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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

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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

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).

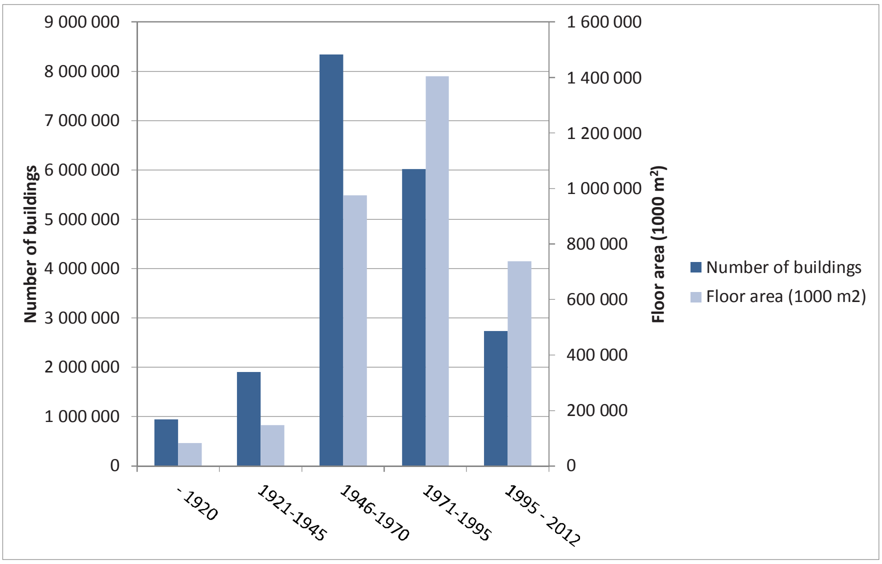

Figure 1. Russian residential buildings by the year of construction (Source: Federal Service for State Statistics, 2013).

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.

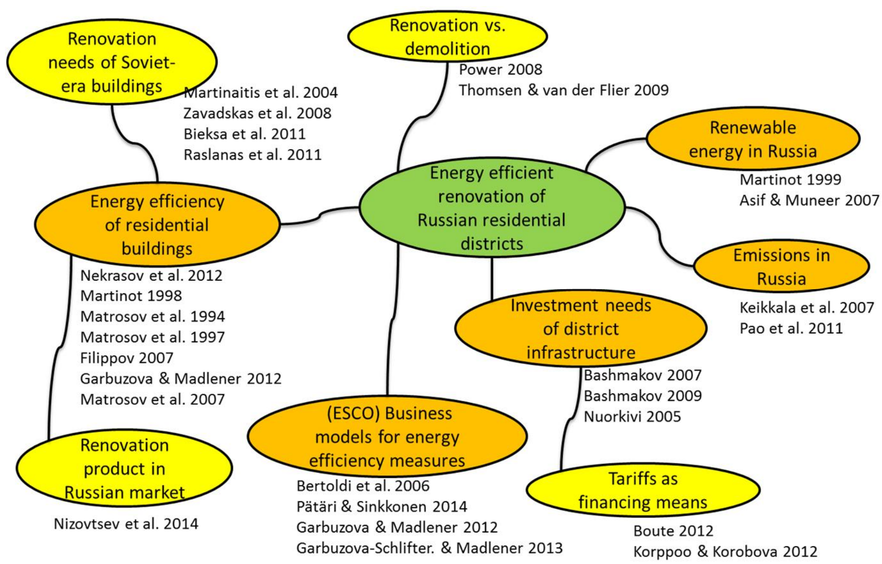

Figure 2. Issues addressed in the international scientific literature.

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).

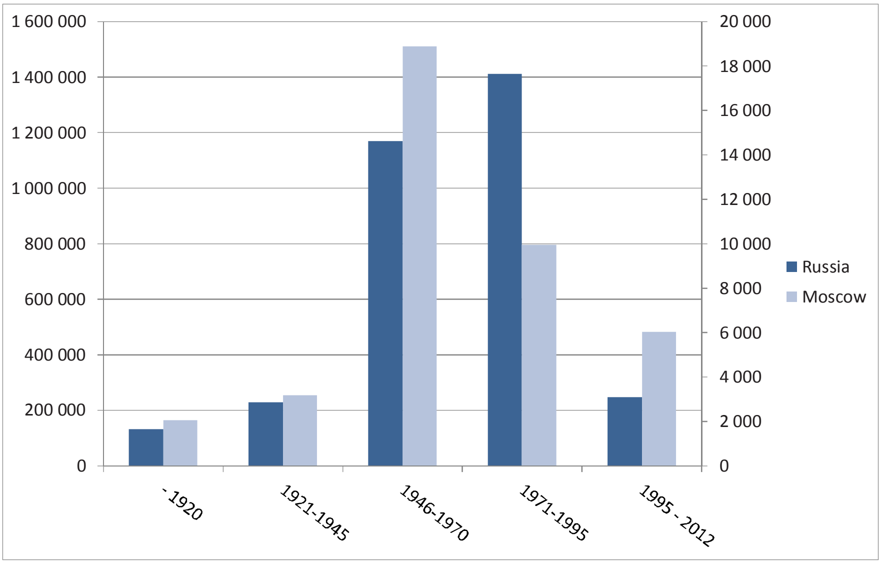

Figure 3. Number of apartment buildings by the year of construction in Russia and in Moscow (Source: Federal Service for State Statistics, 2013).

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 R E A L E S T A T E 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 1,451 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 23 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 Sozoreva, 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.

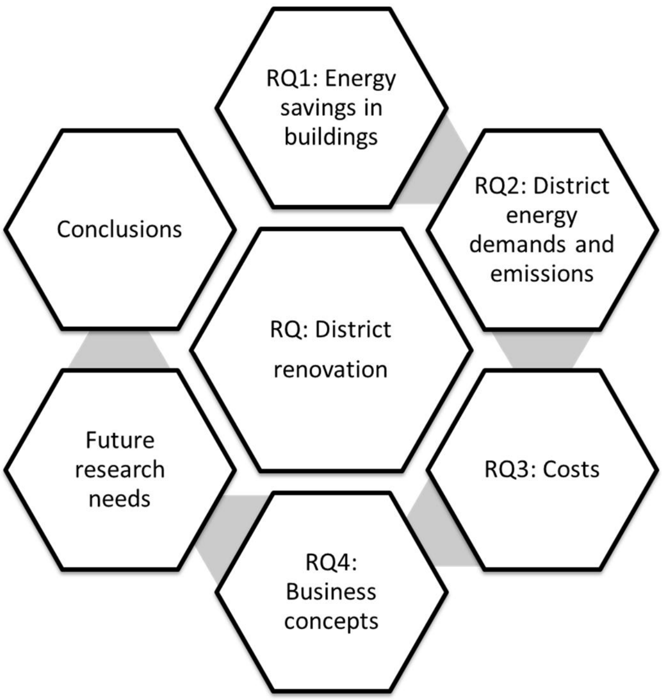


Figure 5. The research process with the main topics of the research questions.

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.

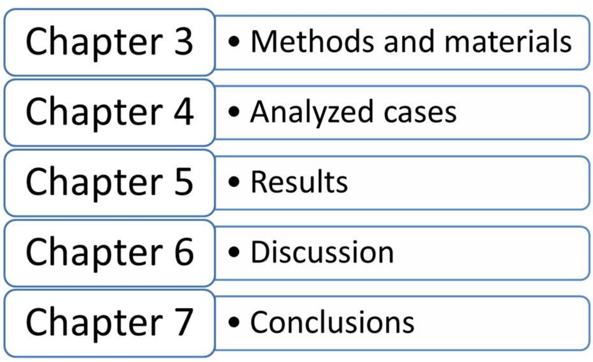


Figure 6. Main contents of the remaining chapters.

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.

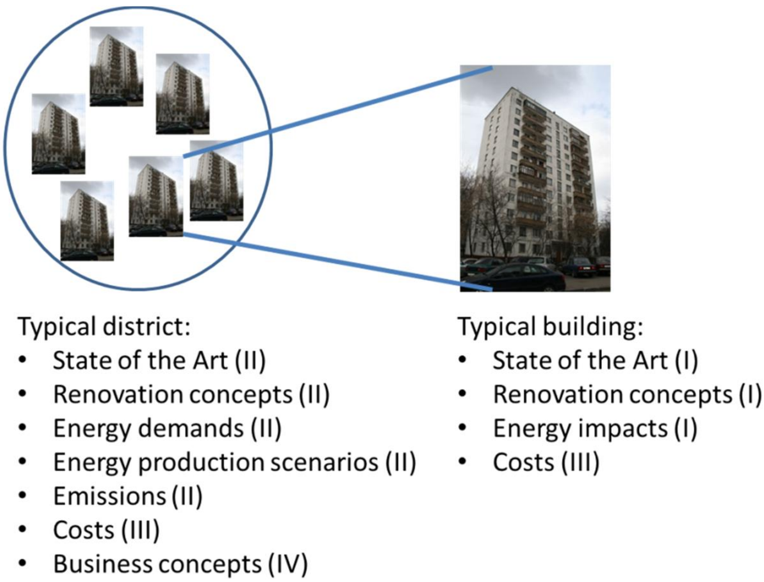


Figure 7. Frame of the materials used.

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.

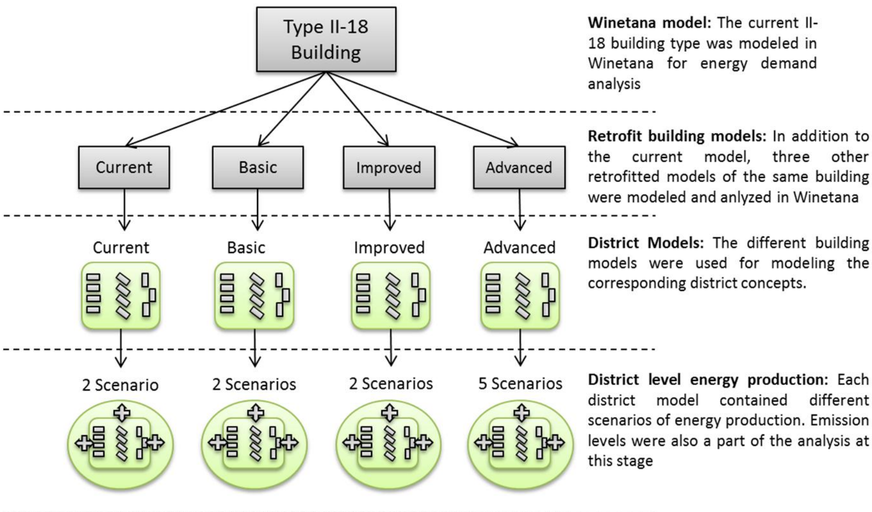


Figure 8. Overview of the process of conducting the energy and emission analyses. (WinEtana is computer software for making building energy analyses developed by VTT Technical Research Centre of Finland.)

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

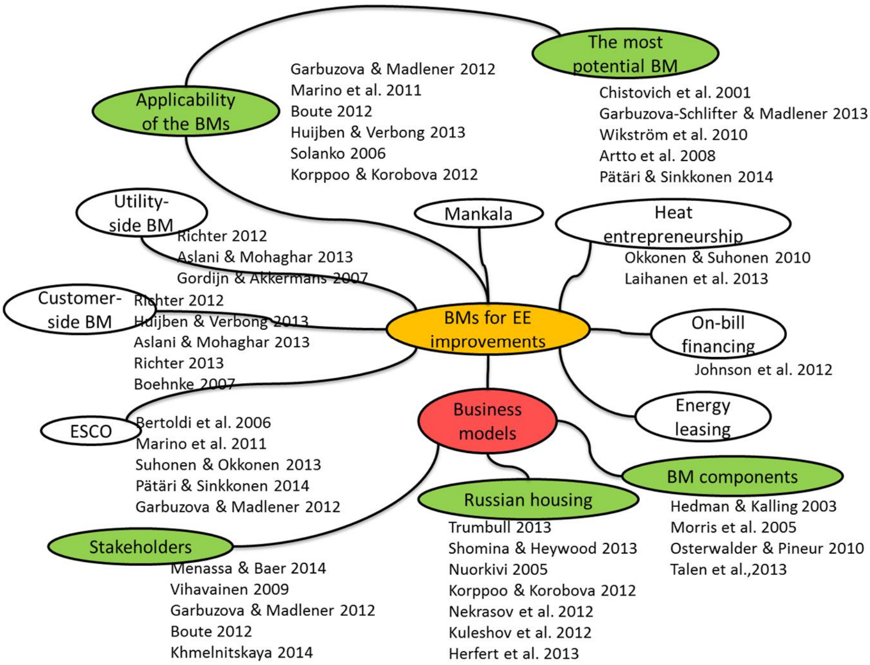


Figure 9. Scientific literature utilized in Publication IV.

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	1.1	0.5	0.32	0.15
• base floor	1.1	–	–	–
• roof	1.1	0.25	0.24	0.15
• windows and doors	2.9	1.85	1.5	1.0
Ventilation	Natural	Restoration of existing natural ventilation. 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 re-placement	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.

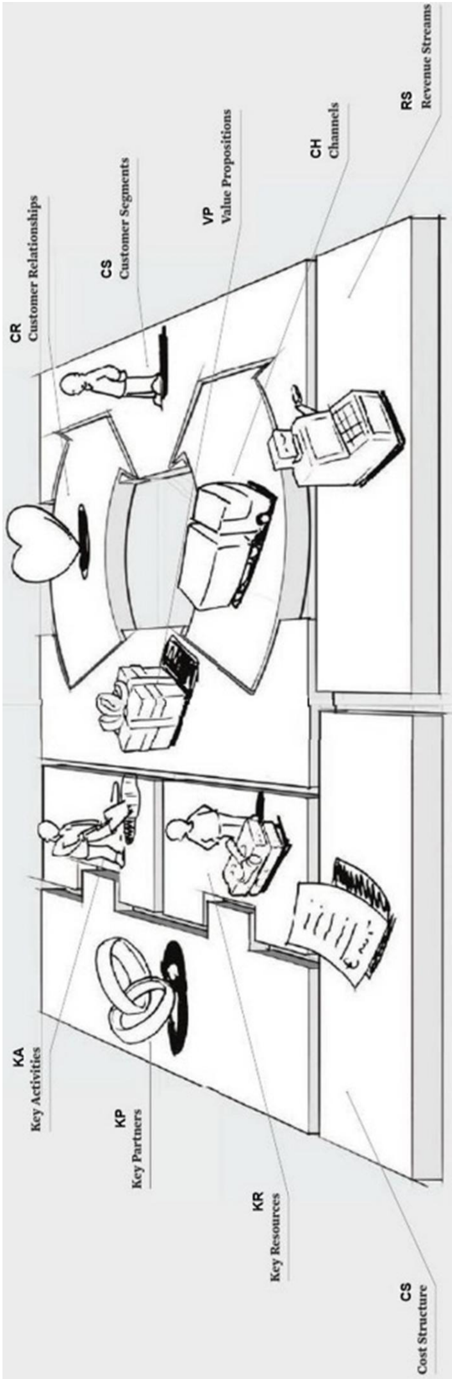


Figure 10. General business model canvas by Osterwalder and Pigneur (2010).

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.

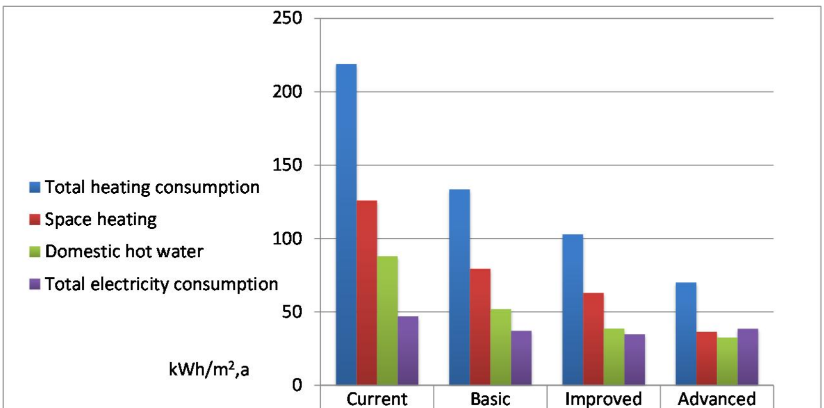
Business model component	**Main aspect**
Customer segments	renovated buildings and the related infrastructure, knowledgeable customers required
Value proposition	energy-efficiency in combination with other values and benefits
Channels	due to many involved stakeholders several are needed including personal 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%.

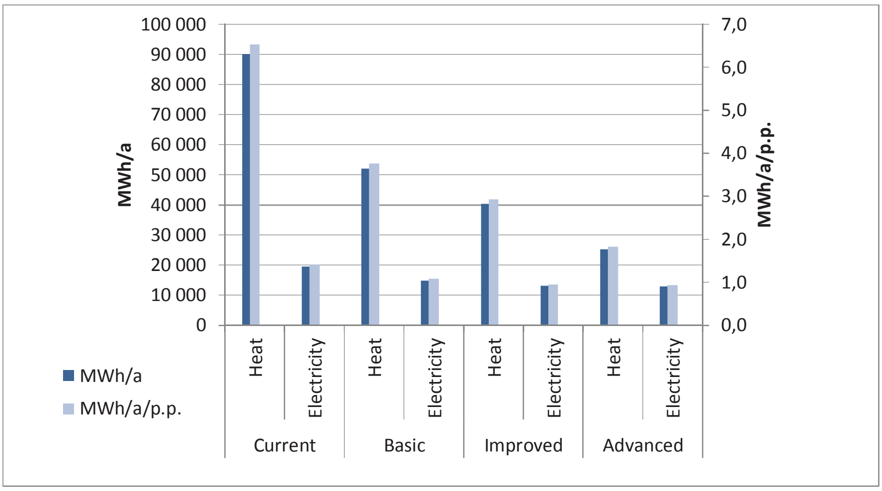


Figure 12. The annual energy demands for the different district concepts. The total demand is given on the left and the demand per inhabitant on the right.

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.

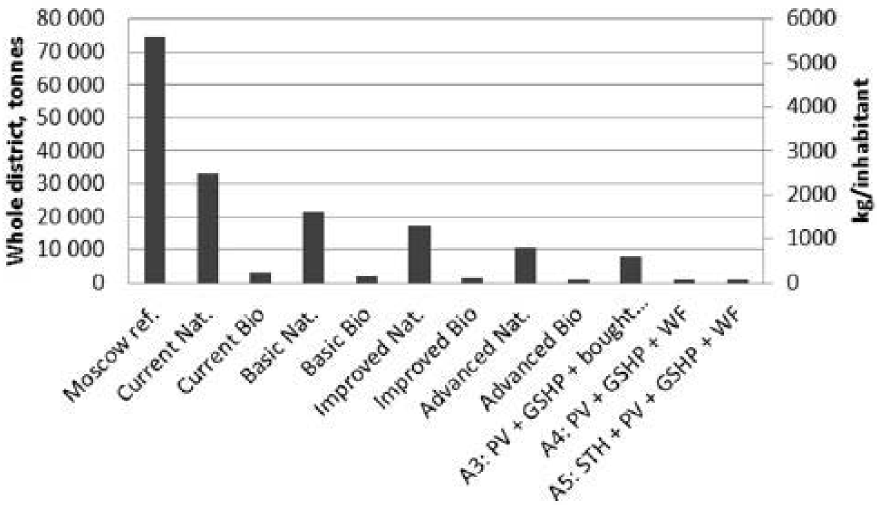


Figure 13. CO_2-equivalent emissions of the district energy production scenarios.

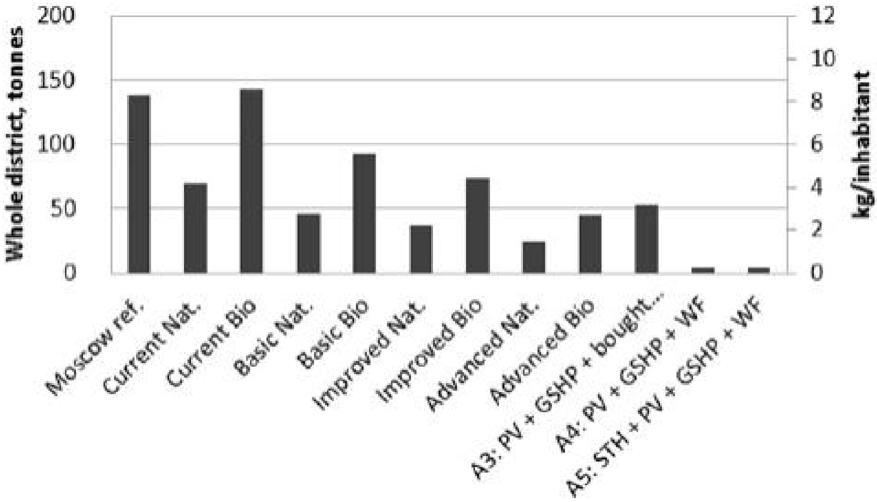


Figure 14. SO_2-equivalent emissions of the different energy production scenarios.

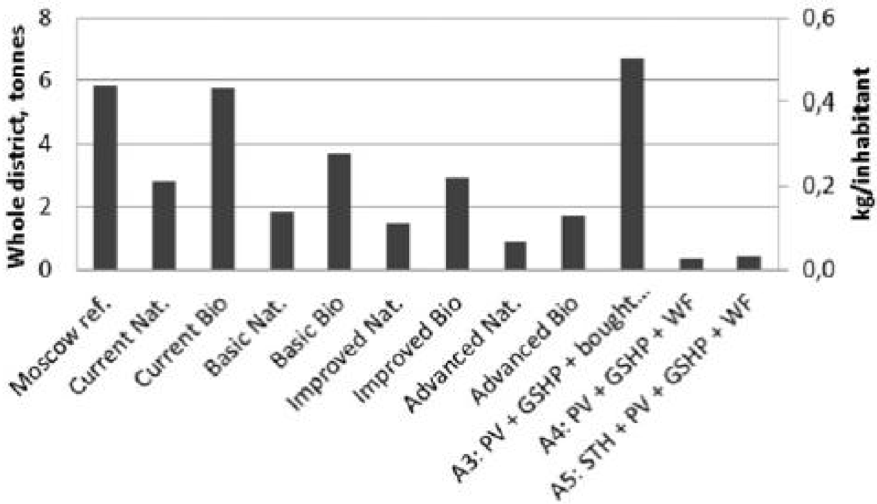


Figure 15. Particulates of the district energy production scenarios.

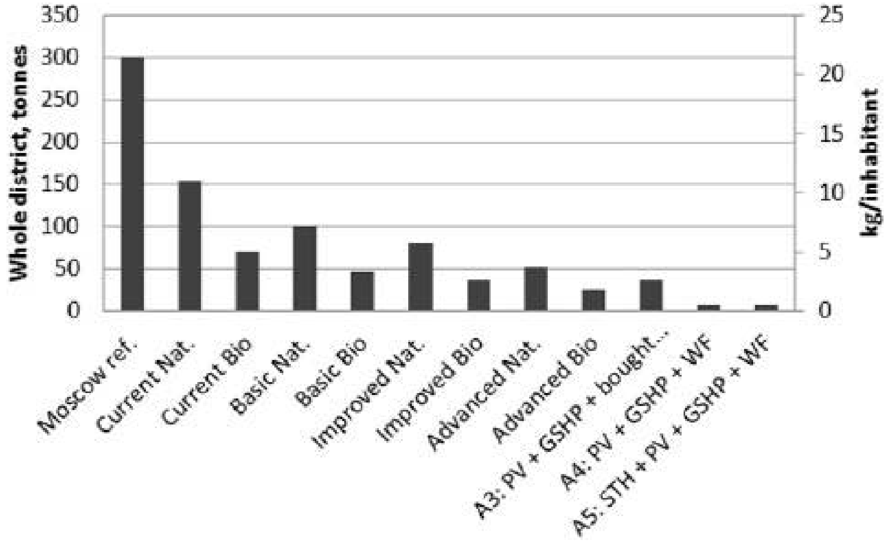


Figure 16. TOPP-equivalent emissions of the district production scenarios.

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.

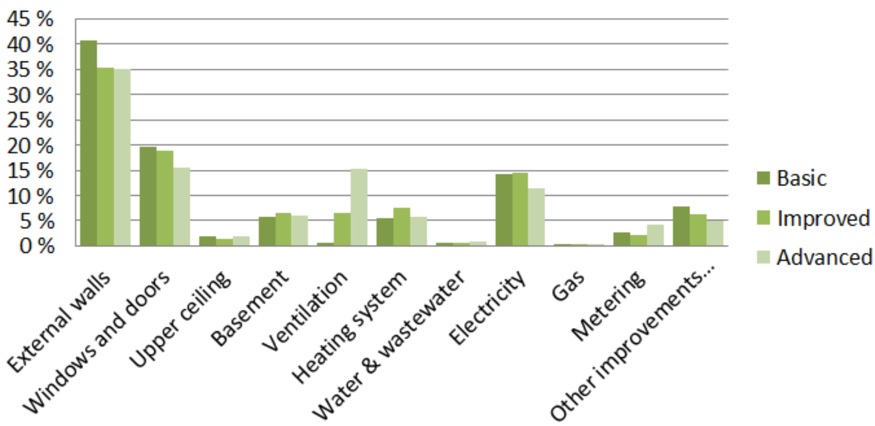


Figure 18. Shares of the categorized measures of the total building renovations costs.

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.

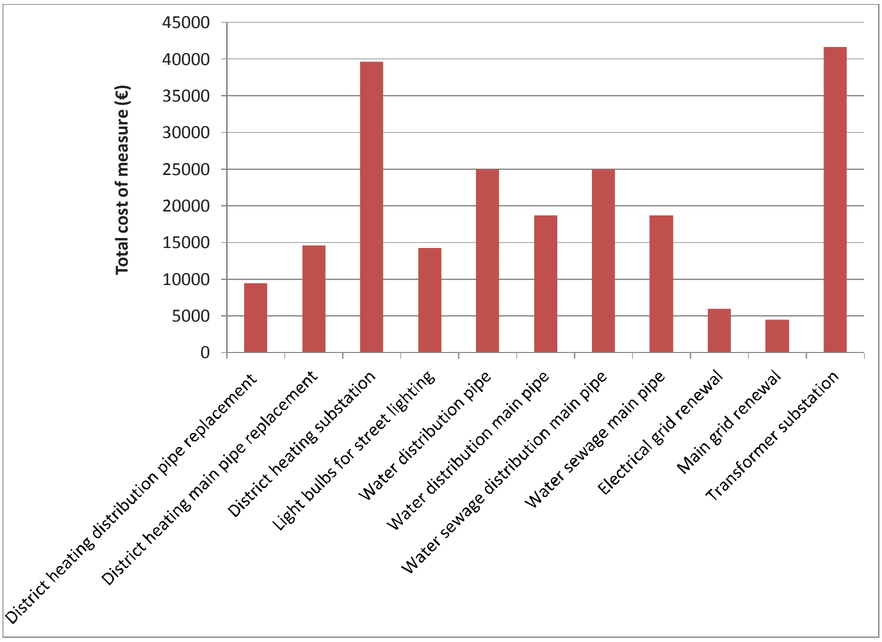


Figure 19. Costs of upgrading the surrounding infrastructure for the II-18 type building.

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

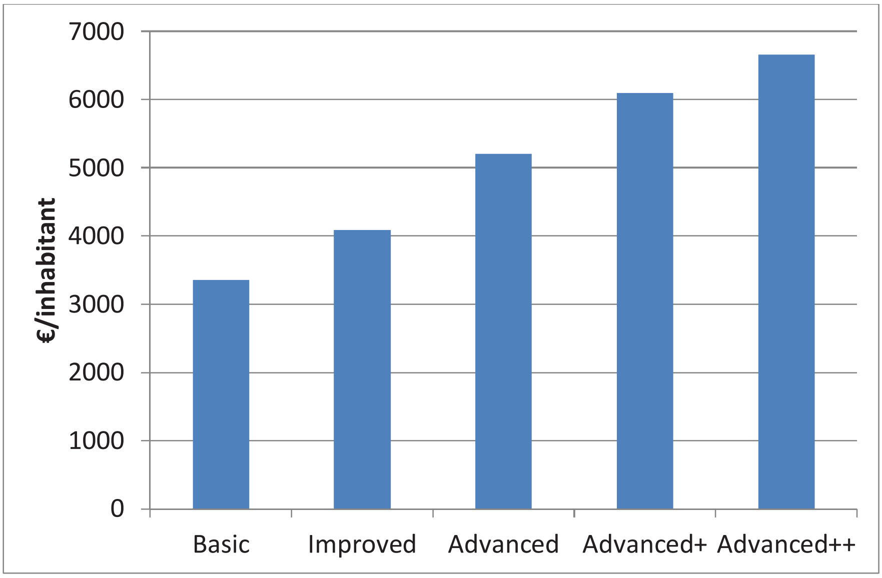


Figure 20. The total investment costs per inhabitant of the different renovation packages including both the building-level renovations and the district-level renovations.

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														
		Annual energy price growth rate, %												
		3	4	5	6	7	8	9	10	11	12	13	14	15
Discount rate, %	3	I	I	I	I	I	I	I	I	I	A	A	A	A
	4	I	I	I	I	I	I	I	I	I	I	A	A	A
	5	I	I	I	I	I	I	I	I	I	I	I	A	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
	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

Basic = B
Improved = I
Advanced = A

20 year period, constant water tariff growth at 5%

District renovation														
		Annual energy price growth rate, %												
		3	4	5	6	7	8	9	10	11	12	13	14	15
Discount rate, %	3	I	A	A	A	A	A	A	A	A	A	A+	A+	A++
	4	I	I	A	A	A	A	A	A	A	A	A	A+	A+
	5	I	I	I	I	A	A	A	A	A	A	A	A	A+
	6	I	I	I	I	I	A	A	A	A	A	A	A	A
	7	I	I	I	I	I	I	A	A	A	A	A	A	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
	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

Basic = B
Improved = I
Advanced = A
Advanced+ = A+
Advanced++ = A++

20 year period, constant water tariff growth at 5%

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, Den-mark, 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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Energy saving potentials of Moscow apartment buildings in residential districts

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ABSTRACT

This study estimates the energy savings potentials of Moscow apartment buildings through different renovations concepts. Also the reductions of the district level energy demands resulting from the possible building level energy savings were estimated. The principles of these energy chain analyses are also described.

Most of the apartment buildings in the Soviet Union were constructed between 1960 and 1985, and as a result the urban housing stock today consists mainly of a few standard building types. Energy efficiency of buildings is typically poor. A typical residential district was selected for the analyses. The energy consumption of a typical Russian building was estimated by calculating heating of living spaces, heating of domestic hot water, and the consumption of electricity. The energy consumption of the selected building stock was based on the calculated consumptions of the type buildings. The present state of the district level was studied first, including energy chain analyses. Then the energy savings potentials for three different renovations concepts were estimated. In addition, non-technical barriers to energy efficient renovations are discussed.

1. Introduction

Energy strategy of Russia for the period up to 2030 states that Russia must improve its energy efficiency and reduce energy intensity of its economy to the level of countries with similar climatic conditions such as Canada and the Scandinavian countries [1]. In addition, it is required that Russia's living standards must correspond with those of the developed countries.

According to national statistics service the share of dilapidated and emergency-state housing is around 3% of the total area of the Russian housing stock [2]. However, it is estimated that more than 290 million m^2 or 11% of the Russian housing stock needs urgent renovation and re-equipment, 250 million m^2 or 9% should be demolished and reconstructed [3]. Some 58–60% of the country's total multi-family apartment buildings are in need of extensive capital repair [4].

In 2005; the Russian residential, public, and commercial buildings were responsible for 144.5 Mtoe (million tonnes of oil equivalent), i.e. 1680 TWh, of final energy use (34%) and for 360 Mtoe, i.e. 4186 TWh, of primary energy (55% of overall primary energy consumption). The technical energy efficiency potential of the buildings was assessed at 68.6 Mtoe, i.e. 797,820 GWh [5]. Residential buildings are evaluated to have the largest energy savings potential out of all building types. The largest part (67%) of the energy savings could be implemented through the more efficient utilization of district heating in space and water heating. An estimated 60% of the Russian district heating network is in need of major repair or replacement [6]. The investment needs for rehabilitating the district heating systems is Russia are estimated at US$ 70 billion by year 2030 [7].

The majority of Moscow housing stock is built after World War II [2] and need modernization. Sustainability should be taken to account when renovating these buildings. Thus, energy efficiency of buildings and districts is one of the core issues. Before deciding any renovation solutions, the energy consumption levels need to be estimated. After the estimation, different renovation concepts can be compared with the current situation. This paper describes the principles of the energy analysis process, estimates the present state energy consumptions of a typical Moscow apartment building and a typical district (neighbourhood), and then analyses different building level energy renovation concepts.

Often technical solutions exist for energy renovations of buildings but other obstacles hinder or delay their realization. These non-technical barriers to energy efficient renovations of Moscow residential districts are also described in this paper.

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2. The Moscow housing stock

Construction in Russia [2] state that the total Russian housing stock in terms of total residential floor area was 3177 million m^2 in 2009. Total area of the housing stock per capita was 22.4 m^2.

According to the statistics from 2004, 95% of the Moscow dwelling space is built after World War II, from which 52% of the residential buildings were built during 1946–1975 and 43% in 1976 or later. According to Rosstat [2], there were 39.801 residential buildings in Moscow in 2009. The amount of residential buildings equals 3,835,000 apartments and the total floor area of 214 million m^2. The average floor area of an apartment in Moscow was 55.8 m^2 and the average number of residents per apartment was 2.8. The figures do not account for administrative expansion of Moscow implemented in summer 2012.

2.1. Typical apartment buildings in Moscow

It is important to understand the general situation in the target place before conducting energy analysis. In 2004 United Nations published Country Profiles on the Housing Sector Russian Federation [3], which helps to form an overview of typical building solutions in Moscow and in Russia. First of all, the industrialization of construction started in the Soviet Union in the 1950s, after which the precast concrete large-panel construction developed quickly. Most of the apartment buildings were constructed between 1960 and 1985, and as a result the urban housing stock today consists mainly of a few standard building types. [3]

In general, there are three basic categories for residential panel buildings [3]:

- First generation is five-storey buildings often called *khrushchevky*. Khrushchevky have been built between 1959 and 1969 and about 10% of residential buildings belong to this category. Typically their state is quite poor nowadays and they are situated in fairly attractive areas, not far from city centres.
- Second generation buildings were constructed between 1961 and 1975. The number of storeys varies but nine-storey buildings are the most common. The buildings are long and there are usually five to nine staircases in each. The external walls are different lightweight concrete structures without separate thermal insulation material. The housing norms of 1963 regulated their design and construction. The dwellings in this category are more comfortable than those in the first-generation buildings.
- Third generation buildings were built mainly after 1975 in the suburbs. Large elements and prefabricated modules were used. These buildings are nine-storey or higher, tower type blocks of flats or long, narrow buildings with four to seven staircases. The external walls are usually 32–35 cm thick expanded-clay lightweight concrete.

Natural ventilation is a typical solution in Russia [8]. District heating networks supply heat to about 80% of Russian residential buildings and about 63% of the hot water used by Russia's population [6].

Energy efficiency of these apartment buildings is typically poor. The thermal insulation of the precast panel walls does not meet modern standards, and may cause moisture and mould problems. Moreover, the surroundings like streets, courtyards and parks are usually poorly maintained. The limited variation in the urban housing stock results in suburbs of large uniformity, where individual wishes or needs are rarely met. [3]

There is one more issue that should be considered when studying Russian buildings. It is quite difficult for researchers from outside of Russia to find and correctly interpret Russian data. According to Opitz [9], the central government has a desire to conceal important production and financial facts, which means that the clarity and consistency in published statistics is often rare, and a lot of interesting information is simply unavailable to the general population. Moreover, the statistical reports published in several forms by Goskomstat (the State Committee on Statistics) were incomplete and often inconsistent. The accounting methods and definitions varied among sources and even within the same source in different years. Opitz [9] states that the data almost seem designed to confuse. The data used for this paper was gathered from several sources, and cross-checked when appropriate sources were found.

2.2. The selected housing district

A typical residential district was selected to be analyzed in the project. The selected district mostly represents 4-th Microrayon of Zelenograd, Moscow (longitude 37° east and latitude 55° north). Zelenograd is located about 35 km to the North-West from Moscow City centre. The district dimensions are approximately 1 × 0.5 km. It represents a typical residential district of Moscow and Moscow region with high-rise apartment buildings constructed for the most part in 1960s and 1970s. The district is heated with 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 build between 1966 and 1972. Each building series represents a specific building design [8]. There are also other apartment buildings, schools, kindergartens, shops, a bank in the area, but since this project concentrates on modernization of buildings, these newer buildings from the 90s and from the beginning of 2000 are excluded from these energy calculations. The more detailed data about the older apartment buildings is presented in Table 1 and these buildings were the main target of the first calculations of this study. After the initial analysis the most common building type II-18 was selected for further analyses.

In total there are approximately 13,800 residents in the buildings that are included in the calculations. The total floor area of the studied buildings is 327,600 m^2. The number of residents is estimated based on the assumption that the average occupancy rate per flat is 2.7 persons [3].

3. Principles of the energy analyses

The main objective for the energy analyses was to form an overview of average energy consumption, energy production quantities, and energy efficiency in Moscow, Russia. The energy analysis is important, because it helps to recognize the best ways of how to improve the energy efficiency of entire districts and energy systems. The key questions are: "How the energy is currently produced for buildings and districts?", "What are the most efficient ways to reduce energy consumption and how much can it be reduced?", "What is the environmental impact of energy production and how emissions caused by it can be reduced?" and "What are the life cycle energy costs of different alternatives?".

The general methodology of energy analyses is presented in Fig. 1. At first the state of the art was studied for both old apartment buildings and the entire residential district in the Moscow region. This means that the typical apartment building parameters were identified, and an example district was selected for the calculations. Most of the buildings in the example district are built between 1966 and 1972. A few different typical apartment building types was studied: their monthly energy consumption levels were calculated, and then from those results the energy demand of the entire district was calculated including also the energy demands for

Table 1
Apartment building types and their basic data in the studied district.

Description	Long apartment building	Long apartment building	Higher apartment building	Apartment building	Apartment building
Series	II-57	II-49	AK-1-8	II-18	Mr-60
Construction year	1967–1968	1966–1969	1971–1972	1965–1966	1967–1968
Number of buildings[a]	4.6	11	6	10	4
Apartments per building	358	143	102	84	111
Residents per building[b]	967	386	275	227	300
Floor area (m^2)	22,827	8951	7140	4911	8042
Number of floors	9	9	17	12	16
Shape	Rectangle	Rectangle	Rectangle	Rectangle	Rectangle
X/*Y* ratio[c]	0.07	0.16	0.40	0.60	0.38

[a] 0.6, because there is one smaller similar building.
[b] Assumption: an average flat has 2.7 residents (United Nations 2004).
[c] Shape of the building: *X* is width of the building and *Y* is length of the building.

waste and water management and street lighting. The next step was to evaluate the energy saving potentials that can be achieved with renovating these old apartment buildings. This was done by calculating different scenarios for renovated apartment buildings. As a result knowledge of total energy consumption levels in different scenarios in the typical Moscow residential district was achieved.

The last phase of the energy chain analyses is to study the energy production. This part also starts with the state of the art of the existing or typical energy production and distribution systems. Then improvements and renewal of these systems can be identified. Finally, the life cycle emissions for different energy production solutions can be calculated.

4. The state-of-the-art energy analyses

4.1. The energy consumption of buildings

The energy consumption of a typical Russian building was estimated by calculating heating of living spaces, heating of domestic hot water, and the consumption of electricity. First the current states of the selected building districts, chosen to be renovated or modernized, were analyzed by means of typical buildings. The analysis took into account structural solutions, heating, ventilation, water and drainage, electrical and other technical systems.

The energy consumption of the type buildings was calculated with WinEtana, which is a building energy analysis tool developed by VTT Technical Research Centre of Finland. The average monthly temperatures in Moscow were adjusted in the calculation tool to get more accurate results. The temperature data of Moscow region was retrieved from the website of EnergyPlus Energy Simulation Software by U.S. Department of Energy [10].

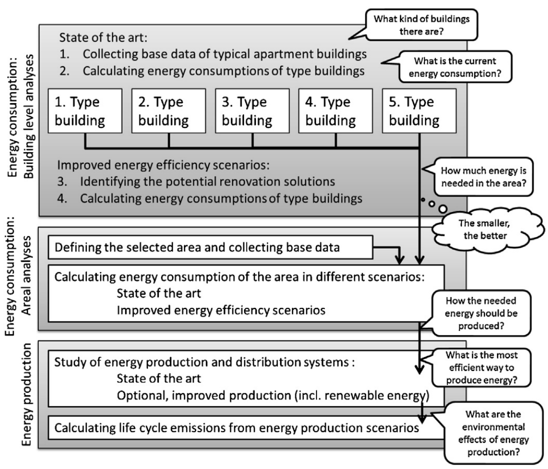

Fig. 1. The general methodology of the energy analyses.

Typical building parameters in Russia and in Moscow were used in the calculations. We used the value 18 °C in our calculations as the default indoor temperature for living spaces in multi-family buildings located within the case districts. According to Russian construction norms on thermal performance of buildings, the value of building air tightness at 50 Pa pressure difference (n50) must not exceed 2 h^{-1} for mechanical and 4 h^{-1} for natural ventilation. However, based on the results of field measurements with blower door tests [11] for a 9-storey building, which represents closest to the buildings in the case district – the average values were 7.5 h^{-1} (vents sealed) and 6 h^{-1} (vents and windows sealed). In our calculations we used a rather conservative estimate of air density factor n50, 6.5 h^{-1} so that it represented recent improvements in air tightness of windows due to massive installation of plastic-aluminium windows by residents of apartment buildings in Russia.

Natural ventilation is a typical ventilation solution in Russia [8]. Type of base floor in the buildings is assumed to be ground-supported slab. The typical *U*-values in Moscow buildings are approximately 1.1 W/m^2C° for wall constructions and 2.9 W/m^2C° for fenestration (converted from transmission R values by Matrosov et al. [12]). Opitz et al. [8] point out that the design R values differ minimally among older buildings built between 1954 and 1979, and they are essentially the same among buildings even with different wall structures (except for recently constructed buildings with 3-layes panel walls).

Because Estonia was part of the Soviet Union, there still remain numerous apartment buildings built during the Soviet era. The typical annual Estonian water consumption is between 180–290 l/capita/day [13]. We estimated that the average water consumption in the selected buildings is 272 l/capita/day, of which hot domestic water consumption is 46%, thus 126 l/capita/day). The hot water consumption is based on expert estimations and average Finnish water consumption data.

Electricity consumption of the building was estimated based on the assumed typical electrical equipment and their energy efficiency classes. It included lighting, household electrical equipment: (laundering, dish washing machine, entertainment, computer, stove, refrigerator, freezer, and other equipment), as well as outside lighting, and facility electric consumption (parking slot (preheating of cars), elevator and pumps). The average energy efficiency class of electrical equipment was assumed to be class D (typical in Finland).

As for the part of internal heat gains, the following values were used based on the experiences of Finnish experts [14]: 0.96 kWh/m^3/month from domestic hot water (30% of the heat demand [15] for hot water), 1.42 kWh/m^3/month from electrical equipment and 0.4 kWh/m^3/month from people.

Table 2
Annual energy consumptions per floor area of the type buildings in the selected district.

	Long apartment building	Long apartment building	Higher apartment building	Apartment building	Apartment building
Building series	II-57	II-49	AK-1-8	II-18	Mr-60
Space heating (kWh/a, m^2)	120	126	127	126	123
Hot domestic water (kWh/a, m^2)	88	88	88	88	88
Losses (kWh/a, m^2)	4	4	4	4	4
Total heating energy consumption (kWh/a, m^2)	212	218	219	219	216
Total electricity consumption (kWh/a, m^2)	42	45	38	47	39

The calculated energy consumptions per building floor area are presented in Table 2. According to the calculations the average heating energy consumption of typical old apartment buildings in Moscow was 217 kWh/m^2,a and the average electricity consumption 42 kWh/m^2,a. The result is quite well in line with some reference studies, e.g. [13]. The differences in energy consumption calculations may result from the divergence of the base data. Russian structures and used system solutions of buildings may vary in different buildings (even within same building series) or even within single buildings. Moreover, according to the Moscow city programme [16] "Energy Conservation in Construction in the City of Moscow During 2010–2014 and Until 2020" the thermal insulation of buildings comply with norms only 'on the paper', which may also explain the differences in results. Also the air tightness of the building has a big significance.

Since the variations of the annual heating and electricity consumptions were small, only the most common building type (II-18) in the district was chosen for the further analyses. A general picture of the energy flows going in and out of the building II-18 is presented in Fig. 2.

4.2. The district level energy consumption

The annual heating energy consumption of the most common building type II-18 (Table 2) was 219 kWh/m^2,a and the annual electricity consumption 47 kWh/m^2,a, respectively. Heat is distributed in the district through district heating network. In Russia, an estimated 20–30% of heat is lost through the heat distribution network before it reaches the end consumer [6]. So, it was assumed that the heat distribution loss in the network is 20%. The transmission losses of electricity are typically approximately 10% in Russia [17] which was also used in the calculations. Then, the total annual heating energy consumption of the apartment buildings in the selected area was 71.8 GWh/a, and the total annual electricity consumption was 15.5 GWh/a. This means that annually the buildings in the selected district need heating energy production of 89.8 GWh and electricity production of 17.2 GWh.

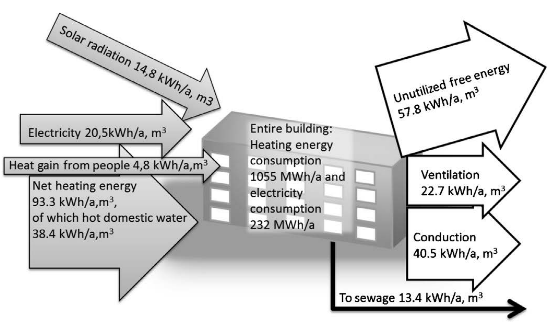

Fig. 2. The calculated energy streams of the apartment building II-18.

Energy needed for water purification was estimated to be 7 kWh of heating and 49 kWh of electricity per person in a year, and respectively 23 kWh of heating and 62 kWh of electricity for wastewater treatment [18]. Outdoor lighting was estimated to consume 350 kWh per lamp in a year, while a quote of 0,167 lamps per inhabitant was used [19,20]. Taking these into account the total annual heating energy demand without distribution losses for the district is 72.2 GWh and the total annual electricity demand without transmission losses 17.8 GWh, respectively. Adding the losses mentioned above will result in the total annual heating demand of 90.2 GWh and the total annual electricity demand of 19.5 GWh.

Heating energy in Moscow is up to 70% generated by large scale combined heat and power (CHP) plants and they are usually using natural gas [16]. Assuming that the heat and the power for the examined district are produced by a natural gas CHP plant, the related annual CO2-equivalents are for the heating 24.3×10^6 kg/a and for the electricity 9.9×10^6 kg/a (Table 7), respectively. These equal to the annual total CO_2-equivalent of 34.2×10^6 kg/a and the total per person of 2.5×10^3 kg/a/p.p. As a comparison, the heating of buildings in Finland accounted for 3.97×10^9 kg of CO_2-equivalents in 2009 which per citizen would correspond to 0.74 kg in a year. This would be less the than half of the corresponding values for case district (1.77 kg/a/p.p).

5. The energy analyses of alternative building renovation concepts

Three alternative renovation concepts were selected for closer analysis (Table 3). The cases had different values for the following characteristic: the *U*-values of building structures (outer wall, base floor, roof, windows and doors), ventilation type, air tightness factor, lighting (indoor), electricity consumption/electrical equipment and water consumption. The renovation cases are adjusted in such a way that each of them result as an improvement from a previous one when it comes to the total annual energy consumption. The basic renovation refers to minimum, low-cost or easy-to-do retrofit measures. The improved renovation solutions outputs better energy or eco efficiency. The advanced renovation column suggests the most progressive solutions. If not otherwise stated, the improved and advanced solutions always include the solutions mentioned in the previous renovation.

The annual results from the simulations are shown in Table 4, from which emerges that each case consumes less energy than the previous one. The same goes also for heat consumption while the consumption of electricity is higher for the Advanced-case in comparison with the former Improved-case. The cause of this was the change of the ventilation system to a mechanical one consuming more electricity. However, since the improved ventilation system recovered 60% of the heat of the exhaust air that otherwise would have been lost it resulted in energy savings in the end in form of heat. In Table 5, there are the results presented as percentages by comparing each value of the cases to the same value of the State of the art-case (the current case). Table 6 represents the yearly energy consumption per floor area for each of the cases.

Table 3
Building level renovation concepts. If not otherwise stated the improved and advanced concepts always include the solutions mentioned in the previous renovation.

Technology/system	Current status	Basic renovation	Improved renovation	Advanced renovation
Structures: *U*-values (W/m² K)				
•Outer walls	1.1	0.5	0.32	0.15
•Base floor	1.1	–	–	–
•Roof	1.1	0.25	0.24	0.15
•Windows and doors	2.9	1.85	1.5	1.0
Ventilation	Natural ventilation	Natural ventilation, repairing the existing system (ensuring sufficient air exchange rate) Installing outdoor valves	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	
Electricity consumption/electrical equipment		Car parking places (electricity: max two hour control) Energy efficient household appliances Energy efficient lighting of staircases and public spaces	Energy efficient pumps and fans	Lifts – braking with recovering energy Demand based control of lighting of staircases and public spaces
Water consumption (l/day/occupant)	272/of which hot water 126	Installation of modern fixtures and appliances (160)	Installation of water saving fixtures and appliances (120)	Separate metering (100)

Table 4
The annual energy consumptions of the building type II-18 with different renovation cases.

	Current	Basic	Improved	Advanced
Total energy consumption (kWh)/building,a	1,308,003	840,731	675,755	518,897
Heating consumption (kWh)/building,a	1,076,373	658,288	511,189	348,027
Space heating	620,766 (58%)	388,946 (59%)	308,833 (60%)	180,245 (52%)
Domestic hot water	434,076 (40%)	256,176 (39%)	192,132 (38%)	160,104 (46%)
Losses	21,516 (2%)	13,164 (2%)	10,212 (2%)	6,936 (2%)
Electricity consumption (kWh)/building,a	231,630	183,510	172,000	190,460

Table 5
Energy consumptions of different renovation cases compared to the current.

	Current	Basic	Improved	Advanced
Total energy consumption	100%	64%	52%	40%
Heating consumption	100%	61%	47%	32%
Space heating	100%	63%	50%	29%
Domestic hot water	100%	59%	44%	37%
Electricity consumption	100%	79%	74%	82%

In Fig. 3, there is a chart of the energy consumptions of the building II-18 for different renovation cases. The total energy consumption, the heating consumption, the electricity consumption, the energy consumed for space heating, the energy consumed for domestic hot water and the energy losses of the building are shown in the figure. The total energy consumption is composed of the total heating and electricity consumptions, while the total heating consumption is a sum of the space heating and the domestic water heating. The losses curve represents efficiency based energy losses of the heating systems.

All the heating (total heating, domestic hot water, space heating) curves show a steep decrease from the state of the art to the Basic renovation-case; this has to do with the proportions in the characteristic values. The *U*-values were decreased with 65% for the outer walls, 77% for the roof and 36% for the windows from the State of the art to the Basic renovation case. The corresponding values were 36%, 4% and 19% from the Basic to the Improved renovation case and 53%, 56% and 33% from the Improved to the Advanced renovation case.

Table 6
The annual heating and electricity consumptions per floor area for each renovation case.

	Current	Basic	Improved	Advanced
Heating consumption (kWh/m²,a)	219	134	104	71
Electricity consumption (kWh/m²,a)	47	37	35	39

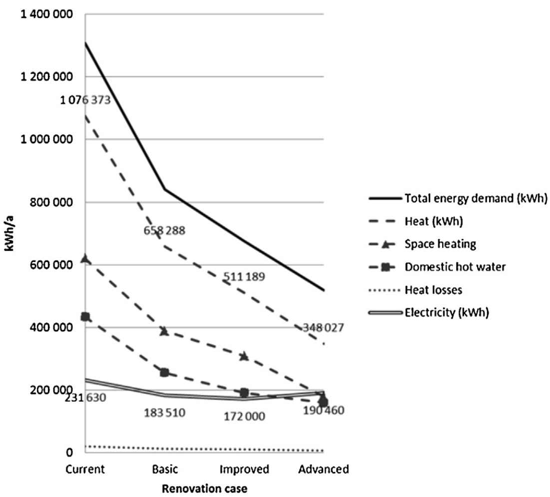

Fig. 3. Energy demand graph for the different renovation cases of the building II-18.

Table 7
CO_2-equivalents from natural gas CHP energy generation for different concepts.

	Current	Basic	Improved	Advanced
Heat (kg/a)	24,296,019	14,060,219	10,767,202	5,656,596
Electricity (kg/a)	9,913,875	7,811,025	6,851,705	6,144,183
Total (kg/a)	34,209,894	21,871,245	17,618,907	11,800,779
Total per person (kg/a/p.p)	2477	1583	1276	854

The space heating is showing a steep decrease again between the Improved- and the Advanced-case, partially because of changes in the U-value and partially since the losses are being recovered by the ventilation system (not the same losses as in Fig. 3). However, the water heating curve between the same cases is behaving oppositely which results in only a smaller change in the total heat curve.

The heat consumption for domestic water is corresponding to the amount of water consumed which is decreased with 41%, 25%, and 17% from each case to another (Current, Basic, Improved, Advanced). The electricity consumption is also the steepest between the State of the art and Basic cases, since all household appliances are changed to more energy efficient ones. Smaller improvements are being made in the energy consumption of electrical appliances between the Basic and Improved cases. The energy consumption rises between the Improved and Advanced cases due to the ventilation system even though some improvements are being made with the elevator system. However, the electricity consumption in the Advanced case does not surpass the State of the art case.

Grouping all the energy consumption together the curve is steep from the Current to the basic case, while the development is less steep and constant for the rest of the cases. What can be observed from these results is that space and water heating is consuming the larger part of the total energy. A considered amount of the consumption can therefore be reduced through improving insulation (U-values) and reducing water consumption habits. Also, heat recovery from the exhaust air is proven to be a way of saving energy significantly but results in increased electricity consumption.

In Table 7, there are listed the CO_2-equivalent greenhouse gases for different renovation concepts assuming that the energy is produced by natural gas CHP plant. Even the Basic renovation concept reduces the total CO_2-equivalents by 36%. The reduction with the Improved concept is 48% and with the Advanced concept 66%, respectively.

6. Non-technical barriers to energy efficient renovations

There are a number of obstacles that prevent Russia from benefiting from the existing potential of improved eco- and energy-efficiency in buildings. Common, well-documented ones include relatively low energy tariffs (e.g., [13,21]), higher up-front investment costs of implementing renovation solutions, as well as high interest rates [22].

The most important obstacle in building renovation in Russia is outdated norms and long permission processes [23]. The norms do not acknowledge the existence of new efficient technologies and materials. Even though the systems and materials can be relatively easily certified, the old norms are used by the authorities when checking the acceptance of a specific design solution. It may be very difficult to prove that a new type of heating system will be able to provide enough heat, or that connection capacity could be reduced because thermal insulation is improved.

Apartment-specific sub-metering is required in all buildings for electricity and hot and cold water as well as heating, although with respect to the latter these requirements have not always been fulfilled. In existing buildings water meters are not always installed by residents despite the requirement, even though the meter and installation usually pays for itself rather quickly, the resistance to install the meters most likely has to do with lack of information.

In residential buildings mechanical ventilation is neither allowed nor prohibited, and the officials in charge of issuing building permits or parties approving renovation plans refrain from assuming responsibility in the absence or clear official guidance as to how the connection capacity of space heating system should be dimensioned and mechanical ventilation systems designed, installed and maintained, even when there is an understanding that natural ventilation is less energy-efficient especially in high-rise residential buildings than a mechanical system with heat recovery.

There are differences in operation practices that should be considered when implementing an eco-efficient renovation. Often when remodelling the apartments, the owners introduce significant changes to buildings' technical systems, e.g. they seal an apartment from a ventilation channel, or even block a building's ventilation channels, install exhaust ventilation, alter a space heating system (e.g. connect under-floor heating). These often illegal changes affect the proper functioning of systems during the building's operational phase. It is strictly prohibited for a service company or inspectors to enter the apartments to check whether this kind of change was made, or even to maintain the system. The access is only possible with a decision of a court in the case when a tenant is absent or opposes the entry. A possible solution is to even at the design stage to try taking the engineering systems out of the apartments to the extent possible and providing service access from public areas.

6.1. Political and administrative obstacles

The question of the liability of the state in renovating the privatized buildings constitutes one of the political obstacles. The current legislation in this regard is ambiguous: on the one hand, there is a decision of the High Court confirming the obligation of the state to implement the repairs and provisions of the Housing Code, claiming that the residents must jointly take on all the responsibilities concerning their buildings. This question is regularly raised both by representatives of elected bodies of state power and, at a broader level, by the community, and is tool of political struggle, especially so in the election race. When citizens' law suits are filed with courts, the latter typically obligates municipal administrations to conduct the renovation of the apartment building and hence-society expects that the state will conduct (finance) the renovations of the formerly privatized apartment buildings [24].

Given the above, it is common for municipal administrations to conceal information on the actual technical state of residential buildings in case they are declared as "dilapidated" or "dangerous" as then the administrations would have to resettle the residents and provide them with substitute housing of comparable standard at the expense of a regional budget where funds for this purpose are typically insufficient. In addition, the quality of information on the actual technical condition of buildings is typically low: for most of the buildings technical inspections to assess the actual wear of individual buildings are not conducted. Typically, the wear is estimated as a total "percentage of worn-out structures", which does not provide enough information for decision-making.

The sector of residential construction is highly dependent on administrative bodies, the system of urban planning and land use remains the source of administrative rents [22]. Most international assessments rank Russia as one of the most corrupt major economies in the world. According to Transparency International, public officials and civil servants, including the police, are seen as belonging to the most corrupt institutions in Russia, followed by the education system and parliament [25].

6.2. Social aspects

In the renovation business, social aspects are vital and need to be considered in advance. The distrust of apartment owners is the first obstacle an investor will face at the beginning of the project. A possible solution is to partner with local authorities to keep the residents informed, similar to the current budget co-funded renovation practice in Moscow and, ideally, involve the residents into the planning process. This way, different kind of rumours and disinformation of residents can be efficiently managed, despite the fact that it is common for Russians not to trust the authorities, institutions, builders, etc. This distrust is also one of the causes of passivity on the part of people in joint planning activities (e.g. public hearings of renovation projects). Therefore, the involvement of residents, openness, transparency and the possibility of the residents influencing the decision making is important for success.

In cases where the need for renovation is substantial and requires a temporary resettlement it may turn into the biggest obstacle, as agreement with each apartment owner would need to be reached [26]. Another important aspect is that income levels may vary among the residents of the same building, which complicates joint decision making on building renovation.

7. Discussion

The need to modernize and upgrade buildings in Moscow districts is evident, because only minor share of residential building stock aged over 35 years has been renovated to date. Indoor conditions are poor and the energy losses from buildings are significant. Energy efficiency improvements should be considered when upgrading the districts to benefit from opportunities to reduce energy consumption.

It is evident that there is a need for local knowhow when analysing the energy efficiency of districts in Moscow. A correct interpretation of statistics requires knowledge about Russian conditions. The analysis of buildings is eased by the fact that there are only a few building types, but on the other hand, in reality the used materials and their parameters can vary significantly also within the same building series. In this research it also turned out that the energy performances of the different building types are not differing significantly, and an adequate analysis can be made even by using only one building type.

The district heating network has a big potential for improving the energy efficiency of Moscow, because there are lots of heat losses in the heating network present day. One important renovation target is to install completely automatic individual substations in every building and so pass from the old four-pipe to new two-pipe district heating systems [27] with heat exchangers enabling control of heat distribution into buildings and apartments based on the actual heat demand. On the building level, the air tightness of the structures is one key issue that needs to be addressed in the retrofit solutions. Based on this study, the building level energy savings potential for the heating energy is up to 68% and for the electrical energy up to 30% based on these calculations. In addition, the CO_2-equivalent greenhouse gases may be reduced up to 65%.

To achieve a universally efficient energy solution in Moscow, the entire energy chain needs to be analyzed and improvements made bearing in mind the whole energy chain. The results of this study showed that improved indoor conditions and reduced heating consumption often lead to increased electricity consumption. By analysing indoor conditions energy efficiency and the building overall energy efficiency instead of energy consumption the issue of increased electricity consumption is put to correct context and the improved "output" of the consumed energy is considered properly.

The different renovation concepts were not analyzed from the economical point of view. This should also be done in order to form an understanding on what renovation solutions are feasible in Moscow apartment districts. Some solutions may also turn out unsuitable in practice. In addition, several non-technical barriers exist for renovations in Moscow. These need to be solved too in order to get progress.

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PUBLICATION II

Energy and emission analyses of renovation scenarios of a Moscow residential district

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Energy and emission analyses of renovation scenarios of a Moscow residential district

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ABSTRACT

Three building level renovation concepts of a typical Moscow residential district are defined and their energy saving potentials evaluated in a recently published study [1]. This study extends these analyses and concentrates on energy and emission analyses of different energy renovation solutions and energy production alternatives at the district level using the same case district as in the previous study [1].

At the district level, four different energy renovation scenarios, called Current, Basic, Improved and Advanced, were analyzed in terms of energy demand and emissions. Considerable energy savings could be achieved, up to 34% of the electricity demand and up to 72% of the heating demand, using different district modernization scenarios.

As for the emission analyses, switching from natural gas to biogas would result in decreasing greenhouse gas emissions, but increasing generation of SO_2-equivalent and particulate emissions. A better solution would be to still switch to biogas while maximizing renewable energy production from local non-combustion technologies at the same time.

1. Introduction

In Russia, climate change causes environmental, economic and social stress, why a future reduction in energy consumption could benefit the national economy [2]. In an energy-inefficient country like Russia, there is the potential to weaken the link between GHG (Greenhouse Gas) emissions and economic growth by improving energy efficiency [3]. Ever since the year 2000, Russia's economy has witnessed an upswing, and the government has started to take effective measures to curb energy intensity and reduce CO_2 emissions [4].

Energy efficient renovation increases the value of a building [5]. Improved cost-effectiveness of energy efficiency measures is achieved when they are implemented as part of a building renovation. It is often important to examine the impacts of building level renovation solutions in a wider perspective, since energy renovations reduce the energy demand from the grid or network [6], as well as the primary energy consumption. Greater overall energy efficiency can often be achieved through a district-scale building and district infrastructure renovation. The renovation of buildings should not be separated from the improvement of the surrounding environment. If the surrounding environment is improved, the market value of the land will considerably increase and the area will become much more attractive to investors. Therefore, it is clear that the renovation of a neighbourhood should not be restricted to the renewal of buildings, but should be extended to the whole region [7].

Some general principles for improving energy-efficiency at the district level include: improving the energy-efficiency of buildings, outdoor lighting, energy networks and grids (especially by reducing distribution losses), replacing fossil fuels with renewable energy sources, improving the energy-efficiency of waste and water management systems, reduction of emissions (e.g. change of fuel or flue gas treatment), and energy-efficient transportation [8]. Modernization must follow the urban structure which reflects the principles of sustainable development and corresponds to the quality of life: compactness, multifunctional use of territories, sustainable transport, ensured public interests and visually attractive (unpolluted) environment [9]. Outdoor amenities, i.e. pedestrian and bicycle paths, parking lots, children's playgrounds, sports grounds, benches, litterbins, street lamps, etc., should be renovated and rebuilt because the quality of housing largely depends on them [7].

Paiho et al. [1] present three different renovation concepts for apartment buildings in a Moscow residential district. The energy consumption of a typical Russian apartment building was

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estimated by taking into account heating of living spaces, heating of domestic hot water, and the electricity consumption. The energy consumption of the selected building stock was thereafter calculated based on the estimated consumptions of the type buildings. First the present state of the district level was studied, including energy chain analyses. The energy saving potentials for the three different building level renovations concepts were thereafter estimated. Results from the calculations showed that the building level energy saving potential could be up to 68% for heating energy and 26% for electricity, respectively.

The energy analyses are continued further in this paper by looking at three district level energy renovation concepts. In combination with this, the paper introduces different energy production scenarios and estimates the annual emissions for each examined case. The purpose was to assess how low emission values could be achieved by comparing and combining technologies for energy generation, and clarify which of the combinations presented would be better in terms of produced emissions.

This study tested the hypothesis that energy renovations are more efficient at a district level than on a building level, thus including the whole energy chain from production to consumption and taking into consideration not only building scale renovations, but also improvements on the energy supply systems. Furthermore, this study aims to explore whether emissions to air correlate with energy efficiency.

2. Background

It is estimated that more than 290 million m^2 or 11% of the Russian housing stock needs urgent renovation and re-equipment, 250 million m^2 or 9% should be demolished and reconstructed [10]. Some 58–60% of the country's total multi-family apartment buildings are in need of extensive capital repair, rising to 93–95% in those apartment blocks with an average age of less than 25 years [11].

The energy strategy of Russia for the period up to 2030 [12] states that one main problem in heat supply is the unsatisfactory state of heat supply systems characterized by high depreciation of fixed assets, especially of heat supply networks and boiler rooms, insufficient reliability of operation, large energy losses and negative impact onto the environment. The high level of technical abrasion and a low level of investments into modernization of the Russian energy industry cause huge energy wastage and carbon emissions [13]. With the exception of hydropower, Russia's utilization of renewable energy sources remains low relative to its consumption of fossil fuels [14]. In the absence of a clearly formulated long-term strategy for bioenergy and renewable energy, the legal and political processes in this field have been fragmented and weak [15].

2.1. Literature review

There is no relevant literature related to the energy consumption of Russian buildings. Also nothing has been found on the impacts of different options for energy renovations of residential buildings or districts in Russia. Furthermore, no studies have been found, taking into account the different emissions of energy production types when analysing the whole energy chain from production to consumption in residential buildings.

Studies on the energy consumption of Russian buildings have been made in the 1990s by Matrosov et al. in 1994 [16] and Opitz et al. in 1997 [17]. More recent studies on energy consumption analyses of buildings elsewhere than Russia have been made by e.g. Balaras et al. in 2005 [18] (heating energy consumption of European residential buildings); Choi et al. in 2012 [19] (comparison of energy consumption according to building shape and utilization) as well as Kyrö et al. in 2011 [20] and Kim et al. in 2011 [21] (the impacts of residents' behaviour on building's energy consumption). Studies on the reduction of buildings' energy consumption through renovations have been published by e.g. Tommerup and Svendsen in 2006 [22] (energy-saving potential of Danish dwellings through energy-saving renovations), Ouyang et al. in 2009 [23] (life cycle cost analysis for energy-saving renovations of residential buildings) and Siller et al. in 2007 [24] (on reducing energy consumption and greenhouse gas emissions of the building stock through renovations).

The first study on reduction of energy consumption through district renovations was published by Oujang et al. in 2008 [25]. This paper represents the Hot Summer and Cold Winter Region of China and examines buildings which are at least seven years old and are becoming dilapidated. Opposite to the study in China, where even quite new buildings are typically demolished and new constructed [25]; the situation is different in Russia where the designed life time of buildings is significantly longer.

2.2. Moscow residential districts

As of 2012 the need for renovations was estimated at 108 million m^2 (over a half of the total floor area) in 26.3 thousands of Moscow apartment buildings based on their age [26]. From an architectural perspective, residential areas with typical apartment houses look monotonous, lack vitality and are less aesthetically pleasing [9].

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 [10]. Each building series represents a specific building design [9,17,27]. Correspondingly, residential districts in Moscow have been built with only a few building types. Examples of these building types are clearly defined for example in [1,10,27]. Therefore the energy demand of the whole district can be estimated by using these building types and multiplying their performance with the number of buildings in the area.

In these buildings natural ventilation is dominating. Almost no buildings have mechanical ventilation [28,29]. Changing the inner layout of panel houses is hardly possible because the spacing between the external and internal bearing walls is small [7,9].

Energy efficiency of these apartment buildings is typically poor [10]. The thermal insulation of the precast panel walls does not meet modern standards. District heating networks supply heat to about 80% of Russian residential buildings and about 63% of the hot water used by Russia's population [30].

2.3. The selected housing district

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

The apartment buildings in the area are built between 1966 and 1972. After the initial analysis the most common building type II-18 was selected to represent the average building in further studies since a comparison of the demands of the buildings showed only minor differences [1]. There are also a few other newer buildings but since these analyses concentrated on modernization of buildings, these newer buildings are excluded from the studies.

In total there are approximately 13 800 residents in the buildings that are included in the calculations which is about 0.12% of

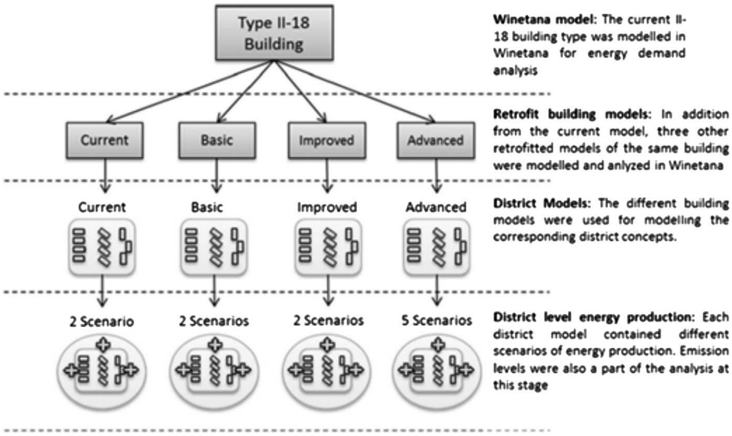


Fig. 1. Overview of the energy analysis process in this study (WinEtana is a computer software for making building energy analyses developed by VTT Technical Research Centre of Finland).

the total population of Moscow. The total floor area of the studied buildings is 327 600 m^2 and the total roof area 31,230 m^2. The number of residents is estimated based on the assumption that the average occupancy rate per flat is 2.7 persons [10].

3. Methodology

The principles of the energy chain analyses used are discussed in [1]. At first the present state was studied by selecting both a typical old apartment building and an entire residential district in the Moscow region for the calculations. The renovation concepts were assessed from the perspective of energy demand and associated environmental impacts. The assessment started with development of a "Current" energy and water demand model of the most common building type (II-18) which represented an average apartment building. From this model, other renovation models were generated. The four models where named according to the concept on which they were based: Current, Basic, Improved and Advanced.

In this study, the building models were used in the energy demand analyses of their corresponding district concepts, also named Current, Basic, Improved and Advanced. Each district concept was further used to examine different scenarios of energy production and the resulting environmental impacts. See Fig. 1 for further clarification of the different steps of the energy analysis process.

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 also taken into account the existing Moscow building codes for new construction. Relevant detailed building codes, standards etc. do not exist for renovation. The opportunity to utilize renewable energy production was also emphasized.

The scenarios were selected primarily with the view on practical implementation of building renovations as follows: (i) only restoration of buildings to initial condition, (ii) restoration of buildings using nowadays materials available on the market, which properties have improved over the past 40 years, (iii) significant improvement of buildings to meet local requirements to new construction, and (iv) improvement of buildings going beyond the local requirements to new buildings but being "normal" to renovation projects in Finland and Northern Europe.

After the energy demands were analyzed, the life cycle emissions for different energy production scenarios were calculated. CO_2-equivalents, SO_2-equivalents, TOPP-equivalents (tropospheric ozone precursor potential) and particulates were selected to represent the environmental impact of the energy production alternatives. *CO_2-equivalent* emission is a total measure, in which the emissions of different greenhouse gases are summed up according their global warming potential (GWP) factor [31]. *SO_2-equivalent* signifies the total acidification potential, which is the result of aggregating acid air emissions [31]. In the calculation of SO_2-equivalent emissions, the utilized software GEMIS (Global Emission Model for Integrated Systems software) [32] includes SO_2, NO_x, HF, HCl, H_2S and NH_3. *TOPP-equivalent* signifies tropospheric ozone precursor potential [31]. It is the mass-based equivalent of the ozone formation rate from precursors, measured as ozone precursor equivalents. The TOPP represents the potentially formation of near-ground (tropospheric) O_3 which can cause smog. TOPP includes emissions of NO_x, NMVOC (non-methane volatile organic compounds), CO and CH_4 [31]. *Particulates* have a significant effect on the local air quality level [33].

Table 1
Corresponding emissions for heat and electricity generation based on the partial substitution method for a 1 heat/0.85 electricity for natural gas CHP plant, a 1.5 heat/1 electricity for biogas CHP plant and a 1 heat/0.345 electricity for waste incineration CHP plant.

Emissions into air	Heat for natural gas CHP (kg/MWh)	Electricity for natural gas CHP (kg/MWh)	Heat for biogas CHP (kg/MWh)	Electricity for biogas CHP (kg/MWh)	Heat for waste incineration CHP (kg/MWh)	Electricity for waste incineration CHP (kg/MWh)
SO_2 equivalent	0.59	1.2	1.3	2.0	0.4	0.3
TOPP equivalent	1.3	2.6	0.63	0.97	0.68	0.54
Particulates	0.024	0.047	0.053	0.081	0.006	0.004
Greenhouse gases						
CO_2 equivalent	285	559	26	40	36	29

3.1. Emissions calculation

The values for emissions per produced energy (kg/MWh) were retrieved from GEMIS [32] and account for the life cycle of the facility by which the energy is generated. In all, emission values were retrieved for electricity bought from the Russian grid, natural gas combined heat and power plants (CHP), (building integrated) solar photovoltaic (PV), solar collectors, wind farms (WF), Ground source heat pumps (GSHP), biogas CHP plants, natural gas boilers and biogas boilers with flue gas cleaning.

The emission values for the natural gas and biogas CHPs needed to be divided into the proportions for heat and electricity generated. This was done by the *partial substitution method*, 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. For this, the following formulas were used:

$$\varepsilon'_{hi} = \frac{E_h}{n_h} \quad (1)$$

$$\varepsilon_{hi} = \frac{\varepsilon'_{hi}}{\varepsilon'_{hi} + \varepsilon'_{ei}} \times \varepsilon_i \quad (2)$$

$$\varepsilon'_{ei} = \frac{E_e}{n_e} \quad (3)$$

$$\varepsilon_{ei} = \frac{\varepsilon'_{ei}}{\varepsilon'_{hi} + \varepsilon'_{ei}} \times \varepsilon_i \quad (4)$$

In equation 1, ε'_{hi} denotes the heat energy to efficiency quotient where E_h is the share of heat generated (in combined heat and power), and n_h the efficiency of the heat generation. The corresponding denotations for electricity generation are shown in Eq. (3). In Eq. (2), ε_{hi} represents the partial share of a certain emission type *i* per produced heat while ε_i is the reference value for the same emission type (Table 1). The corresponding value for the partial fraction of a certain emission type coming from electricity generation is calculated according to Eq. (4).

The ε_i emission values for natural gas was retrieved for a 1/0.85 (E_h/E_e) heat to electricity quote and 0.9/0.39 (n_h/n_e) heat to electricity efficiency CHP plant in GEMIS. The corresponding values were retrieved for a biogas CHP plant with 1.5/1 (E_h/E_e) and 0.9/0.39 (n_h/n_e), and for a waste incineration CHP plant 1/0.345 (E_h/E_e) and 0.9/0.39 (n_h/n_e). The results for the partial fractions of emission for heat and electricity of both of the CHP plants types can be found in Table 1. Values for the other energy technologies are found in Table 2. The emissions were thereby calculated by multiplying the energy produced by the emission factors of the corresponding energy system (and the partial share of heat and electricity in cases for CHP plants) as in (5).

$$\text{Generated emissions} = \text{Amount of energy produced } (\varepsilon) \times \text{emissions per unit of energy for specific energy production (GEMIS)} \quad (5)$$

4. Energy and emission analyses

4.1. Energy analyses

The energy demands of several renovated district concepts were analyzed and compared to that of the Current concept. Each of the proposed Current, Basic, Improved and Advanced districts contained buildings with the corresponding level of renovation and additionally the improvements suggested in Table 3.

In the Current district, the annual energy demands per floor area were 219 kWh/m^2,a and 47.2 kWh/m^2,a for heating and

Table 2
Emission coefficients according to produced energy for the different types of facilities or technologies.

Emissions (kg/MWh) [32]	Russia electricity 0-level; IEA numbers	Natural gas CHP plant, 1 heat/0.85 electricity (MWh)	Solar photo-voltaic (PV)	Wind farm (WF)	Solar Thermal Heat (STH)	Ground source heat pump (GSHP), COP 3	Biogas CHP, 1.5 heat/1 electricity (MWh)	Boiler Natural gas
Emissions into air								
SO_2-equivalent (kg/MWh)	3.7	1.8	0.18	0.067	0.20	0.015	3.3	0.30
TOPP-equivalent (kg/MWh)	2.3	3.9	0.16	0.090	0.18	0.018	1.6	0.58
Particulates	0.49	0.072	0.026	0.015	0.041	0.0027	0.13	0.018
Greenhouse gases								
CO_2-equivalent (kg/MWh)	552	845	110	28	37	4.6	65	387

Table 3
District level renovation concepts compared to the current status. If not otherwise stated the improved and advanced solutions always include the solutions mentioned in the previous renovation.

Technology/system	Current status	Basic renovation	Improved renovation	Advanced renovation
Energy production	Energy produced in large-scale plants, mainly using natural gas.	Increasing energy-efficiency of energy generation processes	Reduction of emissions (e.g. change of fuel, or flue gas treatments).	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 controlling High distribution losses	Replacing 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 (for example excess solar heat production).
Electricity distribution	Electricity distribution networks design does not allow to feed locally produced electricity to the grid, one-way flow. In some cases networks operate close to their limits, low power factor possible, old equipment (e.g. transformers)	Replacement of old equipment and cables, power factor and harmonics compensation where necessary		The basic scenario & review of automation systems to allow for connection of distributed generation. Smart metres (in case of demand response and local controllable energy generation)
Lighting (outdoor)		Energy-efficient street lighting	Street lighting designed to avoid light pollution	Smart outdoor lighting (sensor driven), street lighting electrified with solar PV's.
Water purification and distribution waste water collection and treatment	Drinking water not safe. 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 wastewater treatment)
Waste	Mixed waste collection >60% municipal solid waste (MSW) landfilled (27% incinerated, 10% recycled)			Increased recycling and energy utilization: ~22% municipal solid waste (MSW) landfilled (24% incinerated, 54% recycled)
Flexible/multifunctional use of spaces Dense city planning Transportation	Services are placed in nearby resident buildings which reduces transportation needs. City structure is rather dense.	Safe cycle parking facilities at train and metro stations. Cycle lending system (bike pools)	Improved cycle routes, separating cycles from cars and pedestrians. Improved public transportation.	Charging points for electrical vehicles. Charging points with embedded PV panels.

electricity, respectively [1]. The heating demand of the buildings was estimated to be fully covered by district heating with 20% heat distribution losses [30], while transfer losses of the electrical grid were estimated to be 10% [34]. Energy needed for water purification was estimated to be 7 kWh of heating and 49 kWh of electricity per person in a year, and respectively 23 kWh of heating and 62 kWh of electricity for wastewater treatment [35]. Outdoor lighting was estimated to consume 350 kWh per lamp per annum, while a factor of 0.167 lamps per inhabitant was used [15,36].

The Basic district consisted of buildings where the annual calculated demand of heating was 134 kWh/m^2, a and of electricity was 37 kWh/m^2,a. Distribution losses of the district heating network were reduced to 15% by system improvements, while transfer losses of the electrical grid remain the same as in the Current district. The energy demand for water and wastewater treatment was reduced by 36% and outdoor lighting by 50% from the previous concept.

For the Improved district, each square metre of floor area was calculated to require 104 kWh/m^2,a of heating and 33 kWh/m^2,a of electricity on an annual basis. The losses of the district heating network and the electrical grid were kept to the same as in the Basic district. The energy needed for water and wastewater treatment was 48% less than for the Current district, while the outdoor lighting electricity demand was reduced by 70%.

The advanced district was not only a further improvement on the previous district in terms of energy demand. It was further used in several scenarios for energy generation from various combinations of renewable energy sources. These alternatives will be discussed further in the emission analyses. The annual energy demands per square metre of floor area in the Advanced district

Table 4
Resulting annual energy demand for the district concepts (MWh/a).

	Current		Basic		Improved		Advanced	
	Electricity	Heat	Electricity	Heat	Electricity	Heat	Electricity	Heat
Buildings	17 168	89 753	13 495	51 691	12 125	40 194	11 899	24 963
Street lights	806		403		242		242	
Water and wastewater treatment	1533	414	981	265	797	215	675	182
Total	19 507	90 167	14 879	51 957	13 164	40 410	12 816	25 146

Table 5
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, electricity from wind farms				x
A5 scenario: solar collectors, solar panels, ground source heat pumps, electricity from wind farms				x

were 71 kWh/m^2,a and 35 kWh/m^2,a for heating and electricity, respectively. An exception of the Advanced district from the others is that smart metres are used in the buildings, which lowers their electricity demand by 5% (estimation based on [37]). Distribution losses of the district heating network were estimated at 7% (which is a typical level in Nordic countries), while transfer losses of the electricity grid were reduced to 9%. Energy demand for water purification and wastewater treatment is now reduced by 56% from the Current district, while electricity needed for outdoor lighting was 70% less.

The data for distribution losses of the district heating network and the transfer losses from the electrical grid used in the models were derived from [34,38]. Radocha and Baumgartner [36] and Echelon [39] were consulted for estimating electricity consumption of the different district concepts. Corresponding values for water and wastewater consumption have been obtained from [27,40].

Calculations show that the energy need is mainly affected in the Basic and Advanced concepts. This has mostly to do with the fact that the buildings are accounting for close to all the energy demand of the case district. The calculation results are shown in Table 4 where the energy demand of the district has been categorized into buildings, outdoor lighting, and water and wastewater treatment. Transfer and other losses have been accounted for in the numbers presented. Looking at electricity and heating demand separately, it is notable that the potential for reduction is 34% and 72%, respectively.

It has to be noted that transportation or other services resulting in further energy demand were not accounted for in the district energy analyses that have been carried out. These usually form a significant share of the total energy consumption in a district but were left outside the scope of the analyses where the focus was on buildings and infrastructure. Also, some of the improvements presented in Table 3 are directly related to pollution or the comfort level of the inhabitants, and would not be notable in the results from the energy.

4.2. Emission analyses

All the concepts presented were further extended with different scenarios of how the energy needed is either being acquired or produced within the area and the amount of emissions that this would result in. As shown in Fig. 1, altogether 11 district energy production scenarios were analyzed. All the district concepts had two scenarios, except the Advanced, which had five in total.

Since almost all energy produced in the Moscow area comes from natural gas [41], the scenario of heat and energy production from natural gas (Nat) was created for each district type. To evaluate the opportunity for using renewable energy, a scenario where natural gas is being replaced by biogas (Bio) was additionally examined for each scenario. Table 5 summarizes the scenarios analyzed.

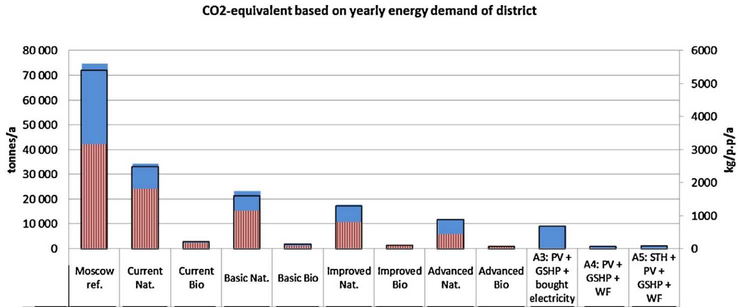
For the Advanced district concept the A3, A4 and A5 scenarios involving renewable energy were created in addition to the natural and biogas scenarios. In the A3 scenario, solar panels (PV) mounted on the roofs of the buildings was calculated to cover 7.5% of the total electricity demand, while the rest would be bought from the Moscow grid. All the heating needed would in this scenario be provided by ground source heat pumps (GSHP), which on the other hand would consume a considerable amount of electricity. The A4 scenario differed from the A3 in the way that all grid electricity was bought from a wind farm (WF). In addition to the A4 scenario, 30% of the energy needed for domestic hot water in the district was produced by solar thermal collectors (STH) in scenario A5. This would eventually lead to fewer boreholes and less electricity needed for ground source heating.

4.2.1. Emissions for the Current district

The reference emissions of the Current district (Moscow Ref.) were calculated using the equivalent values for the whole Moscow multiplied by the number of inhabitants in the selected district. Heating energy in Moscow is up to 70% generated by large scale combined heat and power (CHP) plants, 5% by small scale CHP plants and 25% by heat only boilers (HOB) [42]. This corresponds to 79.290 GWh of heat generated by the large scale CHP plants, 5.664 GWh from the small scale CHP plants and 28.318 GWh from the heat only boilers. The fuels used in large scale CHP plants are 98% natural gas, 1.4% coal and 0.6% heavy fuel oil. The fuel used in both small scales CHP plants and HOBs is 100% natural gas [42]. The fuels were in the calculations presumed to be 100% natural gas since the share of coal and heavy fuel oil was considered to be insignificantly small in comparison to the total. The total electricity production corresponding to the consumption in the city[1] was split into 45.045 GWh produced at large-scale CHP plants and 3.234 GWh produced at small-scale CHP plants. The emission values for the Moscow reference case were calculated based on this data.

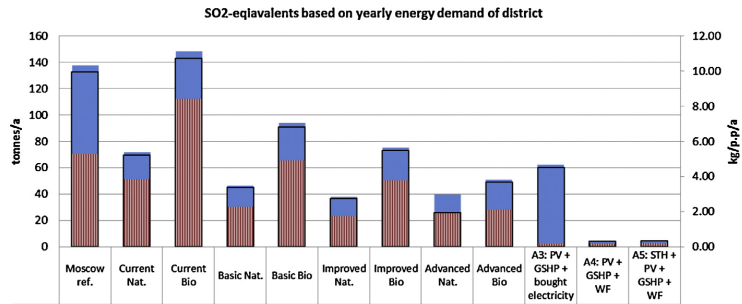
Based on the calculated energy demands (Table 4) the emissions for the Current district were calculated both for the existing natural

[1] The City of Moscow is characterized by a surplus electricity balance, i.e. more electricity is produced than it is consumed and the excess is exported to the surrounding Moscow region.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	32440.07	9913.87	725.61	7837.35	583.34	6878.03	510.90	6196.83	487.19	9026.98	683.26	653.18
Heat	42259.08	24296.02	2278.04	15328.07	1156.41	10863.04	1066.75	5848.27	701.74	282.01	282.01	385.42
kg/p.p	5407.89	2476.64	217.45	1592.22	140.62	1284.37	105.37	872.01	68.39	673.93	69.88	75.19

Fig. 2. CO_2-equivalent emissions of the district energy production scenarios.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	67.30	20.78	35.97	16.47	28.48	14.48	25.01	13.28	22.72	60.21	1.90	1.83
Heat	70.42	51.19	112.40	30.15	65.71	23.32	50.55	26.44	28.00	2.25	2.25	2.84
kg/p.p	9.97	5.21	10.74	3.38	6.82	2.74	5.47	1.95	3.67	4.52	0.30	0.34

Fig. 3. SO_2-equivalent emissions of the district energy production scenarios.

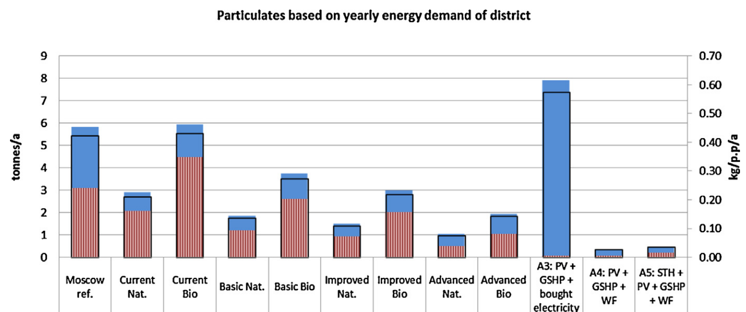
gas CHP plant and for an alternative biogas CHP plant. The emission from all the scenarios are pictured in Figs. 2–5.

4.2.2. *Emissions for the Basic and Improved district scenarios*

The annual emissions from natural gas CHP energy production and from biogas CHP energy production for both the Basic district scenarios and the Improved district scenarios were calculated based on the energy demands (Table 4) and corresponding distribution losses. See Figs. 2–5 for results.

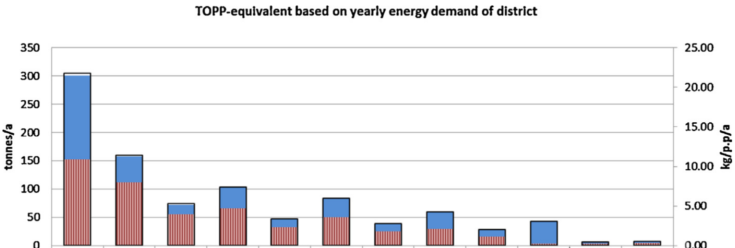
4.2.3. *Emissions for the Advanced district scenarios*

The advanced district scenario is a further improvement of the Improved district case in terms of energy demand (Table 4). Additionally, it contains several alternatives for energy generation from various combinations of renewable energy sources: natural gas CHP biogas CHP, building integrated solar photovoltaic (BIPV), solar collectors (STH), ground heat pumps, wind farms and electricity bought from the grid. The emissions from these can be found in Figs. 2–5.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	2.75	0.84	1.44	0.67	1.14	0.58	1.00	0.53	0.89	7.85	0.29	0.28
Heat	3.09	2.06	4.50	1.21	2.62	0.93	2.01	0.51	1.05	0.08	0.08	0.21
kg/p.p	0.42	0.21	0.43	0.14	0.27	0.11	0.22	0.08	0.14	0.57	0.03	0.03

Fig. 4. Particulates of the district energy production scenarios.



	Moscow ref.	Current Nat.	Current Bio	Basic Nat.	Basic Bio	Improved Nat.	Improved Bio	Advanced Nat.	Advanced Bio	A3: PV + GSHP + bought electricity	A4: PV + GSHP + WF	A5: STH + PV + GSHP + WF
Elec	148.23	45.68	17.64	36.19	14.04	31.80	12.38	29.07	11.65	38.52	2.70	2.60
Heat	152.77	112.39	55.31	66.05	32.89	51.01	25.61	29.47	16.12	3.98	3.98	4.50
kg/p.p	21.79	11.44	5.28	7.40	3.40	6.00	2.75	4.24	2.01	3.08	0.48	0.51

Fig. 5. TOPP-equivalent emissions of the district energy production scenarios.

For generating energy from solar radiation, the photovoltaic potential estimation utility Photovoltaic Geographical Information System (PVGIS) was used for estimating solar irradiation in Moscow [43]. According to this, the average yearly solar radiation on a horizontally inclined surface is 1.154 kWh/m^2 for an optimal surface in Moscow that has an inclination angle of 39° and south-orientation.

The annual electricity generation of the *solar photovoltaic* (*PV*) *system* was calculated as follows. Using CIS technology based solar panels (copper–indium–selenium) would give an annual generation of 1.060 kWh/kW$_p$ (temperature and reflectance losses included) which means that for every kW-peak power installed we get a 1.060 kWh of electricity in a year. Further losses (wiring, inverter, array mismatch and distribution) of the PV system were estimated to be a total 20% of the whole production [43,44]. The peak power per square metre ratio for the system was presumed to be 0.125 kW$_p$/m^2 [45]. The same number was multiplied with half of the roof surface of the buildings in the district for estimating the total annual electricity generation. Half of the roof area of the district was accounted for installing solar panels, and further that the roofs were horizontal which meant that solar panels could be oriented and inclined for optimal solar gain. The total annual production from the PV system is 1.655 MWh.

Solar collectors are estimated to cover for 30% of the energy for heating of domestic water which is a rough estimation based on the results of a pilot project in Helsinki in Finland [46]. The performance of *solar thermal heat* (*STH*) systems that were installed on multi-storey buildings was evaluated in the report. However, the saving potential of STH varies with solar radiation availability, system efficiency, outside temperature and utilization of heat collected which all complicates any accurate prediction. By accounting for solar thermal energy, the yearly demand for domestic water heating for an Advanced building will decrease from 32 kWh/m^2 to 23 kWh/m^2 resulting into a total heat demand of 61 kWh/m^2. This means that the total heating energy needed for the buildings in the Advanced district will become 20.011 MWh/a which is over 14% overall decrease when including solar thermal heating. One collector square metre produces annually 200–400 kWh for different types of systems and locations in Finland [47], and 450 kWh in Germany [48]. Results from PVGIS shows that the potential in Moscow is closer to that of Berlin than Helsinki. The value 400 kWh was used meaning that the total needed surface area needed for the solar collectors would be 8.011 m^2. The solar collectors might be roof-installed or placed on an open field and thereafter interconnected to form a large scale solar thermal heating system. The solar panels would occupy around 50% of the roof total roof area of the buildings and the collectors around 30% in case they were to be roof-top mounted.

The *ground source heat pumps* (*GSHP*) were decided to have a coefficient of performance (COP) value of 3, which means that each unit of electricity put in will generate three units of heat. Depending on how much heating is required there will be a certain amount of vertical boreholes needed for the ground source heating pumps. The amount of boreholes was calculated by calculating the total pipe length needed and dividing this with twice the maximum depth of a vertical borehole (200 m). Based on the demanded heating energy D_h, the length L of the pipe is calculated by

$$L = \frac{D_h}{G} \times 0.67 \quad [49] \tag{6}$$

The term G denotes the extractable amount of energy from ground which depends on the type of soil. In this study, the soil was assumed to be clay with the amount of extractable energy of 55 kWh/m^3. The value 0.67 in formula 1 comes from the ration of heat production for a GSHP with a COP value of 3. The pipe length can be twice the depth of a vertical borehole since it makes a loop in the end and return back to the surface again. This means that the total amount of vertical boreholes was calculated by dividing the total pipe-length for the whole district by 400.

Boreholes are to be placed 15 m from each other [49], which means that one borehole occupies at most 177 m^2 of ground surface. It has been considered that each II-18 building has a total floor area of 4.911 m^2 while the total floor area of the district is 327.581 m^2. The district scenarios in this study were considered to contain solely of II-18 buildings which means that the number of buildings in each scenario is 67. This number was later used for calculating how large area is required around each building for the installation of the boreholes.

In the *alternative 3*, 7.5% of the total electricity demand is generated by building integrated solar panels (BIPV), a total of 15 600 m^2 of panels, while the rest is bought from the grid. These would occupy half of the roof area as earlier mentioned. The heating demand is covered by ground source heat pumps (GSHPs) which in turn demand a considerable amount of electricity (included in the total demand). This alternative would require 556 boreholes and the ratio between the floor area and area needed for GSHP is 1/0.382. The energy demand and generation for this alternative are shown in Table 6 and the generated emissions in Table 7.

Alternative 4 is similar from the previous alternative except from the part that the additional electricity from the grid will be bought from wind farms (WF) located elsewhere. The energy demand and generation for this alternative are shown in Table 8 and the emissions in Table 9. The solar photovoltaic efficiency, and amount of boreholes and the area required for these are the same as in Alternative 3.

Table 6
Energy demand and generation for the advanced district alternative 3.

Annual energy demand (MWh/a)			Annual energy generation (MWh/a)		
Type	Heat	Electricity	Type	Heat	Electricity
Buildings	23 379	9943	BIPV		1655
Water and wastewater treatment	182	675	GSHP	23 561	
Street lights		242	Electricity from the grid		17 057
GSHP		7854			
Total	23 561	18 712	Total	23 561	18 712

Table 7
The emissions for the Advanced district scenario alternative 3 (A3: PV + GSHP + bought. . .).

	BIPV (kg/a)	GSHP (kg/a)	Grid (kg/a)	Waste incineration (kg/a)	Total (kg/a)	Total per person (kg/a/p.p)
Emissions into air						
SO_2-equivalent	291	293	59 378	2494	62 456	4.5
TOPP-equivalent	265	363	37 260	4613	42 500	3.1
Particulates	43	54	7794	38	7929	0.57
Greenhouse gases						
CO_2-equivalent	181 817	90 342	8 792 514	244 317	9 308 990	674

Table 8
Energy demand and generation for the advanced district alternative 4.

Annual energy demand (MWh/a)			Annual energy generation (MWh/a)		
Type	Heat	Electricity	Type	Heat	Electricity
Buildings	23 379	9943	BIPV		1655
Water and wastewater treatment	182	675	GSHP	23 561	
Street lights		242	WF		17 057
GSHP		7854			
Total	23 561	18 712	Total	23 561	18 712

In the *alternative 5*, solar collectors (STH) are producing 30% (8000 m^2) of the heating energy needed for the domestic hot water. The rest of the heat demand is covered by ground heat pumps (GSHP) which use also electricity for operation. Solar panels (PV) are producing the same amount of electricity as in alternatives 3 and 4 while the rest of the electricity demand is generated by wind farms (WF). The total amount of boreholes in this case is 458 which is less than for the precious cases since a share of the heating demand is covered by solar collectors. The ratio between the floor area and area needed for GSHP is thereby 1/0.314. The energy demand and generation for this alternative are shown in Table 10 and the emissions in Table 11.

4.2.4. Comparison of the different district cases

Generated emissions from the different scenarios are compared to each other and the value for the Moscow area (Moscow ref.) in Fig. 2 (CO_2-equivalent emissions), in Fig. 3 (SO_2-equivalent emissions), in Fig. 4 (particulates), and Fig. 5 (TOPP-equivalent emissions). The Moscow reference values are average emission values from energy production for the whole of Moscow. In order to

Table 9
The emissions for the Advanced district scenario alternative 4 (A4: PV + GSHP + WF).

	BIPV (kg/a)	GSHP (kg/a)	Wind farms (kg/a)	Waste incineration (kg/a)	Total (kg/a)	Total per person (kg/a/p.p)
Emissions into air						
SO_2-equivalent	291	293	1073	2494	4151	0.30
TOPP-equivalent	265	363	1436	4613	6677	0.48
Particulates	43	54	241	38	376	0.027
Greenhouse gases						
CO_2-equivalent	181 817	90 342	448 794	244 317	965 270	70

Table 10
Energy demand and generation for the advanced district alternative 5.

Annual energy demand (MWh/a)			Annual energy generation (MWh/a)		
Type	Heat	Electricity	Type	Heat	Electricity
Buildings	23 379	9943	BIPV		1655
Water and wastewater treatment	182	675	GSHP	20 356	
Street lights		242	STH	3205	
GSHP		6785	WF		15 989
Total	23 561	17 644	Total	23 561	17 644

Table 11
The emissions for the Advanced district scenario alternative 5 (A5: STH + PV + GSHP + WF).

	BIPV (kg/a)	GSHP (kg/a)	Wind farms (kg/a)	STH (kg/a)	Waste incineration (kg/a)	Total (kg/a)	Total per person (kg/a/p.p)
Emissions into air							
SO_2-equivalent	291	246	1001	636	2494	4667	0.34
TOPP-equivalent	265	304	1340	573	4613	7095	0.52
Particulates	43	45	224	132	38	482	0.035
Greenhouse gases							
CO_2-equivalent	181 817	75 745	418 716	118 005	244 317	1 038 600	75

be comparable, these have been converted to emissions per inhabitant and thereafter multiplied by the number of inhabitants of the case district.

Using biogas instead of natural gas would result in larger reduction of CO_2- and TOPP-equivalents but higher levels of SO_2-equivalents and particulates with all examined solutions. The reduction potential is especially high for CO_2-equivalents which can be reduced to below 10% for each scenario when switching to biogas. Buying electricity from the grid is not favourable and would cancel out the effect of using ground source heating pumps for reducing emissions in alternative 3.

By comparing the emission levels, alternative 4, involving PV, GSHP and WF, would generate lowest emissions. However alternative 5, involving STH, PV, GSHP and WF, was almost as good alternative because energy produced by a ground source heat pump is considered to result in fewer emissions than energy produced by solar collectors due to the fact that the electricity used by the heat pump was produced by wind energy. Storing excess heat from the solar collectors in the ground during hot seasons (summer) with help from GSHPs was not considered. Taking this into account could possibly have made alternative 5 the winning scenario.

5. Discussion and conclusions

5.1. Conclusions

At the district level, different improvement scenarios in terms of energy demand, energy production and emissions were analyzed. The district scenarios, named Current, Basic, Improved and Advanced, comprise the building renovation cases of the most typical apartment building type. The improvements accounted for in the district scenarios were the energy consumption of buildings, outdoor lighting, water purification, wastewater treatment, and transfer losses of district heating and electrical grid, and energy generation from renewable energy sources. Several studies [14,15,50–54] show the technical feasibility of renewable energy solutions in Russia.

Considerable energy savings could be achieved in a district through different modernization scenarios. Even with the basic district concept, the total annual electricity demand would reduce 24%, and the total annual heating demand 42% according to calculations. With the improved district concept, the corresponding reductions would be 33% and 55%. With the advanced district concept, potential reductions would be 34% for electricity demand and 72% for heating demand. It is clearly seen that savings in heat demand are easier to achieve than savings in electricity demand. One reason for this is that electricity demand is more connected to people's behaviours than the heat demand and is therefore harder to calculate and forecast. Almost all renovation activities also improve the quality of living, one such is the instalment of mechanical ventilation which often lower heat demand but increases electricity demand. It needs to be understood that a holistic approach to the analysis of the renovation activities is essential to draw the right conclusions.

The importance of analyzing the whole energy chain becomes evident when looking at cases where heat losses in the heat distribution network are very big and heat exchangers are lacking between networks and the buildings (as is the case in Russia). This leads to a situation where the reduced energy demand in a building does not lead to savings in the beginning of the energy chain but may instead even lead to overheating of the building. The energy saving investments might then be beneficial for the building occupants (if the investments also include control devices), but looking at the total benefits for the society such renovations would not bring such benefits as reducing air pollution, global warming, unnecessary investments into utility-level energy (and water) infrastructure etc.

The emission analyses show that the amount of each emission type produced might depend on different factors. As for CO_2-equivalents, changing fuels from natural to biogas would be an efficient choice of reduction. The same also goes for TOPP-equivalents, where it can be noted that changing fuel type would result in further reduction than implementing the next standard (e.g. Current to Basic) renovation. However, doing so would on the other hand also result in twice the amount of produced SO_2-equivalents and particulates. Concluding, producing energy from other renewable technologies than biogas, such as ground source heat pumps, solar panels, solar collectors or wind turbines, would be a better solution than switching to biogas when it comes to reduced SO_2 particulates emission levels compared to the current situation.

It can be concluded that there is no straight forward answer to which scenario is the best one, not even in terms of reduced emissions. Looking at CO_2 and TOPP emissions gives another conclusion than looking at SO_2 and particulates emissions. It needs to be clear what the objectives of the improvements are in order to make the right decisions in choosing the most efficient improvement scenario.

6. Discussion

There is no relevant scientific literature related to energy renovations of Russian residential districts, this study can be seen as a pioneer and forerunner in this sector. Even though the district examinations were made to one pilot area, their results can be generalized to other similar residential areas existing in Moscow as well as in other parts of Russia. The energy renovation of such districts requires often improvements to the whole energy chain while many building level renovations would only improve the energy-efficiency of the building itself. This means that if the same amount of energy is supplied to the building through uncontrollable district heating, the building energy consumption and emissions do not reduce.

The performed analysis highlights also the issue of a wide variety of stakeholders being involved in such renovation activities. City planning aspects need to be considered for example when considering the need for land use for bore holes or local heating plants. The roof top solar installations' inclination angles influence the solar energy production etc. Energy companies naturally have a big role in the infrastructural renovations of the energy infrastructure both considering production plants and the transmission lines and pipes. Ownership and management questions regarding ownership of energy plants, transmission networks and the buildings play a role in making the concepts realized.

Business models for carrying out such large scale renovation activities need to further investigated. The benefits of the different stakeholders, the incentives for realizing energy efficient district renovation concepts need to be elaborated. If energy is being subsidized the economic incentives might be lacking. If investments are paid by other stakeholders than the ones getting the benefits there is a barrier for executing the concepts. Public authorities need to have a clear role and strong will to make the concepts become reality.

Based on the result of this study it can be concluded that the renovation of a neighbourhood should not be restricted to the renewal of houses, but should be extended to the whole territory and whole energy chain in order to achieve the holistically best results. Furthermore, this study has shown (see Figs. 2–4) that the emissions to air correlate not only with energy efficiency, but are also highly dependent on the source of energy. For certain types of emissions (e.g. particulates) the effect of energy source is especially pronounced.

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Cost analyses of energy-efficient renovations of a Moscow residential district

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ABSTRACT

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

In the buildings, the estimated costs included both mandatory less energy efficient repairs and suggested energy efficiency improvements. At the building level, the costs of different renovation packages varied between €125 m^{-2} and €200 m^{-2} depending on the selected renovation package. The estimated district renovation costs include both the renovation costs of the buildings and the costs of improving district energy and water infrastructure. At the district level, the costs of the main cases per inhabitant varied between €3360 and €5200.

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

1. Introduction and literature review

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

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

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

Previous recent studies (Paiho et al., 2013; Paiho, Hoang, et al., 2014) show remarkable energy saving potentials of a Moscow Soviet-era residential district by adapting different holistic energy renovation concepts both in the buildings and at the district level and taking into account the whole energy chain from production to consumption and thus considering not only building scale renovations, but also improvements on the energy supply systems. In the buildings, the concepts focused on measures reducing heating and electricity demand, reducing water use, and improving ventilation. At the district level, the focus was in improving the related energy and water infrastructure as well as introducing energy production

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from renewable sources in the most advanced concepts. In addition, Paiho, Hoang, et al. (2014) analyze the emissions of different energy production scenarios. Even though the examinations were made as case studies to one pilot area, their results can be generalized to other similar residential areas existing in Moscow as well as in other locations and countries including Soviet-era residential buildings.

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

1.1. Literature review

Even research from the 1990s indicates the need for energy-efficiency improvements of the Russian housing (Martinot, 1998; Opitz, Norford, Matrosov, & Butovsky, 1997). Still, several recent references (Bashmakov, Borisov, Dzedzichek, Gritsevich, & Lunin, 2008; Filippov, 2009; Garbuzova & Madlener, 2012; Masokin, 2007; the World Bank and IFC, 2008; UNDP & GEF, 2010; UNDP, 2010) show considerable potential for improving energy-efficiency in Russian residential buildings and the related infrastructure in districts. However, there are only a few scientific papers related to energy renovations of Russian residential districts (Paiho et al., 2013; Paiho, Hoang, et al., 2014). Even less work is reported about the economic analyses of the energy-efficiency measures or energy renovations of Russian residential districts. Some partly relevant literature is available from Soviet-era residential buildings from other countries. In the following, this literature related to cost analyses made about renovating Soviet-era apartment buildings is shortly reviewed and reference data and information given for assessing the results of this study in a relevant context.

In a general level, Bashmakov (2007) assesses that technologies already applied in Russia may cost-effectively halve its energy consumption. Bashmakov (2009) estimates energy-efficiency potentials and costs of various energy supply and consumption sectors in Russia. Incremental capital costs of implementing the energy efficiency potential were assessed at the following values: in power generation at about $US 106 billion; in district heating renovation at $US 27 billion; in pipeline transportation at $US 23–30 billion; and in buildings at $US 25–50 billion. These numbers show the significant modernization markets even if the exact values may differ.

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

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

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

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

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

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

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

2. Background

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

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

2.1. The housing district selected

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

2.2. Considered building and district renovation concepts

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

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

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

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

3. Principles of the economic analyses

3.1. Principles from the literature

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

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

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

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

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

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

Jacob (2006) empirically quantifies the marginal costs of building energy efficiency investments (i.e. additional insulation, improved window systems, ventilation and heating systems and architectural concepts). The approach is more targeted to illustratively compare costs of individual refurbishment actions, such as different façade insulation thicknesses, rather than for analysing costs of preselected holistic renovation packages. Besides marginal costs of energy efficiency measures and architectural concepts, Jacob (2006) presents economic value of co-benefits (comfort,

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

Technology/system	Current status	Basic renovation	Improved renovation	Advanced renovation
Structures: U-values (W/m^{2}K)				
Outer walls	1.1	0.5	0.32	0.15
Base floor	1.1	–	–	–
Roof	1.1	0.25	0.24	0.15
Windows and doors	2.9	1.85	1.5	1.0
Ventilation	Natural	Restoration of existing natural ventilation. 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^{-1})	6.5	4.0	2.0	<2.0
Heating and hot water systems	Centralized control, 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 breaking. 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)

reduced noise, better indoor air), and claims the co-benefits are of the same order of magnitude as energy-related benefits. Their cost-benefit analysis takes into consideration the future reduction of investment costs through experience curve approach. Our work intentionally did not focus on quantifying the co-benefits, as the objective was to look at financial viability of an investment first of all from the point of view of a private third-party (e.g., an ESCO).

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

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

3.2. The approach used

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

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

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

Since the Soviet-era residential apartment buildings are in urgent need of capital repairs (IFC & EBRD, 2012) the baseline used

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

Technology/system	Current status	Basic renovation	Improved renovation	Advanced renovation
Energy production	Energy produced by large-scale plants, mainly using natural gas	Increasing energy-efficiency of generation processes	Reduction of emissions (e.g. change of fuel, or flue gas treatment).	Replacing fossil fuels with renewable energy sources (fuel cells, photovoltaic panels, heat pumps, etc.) and/or increasing plants' efficiency, e.g. increasing the share of CHP plants
District heating network (Heat losses, substations, flow/energy/adjustment/control)	Poor control High distribution losses	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, Shemeikka, & Klobut, 2006) (for example excess solar heat production)
Electricity distribution	Electricity distribution networks design does not allow to feed locally produced electricity to the grid, one-way flow. In some cases networks operate close to their limits, low power factor possible, old equipment (e.g. transformers).	Replacement of old equipment and cables, power factor and harmonics compensation where necessary		The basic scenario & review of automation systems to allow for connection of distributed generation. Smart meters (in case of demand response and local controllable energy generation)
Lighting (outdoor)		Energy-efficient street lighting	Street lighting designed to avoid light pollution	Smart outdoor lighting (sensor driven), street lighting electrified with solar PV's
Water purification and distribution, waste water collection and treatment	Drinking water not safe. 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)

included restoration of buildings to their initial conditions (referring to the mandatory non-energy related repairs) and restorations of buildings using nowadays materials available on the market, which properties have improved over the past 40 years. This baseline is referred to as "the basic renovation".

The simple payback time was calculated for the renovation solutions going beyond the basic baseline renovation using the following formula:(1)$payback\ time = \frac{additional\ investment}{additional\ annual\ savings}$

In addition to the previously mentioned calculations and as a last step in the analysis, it was decided to make a further analysis by accounting the net present values for the expected future growth of energy prices since it was noticed that the simple payback times are very long. Net present value (NPV) is one of the most typical techniques used for economic analyses (Remer & Nieto, 1995), for example used by Ferrante (2014), Kurnitski et al. (2011), Kurnitski et al. (2014), Ristimäki, Säynäjoki, Heinonen, and Junnila (2013), Rysanek and Choudhary (2013), Tommerup and Svendsen (2006), Verbeeck and Hens (2005) and Winkler, Spalding-Fecher, Tyani, and Matibe (2002). The NPV is also suggested by the Energy Performance of Buildings Directive (EPBD) recast of the European Commission as a method for an economic assessment (BPIE, 2010). The net present value of a renovation package is the difference between the present costs of a baseline package and of the considered renovation package. Formula 2 was used to calculate the present cost (PC) of a renovation package over a time period of N years (as being the sum of the investment and the discounted future consumption costs):(2)$PC = I + \sum_{r}\sum_{t=0}^{N-1}\left(\frac{1+g_r}{1+d}\right)^t \times C_r \times P_r$where I – initial investment; C_r, P_r – annual consumption and initial price of resource r (electricity, heating, water); g_r – average growth rate of a resource price over future period t [%/100]; d – discounting rate [%/100]. Then the NPV was calculated as follows:(3)$NPV = PC_{basc\ case} - PC_{package}$

4. Cost analyses

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

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

Building (II-18) properties		District properties	
Total gross floor area	4911 m^2	Total gross living area	327,581 m^2
Roof area	410 m^2	Total roof area	31,230 m^2
Total façade area	3060 m^2	Total population	13,813
Area of apartment windows	670 m^2	Total surface area of solar photovoltaic	15,615 m^2
Other glazing	28 m^2	Total surface area of solar collectors	8012 m^2
Area of walls	2355 m^2		
Building length/width/height	28/14.5/36 m		
Number of floors	12		
Number of residents	207		

measures, it is reasonable to create renovation packages first and only then proceed with evaluation of their economic attractiveness.

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

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

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

4.1. Building level case

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

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

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

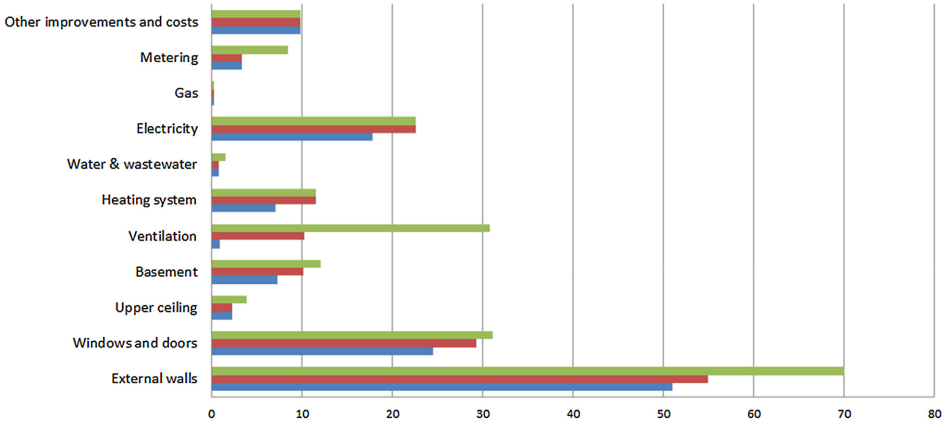
The **Improved renovation package** includes improvement of thermal insulation of walls to meet the current requirements for new buildings, installation of better performing windows, introduction of mechanical exhaust ventilation and building-level heat substations. It was assumed that the residents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

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

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

4.2. District level cases

The district renovation concepts were aligned with the building renovation packages, and the costs of building renovations were included in the costs of improving district energy and water infrastructure. The projection of building renovation costs to district level was based on specific costs per square meter of gross floor area of buildings. Following the analysis of the existing infrastructure in the pilot district, it was decided to utilize a nodal representation, meaning that a node is a location where local distribution infrastructure is connected to main utility networks, the lengths of distribution legs is the same for electricity, heating, water and sewage lines and there are five such legs per node. In practice, this



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

Fig. 1. The categorized measures included in the renovation packages of the II-18 type building and their costs per square meter of gross floor area [€/m²]. Prices were calculated in rubles and converted to euros assuming an exchange rate of 40 RUR/€.

means that one district heating substation or one electricity distribution substation supplied energy to five apartment buildings. In addition, an estimated length of main/trunk utility lines, connecting the nodes with a district connection point located on the edge of the residential area, was allocated to each node. This allowed for distribution of a certain amount of district infrastructure to apartment buildings to make a further estimate of the costs of district infrastructure renovation attributed to one building and compares the costs and effects of building and district renovation cases. The distribution of infrastructure is presented in Table 5. The specific district level costs for each renovation case were thereafter aggregated by extending them onto the total amount of residential gross floor area in the district.

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

Table 4
The estimated annual energy consumptions per gross floor area (kWh/m², a), the corresponding energy savings (%) and the total costs of different renovation packages per gross floor area (€/m²).

	Basic renovation package		Improved renovation package		Advanced renovation package	
	Heating	Electricity	Heating	Electricity	Heating	Electricity
Annual energy consumption (kWh/m², a)	134	37	104	35	71	39
Energy savings (%)	39	21	53	26	68	18
Total costs (€/m²)	125		155		200	

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

Measure	Quantity	Unit	Cost per unit (+ installation cost) (€)	Total cost of measure (€)
District heating distribution pipe replacement	40.00	meter	237.5	9500
District heating main pipe replacement	30.00	meter	487.5	14,625
District heating substation	0.17	Pcs.	237,500.0	39,583
Light bulbs for street lighting	34.51	Pcs.	412.5	14,237
Water distribution pipe	40.00	meter	625.0	25,000
Water distribution main pipe	30.00	meter	625.0	18,750
Water sewage distribution main pipe	40.00	meter	625.0	25,000
Water sewage main pipe	30.00	meter	625.0	18,750
Electrical grid renewal	40.00	meter	150.0	6000
Main grid renewal	30.00	meter	150.0	4500
Transformer substation	0.17	Pcs.	250,000.0	41,667

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

Energy production system	Installed amount	Unit	Price (€/unit)	Total cost of system (€)	Cost per living area (€/m^2)
Solar PV peak capacity	29	kWp	2500	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

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

Model	Healing 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€]	Tariff savings vs. basic model * [k€]
Building level (II-18)							
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%	715	149	39.79	10.46
Advanced	47.2%	-3.8%	37.5%	946	379	47.29	17.96

Model	Healing 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€]
District level							
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	18

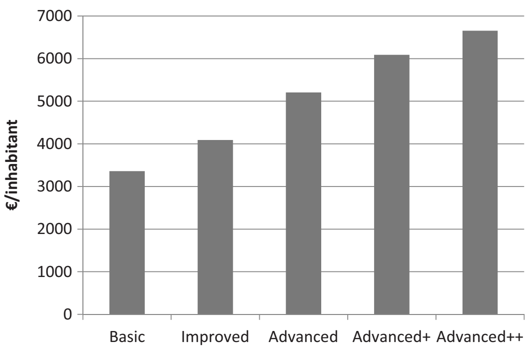


Fig. 2. The total renovation costs per inhabitant of the different renovation packages including renovations of all the apartment buildings in the area and the district energy and water infrastructure modifications.

heating infrastructure was excluded in both the Advanced+ and Advanced++ solutions since the heating energy would then be locally produced. Table 6 shows the additional costs of the on-site energy production solutions in total and floor area-specific terms for the II-18 building.

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

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

4.3. *Profitability of the renovation solutions*

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

The Advanced+ and Advanced++ solutions are unlikely to be feasible unless a rapid growth of energy prices in combination of low capital cost is assumed. At the same time, implementation

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

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

Building renovation

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

of such renovations may substantially reduce emissions (Paiho, Hoang, et al., 2014).

5. Discussion and conclusions

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

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

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

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

The district renovation concepts were aligned with the building renovation packages, and the costs of building renovations were included in the costs of improving district energy and water infrastructure in the pilot district. Apart from the Basic, Improved and Advanced cases, two additional alternatives were explored. The additional alternatives, called Advanced+ and Advanced++ renovation packages, both representing an extension of the advanced district renovation package, were also calculated. In the district level, the costs per inhabitant varied between €3360, €4090 and €5200 for the Basic, Improved and Advanced renovation packages, respectively. The costs of the additional alternatives per inhabitant were over €6090.

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

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

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

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

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

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

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PUBLICATION IV

An analysis of different business models for energy efficient renovation of residential districts in Russian cold regions

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An analysis of different business models for energy efficient renovation of residential districts in Russian cold regions

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ABSTRACT

The Russian apartment building stock is old and its energy efficiency is poor. 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.

This paper analyzes potential business models for energy efficient renovation of Russian residential districts in cold urban regions. After giving background information on Russian housing, the principle idea and planned contents of the Russian district renovations with main stakeholders and business model components are described. Potential business models are identified and their applicability for the Russian district renovations is analyzed. None of the analyzed business models as such suit for the district renovations in Russia but they all would need modifications. Crucial aspects for modifying the ESCO model, selected as the most potential one, are also addressed.

1. Introduction

About 60% of Russia's total multi-family apartment buildings are in need of extensive capital repair (IFC & EBRD, 2012). The Russian apartment buildings are not energy efficient and the losses in heat distribution networks and electricity transmission grids are high (e.g., Bashmakov, Borisov, Dzedzichek, Gritsevich, & Lunin, 2008; McKinsey & Company, 2009; The European Commission & The Russian government, 2013; The World Bank & IFC, 2008). Building renovation is an important opportunity to upgrade buildings in order to meet current and future energy- and eco-efficiency requirements, including people's increasing needs for improved indoor air quality. The energy saving potential of Russia's residential buildings exceeds 55% of their total energy consumption (UNDP, 2010).

The energy renovation of Russian residential districts requires often improvements to the whole energy chain while many building level renovations would only improve the energy efficiency of the building itself (Paiho, Hoang, et al., 2014). So in Russia, it is important to consider renovation and modernization of whole residential districts. 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.

The essence of a business model is in defining the manner by which the enterprise delivers value to customers, entices customers to pay for value, and converts those payments into profit (Teece, 2010). According to Osterwalder (2004), a business model 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.

Russian Federal Law No. 261-FZ "On Energy Saving and Energy Efficiency..." 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). In order to exhaust the opportunities for the reduction of energy and carbon intensity, Russia requires new business models to attract and secure extensive investment funds, and to reduce transactional barriers and risks (Garbuzova & Madlener, 2012).

The aim of this paper is to analyze if there are suitable business models for holistic energy efficient renovations of Russian residential districts in urban cold regions. After giving background information on Russian housing, we introduce the principle idea and planned contents of the Russian district renovations with main stakeholders and business model components. Then, the

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main features of business models identified from the literature are introduced, following the analysis of their applicability for the Russian district renovations. Finally, we conclude by summarizing the advantages and disadvantages of the identified business models and addressing crucial aspects needing modifications by the most potential business model.

1.1. The methodology used

The research is based on critical review of scientific and non-scientific literature. 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. The research utilized an iterative process where data was cross-checked and updated when relevant references and sources were found. The analysis was carried out in the following steps:

A. Describing typical features of Russian housing forming the general background for the study.
B. Introducing the core contents of district renovations establishing the case studied.
C. Categorizing and analyzing the main stakeholders who would be involved in district renovations.
D. Analyzing the business model components in the context of Russian district renovations.
E. Identifying potential business models from the literature.
F. Analyzing and discussing the applicability of the identified business models for Russian district renovations.
G. Selecting the most potential business model and addressing modifications it would require.

2. Russian housing

The housing stock of the Russian Federation amounted to 19,650 thousand buildings of the total floor space 3177 mln. m^2 as of 2009 year end (IUE, 2011). The housing stock included 3224 thousand apartment buildings of the total floor space 2237 mln. m^2. Majority of the apartment buildings were constructed between 1960 and 1985 during the Soviet-era with only a few building types (United Nations, 2004; Trumbull, 2013).

The housing stock in Russia has a rather high level of amenities. An average of 61.4% of housing is provided with all the amenities. In 2009, 89% of urban housing stock had access to water supply, 87% to sewerage, 92% to heat supply, and 80% to hot water. (IUE, 2011)

Total population of Russia is 143 million of which 74% live in urban areas. The average living area per inhabitant is 23.4 m^2 (Federal State Statistics Service, 2014) and the average occupancy rate per flat is 2.7 persons (United Nations, 2004). In 2012 (Federal State Statistics Service, 2014), monthly average per capita money income was 22,880 RUR (approximately €570). As Moscow is the richest Russian region, the average wages there are about the double compared to the national average. Of the money expenditures and savings, purchasing of goods and payment for services forms the biggest share being around 74% while acquisition of real estate is around 4% (Federal State Statistics Service, 2014).

Majority of the Russian housing is privately owned due to the free privatization of the housing stock after the Soviet collapse. The apartments were privatized by the tenants "as is", and the technical condition of the buildings/apartments was not systematically documented at the time. The law on privatization of apartment buildings of 1992 stipulates an obligation of the former lessors of residential units (the Soviet state and municipalities) to carry out the first capital repairs. This substantial involvement of public authorities in maintenance and renovation of the old housing stock and the so-called yard territories and communal infrastructure is the major significant difference from the practices in Europe. Due to this no-cost transfer of ownership, Russia has become a country of poor owners who cannot afford property maintenance and taxation leading to discussions whether ownerships should be returned back to the municipalities (Shomina & Heywood, 2013).

District heating covers 70% of the total residential heating market in urban areas (Nuorkivi, 2005). Heat distribution losses and electricity transmission losses are high in Russia (Bashmakov et al., 2008). Residential consumers are charged for communal services such as heat, water, sewage, and waste disposal in one bill (Korppoo & Korobova, 2012), where heat is the dominant item, with regional variations of 47–65% of the total. During the last decade (2000–2009), heating tariffs have increased many times in Russia and the rise in heating price has been steeper compared to other utilities (Nekrasov, Voronina, & Semikashev, 2012). Regulated tariffs for residential customers are subsidized and do not reflect the costs of producing electricity (Kuleshov, Viljainen, Annala, & Gore, 2012) nor heating (Korppoo & Korobova, 2012).

According to the Russian Statistics Service (Federal State Statistics Service, 2014), the average cost of capital repair in 2012 across Russia amounted to 4500 RUR/m^2 (€110/m^2). The recent version of the Housing Code established the obligation for the residents of apartment buildings to pay renovation fees to a renovation fund, which can be used either by the building association itself, provided the residents decide so with majority of their votes (how big majority is needed varies depending on the measure suggested), or by default by a regional operator (Housing Code of Russian Federation, 2013). In several regions, the amount of contributions varies between €0.1 and 0.2/m^2 per month, which is hardly enough to cover the basic costs.

According to a housing survey in St. Petersburg (Herfert, Neugebauer, & Smigel, 2013), only a small proportion of the inhabitants living in large-scale housing estates have considered their residential satisfaction, since to a large extent alternative options in the form of affordable residential offers are not available and the large majority of city dwellers still live in non-refurbished and traditional older buildings.

3. Russian district renovations

This section describes the idea of renovating Russian residential district holistically. The focus is on cold urban areas of Russia. In addition, the main stakeholders who would be involved in such a renovation are introduced. The business model components are also presented.

3.1. The case – district renovations of residential neighborhoods in urban cold regions of Russia

Typically, the energy efficiency of Russian apartment buildings is poor (e.g., Bashmakov et al., 2008; The World Bank & IFC, 2008). So far, the idea of renovating residential districts holistically is not introduced in Russia. However, it is clear that residential buildings and the related infrastructure is in need of major repairs. Due to the technical structure of district heating used in Russia, the buildings do not include any means to control the heating. Thus, in case only the buildings are renovated and their energy efficiency improved the same amount of heating energy will still be produced.

Table 1 shows the main issues to be included in holistic district renovations in Russia. In principle, all the buildings including all the technical systems and the related energy and water infrastructure would be renovated holistically. The renovations would include upgrading the buildings to more energy efficient ones. In

Table 1
Main contents of the district renovation concept.

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

addition, in the most advanced cases the district renovations could include distributed energy production solutions from renewable energy sources.

Paiho, Hedman, et al. (2013) developed different holistic energy renovation concepts for the Russian apartment buildings in cold climates ("Buildings" in Table 1). Paiho, Hoang, et al. (2014) developed corresponding holistic energy renovation concepts for Russian residential districts focusing on energy, water and waste infrastructures and energy production alternatives ("District infrastructure" and "Distributed energy production" in Table 1). In addition, Paiho, Hedman, et al. (2013) and Paiho, Hoang, et al. (2014) describe the current status of different systems and present renovation technologies for each individual system within the concepts. In the buildings, the energy improvements would focus on reducing heating and electricity demands and reducing water use. The key technologies in building renovations would include for example improving *U*-values of structures, improving building air tightness, modernizing heating systems and replacing water fixtures. In addition, for improving indoor conditions ventilation systems would be modernized even if doing so may in some cases increase energy usage. In the district infrastructure, the energy improvements would focus on reducing losses, improving control and replacing old systems. In the most advanced concepts, such technologies as ground source heat pumps and building integrated photovoltaic systems can also be incorporated. This kind of a district renovation approach would reduce the district-scale energy demands and CO_2 emissions considerably (Paiho, Hoang, et al., 2014). Through economics of scale the district renovations could also have other benefits, such as reducing the unit costs and being more interesting for the private sector.

Paiho, Abdurafikov, and Hoang (2014) modified these renovation concepts to renovation packages with real products and solutions available in the Russian market. The economic attractiveness of the suggested holistic energy-efficient renovation packages of multi-family apartment buildings and the related residential districts in a typical Moscow neighborhood were analyzed by comparing the additional improvements to the basic capital repairs that in any case need to be implemented. Simple payback time (i.e., the ratio of initial investment to costs of annual savings) for the additional improvements beyond the basic renovations exceeds 12 years. At the building level, the investment costs of different renovation packages varied between €125/m^2 and €200/m^2 depending on the extent of the selected renovation package. In case the whole district would be renovated (both the buildings and the related energy and water infrastructure) the costs per inhabitant varied between €3360 and €5200. The costs of the building renovations formed about 90% of the total costs. The costs per inhabitants of additional alternatives including renewable energy production solutions were over €6090.

3.2. *Stakeholders in Russian district renovations*

A stakeholder analysis clarifies which stakeholders there are and how they are connected to each other and what benefits they could achieve through renovation concepts. The different building stakeholders can play an important role in determining how, why, and if retrofit measures will be implemented and the development of methodologies that enhance the interaction amongst these stakeholders (Menassa & Baer, 2014). In the following, only the main stakeholders in Russian district renovations are briefly introduced.

3.2.1. *Inhabitants*

In Russia, about 76% of housing units in apartment buildings are reported to be in private ownership (IUE, 2011). Apartment buildings in Russian cities are usually rather big, with several hundreds of apartments (owners), where the residents are rarely familiar with each other and may often have substantially different income levels, which complicates common decision-making process (Paiho, Abdurafikov, et al., 2013).

3.2.2. *Homeowners' associations*

The housing reform that came into force in 2005 obligates all homeowners to organize the management of their house privately (Vihavainen, 2009). One alternative to this, the establishment of a homeowners' association, has since become increasingly common. The other two alternatives are direct management by the homeowners, without an association, and management by a private company still often municipality controlled. A homeowners' association is, by definition, a non-profit organization, established for the management and maintenance of common property in a multifamily building.

3.2.3. *Public bodies*

The local public sector is involved in the renovation and management of old residential building stock (Paiho, Abdurafikov, et al., 2013). Firstly, because of an obligation to implement renovations, secondly, because the scope of renovation is enormous and public funds are not sufficient – maintenance is the only way to keep social stability. The housing sector in Russia has a poor reputation due to its non-transparency, inefficiency and corruption. The municipality plans the district and has the overall responsibility for providing comfortable and sustainable living surroundings. The city can influence what is being renovated and how it is being done. The involvement of the municipalities is crucial also in implementing requirements from the federal level.

3.2.4. *Utility and network operators*

District heating is widely used for space heating in Russia (The World Bank & IFC, 2008). The majority of the CHP (Combined Heat and Power) plants now are over 30 years old and are nearing the end of their useful lives (Masokin, 2007). Most CHP installations are controlled by Territorial Generation Companies ("TGKs") (Boute, 2012). There has been little investment in networks over the last two to three decades in Russia (Cooke et al., 2012). Losses on electricity transmission and distribution networks in Russia are high (The World Bank & IFC, 2008).

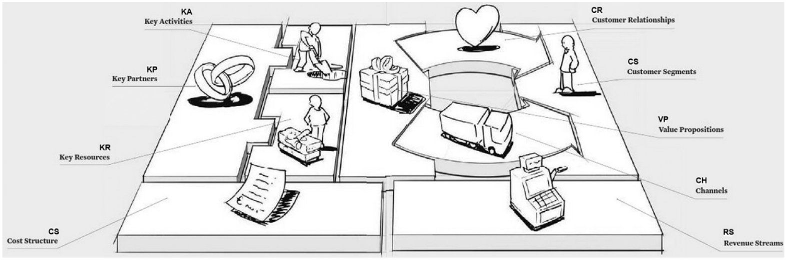

Figure 1. General business model canvas by Osterwalder and Pigneur (2010).

3.2.5. Construction companies

Typically, the companies implementing the renovations are smaller than those involved in new construction (Paiho, Abdurafikov, et al., 2013). The qualification of employees is generally at a sufficient level, however, though some errors in the final product are possible (e.g. differences from the design documentation), which appears to be connected with poor quality control of the work.

3.2.6. The financial sector

The interest rates on housing credit in Russia are noticeably high by international comparison (Khmelnitskaya, 2014). On one hand, Russians do not trust the banks (Lipman, 2012), on the other hand, Russian commercial banks are not willing to provide the loans for investments in energy efficiency and carbon mitigation projects, as these are classified as highly risky (Garbuzova & Madlener, 2012). To modernize the Russian heating sector, investors need to rely on tariff methodologies and structures that enable them to recover the capital costs of their energy efficiency investments and to earn a reasonable return on capital (Boute, 2012).

3.2.7. Other relevant actors

There are numerous products needed in energy renovations. So, various product manufacturers and system providers are involved. Russian companies tend to prefer to purchase from Western manufacturers when quality is essential (Lychuk, Evans, Halverson, & Roshchanka, 2012). In addition, the renovations need designing.

3.3. Business model components for Russian residential district renovations

There are many ways to structure business model components, e.g., The U.S. Department of Energy (2012), Hedman and Kalling (2003), Morris, Schindehutte, & Allen (2005) and Osterwalder and Pigneur (2010). Following analysis includes some considerations based on the business model canvas developed by Osterwalder and Pigneur (2010), shown in Fig. 1, of what kind of issues a service-oriented company should consider in able to access energy-efficient renovation market in cold climates of Russia.

3.3.1. Customer segments

The greatest benefits may be obtained when the whole district is being developed to more energy efficient. Even if the improved energy-efficiency benefits end users, the optimal customers for these larger services are mainly municipalities along with the representatives of the inhabitants, for example homeowners' associations and management companies. Energy-efficient renovation services require knowledgeable customers who are also aware of the key technologies in buildings such as improved insulation, ventilation with heat recovery, energy-efficient windows and doors, energy-efficient lighting and electrical equipment, and efficient heating solutions as well as the key technologies in districts such as efficient district heating solutions, replacing fossil fuels with renewable energy sources, smart metering and energy-efficient street lighting.

3.3.2. Value proposition

Energy-efficiency itself rarely is enough to justify more expensive investments attached to renovation. Legislation can force into some actions, but laws and norms are always behind the technological development. Savings in future energy costs, secure cash flows, reduced technical risks or increased value of the asset are some of the possible benefits to improve energy-efficiency when there are renovation needs.

For single resident in apartment building the improved energy-efficient can bring, for example savings in energy costs or more comfortable indoor conditions. Apartment or utility owners can benefit from reduced risk levels, secure cash flows and perhaps increased value of the asset. Through district renovations, public bodies may for example gain the peoples' trust and meet regulatory requirements. Such systems as the LEED rating system for neighborhood development (Talen et al., 2013) could support information dissemination & awareness rising among the people.

3.3.3. Channels

As marketing channels, organized events for professionals play central role in creating awareness. In addition, the creation of awareness among end users helps to raise the demand for such services. These cannot replace personal contacts. Actions in municipality levels are required too.

3.3.4. Customer relationships

Customer relationship with institutional customers differ also from direct consumer relationships, even different legislation is applied. Here the institutional customers are considered more potential customers for energy-efficient renovation services due to unified decision making. Similar building stock provides opportunity to mass-customization. However, entering to the different sub-markets and features of clients require personalized service, but on the other hand create fruitful ground for co-creation. In Russia, the creation of trust plays important role in business relationships.

3.3.5. Revenue streams

Existing services often try to tie pricing mechanisms with energy prices. There are well based reasons for this, but predicting price development is very risky. Instead, other value propositions than saving money could be included into services.

3.3.6. Key resources

Renovation activities are often labor intensive. Finding knowledgeable people and managing multicultural workforces create own challenges. Economies of scale can bring another challenge that the production capacity is not extensive enough. The size of projects in Russia can be very large compared to for example Nordic residential areas.

3.3.7. Key activities

There might be a need to include several different activities to the service, for example marketing, energy audits, detailed planning of renovation, financing, installation, after sales. Customer is easily buying only technical devices, but the service is not comprehensive if, for example the delivery time and quality are not considered.

3.3.8. Key partners

Knowing customer or customer segments are not enough, but defining and finding key partners create an essential ground for business. Transferring the production near the market can be required. These activities might require a creation of joint ventures with local actors. Marketing activities and creation of business relationships might also require "a partner, who opens doors".

3.3.9. Cost structure

Energy-efficient renovation services are value driven rather than cost driven. There are possibilities for leaner cost structure after services have been established in the market. Currently studied pre-fabrication methods, and the use of building information modeling during design, planning and production phases can shorten the delivery times in the future. Use of local workforce makes a large difference in cost structure, but requires time and money that necessary people are trained. Russia's residential energy-efficient renovation market provides unique opportunity for companies to offer renovation services.

4. Potential business models identified from the literature

Several business models meant for energy efficiency improvements have been reported, e.g. Frantzis, Graham, Katofsky, and Sawyer (2008), Huijben and Verbong (2013), Lumijärvi and Ollikainen, 2011, Okkonen and Suhonen (2010), Richter (2012), Richter (2013), and Würtenberger, Bleyl, Menkveld, Vethman, and van Tilburg (2012). In this section, the main features of these business models are briefly described. At the end of this section, a summary table of the business model components of each model is presented and compared to the needs of the business model components for Russian residential district renovations (see Section 3.3).

4.1. The ESCO model

Two basic ESCO (Energy Service Company) business models can be distinguished, which provide either useful energy (Energy Supply Contracting – ESC) or energy savings (Energy Performance Contracting – EPC) to the end user. In addition to the two basic models, a hybrid model labeled as Integrated Energy-Contracting (IEC) aims to combine useful energy supply, preferably from renewable sources with energy conservations measures in the entire building (Würtenberger et al., 2012). Bleyl, Schinnerl, Kuhn, Leutgöb, and Varga (2008) propose three EPC-models allowing combining (comprehensive) refurbishment measures of buildings with the advantages and long term guarantees of Energy Contracting models.

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 (Bertoldi, Rezessy, & Vine, 2006). Street-lighting and district heating using the ESCO concept are developed by municipalities but typically the concept has been used in energy efficiency measures of public, commercial and industrial buildings (Marino, Bertoldi, Rezessy, & Boza-Kiss, 2011). The ESCO model has also been suggested as a business model for local heat entrepreneurship (see Section 4.5) (Suhonen & Okkonen, 2013).

An important difference between 'do-it-yourself' implementation and outsourcing to an ESCO root in the functional, performance and price *guarantees* provided by the ESCO and the assumption of technical and economic risks by the ESCO (Würtenberger et al., 2012). ESCOs must clearly demonstrate the measurable and observable benefits of their projects (Pätäri & Sinkkonen, 2014). The ESCO takes the technical risks of the investment and gets financial benefits from that risk taking (Bertoldi et al., 2006). The main share of revenue of an ESCO business model comes from the achieved reduction either of energy costs, energy usage, or carbon emissions (Garbuzova & Madlener, 2012).

4.2. Customer-side renewable business model

In this business model the renewable energy systems are located on the property of the customer (Richter, 2012). The systems can also be owned by the customer (Frantzis et al., 2008; Huijben & Verbong, 2013). In small-scale business, the dominant sources or renewable energy are typically wood pellet stoves, small wind turbines, and small-scale combined heat and power systems (CHP), solar thermal collectors, solar photovoltaic systems, geothermal, and heat pumps (Aslani & Mohaghar, 2013). The size of the systems usually ranges between a few kilowatts and about 1 MW (Richter, 2012). For example, a number of energy companies in the Netherlands are selling PV panels to their customers and providing additional services like installation and monitoring (Huijben & Verbong, 2013).

In Germany, even the utilities that see distributed generation as a potential market severely struggle to develop value propositions for this field (Richter, 2013). Boehnke (2007) lists potential values, such as minimize trouble for final consumers, feature technologies with low maintenance requirements, a single contact for all issues, and moderate initial investments. In Germany, there are new products and services invented but mainly for the creation of political goodwill and customer relationship (Richter, 2013).

Cost structure becomes more complex due to many small instead of few large investments (Richter, 2012). Typically, the feed-in tariff (FIT) payment is sized to cover both installation and operating costs, but the tariff is only paid for actual energy production (Gifford, Grace, & Rickerson, 2011). This makes it most suitable for technologies that are available off-the-shelf (Würtenberger et al., 2012).

4.3. Utility-side renewable business model

In this model, the projects range from one to some hundred megawatts (Richter, 2012). In large-scale business, the dominant sources of renewable energy are typically biomass and biogas plants (or CHP plants), on/offshore wind energy, large-scale photovoltaic systems, and solar thermal energy like concentrated solar power (Aslani & Mohaghar, 2013).

Customer segmentation allows increasing customer base and earning "eco" price premium (Richter, 2012). For the utility management, clean energy and energy efficiency are often a lower priority than reliability and cost (The U.S. Department of Energy, 2012).

Revenue models for the utility-side business model exist and can easily be adapted by utilities (Richter, 2012). Decoupling and cost-recovery mechanisms allow utilities to recover some of the revenue lost from demand side management or other energy efficiency programs (The U.S. Department of Energy, 2012).

Cost structures are in favor of utilities experiences with large scale infrastructure financing (Richter, 2012). Demand response services may reduce the electricity bill of a final customer with distributed generation capacity by over 15% (Gordijn & Akkermans, 2007).

4.4. Mankala company

In a Mankala arrangement the shareholders establish a limited liability project company, the purpose of which is to operate like a zero-profit cooperative to supply electricity to shareholders at cost price (Lumijärvi & Ollikainen, 2011). The owners gain electricity in proportion to their ownership at a cost price. The owners, consisting mostly of wholesalers and retailers and on the other hand of companies with large energy consumption, such as large industrial companies, can use the electricity in their own production or sell it on through the exchange or bilaterally (Puikkonen, 2010).

Market risks are taken by the end users (Lumijärvi & Ollikainen, 2011). The joint owners get the profit, other earning, through low procurement costs. This other earning is tax free, which is one of the main benefits of the model (Puikkonen, 2010).

So far the Mankala principle has been applied in several energy investments in Finland, including for example wind, hydro and nuclear power (Lumijärvi & Ollikainen, 2011). In Finland, The Mankala-model can be described as a long, and in principle a forever-lasting contract, in which the companies bind themselves to the obligations of the joint owners, which in turn leads to the fact that new companies' entry to the partnership is hindered (Puikkonen, 2010).

The structure is heavy, entails extensive legal and financial arrangements and documentation, and therefore high transaction costs (Lumijärvi & Ollikainen, 2011). The price of other earning from the company is defined in the shareholder and other agreements and is the same for all owners within the different production forms (Puikkonen, 2010).

4.5. Heat entrepreneurship model

"Heat entrepreneurship" refers to a business model which is to some extent similar to traditional energy companies' district heating business but in small scale (Lumijärvi & Ollikainen, 2011). A heat entrepreneur or enterprise can be a single entrepreneur, entrepreneur consortium, company or cooperative providing heating for a community (Okkonen & Suhonen, 2010). Often the scale of the heating units are small, at the maximum a few megawatts (Motiva, 2013).

The heat entrepreneur develops designs, constructs and invests in the heat system (Lumijärvi & Ollikainen, 2011). The entrepreneur can either sell the heat directly to a building, or it can sell the heat to the local heating network (Motiva, 2013). It could also be possible to include other services, such as property management and guarding, to the offering (Pakkanen & Tuuri, 2012). The heat entrepreneur requires constant fuel supply. For example, low quality forest fuel could cause unscheduled stoppages and lower the profitability of cost sensitive heat production (Laihanen, Karhunen, & Ranta, 2013).

4.6. On-bill financing

On-bill tariffs are a mechanism for charging customers for energy efficiency investments or upgrades provided as a service by the utility (Bell, Nadel, & Hayes, 2011). Preferably the overall utility bill should still be lowered, because of the associated energy cost savings (Würtenberger et al., 2012).

This model is originally targeted to owner-occupied single-family houses and small commercial buildings (Würtenberger et al., 2012) but it could be extended to apartment buildings at least if energy is billed based on building-level metering. There are examples from the United States where this model has been applied to large multi-family buildings (ACEEE, 2012). In case of billing based on apartment level sub metering the model is more challenging. Offering standard information and programs to customers can help to avoid some agent problems (Sweatman & Managan, 2010).

On-bill financing generally needs to be complemented with other approaches such as technical assistance, contractor training, and cash incentives to reduce the amount of loan needed or buy down interest rates (Bell et al., 2011). The utility may rely on additional partners for financing, such as banks or government bodies (Würtenberger et al., 2012). These programs are most successful when the application process is simple and straightforward and the contractors receive prompt payment for their services (Johnson, Willoughby, Shimoda, & Volker, 2012). Installers of renewable energy equipment may be involved by partnering with the utility (Würtenberger et al., 2012).

4.7. Energy leasing

Energy leasing enables a building owner to use an energy installation without having to buy it. There are two main types of leases: operational lease and financial lease. Leasing can be a central component of the business model of an Energy Service Company (see Section 4.1). Leasing can also be a central component of the business model of a company that introduces a specific new technology to the market via a leasing arrangement, including a service and maintenance package. (Würtenberger et al., 2012)

In a leasing arrangement the leasing company ("lessor") owns the equipment and makes an agreement with the customer ("lessee") on the use of the equipment (Lumijärvi & Ollikainen, 2011). The latter pays a monthly fee to the former for the right to use the equipment. The transaction costs involved in leasing on a small scale would be high, relative to consumer credit, and there would be greater risk for the lender, and cost for the borrower, in projects with a low component of physical assets (OECD/IEA & AFD, 2008). Leasing is not suitable for renovating certain vital building parts or components, like windows, façades or ceilings, which cannot be removed after the end of the lease term (Würtenberger et al., 2012).

The equipment given for clients to produce or save energy provide the main service offered. In addition, the leasing also covers the funding of these investments. By leasing via an energy service contractor, the building owners may profit from additional services such as specific financial, legal, fiscal and administrative consultancy, and operation and maintenance services (Würtenberger et al., 2012).

4.8. Business model components compared to the main aspects in Russian district renovation

In Section 3.3, some issues were considered which are relevant for a service-oriented company to access the energy-efficient renovation market in cold urban Russian areas. The analysis was based on the business model canvas by Osterwalder and Pigneur (2010). In Table 2, the main aspects of these components are shown in relation to the corresponding components of business models presented. In addition, the main scopes of the models are listed.

Table 2
The main aspects of the business model components and the corresponding aspects in Russian district renovations.

	Russian district renovation	ESCO model	Customer-side renewable energy business model	Utility-side renewable business model	Mankala company	Heat entrepreneurship	On-bill financing	Energy leasing
Scope	Energy-efficient renovation of residential districts including renovations of both the buildings and the related infrastructure	Energy services (Bertoldi et al., 2006)	Energy production from renewable sources at customer-side (Richter, 2012)	Renewable energy production (Aslani & Mohaghar, 2013)	Energy company ownership (Lumijärvi & Ollikainen, 2011)	Providing heating for a community (Okkonen & Suhonen, 2010)	Utilities providing financing for renewable energy and energy efficiency measures (Würtenberger et al., 2012)	Transferable energy installation without having to buy it (Würtenberger et al., 2012)
Customer segments	Renovated buildings and the related infrastructure, knowledgeable customers required	Final energy users (Bertoldi et al., 2006)	Energy end users (Richter, 2012)	Customers valuing clean energy (Richter, 2012)	Joint owners (Puikkonen, 2010)	Public buildings, private houses and industrial estates (Okkonen & Suhonen, 2010)	Originally targeted to owner-occupied single-family houses and small commercial buildings (Würtenberger et al., 2012)	All types of buildings (Würtenberger et al., 2012)
Value proposition	Energy-efficiency in combination to other values	Functional, performance and price guarantees (Würtenberger et al., 2012)	Not clear yet (Richter, 2013)	Possibilities to additional environmental value (Richter, 2012)	No market risks (Lumijärvi & Ollikainen, 2011)	Heat service (Motiva, 2013)	Providing services for energy efficiency investments and upgrades (Bell et al., 2011)	Opportunity to use an equipment without initial investments (Würtenberger et al., 2012)
Channels	Several needed due to many involved stakeholders	Further experience needed (Marino et al., 2010)	Improved information exchange between the utility and the customer (Richter, 2012)	Existing ones used (Richter, 2012)	Marketing is not needed (Puikkonen, 2010)	Local media and direct contacts	Can leverage utility's relationship with energy customers (Bell et al., 2011)	Need development (Würtenberger et al., 2012)
Customer relationships	Trust creation is mandatory	Mutual trust and confidence needed (Marino et al., 2011)	Business-to-business relationship (Richter, 2013)	No change to current ones needed (Richter, 2012)	Business-to-business relationship (Puikkonen, 2010)	No resources for developing customer relationships	For example targeted programs (Würtenberger et al., 2012)	Not many examples since the model is not common
Revenue streams	Perhaps partly tied to tariffs and partly to services	Through reduction in energy costs, energy usage or carbon emissions (Garbuzova & Madlener, 2012)	New ones needed (Richter, 2012)	Existing models can be adapted (Richter, 2012)	No taxable profit (Puikkonen, 2010)	Selling heat (Motiva, 2013)	Additional charges (ACEEE, 2012)	Leasing arrangement (Lumijärvi & Ollikainen, 2011)
Key resources	Skillful labor	Financing (Bertoldi et al., 2006)	Operating decentralized renewable energy systems (Richter, 2012)	Energy generation and distribution assets (Lumijärvi & Ollikainen, 2011)	Energy production equipment	Heat production and distribution systems	Service providers (Brown, 2009)	Depend on the model structure, can be the same as in ESCO
Key activities	Comprehensive services	A general contractor (Würtenberger et al., 2012)	New approaches needed (Richter, 2012)	Possibly the whole value chain (Richter, 2012)	Participating investors (Lumijärvi & Ollikainen, 2011)	Designing, constructing and investing in the heating system (Lumijärvi & Ollikainen, 2011)	Linking payments to utility bills (Würtenberger et al., 2012)	Equipment provided for clients to produce or save energy (Würtenberger et al., 2012)
Key partners	Local actors including public bodies	Financial institutions, technology providers and energy suppliers (Marino et al., 2011)	System manufacturers, installation companies and financing services (Richter, 2012; Boehnke, 2007)	Knowledge and experience not available in the organization (Richter, 2012)	Involved shareholders (Lumijärvi & Ollikainen, 2011)	Fuel supplier (Laihanen et al., 2013)	Technical assistance, contactor training, financing services and installers (Bell et al., 2011; Würtenberger et al., 2012)	ESCO or a building owner and a bank (Würtenberger et al., 2012)
Cost structure	Value driven	Cost driven (Bertoldi et al., 2006; Bleyl et al., 2008)	Possibly feed in tariffs (Gifford et al., 2011)	For example demand response services (Gordijn & Akkermans, 2007)	Same price for all owners (Puikkonen, 2010)	Customer paying for energy consumed (Lumijärvi & Ollikainen, 2011)	Financing mechanisms (Bell et al., 2011)	Physical assets form greater bulk of the expenditure (OECD/IEA & AFD, 2008)

5. Applicability of the identified business models for the Russian district renovations

In this section, it is evaluated how the business models identified from the literature would fit to energy-efficient renovations of Russian residential districts.

5.1. The ESCO model

In Russia, ESCO activities are still in a nascent stage at least when referred to a "Western-ESCO". Energy Performance Contracting (EPC) is not used in the Russian ESCO model. According to Russian legislation, leasing schemes seem to be very promising for the Russian ESCOs. (Garbuzova & Madlener, 2012)

Lack of appropriate forms of finance, public procurement rules, unstable customers, and a perceived high business and technological risk are seen as strong overarching barriers that hinder ESCO market development in Russia (Marino, Bertoldi, & Rezessy, 2010). Other constraints for ESCOs are: the lack of stability for operations of small and medium business and with the traditional economic system of centralized planning, low energy tariffs which fail to provide incentives for energy saving and fairly high end-user prices compared to the average income level (United Nations, 2010).

Companies operating as providers of energy services are of quite small size; some offer ESCO-type contracts as an added value to their core business, such as energy equipment manufactures integrating the ESCO concept into energy supply business (Marino et al., 2010). Further sources of revenues of the Russian ESCOs are based on the energy audit and technical services for the implemented equipment during the project, and not on the energy savings as in Western-ESCOs (Garbuzova & Madlener, 2012).

An important aspect for ESCO projects' implementation relates to ensuring payback guarantees as risk control would be problematic at all phases of project implementation. Such guarantees may be ensured by financial institutions or Russian government authorities. ESCO operations in the Russian Federation need to be supported by a corresponding clearly-defined legislation and predictable taxes. Improving public awareness of the energy saving issue and ESCOs as an energy saving tool is to become a priority task. (United Nations, 2010)

For the Russian district renovations, this model could be applicable in a modified form provided that the ESCO business becomes more common in Russia. This would perhaps require completely new actors in this field.

5.2. Customer-side renewable energy business model

Because of the flexibility in choosing categories and tariffs, government can use a feed-in scheme to stimulate private sector investments into specific technologies or niche markets (Würtenberger et al., 2012). Even though feed-in policies are widely used around the world Russia has not adopted them yet (REN21, 2013). Customer-side energy production needs a feed-in scheme so that the possible extra production could be sold to other energy users.

For the Russian district renovations (Paiho, Abdurafikov, et al., 2013), the energy production units serving only one building would be within this size limit. In this business model, there exists two key actors both producing energy, namely the energy utility and the distributed renewable energy producers at customer locations. In Russia, the energy utility, also owning the energy networks, is most often a public body. The energy production facilities and the energy distribution equipment are old and in need of renewal. In case, whole residential districts would be renovated the energy demands of these districts would be smaller as well as the required energy production capacities. This smaller energy need could be produced at the customer-side by renewable energy. The energy would have ecological value and at the same time result in smaller transfer losses compared to the current situation. The business for the energy producers could be, in this case, to maintain and "rent" the distribution capacity and offer maintenance services (maintenance, balancing, storage capacity etc.) regarding the customer owned energy systems.

5.3. Utility-side renewable business model

For the district renovations, the energy production units serving the whole district would be within this size limit (Paiho, Abdurafikov, et al., 2013). Municipal and state owned companies play a major role in the energy business, even if it is becoming more privatized and opened for competition in Russia. Since 2003, the Russian electricity market has gradually opened to competition, and the end of 2010 marks the final stage of this transition (Boute, 2012). The heat market is still regulated (Boute, 2012). Due to the dominating role of the traditional energy companies, any considerable change in the energy generation mix will include involvement by the municipal and state (and industry's) energy companies. On the other hand, experiences indicate that the energy companies are not typical early adopters of new technologies and business models (Lumijärvi & Ollikainen, 2011).

If residential districts in Russia were renovated to more energy-efficient ones, their energy demand would reduce. The needed energy could thereby be produced locally from renewable energy sources. From the utilities point of view the business would change in the way that they would sell less energy but the energy that they generate would contain ecological value, and at the same time result in smaller losses and infrastructure costs (instead of long distance transfer and maintenance of distribution network).

For the district renovations, the implemented new energy production units would serve the whole district. They could be owned by the homeowner's associations in the area, by the building operations and maintenance companies, by the municipalities or by the energy utility. In the Netherlands, there are examples of community shared projects where apartment complexes own the PV production facilities (Huijben & Verbong, 2013). If there is periodically or always more electricity produced than needed in the area, this can be sold to the grid for profit. If the heating energy is locally produced from renewable energy sources only the local district heating network will be in need of renewal.

5.4. Mankala company

In Finland, the Mankala model has been used in very large energy investment projects quite different to those needed in Russian residential districts. The model is complicated and it contains questionable features, such as competition issues (Puikkonen, 2010). However, in some lighter and revised form it could perhaps be adapted to energy-efficient renovations of Russian residential districts. This would require a several number of bodies or stakeholders to have a common vision and will toward energy-efficiency improvements of residential districts. Then, the model could perhaps be utilized in other similar cases as well.

5.5. Heat entrepreneurship model

In Finland, heat entrepreneurship is typically very local and quite small-scale heat production (Lumijärvi & Ollikainen, 2011). In Russia, in general private industrial enterprises (especially large-scale) have been involved in provision of district heating services to communities (Solanko, 2006). For example, in Moscow third-party investors own two heating plants: one on the territory of the former ZIL truck plant and another one–a heating plant converted

Table 3
Pros and cons of different business models in Russian residential district renovations (authors' analysis).

Business model	Advantages	Disadvantages
ESCO model	• One actor takes responsibility of 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 depended 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	• 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 to 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 stakeholder which could make it complicated to reach an agreement

from using coal to gas and supplying heat to an area of high-rise office buildings known as "Moscow-City". The size of these plants is typically over 100 MW (City of Moscow, 2009). So, this model may have certain potential in Russia but in different scale than in Finland. The main idea is that a local actor is in charge of heat (or in general energy) production.

5.6. On-bill financing

The 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). The cost-plus tariff methodology used in Russia discourages heating suppliers from investing in any measures that save operating and maintenance costs (which include energy costs) (The World Bank & IFC, 2008). However, energy efficiency measures improve the reliability of heat supply and reduce the dependency on primary energy fuels for regions that do not produce energy and are dependent on energy imports from other regions in the Russian Federation (Boute, 2012).

Heating tariffs fail to cover the costs of production, distribution, and the massive need for modernization (Korppoo & Korobova, 2012). Some estimates suggest that residential electricity prices may need to nearly double to reach cost-reflective levels (Cooke et al., 2012). Precise estimations of the financial value of cross-subsidization are problematic because its existence is partially denied by the state (Kuleshov et al., 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 local authorities have a vital role in boosting toward energy-efficiency. Renovated buildings must be equipped with heat meters to the extent technologically possible (Korppoo & Korobova, 2012). So, on-bill financing could be one suitable model even though it would, even dramatically, increase the customer payments. However, Russian tariff law strictly regulates the type and amount of costs that investors can recoup through tariffs (Boute, 2012). One major challenge would also be the persistent non-payment of energy bills (Garbuzova & Madlener, 2012; AEB, 2013).

5.7. Energy leasing

In Russia, implementation of leasing schemes is advisable in order to minimize the financial risks of ESCO in its relationships with the Client and to obtain an additional mechanism of control over the Client's operations within the frame of the energy-saving system and technologies (Efremov, Smirnyagin, Valerianova, & Hernesniemi, 2004). Leasing is only suitable for equipment and different services systems. So, when renovating Russian residential districts leasing could be used for example for renewal of energy equipment but it could not be used for renovation of parts integrated in buildings.

6. The most potential business model

This section first summarizes the advantages and disadvantages of the identified business models and then addresses relevant aspects needing modifications by the most potential business model, the ESCO model, in order to suit for the district renovations.

6.1. Advantages and disadvantages of the identified business models

As can be seen from Table 3 the business models identified from the literature 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 in cold urban regions. If one actor takes the responsibility of 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.

6.2. Crucial aspects for the modified ESCO model

Creation of ESCOs was suggested for heating system modernization in St. Petersburg already in 2001 (Chistovich, Godina, & Chistovich, 2001). Since among the business models identified, the ESCO model is the only one already somehow known in Russia (Garbuzova-Schlifter & Madlener, 2013; IFC, 2011) it was selected as the most potential one in the long run. This section addresses some key issues which need to be further developed for the ESCO model to be suitable for district renovations in the Russian market. In this relation, the new model needed is referred as “the modified ESCO”.

The district renovation can be regarded as project business since for example it will be limited in time and customers will be delivered predefined products and systems. Typically projects involve a range of actors, firms and experts with sometimes conflicting ideas and priorities (Wikström, Artto, Kujala, & Söderlund, 2010). This would also be the case in the Russian district renovations. Services will also be provided between and for the stakeholders before, during and perhaps even after the renovations. Thus, the district renovation can also be classified as service business (Artto, Wikström, Hellström, & Kujala, 2008). Both project and service business related items would be needed to be included in the modified ESCO model.

Studying the need to renew the ESCO business model Pätäri and Sinkkonen (2014) conclude that a strong emphasis ought to be put on both the visible and the invisible benefits. This is apparent in Russian district renovations in cold urban areas since both the idea of renovating districts holistically and the ESCO business model in general and as a means for realizing renovations need to be better known and understood among the common people and the municipalities.

The Russian ESCOs often provide only consulting services and they are not ready to take investment risks (IFC, 2011). The offering of the modified ESCO should include at least: all the renovation works, engineering, financing, product and system deliveries, installations, providing the mandatory permits, collecting agreements from the apartment owners and arranging the financial guarantees (bonds) for the construction period. In addition, the offering could include other services such as energy auditing, design, operation and maintenance after the renovations and consulting. Due to the extensive offering needed partnering places a central role in the modified ESCO model. Garbuzova-Schlifter and Madlener (2013) highlight that the Russian ESCO market could extremely benefit from joint venturing with foreign partners by securing know-how, financing, risk management, and technology transfer. However, it is of vital importance to also involve Russian organizations since they are needed for trust creation and contacting between stakeholders.

The contractual form “guaranteed savings” is more important in the Russian ESCO market, while “shared savings”, presumably due to risk-sharing with a client, does not seem to be an attractive option for the emerging market (Garbuzova-Schlifter & Madlener, 2013). In a guaranteed savings, the client essentially applies for a loan, finances the project and makes periodic debt service payments to a financial institution (IFC, 2011). In Russian district renovations, financing is one of the key issues needed for the renovations. Thus, even if the actual financial contracts were made between the financial institution and the client, the ESCO should at least identify the actual financer and perhaps even negotiate the contracts.

Pätäri and Sinkkonen (2014) address several common external and internal barriers limiting growth in the ESCO market in general. Some of them equal to those Garbuzova-Schlifter and Madlener (2013) point out in the Russian energy service industry. The main problems addressed in the Russian market are: lack of government support, high credit risk of energy efficiency projects, lack of awareness of the energy efficient potential, weak legal and contract enforcement framework, and bureaucracy. These cannot be solved through ESCOs alone but need policy actions as well.

Perhaps the major obstacle for applying ESCOs in the Russian residential sector is the decision-making of apartment owners. While housing laws require 50% agreement of all residents, the energy saving law demands 100% agreement confirmed in writing (AEB, 2013). Convincing the inhabitants and collecting the signatures in big apartment buildings will be a huge effort.

7. Discussion and conclusions

In urban Russian residential districts in cold regions, building renovations alone are seldom sufficient, since typically the district heating supply cannot be controlled. So, if only building structures and systems are renewed, the same amount of heating energy will be produced and no energy savings will be achieved. So, the whole districts, instead of just single buildings, should be renovated. This led to analyzing potential business models from holistic district renovations points of view.

Since the business models identified from the literature are mainly meant for some large-scale energy production solution or for limited energy-efficiency improvements in buildings, they do not as such suit for Russian district renovations including renovations of both the buildings in the area and modernizing the related energy and water infrastructure. The scope of Russian district renovations is much wider and includes much more stakeholders. Integration of various services into the offering of an existing business model is difficult (Wikström et al., 2010). Thus, 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. Which of the existing actors would take the lead is to be seen. In addition, this analysis pointed out some features of the identified models which should rather be excluded from the actual business models for the district renovations.

Renovation of whole districts could 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, all the possible business models somehow include energy saving obligations (Würtenberger et al., 2012) which are one form of policy instruments. It is estimated that tariff reform can do the most to improve energy efficiency in the Russian heating sector (The World Bank & IFC, 2008). So, this could form one basis of a suitable business model. Since the role of the public sector is pronounced in Russia, some form of Public-Private-People Partnership (4P) could also be suitable (Kuronen, Luoma-Halkola, Junnila, Heywood, & Majamaa, 2011).

In district renovations, there are various stakeholders involved. Value networks could be utilized to show the relationships and the value transferred between key stakeholders, as was done by Frantzis et al. (2008) when analyzing photovoltaic business models. Therefore, analyzing the value networks of different possible business models could be helpful for forming the most relevant business model.

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 which were also addressed. Even in the Western countries, ESCO activities have been realized mainly in public, commercial and industrial buildings (Bertoldi et al., 2006; Marino et al., 2011; Würtenberger et al., 2012) while the residential sector is found to be more challenging. Due to the large offering required perhaps only parts of district renovations may be realized through ESCO activities, such as the district infrastructure renovations.

Since the idea of holistic district renovations of Russian residential districts is just recently introduced (Paiho, Hoang, et al., 2014) it is to some extend a hypothetical case. However, it is evident that such an approach would have obvious benefits, such as guaranteed energy savings and reduced emissions through the improvements to the whole energy chain. In addition, compared to just renovating individual buildings industry actors could be more interested in the approach due to the bigger scale. For the public sector, the district renovations would provide better opportunities to enforce higher-level environmental and social policy targets. Also the inhabitants would profit through upscale of the whole district.

Technical solutions exist for the district renovations though new ones could also be developed. Still, the challenges and obstacles are mainly related to other than technical issues. Perhaps, the two dominant challenges would be financing of the renovations and joint decision-making among apartment owners. The business models would need to include features to overcome these challenges. New policy instrument may also be needed to support the implementation. In addition, Russian stakeholders ought to be responsible for collecting the mandatory agreements from the apartment owners and acquiring the construction and other permits. This is recommended since trust forms a vital part in the Russian business environment and even for fluent Russian speakers such partly bureaucratic issues are more difficult to handle than for native Russian citizens.

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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 €/m² ja 200 €/m² 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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