other means to control heating within buildings. Thus, the entire energy chain in residential districts, from production through distribution until usage, needs to be improved, as suggested in this study. In addition to improved system operation, this would result in remarkable energy savings, supporting the national modernization targets set in the energy strategy of Russia for the period up to 2030 (Ministry of Energy of the Russian Federation, 2010). Reduced peak loads were not taken into consideration in the analyses made. This could be an issue of further research, also reducing operating costs of the energy systems.

Typically, neither energy production nor consumption is metered in Russia (Korppoo & Korobova, 2012; Kuleshov et al., 2012) but existing legislation requires that renovated buildings must be equipped with heat meters to the extent technologically possible (Publication III). This can also stimulate users to pay more attention to their energy usage if also the energy billing follows the energy metering. Then, reducing energy consumption through user behavior would be a subject worth investigating in the Russian context. However, Finnish study of non-renovated, but apartment specific thermostat controlled, multi-family apartment buildings show that occupant behavior has only limited effect on the energy consumption when multi-family housing is connected to district heating (Kyrö et al., 2011).

Considering the emissions, there is not an easy answer as to which energy production scenario is the best one. Observing only CO_2-equivalent and TOPP-equivalent emissions in the case district, all the suggested alternatives would be better than the Moscow reference values, and changing a CHP plant from natural gas to biogas would be favorable. Considering also SO_2-equivalent emissions and particulates, the issue is more complicated, and only the most advanced energy production scenarios could be recommended. However, usually only CO_2 emissions are considered, and just raising the issue that other emissions could also be investigated is important.

Based on the net present values, the long-term viability of the renovation solutions varied significantly depending on the scenario of assumed discounting rates and rates of energy price growth. The results suggested that holistic renovations could be more feasible on a district scale than on individual buildings. Since building retrofits are subject to many uncertainty factors (Ma et al., 2012), risk assessment could provide further information to decision-makers.

Even in traditional construction projects, early stakeholder involvement and integration can increase project value creation (Aapaoja, 2014). Since holistic district renovations would include even more and more dispersed stakeholders, whose requirements could differ remarkably, early stakeholder involvement should be emphasized before successful realization in order to provide benefits for all. This could also help in meeting the non-technical barriers to energy-efficient renovations in Russia, as addressed in Publication I.

Since integration of various services into the offering of an existing business model is difficult (Wikström et al., 2010), developing a completely new business model for the Russian district renovations may be needed. Renovation of whole districts could also offer business opportunities for new actors, providing full-service concepts such as the one-stop-shop business model (Mahapatra et al., 2013) introduced for single-family houses in Nordic countries. In addition, adapting modified Western ESCOs with well-defined financial guarantees could work in Russia. They could also provide financing solutions, as lack of financing may hinder the realization of renovations. Since the role of the public sector is pronounced in Russia, some form of Public-Private-People Partnership (4P) could also be suitable. The private sector, and especially the investors, would be more interested in involving large-scale refurbishment rather than just individual buildings, which can only happen when a district is considered as a whole (Kuronen et al., 2011).

This dissertation dealt with the energy-efficient renovation of residential districts through cases from Russia. In addition, the idea of holistic district renovations was introduced, including **both** renovations of the buildings and all their technical systems, **and** modernization of heating energy production and distribution systems, renovation of local electricity production and transmission systems, renewal of street lighting, renovation of water and wastewater systems, and modernization of waste management systems. Table 17 summarizes arguments related to district renovation compared to renovating individual buildings only. The idea of holistic district renovations where improvements are made to the whole energy chain could be applied to other countries as well, especially if energy production is centralized.

Table 17. Arguments related to district renovations compared to mere building renovations.

	Benefits	**Challenges**
Issues studied in the dissertation	• technological solutions exist • guaranteed increased energy-efficiency and reduced emissions through improvements in the whole energy chain • easier to consider renewable energy solutions due to bigger systems with smaller unit costs • economically more profitable • more extensive business opportunities • more interesting for the private sector through economics of scale • opportunities for new actors	• more stakeholders • no tested business models
Other aspects	• reduced costs due to mass customization and economics of scale • the whole area renewed at once • learning during the process (improving and making the renovation activities faster from site to site) • provides better opportunities to consider higher-level targets • possibilities to apply new products	• more difficult to make decisions • getting finance • needs development of renovation processes • requires more employees since renovations are often labor intensive in any case • new products need field testing before market entry

For example, Fey and Shekshnia (2011) address the challenges in doing business in Russia. However, Russia also offers exciting business opportunities in energy renovations of residential districts, as shown in this dissertation. Since the climate in Finland is rather similar to that in Moscow and in the cold regions of Russia, many tried and tested building and energy solutions used in Finland could also be utilized there. In addition, Finnish experiences of cold climate buildings could be of use in updating Russian and Eastern European residential districts to become more energy-efficient. In a technical sense, there is clearly a huge market for companies to respond to the great renovation needs in Russia. So far, Finnish construction companies have not been that interested in this market. However, as shown in the dissertation, many other industry partners would also be involved in district renovation, such as the energy sector. This dissertation brings new insights and ideas to the whole topic, and hopefully encourages new openings from the industrial points of view.

6.1 Potential policy instruments

Perhaps the two dominant challenges in Russian district renovations would be the financing of the renovations and the joint decision-making among apartment owners (Publication IV). In addition, outdated norms are important obstacles in building renovation (Publication I). Policy instruments could help to overcome these challenges. This chapter deals with policy instruments addressed in the scientific literature, and if some of them could be applied in Russia for promoting energy renovations.

Table 18 addresses the policy instruments discussed in the renovation-related scientific literature. In Table 18, the economic instruments include all measures, including some sort of monetary benefit (grant, subsidy, loan, tax reduction, etc.). In addition, studies may include aspects not relevant to renovation, since it is not necessarily distinguished which instruments are targeted at renovations only. The most typical instruments are economic, codes and regulations, information dissemination, and certifications and labels. Typically, no impacts are analyzed. It should also be noted that only one paper deals with Russia.

Table 19 addresses the policy instruments discussed in energy-efficiency related studies that have no special focus on renovation. None of these studies deals with Russia. The instruments addressed are more spread than in the renovation-related literature. Both Table 18 and Table 19 may indicate that analyzing the effects of certain policy instruments is hard, since only some studies report those. This should also be better taken into consideration when developing new policy instruments for energy-efficiency in any country. Developing policy instruments for renovations and energy-efficiency could also be one form of cooperation between the EU and Russia (the European Commission & the Russian government, 2013).

Table 18. Policy instruments addressed in renovation-related studies (may include other issues as well).

Reference	Target sectors	Countries	Codes & regulations	Certifications & labels	Standards	Economic instruments	Information dissemination & awareness raising	Voluntary agreements	Programs & campaigns	Others	Comments
Ástmarsson et al., 2013	rented residential buildings	Denmark		x		x	x	x	x	x	list of instruments, not information given on the effectiveness
Baek & Park, 2012a	residential buildings	Denmark, France, Germany, Sweden	x	x		x				x	review how renovation policies are changing, and what political strategies promote housing renovation, no effects reported
Baek & Park, 2012b	residential buildings, mainly single-family houses	Denmark, France, Germany, Korea, the Netherlands	x	x		x	x				barriers and instruments introduced, no effects reported
Dowling et al., 2014	buildings, energy supply	Australia	x		x	x	x		x		some effects reported, not actual standards for building renovation presented (rather referred to regulations and performance standards)
Galvin, 2010	existing homes	Germany	x			x					cost-effectiveness of building codes, not reported how they would function in practice
Gram-Hanssen, 2014	single-family houses	Denmark	x	x			x				no effects reported
Jones et al., 2013	housing stock	the UK	x			x			x		programs analyzed for energy savings, CO_2 reduction, and costs

Karvonen, 2013	housing stock	the UK	x			x	x		x		introduced community-based partnership includes several stakeholders. Could in some form be applied to Russia. Some examples of the effects given.
Korppoo & Korobova, 2012	residential heating	Russia	x		x	x			x	x	existing policies analyzed, no known effects at the time of writing, obstacles discussed, possible changes of heat consumption standards (not mentioned which ones)
Lewis, 2012	neighborhoods	Baltimore City, the USA				x			x		focus on spatial analyses, probability of residential renovation is examined (i.e., compared to, for example, how close to public transportation)
Meijer et al., 2009	residential building stocks	Austria, Finland, France, Germany, the Netherlands, Sweden, Switzerland, the UK	x	x		x	x		x		some data on the contents and effects of the policies and incentives
Murphy et al., 2012	residential dwellings	the Netherlands	x	x		x	x	x			results demonstrate weak impact of some key instruments
Sunikka, 2006	housing stock	European countries, mainly Finland, France, Germany, the Netherlands, & the UK	x	x		x	x	x			analyzing and suggesting policies, no effects reported
Sunikka-Blank et al., 2012	social housing	the UK		x		x	x				results on effects in a case house
Number of papers dealing with the issue:			11	8	2	13	9	3	6	3	

Table 19. Policy instruments addressed in energy-efficiency related studies (no focus on renovation).

Reference	Target sectors	Target policies	Countries	Codes & regulations	Certifications & labels	Standards	Economic instruments	Information dissemination & awareness raising	Voluntary agreements	Programs & campaigns	Others	Comments
Al-Mansour, 2011	residential, industrial, transport and tertiary sectors	energy-efficiency	Slovenia	x	x	x	x	x		x		some energy-efficiency improvements explained due to instruments
Boza-Kiss et al., 2013	building stock	building energy-efficiency	several (not Russia)	x	x	x		x	x	x	x	societal cost-effectiveness and lifetime energy savings given
Geller et al., 2006	appliances, buildings, industry, transport	improving energy-efficiency	Japan, the USA, & Western Europe	x	x	x	x		x	x	x	energy savings estimates given from energy-efficiency policies and programs in the United States
Lund, 2007	energy systems	renewable energy and efficient energy use	20 cases in total from Austria, China, Denmark, the EU, Finland, Germany, Norway, Sweden, the UK, & the USA		x		x	x	x	x	x	impacts on 20 cases given

Noailly, 2012	buildings	improving energy-efficiency	Austria, Belgium, Denmark, Finland, France, Germany, Ireland, the Netherlands, and the UK	x			x				x	not aware of the recent development of building codes in Finland, impacts on environmental policy instruments on patent counts
Oikonomou et al., 2009	energy end-users	energy-saving and energy-efficiency concepts	No focus on any country		x		x	x				no measured effects reported
Štreimikienė, 2014	residential buildings	energy-saving potential	mainly Lithuania, partly also international	x	x	x	x	x	x	x	x	cost-effectiveness of instruments analyzed, no measured effects reported
Zhang & Wang, 2013	buildings	energy-efficiency	China	x	x	x	x	x	x	x		instruments listed, no effects reported
Number of papers dealing with the issue:				6	7	5	7	6	5	6	5	no Russian related studies

Considering the policy instruments presented in Table 18 and in Table 19, perhaps the most promising instrument in Russia could be programs, since they need the involvement of the public sector, which is mandatory in Russian district renovations. This could aid in convincing both the inhabitants and the financiers. In Russia, the creation of trust plays an important role in business relationships (Publication IV). Strong commitment of the public sector, for example through programs or campaigns, could also support trust creation among the various stakeholders.

Since lack of financing was identified as one of the key barriers to energy-efficient renovations (Publication IV), policy measures tackling this issue would be welcomed. It would need more research to evaluate which sort of economic instrument would work best in Russia. For example, it could be a fiscal policy instrument or a direct subsidy.

Due to the outdated norms, the authorities are cautious when accepting new design solutions (Publication I). This may hinder implementation of technologies, which are considered typical outside Russia but which are not widely applied in Russia (Figure 4). Updating regulations could both improve Russian living standards and facilitate product entries to the Russian market.

This research did not deal with how well known are different energy-efficient technologies in Russia. However, according to a poll made with Russian residents, 80% of the respondents had not heard of mechanical ventilation (Nystedt et al., 2010). This may indicate that also information dissemination and awareness raising might be needed in Russia.

6.2 Limitations of the study

Russian conditions were taken into account when defining the renovation concepts and the energy production scenarios. Still, they were based on field experience from energy-efficient renovations in Finland. It could be argued that Russian apartment buildings differ from the Finnish ones and those experiences from Finland cannot be utilized in Russia. However, major areas of both Finland and Russia are placed to the cold and snow climate in the Köppen-Geiger climate classification system (Peel et al., 2007; Kottek et al., 2006), meaning that the climate in large areas of both countries is quite similar. In addition, district heating is widely used in both countries (though the system structures differ) (Nuorkivi, 2005; Statistics Finland, 2014). Typical apartment buildings have concrete based walls (Opitz et al., 1997; Raslanas et al., 2011; Nemry et al., 2008; Häkkinen et al., 2012) but typical U-values of structures of non-renovated buildings are better in Finland (Häkkinen et al., 2012; Lechtenböhmer & Schüring, 2011) than in Russia (Table 5). Thus, due to the similarities in buildings and energy systems, many technologies proven and tested in Finland can be applied to Russian apartment buildings. However, the results are applicable only to heating dominated areas of Russia.

In Russia, inhabitants differ from Finland but user behavior was not within the scope of this dissertation. However, also in Finland occupants have little influence on the overall energy consumption in district-heated apartment buildings (Kyrö et al., 2011) even though heating systems include room thermostats.

The policy context in Russia differs from Finland. This does not prevent developing or suggesting technology solutions but it is a crucial issue when designing and implementing technologies in Russia (Publication I). In general, the role of the public sector in boosting holistic district renovations is dominant. Outdated norms and long permission processes are important obstacles in building renovation (Publication I). Strong commitment of municipalities could help to overcome such obstacles and to deal with the city planning aspects needed to be considered (Publication II). It can be considered as a limitation that input from Russian municipalities is missing in the dissertation.

Measured data on energy and water usage is hardly ever available in Russia (Publication III). Thus, even if there can be large disparity between calculated and actual energy consumptions (e.g., de Wilde, 2014) taken this into account in the Russian conditions would have been challenging. Calculated energy consumptions always contain various input data. Selecting and defining them include potential error sources. In addition, it is often difficult to find and interpret Russian data (Publication I). However, the calculated energy consumptions of non-renovated buildings were well in line with the estimates from relevant references (Publication I). Still, data on actual energy consumptions would give valuable information for further studies.

Transportation and other district services resulting in further energy demand and emissions (e.g., Ahanchian & Biona, 2014; Wu & Aliprantis, 2013) were ignored in the district analyses since the focus was on buildings, and energy and water infrastructures. If residential districts were renovated holistically in Russia, optimum investments in the transportation sectors (e.g., Wu & Aliprantis, 2013) could also be considered.

7. Conclusions

Very little scientific literature is available about the energy-efficiency of Russian Soviet-era residential districts. This dissertation contributes a pioneering work in several fields of this topic. Even the introduced idea about the holistic district renovations, including holistic renovations of both the apartment buildings and the related energy and water infrastructure, is new.

In this dissertation, three renovation concepts for improving the energy-efficiency of both buildings and the district as a whole were developed and analyzed. Both the building- and district-level concepts were named Basic, Improved and Advanced. In the building-level concepts, the focus was on reducing heating and electricity demand, reducing water use, and improving ventilation. In the district-level concepts, the focus was on energy production options, improving energy, water and waste water networks and reducing their losses, improving waste management, and improving outdoor lighting.

The building-level energy savings potential for heating energy is up to 68% and for the electrical energy up to 26% with the suggested energy renovation concepts. With the district renovation concepts, the related energy and water infrastructure would also be modernized. Doing so would result in remarkable energy savings, up to 72% of the heating demand and up to 34% of the electricity demand, in the district.

The CO_2-equivalent greenhouse gases may be reduced by up to 65% by renovating the whole district (both the buildings and the related infrastructures) with the advanced renovation solutions, but continuing to produce energy with the natural gas CHP plant. With the most advanced energy production scenarios, all the examined emissions would be marginal.

At building level, the costs of the different renovation packages for the II-18 type building varied between €125/m^2 and €200/m^2, depending on the extent of the selected renovation package. All the building-level packages covered improvements to external walls, windows and doors, upper ceiling, basement, ventilation, heating system, water and wastewater, electricity, gas, metering, and other improvements and costs, but the selected products and solutions varied from basic through improved to advanced ones. Repairing the external walls forms the biggest share of the costs in all the renovation packages, being around 35–40% of the total costs.

The costs of district heating substations and transformer substations are the biggest when upgrading the surrounding energy and water infrastructure for the II-18 type building. The district renovation costs include both the renovations of the buildings and renovating the energy and water infrastructures in the case district. The Basic district renovation would cost nearly €3,500 per inhabitant, while the most advanced renovations, introducing also renewable energy solutions, would cost over €6,000 per inhabitant.

In addition to the costs, 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. Both at the individual building level and the district level, with most combinations of the interest rate and annual energy price growth rate, the Improved renovation package turned out to be the most profitable.

Possible business models for energy-efficient renovations of residential districts in Russia were also analyzed. None of the business models analyzed as such suit holistic district renovations, but they all include features that could be included in a suitable model. Perhaps even a completely new actor is needed to take over. District renovations require the cooperation of a wide range of stakeholders, whose early involvement is recommended.

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VTT Science 72

Title	**Energy-efficient renovation of residential districts** Cases from the Russian market
Author(s)	Satu Paiho
Abstract	The energy-efficiency of Soviet-era residential districts in cold urban Russian regions is poor. It could be improved by renovating buildings to be more energy-efficient and by reducing the losses in the related energy infrastructure. This dissertation deals with the energy-efficient renovation of such Russian districts. The idea of holistic district renovations is introduced, including both renovations of the buildings and modernization of the related energy and water infrastructures. Based on case studies, solutions are presented and analyzed for renovating upscale Russian residential districts into more energy-efficient ones. Holistic renovation concepts were developed both for individual apartment buildings and for typical residential districts. For the II-18 Soviet-standard type building, the energy saving potential was up to 68% for heating energy and up to 26% for electricity. In the district considered, using different district modernization scenarios, up to 72% of the heating demand and up to 34% of the electricity demand could be saved. CO_2-equivalent, SO_2-equivalent, and TOPP-equivalent (tropospheric ozone precursor potential) emissions, as well as particulates of the different district energy production scenarios, were also analyzed. In view of CO_2-equivalent and TOPP-equivalent emissions in the case district, changing a CHP plant from natural gas to biogas would be favorable. Considering also SO_2-equivalent emissions and particulates, only the most advanced energy production scenarios could be recommended. The costs of different renovation packages for the type apartment building varied between €125/m^2 and €200/m^2, depending on the extent of the selected renovation package. Repairing the external walls formed around 35–40% of the total costs in all renovation packages. If the whole district was renovated (both the buildings and the related energy and water infrastructures), the costs per inhabitant varied between €3,360 and €5,200. The costs per inhabitant of additional alternatives, including renewable energy production solutions, were over €6,090. In addition, business models for such district renovations were analyzed. Developing a completely new business model for the Russian district renovations may be needed, since none of the identified models as such is suitable. Since some ESCO (Energy Service Company) activities have been realized in Russia, adapting modified Western ESCOs with well-defined financial guarantees could work in Russia.
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Nimeke	**Asuinalueiden energiatehokas korjaaminen** Tapauksia Venäjältä
Tekijä(t)	Satu Paiho
Tiivistelmä	Venäjän neuvostoaikoina rakennetut lähiöt eivät ole energiatehokkaita. Tilannetta voitaisiin parantaa korjaamalla rakennukset energiatehokkaammiksi ja pienentämällä energiainfrastruktuurin häviöitä. Tämä väitöskirja käsittelee tällaisten venäläisten asuinalueiden energiakorjaamista. Työssä esitellään ajatus kokonaisvaltaisista alueremonteista, joissa korjattaisiin sekä rakennukset että niihin liittyvät infrastruktuurit. Työssä esitetään ja analysoidaan ratkaisuja, joilla uudistettaisiin venäläiset kylmän ilmaston kaupunkimaiset asuinalueet energiatehokkaiksi. Sekä asuinkerrostaloille että tyypillisille asuinalueille kehitettiin kokonaisvaltaisia korjauskonsepteja. Kuvatuilla ratkaisuilla tyypillisessä neuvostostandardin II-18 mukaisessa asuinkerrostalossa voitaisiin säästää jopa 68 % lämmitysenergiasta ja 26 % sähköstä. Aluetason korjausskenaarioilla voitaisiin säästää esimerkkialueella jopa 72 % lämmöntarpeesta ja 34 % sähköntarpeesta. Erilaisista alueellisista energiantuotantovaihtoehdoista analysoitiin hiilidioksidi-, rikkidioksidi-, ja pienhiukkaspäästöt sekä alailmakehän otsonin esiastetta kuvaavat TOPP-päästöt. Tarkastelemalla vain hiilidioksidi- ja TOPP-päästöjä esimerkkialueella kannattaisi vaihtaa yhdistetty lämmön ja sähkön tuotanto maakaasusta biokaasuun. Jos otetaan huomioon myös rikkidioksidi- ja pienhiukkaspäästöt, voidaan suositella vain kehittyneimpiä uusiutuvaan energiaan perustuvia energiantuotantovaihtoehtoja. Rakennustasolla korjausvaihtoehtojen hinnat vaihtelivat 125 €/m^2 ja 200 €/m^2 välillä riippuen valitusta korjauspaketista. Noin 35–40 % näistä kustannuksista muodostui ulkoseinien korjaamisesta. Jos korjattaisiin koko asuinalue (sekä rakennukset että niihin liittyvä energia- ja vesi-infrastruktuuri), kustannukset asukasta kohden vaihtelisivat 3 360 € ja 5 200 € välillä. Hyödynnettäessä uusiutuvaa energiaa kustannukset asukasta kohden olisivat yli 6 090 €. Lisäksi analysoitiin energiatehokkaan aluekorjaamisen mahdollisia liiketoimintamalleja. Voi olla tarpeen kehittää kokonaan uusia liiketoimintamalleja, koska mikään analysoiduista malleista ei sellaisenaan sovellu. Koska Venäjällä on toteutettu joitakin ESCO-malliin (Energy Service Company) perustuvia energiansäästöinvestointeja, ESCO voisi soveltua muokattuna, kunhan esimerkiksi taloudelliset takuut määritellään hyvin.
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