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82

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Energy-efficient renovation of Moscow apartment buildings and residential districts

Energiatehokkaat korjausratkaisut Moskovan asuinrakennuksille ja asuinalueille. **Satu Paiho, Rinat Abdurafikov, Åsa Hedman, Ha Hoang, Ilpo Kouhia, Malin Meinander & Mari Sepponen.** Espoo 2013. VTT Technology 82. 115 p. + app. 5 p.

Abstract

The majority of Moscow housing stock has been built after World War II and needs modernization. This publication concentrates on energy-efficient and sustainable renovation and modernization of selected Moscow housing stock. The emphasis is on technical solutions and their energy-saving potentials and possible reduction in emissions. In addition, the publication includes an analysis of the non-technical issues and obstacles to building renovation in Moscow. Relevant pilot visits are also presented.

During building renovation, existing and future criteria for sustainability should be taken into account. Sustainability criteria for energy-efficient renovations of Moscow apartment buildings and districts were developed based on criteria developed for new residential districts in Saint Petersburg. The criteria setting includes criteria for planning structure/functional planning, the surrounding terrain, buildings, transport solutions, waste disposal and energy supply.

A typical Moscow residential district was selected for analysis. The pilot district was estimated to contain about 13,800 inhabitants in total, which is about 0.12 % of the total number for Moscow. The total building floor area of the district is about 327,600 m^2, and the total roof area about 31,000 m^2. First, a state-of-the-art was produced of energy performance, and water and waste management of the buildings and of the district. Then alternative energy renovation concepts reducing the environmental impacts of the buildings and the district were developed and analysed.

The building renovation concepts, named Basic, Improved and Advanced, were adjusted in such a way that each of them becomes an improvement on a previous one as regards the total annual energy demand. The basic concept refers to minimum, low-cost or easy-to-do renovation measures. The improved renovation concept outputs better energy or eco-efficiency. The advanced renovation concept suggested the most progressive solutions. Based on the calculations, the building level energy saving potential was up to 68% for heating energy and 26% for electricity.

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

As for the emission analyses, switching from natural gas to biogas would result in lower CO_2-equivalent emissions while increasing SO_2-equivalent emissions and particulates. A better solution would then be to produce energy from renewable technologies such as ground source heat pumps, solar panels, solar collectors or wind turbines which, in comparison, would result in fewer emissions overall.

Currently, the average water demand in Moscow is 272 l/cap/day. With different solutions, this could be reduced even to 100 l/cap/day. Based on the current recycling and recovery rates of Moscow, the target of 78% recovery of waste was suggested. The main environmental impact from the waste management sector is the greenhouse gas emissions from the final treatment of the waste. In order to reduce the environmental impact, a larger proportion of the waste should be recovered as material or energy.

Keywords energy efficiency, renovation, Moscow, districts

Energiatehokkaat korjausratkaisut Moskovan asuinrakennuksille ja asuinalueille

Energy-efficient renovation of Moscow apartment buildings and residential districts. **Satu Paiho, Rinat Abdurafikov, Åsa Hedman, Ha Hoang, Ilpo Kouhia, Malin Meinander & Mari Sepponen.** Espoo 2013. VTT Technology 82. 115 s. + liitt. 5 s.

Tiivistelmä

Valtaosa Moskovan asuinrakennukannasta on rakennettu toisen maailmansodan jälkeen ja tarvitsee modernisointia. Tämä julkaisu keskittyy valitun Moskovan asuinalueen energiatehokkaaseen ja kestävän kehityksen mukaiseen korjaamiseen ja modernisointiin. Pääpaino on teknisissä ratkaisuissa ja niiden energiansäästöpotentiaaleissa ja päästöjen vähentämismahdollisuuksissa. Lisäksi julkaisussa analysoidaan Moskovan rakennusten korjaamiseen liittyviä muita näkökulmia. Julkaisussa esitellään myös vierailukäynneillä tehtyjä havaintoja samantyyppisistä rakennuksista.

Korjausrakentamisessa tulisi ottaa huomioon olemassa olevat ja tulevat kestävän kehityksen mukaiset kriteerit. Kestävän kehityksen kriteeristö Moskovan asuinkerrostalojen ja asuinalueiden energiatehokkaaseen korjaamiseen kehitettiin Pietarin uudisrakennusalueille tehdyn kriteeristön pohjalta. Kriteeristö sisältää rakennus- ja aluetason kriteerit rakennusten korjaamiselle, ympäröivälle maastolle, alueen liikenneratkaisuille, jäte- ja vesihuollolle sekä energian tuotannolle ja jakelulle.

Analysoitavaksi valittiin tyypillinen asuinalue Moskovasta. Tällä alueella asuu arviolta 13 800 asukasta (noin 0,12 % Moskovan koko väestöstä). Alueen rakennusten kokonaiskerrosala on noin 327 600 m^2 ja kokonaiskattopinta-ala noin 31 000 m^2. Ensiksi muodostettiin käsitys alueen ja sen rakennusten nykyisestä energiatehokkudesta sekä vesi- ja jätehuollosta. Sitten kehitettiin ja analysoitiin vaihtoehtoisia energiakorjauskonsepteja, jotka vähentävät rakennusten ja alueen ympäristövaikutuksia.

Rakennustason korjauskonseptit nimettiin peruskonseptiksi sekä parannelluksi ja kehittyneeksi konseptiksi. Ne valittiin siten, että seuraava taso vähentää aina vuositason kokonaisenergiantarvetta. Peruskonsepti viittaa edullisiin ja helposti toteutettavissa oleviin minimikorjaustoimenpiteisiin. Paranneltu korjauskonsepti johtaa parempaan energia- tai ekotehokkuuteen. Kehittynyt korjauskonsepti on vaihtoehdoista edistyksellisin. Tehtyjen laskelmien perusteella rakennustason energiansäästöpotentiaali on lämmitysenergialle jopa 68 % ja sähköenergialle 26 %.

Aluetasolla eri energiakorjausskenaariot analysoitiin energiantarpeen ja päästöjen perusteella. Alueskenaariot nimettiin rakennustasoa vastaavasti: “nykyinen”, “perus”, “paranneltu” ja “kehittynyt”. Merkittäviä energiansäästöjä voidaan saavuttaa myös aluetasolla eri korjausskenaarioilla. Energiansäästö voi olla sähköntarpeessa jopa 34 % ja lämmöntarpeessa jopa 72 %.

Päästöanalyysien perusteella siirtyminen energiantuotannossa maakaasusta biokaasuun johtaisi alempaan tasoon hiilidioksidipäästöjen osalta, mutta kasvattaisi rikkidioksidi- ja pienhiukkaspäästöjä. Tätä parempi ratkaisu olisi tuottaa energiaa uusiutuvia energialähteitä hyödyntävillä teknologioilla, kuten maalämpöpumpuilla, aurinkopaneeleilla, aurinkokeräimillä tai tuuliturbiineilla, jotka aiheuttaisivat pienemmät kokonaispäästöt.

Nykyään keskimääräinen vedentarve Moskovassa on 272 litraa asukasta kohden vuorokaudessa. Eri ratkaisuilla tämä voitaisiin pudottaa jopa sataan litraan. Moskovan nykyisten jätteiden kierrätys- ja hyötykäyttömäärien perusteella projektissa asetettiin jätteiden hyödyntämisen tavoitteeksi 78 %. Jätehuollon tärkeimmät ympäristövaikutukset ovat kasvihuonekaasut jätteiden loppukäsittelystä. Jotta näitä ympäristövaikutuksia voitaisiin vähentää, nykyistä suurempi osa jätteistä olisi hyödynnettävä materiaalina tai energiana.

Avainsanat energy efficiency, renovation, Moscow, districts

Preface

As the second largest end-user of energy in Russia, the residential housing sector has a huge energy savings potential. In addition, apartment buildings are in need of renovation due to their age and indoor air conditions. Building renovation is an important opportunity to upgrade buildings in order to meet the current and future energy- and eco-efficiency requirements, including people's increasing needs for improved indoor air quality.

This publication summarizes the results of the technical analyses performed in the ModernMoscow project. The project concentrated on building renovation in the Moscow District. The main objective was to prepare a wide feasibility study for the energy-efficient and sustainable renovation and modernization of a selected Moscow building stock. The project was funded by the Ministry of Foreign Affairs of Finland.

Since the climate in Finland is rather similar to that in Moscow, many tried and tested building and energy solutions used in Finland could also be utilized there. In addition, the Finnish experiences in cold climate buildings could be of use in updating Moscow buildings to more energy-efficient ones.

In a technical sense, there is clearly a huge market for Finnish companies to respond to the great renovation need in Moscow. However, there are other issues than technical ones that need to be clearly analysed before successfully entering the market. Political, financial and social aspects need to be understood too.

The publication also includes a chapter on the non-technical issues related to modernization of Moscow apartment buildings. Input to this section was partly gathered in a workshop with Finnish experts having expertise in different Russian related issues. The following individuals actively participated in the workshop: Katri Pynnöniemi from the Finnish Institute of International Affairs, Rosa Vihavainen from Helsinki-Uusimaa Region, pensioner Jukka Nykänen having several years' expertice of construction projects in Russia, Yrjö Tyni from the law firm Raimo E.J. Kantola Ky, Päivi Karhunen from the Center for Markets in Transition (CEMAT) of the Aalto University School of Business, Jari Mehto from Finnvera and Mikhail (Mikko) Stepanov from Bauer Watertechnology Oy.

Contents

Appendices

1. Introduction

1.1 Need for building renovations

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 with those of the developed countries.

The majority of Moscow housing stock has been built after World War II (Construction in Russia 2010) and need a modernization. Sustainability should be taken into account when renovating these buildings. Thus, the energy-efficiency of buildings and districts is one of the core issues.

According to Hansa Renovation project (Nyman et al. 1995), common problems in buildings built in the Soviet Union are:

- leakages in outer walls – especially in the window frames
- poor air-tightness of staircases
- insufficient heat insulation of outer walls – lots of thermal bridges and freezing of the outer walls
- mould, freezing of outer walls and moisture problems.

Common problems in heating systems (Nyman et al. 1995):

- lots of leakages in district heating networks and lack or faulty operation of booster pumps
- significant variation in pressure levels of the heating network
- poor quality of hot water in district heating network – mud collectors needed (typically installed in every new branch of a heating network)
- difficulty in balancing and controlling heating networks in buildings, lack of control, control valves needed.

There has not been much improvement since the Hansa Renovation project in 1995, rather the situation is even worse. According to the national statistics service, the share of dilapidated and emergency state housing is around 3% of the total area of Russian housing stock (Construction in Russia 2010). However, it is estimated that more than 290 million m^2, or 11% of the housing stock, need urgent renovation and re-equipment, 250 million m^2 or 9% should be demolished and reconstructed (United Nations 2004). Some 58–60% of the country's total multi-family apartment buildings are in need of extensive capital repair (International Finance Corporation & European Bank for Reconstruction and Development 2012).

In 2005, Russian residential, public, and commercial buildings were responsible for 144.5 Mtoe (million tons of oil equivalent), i.e. 1,680 TWh, of final energy use (34%) and for 360 Mtoe, i.e. 4,186 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 (Bashmakov et al. 2008). Of all building types, residential buildings are estimated to have the greatest energy savings potential. The largest part (67%) of the energy savings could be implemented through the more efficient utilization of district heating in space and water heating. The investment needs for rehabilitating the district heating systems is Russia are estimated at US$ 70 billion by year 2030 (Nuorkivi 2005).

1.2 Moscow housing stock

Construction in Russia (2010) states that the total Russian housing stock in terms of total residential floor area was 3177 million m^2 in 2009. The proportion hare of dilapidated and emergency state housing was 3.1% of the total area of the housing stock. The total area of housing stock per capita was 22.4 m^2.

According to statistics from 2004, 95% of the Moscow dwelling space has been built after World War II, of which 52% of the residential buildings were built during 1946–1975 and 43% in 1976 or later. According to Rosstat (Construction in Russia 2010), there were 39,801 residential buildings in Moscow in 2009. The number of residential buildings equals 3,835,000 apartments, and a 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 the administrative expansion of Moscow implemented in the summer of 2012.

1.2.1 Typical apartment buildings in Moscow

It is important to understand the general situation in the target place before conducting an energy analysis. In 2004, the United Nations published Country Profiles on the Housing Sector Russian Federation, which helps us 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 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. (United Nations 2004.)

In general, there are three basic categories for residential panel buildings (United Nations 2004):

- The first generation is five-storey buildings often called *khrushchevky*. Khrushchevky were 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. More than 25 million m^2 (total floor area) of these buildings was constructed in Moscow (Illustrated catalogue of residential buildings). In 1999,the government of Moscow adopted a programme for renovation of residential districts with the 6 worst performing building types with a total floor area of about 6 million m^2 by way of their demolition and construction of new housing on their place and as of 2013 1.2 million m^2 remained to be demolished (Department of urban development policy 2013).
- The 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. Some of the buildings were based on their successful 5-storey predecessors (e.g. building 1-515).
- The 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. As opposed to the preceding phases, where each typical building design would have its own set of structures and construction elements, this and subsequent generations aimed at using a unified catalogue of typical construction elements for creation of a final architectural design (Illustrative catalogue of residential buildings). This allowed reducing the number of elements used and increasing utilization of production facilities of the homebuilding factories.

The most typical building series built in Moscow are summarized in Table 1 (Illustrative catalogue of residential buildings).

Table 1. Construction of serial residential buildings in Moscow (thousands m^2, total floor area).

Period 1 (according to classification of the General Plan of Moscow from 1999)

constr. years	II-07*	II-32*	II-35*	II-20, II-18	1-303, 1-333	1-447	1-510	1-511	1-515	1605AM (5)*	1МГ-300*	В	К-7*	**Total**
1951-55						5		26						**31**
1956-60	127	13	10	27		132	976	2343	341	37	10	66	115	**4196**
1961-65	22	1138	68	17	13	164	2941	4636	4247	795	83	52	2686	**16862**
1966-70		40			3		256	831	2045	200	224		626	**4225**
1971-75						2	3	91	73		6		8	**183**
1976-85								2	6					**8**
TOTAL:	**148**	**1191**	**78**	**44**	**16**	**303**	**4176**	**7929**	**6711**	**1032**	**324**	**118**	**3434**	**25504**

*building series that are being demolished

Period 2

constr. years	II-18	II-29	II-49	II-57	II-68	1-515 (9-storey)	И-209А	1605AM	**Total**
1956-60	88	327							**415**
1961-65	2488	2021	18	9	7	53	58		**4645**
1966-70	5268	2717	6243	1261	36	1669	901	989	**19084**
1971-75	792	1027	7077	1825	2270	3102	2150	1995	**20238**
1976-80	24	28	3291	5	2823	1669	279	1833	**9952**
1981-85	5		30		1740	63	4	387	**2229**
1986-90					684		5		**689**
1991-95					386				**386**
TOTAL:	**8665**	**6120**	**16659**	**3100**	**7946**	**6556**	**3397**	**5204**	**57647**

Period 3

constr. years	П-22	П-23	П-28	П-3	П-30	П-31	П-32	П-4	П42	П43	П44	П-46	П-47	П-55	1МГ-601	И-552А	И-700А	КОПЭ	**TOTAL**
1966-70															476				**476**
1971-75	48			350	409	25	16	33	14	17	57	102	220		485	13			**1789**
1976-80	40	14		3001	1773	18	8	31	168	892	464	477	1007	21	91	135			**8140**
1981-85	71	13	29	2493	1852	66	20	53		499	4072	1093	887	400	36	336	395	731	**13046**
1986-90				2336	777			32			4479	1279	343	513	20	182	316	1537	**11814**
1991-95				1598	328						4139	1346	19	932		35	41	1099	**9537**
TOTAL:	**159**	**27**	**29**	**9778**	**5139**	**109**	**44**	**149**	**162**	**1408**	**13211**	**4297**	**2479**	**1866**	**1108**	**701**	**752**	**3367**	**44802**

Natural ventilation is a typical solution in Russia (Opitz et al. 1997) and buildings in urban areas are usually heated with district heating. 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). 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-scale CHP plants and HOBs is 100% natural gas. Electricity is most often produced by natural gas, sometimes also by coal or brown coal. (City of Moscow 2009)

Energy-efficiency of buildings is typically poor. The thermal insulation of the precast panel walls does not meet modern standards, and it may even cause moisture and mould problems. Moreover, the surroundings, including streets, courtyards and parks are usually also poorly maintained. The limited variation in the urban housing stock results in suburbs of great uniformity, which are not geared towards individual wishes or needs. However, there are some older buildings and other types of buildings in urban areas, but these are much less common. One example of these is the famous “Stalin-era” buildings, which can be recognized by their typical architecture. These prestigious buildings are situated in good places in city centres. However, their technical condition is also partly problematic. (United Nations 2004)

There is one more thing that it is good to take into account when studying Russian buildings. It is quite difficult for researchers outside Russia to find and correctly interpret Russian data. According to Opitz (1994), the central government has a desire to conceal important production and financial facts, which means that clarity and consistency of 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) are incomplete and often inconsistent. The accounting methods and definitions varied between sources and even within the same source for different years. Opitz (1994) states that the data almost seems designed to confuse. The data used in this study project is gathered from several sources, and it has been cross-checked, if appropriate sources were found.

1.2.2 The housing district selected

A typical residential district was selected for analysis in the project. A general description of the district is given in this chapter. This district was utilized in the analyses made in Chapters 5, 6, 7 and 8.1.

The area selected mostly represents 4-th Microrayon (Figure 1) of Zelenograd, Moscow (longitude 37° east and latitude 55° north, see Figure 3). Zelenograd is located about 35 km to the North-West of Moscow City centre. The district’s dimensions are approximately 1 x 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 the 1960s and 1970s. Renovation of such buildings and districts may be needed in the near future. The area is bounded by two streets: Centralniy prospect (Центральный проспект) and Berezovaya alleya (Березовая аллея). The district is heated with district heating.

The apartment buildings in the area can be divided into groups according to the building series: II-57, II-49, АК-1-8, II-18 and Mr-60, which are apartment buildings built between 1966 and 1972. Each building series represents a specific building design (Opitz et al. 1997). There are also other apartment buildings, schools, pre-schools, shops and a bank in the area, but since this project concentrates on the modernisation of buildings, these newer buildings from the 1990s and from the beginning of the 2000s are excluded from these energy calculations. The more detailed data about the older apartment buildings is presented in Table 2 and these buildings were the main target of the first calculations in this publication. However, after the initial analysis the most common building type II-18 (Figure 2) 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 (United Nations 2004).

Table 2. Apartment building types in the studied district and their basic data.

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	1966-1669	1971-1972	1965-1966	1967-1968
Number of buildings*	4,6	11	6	10	4
Apartments/building	358	143	102	84	111
Residents/building**	967	386	275	227	300
Floor area (m^2)	22827	8951	7140	4911	8042
Number of floors	9	9	17	12	16
Shape	rectangle	rectangle	rectangle	rectangle	rectangle
X/Y ratio	0,07	0,16	0,40	0,60	0,38

* 0,6, because there is one smaller similar building.

** Assumption: average flat has 2,7 residents [United Nations publications, 2004]

Figure 1. General view of the district (buildings II-49 in the front).

Figure 2. One of the most common building types II-18 in the district.

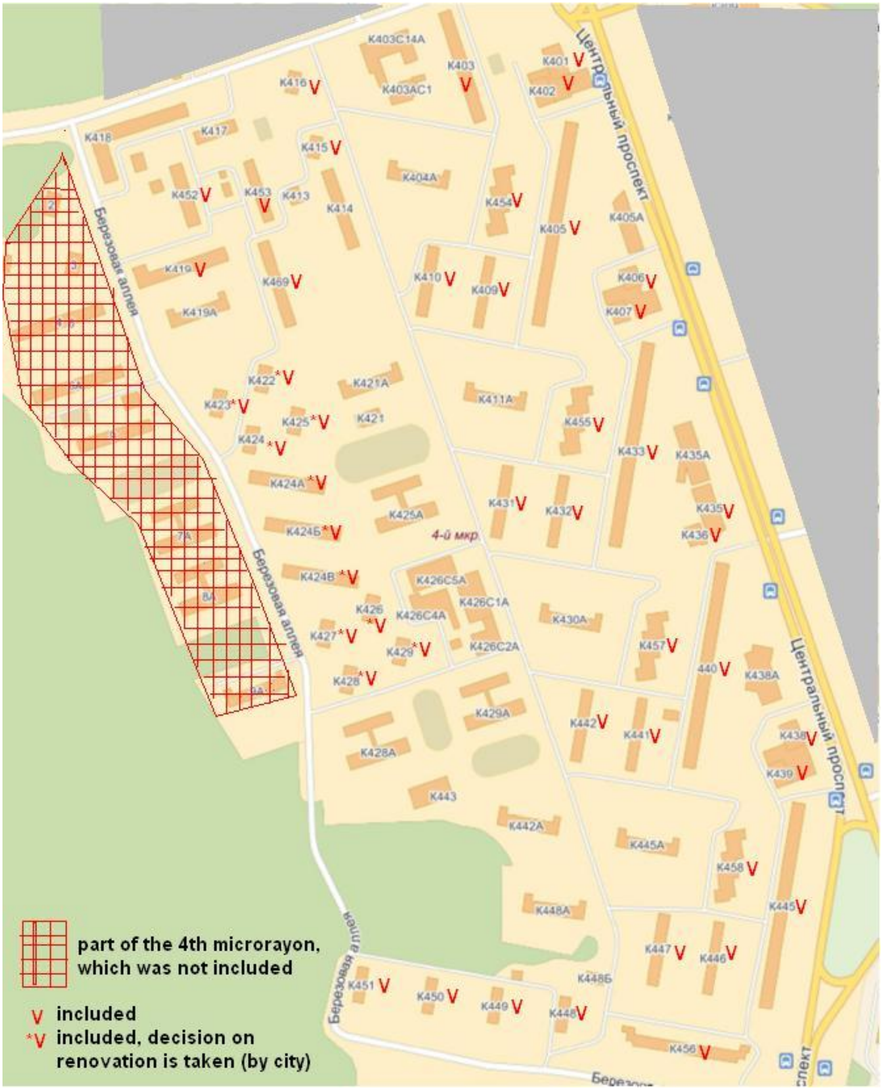

Figure 3. Map of the selected area, 4-th Microrayon of Zelenograd.

It may be noticed from the map of the district (especially on the right-hand side), that it is composed of smaller typical blocks of buildings,

2. Non-technical issues and obstacles to building renovation

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., Korppoo & Korobova 2012, the World Bank & IFC 2008, p. 77), higher up-front investment costs of implementing renovation solutions, as well as high interest rates (they have been above 10% over the past decade), which often makes investments unfeasible in the long term. These, as well as some more specific obstacles, are described in this section.

2.1 Stakeholder analysis

This section analyses the actors (stakeholders) involved in the renovation of residential buildings and districts in Russia. The major significant difference from the practices in Europe is a substantial involvement of public authorities in maintenance and renovation of the old housing stock and the so-called yard territories and communal infrastructure.

This involvement has to do with a specific aspect of free privatization of the housing stock, a reform conducted over 20 years ago. The apartments were privatized by the tenants "as is", and the technical condition of the buildings/apartments was not systematically documented at the time. Later on, after the new laws obligated the residents to be responsible for the technical condition of their buildings and some lawsuits were filed, the Higher Court of Russia ruled, despite the fact that the privatization was free, that as the private apartment owners had never had new buildings, it was not their fault that their buildings were in an unrenovated condition when they were privatized by the Soviet government, and that it is a responsibility of the government to implement the first renovation. Due to enormous need for renovations and the low interest among residents of old, residential buildings in participating in the meetings of homeowners' associations (see Chapter 2.1.2), these buildings are very often operated by municipality-controlled building management companies. In some cities and in Moscow, in particular, these companies receive some support in the form of budget subsidies.

2.1.1 Inhabitants

In the Soviet Union, the state had a monopoly on housing ownership and distribution, as well as on the provision of housing and communal services. The allocation of housing by public authorities and state enterprises enabled strong control of citizens. (Vihavainen 2009.)

The free privatisation has led to a situation where, for many Russians, their apartment is their only financial asset, and they cannot afford to maintain their own living quarters, let alone communal areas. Nor are many people used to considering communal areas as their own property, which can make it difficult to get them to feel responsible for the condition of staircases, courtyards, lifts and other communal areas. (Vihavainen 2009.)

Apartment buildings in Moscow (as well as in other 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.

About 76 % of housing units in apartment buildings are reported to be in private ownership (EBRD 2011).

2.1.2 Homeowners' associations

Since the collapse of the Soviet Union, the state's monopoly position has been reduced, firstly through the privatisation of housing stock in the 1990s. Reform of the housing sector continued with the extensive housing reform that came into force in 2005 and covered the entire housing sector. As a continuation of the housing privatisation, the new Housing Code transferred the management of privatised housing from the public to the private sector. The new legislation ordered homeowners to organise the management of multi-family buildings independently. Homeowners now have three alternatives: to (1) form a homeowners' association, (2) hire a management company, or (3) manage the house directly without an association. A homeowners' association is, by definition, a non-profit organisation, established for the management and maintenance of common property in a multi-family building. (Vihavainen 2009.)

The Housing Code aims to develop the market and improve material conditions, but it also encourages people to be effective actors in the market. Homeowners' associations are the embodiment of this task, the decision-making channel for residents, a sort of experiment in democracy, and an early step towards civic activity at a grassroots level. However, with the ability to take action comes an obligation to take responsibility, whether or not the people involved are willing or capable. (Vihavainen 2009.)

According to the Housing Code, a decision on major building renovation (capital repair) and its financing, using renovation funds, obtaining loans, etc. can be taken only at a general meeting of residents with a majority of at least 2/3 votes (Housing Code of Russian Federation 2013, art. 46).

2.1.3 Management and service companies

As mentioned in Chapter 2.1.2, management companies may take care of the daily management and operation of apartment buildings. So, they may have a view of the most urgent renovation needs and the general condition of a building. In the case where the homeowners have hired a house managing agency or a management company to manage the building, this agency or company still needs the authorisation of the general residents' meeting to select the renovation contractor(s).

The heating and water utilities are supplied to the building management companies, who then distribute the costs to the apartment owners according to the rules set forth by law, taking into account possible submetering of consumption at the level of individual apartments.

Approval of utility companies is required when dimensioning new systems, e.g. space heating systems. Coordination is needed during the implementation phase of energy-efficient building modernization.

2.1.4 Heating and power plants, network operators and other utilities

In Russia, planning of infrastructure provision has its roots in the urban planning of Soviet cities. Most of the classical social infrastructure items such as heating utilities, housing, schools, hospitals, water and sanitation, were designed on a district-wide or city-wide basis. The heating and power plants, as well as other infrastructure, would be operated by either the city utilities or local industrial enterprises according to the plan (Hill & Gaddy 2003).

Even today, the role of large industrial enterprises remains critically important in some district heating areas. In many cases, an enterprise continues to be the monopoly heat provider for the apartment blocks that it used to own or for a whole district. There are two different reasons for private enterprises to engage in the production of complementary capital (heating) in Russia. Firstly, some firms have been forced to invest in their own boilers to substitute for or complement low-quality municipal district heating. Secondly, enterprises are sometimes, by design, themselves responsible for providing district heating for their surrounding area. This unavoidably leads to a somewhat special relationship between those enterprises providing district heating and the local administration. The companies operating distribution networks that connect the heat supplier to residential sector consumers are typically controlled by municipalities or the so-called territorial generation companies. The pipes can also be owned by a municipality and leased to the district heating network operators (Korppoo & Korobova 2012). The heat and electricity distribution business is considered a natural monopoly and therefore regulated in terms of pricing and non-discriminatory access is supervised. The final[1] consumer price for heat is determined by regional energy commissions and municipalities. (Solanko 2006.)

Enterprises producing and providing heating are more likely to have close ties with the local public sector. These enterprises both receive benefits in the form of increased budget assistance or better connections with local administration and face additional costs in the form of contributions to public infrastructure. (Solanko 2006.)

2.1.5 Moscow administration and other public authorities

As noted earlier, the local public sector is involved in the renovation and management of old residential building stock. 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 Moscow as well as in other cities of Russia, has a poor reputation due to its non-transparency, inefficiency and corruption.

The Moscow city administration also implements various building renovation programmes. However, the scope of these programmes has remained limited, and has focused on the renovation of specific building types, e.g. the demolition of old 5-storey buildings or so-called “sanitation” projects for some building types, including the buildings II-18.

Public support to the housing associations and planning to implement renovation measures has so far been fairly modest, and the procedures are complicated. Before 2011, the residents were not involved in financing and all the costs of implemented building renovations were covered by the budget of the City of Moscow. The City is currently running a co-financing programme for the renovation of residential buildings, envisaging covering of 95% of building renovation costs provided that the apartment owners finance 5%. According to programme evaluation, the total amount of subsidies applied for during the first year was twice as much as the amount budgeted for, indicating a strong demand for co-financing (Moscow housing programme 2011).

There are a number of public bodies involved in the process of planning and implementing renovation activities, which involve Moscow housing inspection, city-owned companies operating city-wide as well as, locally, local administrations[2], building management companies and contractors. The privately-owned building management companies are likely to have close ties with local administrations.

The implementation of capital repairs of apartment buildings funded from the budget of the City of Moscow, generally follows the following steps. First, the list of buildings to be renovated is compiled: priority is given to buildings where the de-

[1] Maximum price is decided in Moscow first and then local energy commissions set the final value (which must be equal or lower).

[2] Local in this context means an “administrative okrug” of Moscow. There are 10 “old” and 2 “new” (new territories joined Moscow in 2012) administrative okrugs in Moscow.

gree of wear is higher (information is received from the Moscow housing inspection) and to buildings where the residents were active and have established a housing association or selected another form for management of their buildings (Chapter 2.1.2) The information is collected from local administrations. Second, a short-term plan is prepared and approved by the government of Moscow. Following approval the local authorities and public companies operating locally (so-called GUISes – “engineering services for districts”) work with the residents, whose buildings are included in the approved lists, to initiate and organize general meetings to take the decision on building renovation. The buildings on which the decision is taken are reported to the city renovation programme coordinator, who initiates tendering to conduct technical inspections in order to establish the buildings’ technical condition and consequent development of design documentation. These works are typically conducted by small privately-owned audit and design companies. The design documentation is checked by a dedicated committee of Moscow government. After the design documentation is ready and the scope of renovation is known, tendering by construction companies to implement the renovations is invited. Before the implementation, the different public bodies of the City of Moscow including the local administrations coordinate the renovations with other city programmes, e.g. outdoor lighting, district infrastructure, etc. After the building renovation work is finished, there is a commissioning procedure by which the work is accepted. Information about structural changes is delivered to the Moscow Bureau for Technical Inventory.

2.1.6 Banks

The Russian banking sector is underdeveloped in terms of its size relative to GDP. At the end of 2010, the ratio of the sector’s total assets to GDP was 75%, and own-capital-to-GDP 11%. Deposits are also fairly limited; household deposits amounted to 22% of GDP and deposits of non-financial enterprises and organisations to 25%. Lending to households and non-financial enterprises equalled 40% of GDP. (Bank Rossii 2011)

In practice, the banking sector consists of several subsectors with few links with each other. One reason for the fragmented structure is the lack of trust among banks. This lack of trust is common to the Russian enterprise sector in general and stems from problems in law enforcement and the protection of property rights. (Lainela & Ponomarenko 2012.)

The role of banks is significant for sustainable housing renovations. Housing associations are a rather new phenomenon and are regarded by the banks as unreliable borrowers . In addition, the high interest rates that have persisted in Russia over the past decade have kept investments less economically feasible. For example, the benchmark interest rate in Russia was in January 2013 recorded at 8.25%by the Central Bank of Russia (Trading economics 2013). The official interest rate is the refinancing rate, which is seen as a ceiling for borrowing money and a benchmark for calculating tax payments. The average weighted interest rate on housing loans has been above 10% over the past 5 years – 12.9% in 2008, 14.3% in 2009, 11.9% in 2011, and was estimated to reach 12.5% in 2012 (Ministry of Regional Development 2012).

During a long period up to 2008, there existed no real mechanisms for renovations of apartment buildings. In 2007, a Fund for Housing Sector Reform was established by law with federal funding as a temporary "transitional" solution for the following 4 years[3]. More than half of the activities of the Fund were to provide co-funding for the renovation of apartment buildings. The principles of co-financing were such that more than 50% were provided by the Fund and the rest by regional authorities (e.g. the City of Moscow) and residents. Currently the programmes implemented by the Fund remain the main funding source for residential building renovation projects.

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 decided so with 2/3 of their votes, or by default by a regional operator (Housing Code of Russian Federation 2013). Most likely, most of these fees, which will be collected as from 2014, will be used by regional operators given the low interest and responsibility of the owners of the privatized apartments (Ministry of Regional Development 2012, p. 13), following the already existing planning and prioritization practices utilized when the repairs were co-financed by the Fund for Housing Sector Reform.

2.1.7 Renovation companies

Many construction companies have been involved in designing and implementing apartment building renovation projects. However, the vast majority of these projects have been facilitated by the public authorities in terms of financing, supervision of quality of the design documentation and the construction works implemented, working with the residents, etc. Nevertheless, the sector is technically ready to implement the renovations, some examples of which are presented in section 8.1.5. Typically, the companies implementing the renovations are smaller than those involved in new construction. 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] Originally, the Fund was supposed to close by the end of 2012. The date was extended to the end of 2015 as no other efficient funding mechanisms emerged and some of the originally allocated funds remained unused.

2.1.8 Other relevant industry actors

To date, the role of product manufacturers, system providers, consultants and ESCOs (energy service companies) in implementing renovations have been low (Ministry of Regional Development 2012). Utility companies are actively developing new services for residents, e.g. the owners of buildings can order inexpensive thermal scanning and advisory services. With the emergence of the demand from the homeowners' associations and the increasing profitability of building renovation business, the role of energy service companies and providers of integrated solutions for building renovations will increase.

2.2 Non-technical challenges in energy-efficient renovations

The most important obstacle in building renovation in Russia is outdated norms, which 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. Implementation of a new design element or a new type of space heating system may not be approved or substantially delayed as additional analysis is required. For example, 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.

Permission processes are long. For example, acquiring the construction permit takes from 180 to 500 days.

Russian regulations require that in all buildings the heat consumption is metered at the level of each individual apartment. Although the meters are paid for by residents themselves, this poses technical challenges, as it is difficult to organize in high-rise apartment buildings, especially in the existing ones with traditional "vertical" risers. Many experts believe that apartment-specific heat consumption metering combined with the possibility of regulating space heating systems is the only way to reduce heat consumption in apartment buildings. Some research activities of Russian laboratories are already focused on individual apartment metering systems based on radiator thermal sensors coupled with a wireless data transmission technology. 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, which most likely has to do with lack of information.

In contrast to Finnish practice, where window renovation decision is made by a housing cooperative, in Russia renovation of windows is decided by each individual apartment owner; the same applies to doors, etc.

Mechanical ventilation is essential to avoid mould problems and ensure sufficient air quality during the renovations when making the buildings well insulated and air-tight. Mechanical ventilation is widely used in business and trade centres, there are professional designers, and engineers. In residential buildings it 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.

Another aspect is that on the political agenda the issues of climate change and carbon emissions are significantly less important than that of energy-efficiency, which is associated with high costs in the housing sector and missed energy export opportunities.

2.2.1 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. (EBRD 2011.)

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 (Ministry of Regional Development 2012). 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. (World Economic Forum 2013)

According to a survey conducted among representatives of construction companies operating in Russia in 2010, about 75% assessed the administrative obstacles as high or extremely high. Analysis showed that the Urban Development Code of 2004, providing for a significant reduction of administrative obstacles, is often not followed on practice by municipalities (77% of “additional” procedures were found to contradict the Federal legislation). There is a clear difference between municipalities in terms of administrative burden: e.g. acquiring a new construction permit in Moscow requires 47 procedures and 392 days, whereas in the town of Surgut it needs only 17 procedures and 150 days. The average duration of all the administrative procedures required to construct an apartment building in Russia is about 950 days. These administrative procedures mostly fall into such categories as “design”, “construction” and “commissioning” (Institute of Urban Economics 2012), which though to a somewhat lower extent, are relevant to renovation of buildings as well.

2.2.2 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 practice in Moscow (Chapter 2.1.5) 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.

Another important aspect is that income levels may vary among the residents of the same building, which complicates joint decision making on building renovation.

The situation in the housing sector is one of the major factors worrying the population. According to a survey (WCIOM 2013) conducted in January 2013, the following relevant problems were mentioned which were felt by the population to affect them personally:

- situation in the housing sector (54%)
- inflation and growth of prices (54%)
- corruption and bureaucracy (29%)
- ecology and environment (17%).

Inefficiencies in building operation practices, the use of out-of-date techniques and technologies, poor energy-efficiency throughout the housing sector (Ministry of Regional Development 2012) and rapidly growing energy prices (Table 3) are obviously felt by the population in their everyday life.

Table 3. Year-on-year growth rates of energy prices in Russia, %. est – estimated value, F – forecast. (Ministry of Economic Development 2012.)

	2007	2008	2009	2010	2011	2012est	2013F
Electricity							
-average	10,7	19,5	19,3	17,8	13,6	0,5	12–13,5
-commercial		20,6	20,1	18,6	13,4	0,4	12–14
-population	13	14	25	10	9,6	3	9,1–10,6
Heat		16,7	22,2	15,7	13,5	4,5	12,3
Natural gas							
-average	15	25	15,7	27,4	15,3	7,5	15
-commercial		25	15,9	26,7	15	7,1	15
-population	15	25	15	26,6	17,2	10,4	15

The concept of energy-efficiency is generally understood by residents of apartment buildings, who mostly own their flats and consequently want their property to be efficient and safe. However, willingness to pay to date remains low due to the major obstacles described above.

3. Requirements and criteria for building energy-efficiency and sustainability

3.1 Moscow energy performance requirements for buildings

This chapter summarizes the current energy performance requirements for new and renovated residential buildings in Moscow. These are taken from the city programme “energy conservation in construction in the City of Moscow during 2010–2014 and until 2020” (City of Moscow 2009).

The programme departs from a statement that improvement of energy-efficiency in today’s construction in Moscow is impossible by the sole implementation of traditional passive energy saving-technologies and measures aimed only at augmenting heat insulation of building’s envelope structures, as this resource for energy saving has been already exhausted. Transmission heat losses (through the building envelope) account for only about a quarter of a building’s total heating energy consumption. The remaining ¾ fall on ventilation and hot water supply systems. For this reason, the top priority in the programme is given to active technologies – ventilation systems with heat recovery (from exhaust air or other secondary energy resources), heating and cooling systems based on heat pumps (ground/other sources), two-pipe space heating systems with regulation, energy resource consumption metering and management as well as indoor climate control systems.

Application of such active energy-saving technologies necessitates production of new high-end equipment that has to be tested in actual Moscow climatic conditions. There has been almost no experience of such technologies in operation , except for several experimental sites (energy-efficient houses in microrayons Nikulino-2 and Kurkino, a heat-pump station in Zelenograd). Predominantly it is imported equipment that is currently to be found on the market, which was developed for the climatic conditions of Europe but, as a rule, not adapted to the climatic conditions of Moscow. Therefore, one of the main directions of the programme is the scientific and technical components which enable creation of new energy-efficient technologies and equipment, their experimental testing and development of norms and guidelines for design, installation and operation.

Despite the almost exhausted energy-saving potential through augmenting heat insulation characteristics of building envelopes, the programme envisages an increase of thermal resistance of external walls by 10–15% up to 3.5 $m^2 \cdot °C/W$ and of windows – to 0.8–1.0 $m^2 \cdot °C/W$.

It is stated that such an increase of heat insulation level calls for development and application of new technological and technical solutions. Development of technologies and technical solutions for better quality in the construction of the heat-insulating envelope of buildings (improved thermal insulation of facades, joints and junctions, etc.) is another important element of the programme.

The authors of the programme admit that in many cases nowadays the level of thermal insulation complies with norms only 'on paper', due to violations routinely occurring while mounting facades, panels and other elements, which causes steep reduction of buildings' thermal performance.

Target[4] energy-efficiency parameters to be used in design, new construction, reconstruction and renovation of residential and public buildings in Moscow are presented in Table 4. The reference values for residential buildings are set for buildings of 12-storeys or above and floor area of 1,000 m^2 or above. For buildings of smaller dimensions, these reference values apply with minor adjustments (see below the table).

[4] Non-binding. The programme states that there is a need for the development of such norms. The reference values for residential buildings are set for buildings of 12-storeys or above and floor area of 1,000 m^2 or above. For buildings of smaller dimensions, these reference values apply with minor adjustments (see Table 4).

Table 4. Target energy-efficiency parameters in Moscow for new construction, reconstruction and renovation.

Target parameter	Baseline consumption of heating energy and electricity by existing residential, public and commercial building stock in Moscow as of 01.01.2008	As of 01.01.2010*	As of 01.01.2016*	As of 01.01.2020*
Residential buildings**				
Energy consumption for HVAC, hot water supply, lighting of public spaces, operation of building services systems in apartment buildings, kWh/m^2 per year (per m^2 of heated floor area)	340	160	130	86
- for low-energy buildings	–	80	65	43
Water consumption, liter/person per day	300	210	180	160
cold water	170	115	95	90
hot water	130	95	85	70
Public and commercial buildings (shall be increased by factor 1,2 if less than 4 storeys-high)***				
Energy consumption for HVAC, hot water supply, lighting, operation of building services systems, kWh/m^2 per year	375	140	112	74
- for low-energy buildings	–	70	56	37
Water consumption	same as for residential buildings			
Recommended values for specific energy consumption in construction industry				
-thermal treatment of reinforced concrete, kWh/m^3	522	390	315	260
-production and installation of building envelope external structures (walls and floors), kWh/m^2	172	130	105	86

* Electricity consumption (except for lighting) in peak hours (7:00–10:00 and 17:00–21:00) is calculated with factor 1.5.

**For buildings less than 12-storeys high, the values in Table 4 may be increased by 4% per every reduced floor below 12 and per every reduced 100 m^2 of floor area below 1,000 m^2, when the building's floor area is 300–1,000 m^2, (e.g. 11-storey building of 800 m^2 renovated after 2020, the value would be 1.04 · 1.08 · 86 = 96.6 kWh/m^2 per year).

***The values may additionally be increased by a factor of 1.25 for administrative, public and trade buildings operating 1½ shift, by a factor of 1.4 for public and trade buildings operating 2 shifts, by a *factor* of 1.6 for public and trade buildings operated around the clock as well as for pre-school facilities and hospices.

The programme lists measures for the improvement of energy and eco-efficiency in prefabricated residential construction:

1. New materials, structures, technologies and equipment.
2. Imposing stricter requirements for *thermal resistance* of windows and balcony doors – 0.8–1.0 °C·m^2/W (presently 0.54) by means of heat-reflecting coatings, elimination of aluminium spacers in the IGUs (insulated glass units), the introduction of gas insulation, including krypton and krypton-argon mix and vacuum IGUs
3. Reduction of annual heating and ventilation consumption in residential buildings to the level of 75–80 kWh/m^2. This is to be achieved mainly by improved R-values of transparent structures (windows, balcony doors) and the introduction of heat pumps with heat recovery from exhaust air.
4. Introduction of mechanical ventilation with heat recovery, heat pump-based heat supply systems, heat energy storage, efficient and adjustable space heating appliances, automated metering and indoor climate control systems.
5. Wide-scale introduction of heat-pump systems for space heating and cooling, using unconventional renewable and secondary energy sources, systems for heating pavements and snow-melting areas, etc.
6. Improvement of the power supply system, energy-efficient lighting (presence and daylight sensors) and electrical equipment of buildings, electricity savings, reactive power compensation, reduction of peak loads as well as summer consumption due to application of heat pump cooling instead of traditional cooling systems.
7. Development of norms for cooling, requirements for reduction of electricity peak loads in summer.
8. In new construction – building information systems (BIMs), integrated with city-level systems, fire-prevention, access and security systems. Elevators for people with disabilities.
9. In renovation and reconstruction – installation and replacement of meters (heat, water, electricity), integration of information systems, elevators for people with disabilities
10. Construction of communication channels to allow for data exchange between electricity metering systems and a city-level information system.

In Table 5, there is listed in savings % the expected effectiveness of various energy-saving solutions is listed in savings in % .

Table 5. Expected effectiveness of various energy-saving solutions (savings in %).

1.	Building	
1.1.	Optimal building orientation	4–8%
1.2.	Organized infiltration of air through inter-glaze spacing in 3-glazed fenestration	3–4%
1.3.	Use of insulated-glass units IGUs	5–7%
1.4.	Use of passive solar systems, including glazed balconies	7–40%
1.5.	Regulation of exhaust air ventilation as a function of gravitational component	10–15%
1.6.	Installation of heat reflecting screens behind radiators	0.5–3%
1.7.	Additional sections in entrance tambours	3–4%
1.8.	Elimination of cold bridges in junctions of window casements with walls	2%
2.	Heating system	
2.1.	Installation of radiator thermostats	6–7%
2.2.	Installation of apartment-specific controllers	10–15%
2.3.	Programmed heat supply regulation	3%
2.4.	Installation of apartment-specific heat consumption meters	10–40%
2.5.	Use of non-metallic pipes	reduction of metal consumption by up to 60%
2.6.	Radiation heating systems	25%
2.7.	Air heating systems	10–15%
2.8.	Installation of convectors with mechanical heat activator	7%
3.	Water supply system	
3.1.	Installation of apartment-specific water consumption meters	20–30%
3.2.	Installation of pressure stabilizers	6% per reduction of 1 atm.
3.3.	Installation of water-saving shower heads and faucets	10–15%
3.4.	Installation of two-section sinks	5–7%
3.5.	Installation of two-mode toilet flush tanks	5%
3.6.	Preheating of domestic cold water	15%
3.7.	Elimination of domestic hot water cooling in circulation pipes	10%
3.8.	Use of faucets with automatic thermal regulators	3%
3.9.	Insulation of water supply pipelines	4%
4.	Sewage system	

4.1.	Separation of grey and black waters with heat recovery (heat pump)	30–50%
5.	Ventilation system	
5.1.	Automatic regulation of air exchange to normative values	10%
5.2.	Heat recovery from exhaust air (heat pump)	20–70%
6.	Electricity supply system	
6.1.	Use of energy efficient lighting fittings, energy-saving lamps, LEDs	10–15%
6.2.	Controlled lighting in common-use areas (staircases, etc.)	10%
6.3.	Reactive power compensation	10%

The programme also suggests a list of measures to improve energy-efficiency of the spaces, commonly used by flat-owners[5] in apartment buildings for newly built and reconstructed buildings. For renovation activities, only the measures marked with (*) are mandatory:

1. Improvement of thermal insulation of the building envelope (see Table 6).
2. *Heating system, predominantly two-piped with horizontal inlet to flats, efficient insulation of standpipes and building pipelines equipped with thermostatic pressure regulators and balancing valves, application of automated building heat substation or apartment heat substations (where feasible).
3. *Mandatory installation of flat-specific meters for heat, electricity, hot and cold water.
4. *Lighting systems of common-use areas equipped with energy-efficient bulbs and presence/outdoor light sensors, reactive power compensation.
5. Application of automatic mechanical exhaust ventilation with natural inflow of air through ventilation valves.
6. Heat recovery (exhaust air).
7. Utilization of unconventional, renewable and secondary energy sources.
8. *Application of technical solutions aimed at improvement of thermal homogeneity of building envelope and airtightness of panel joints.
9. *Application of technical solutions for reduction of energy losses in hot water supply systems, including circulation systems, and where possible, heat recovery from waste water.

[5] These spaces are everything else in the buildings excluding residents' apartments – i.e. there are 'spaces owned by the apartment owners' and 'jointly or commonly-used spaces' such as, for example, staircases, cellars/attics, technical rooms, etc.

Table 6. Improvement of thermal insulation of the building envelope.

Structure	Reduced thermal re-sistance, applied as of 01.10.2010 (°C·m^2/W)	Reduced thermal re-sistance, applied as of 01.01.2016 (°C·m^2/W)
External walls, walls in contact with ground	3.5	4.0
Windows and balcony doors	0.8	1.0
Roofs (having no attic floor)	5.2	6.0
Base floor, attic floor	4.6	5.2

3.2 Sustainability criteria utilized

There are several criteria for sustainable renovations. However, three primary aspects of sustainability[6] are environmental, economic and social issues. Each and every sustainable renovation should[7]:

- result in a healthy, non-toxic living environment
- be informed by ecological and holistic design
- be energy-efficient and promote energy conservation
- use sustainable building materials
- practice responsible waste management
- be long-lasting and beautiful.

Botta (2005) has stated goals for different sustainability aspects in renovation projects (Table 7).

[6] http://www.eracobuild.eu/index.php?id=28 [accessed on Jan. 9th, 2013].
[7] http://www.greeninghomes.com/practices/sustainable-renovations [accessed on Jan. 9th, 2013].

Table 7. Goals for different sustainability aspects in renovation projects (Botta 2005).

ASPECTS OF SUSTAINABLE RENOVATION	GOALS IN SUSTAINABLE RENOVATION PROJECTS, besides technical and functional ones
environmental	To decrease the environmental impact of buildings To limit the use of energy, natural resources and unbuilt land To support an environmentally-conscious way of dwelling
social	To provide good and affordable dwellings To facilitate social stability and integration To raise awareness about one's own living place To promote sustainable behaviour
cultural	To preserve and transmit cultural objects and historical and cultural values To upgrade buildings and places while respecting their character
economic	To prolong the use of existing resources To maintain real estate values To safeguard the affordability of dwellings
institutional	To promote participation and involvement of the inhabitants To provide good management and maintenance

In this project, the sustainability criteria were developed based on criteria for new residential districts in Saint Petersburg (Nystedt et. al. 2010), which in turn had been based on the international LEED and BREAM systems, development work with St. Petersburg city planners and a residents' poll performed in 2010 in St. Petersburg. The criteria setting include criteria for planning structure/functional planning, surrounding terrain, buildings, transport solutions, waste disposal and energy supply.

In Table 8 the sustainability criteria are listed; its applicability on a building or district scale is assessed and its level of challenge in technical and financial terms is assessed based on expert evaluation. It should be noted that this list has not been developed together with local experts in Moscow; however, it is based on the EcoGrad criteria list, which was locally adapted with local experts in St Petersburg.

Table 8 aims to gather the means to improve energy-efficiency in existing districts. Building-specific issues are considered with a focus on reducing heating and electricity demand and reducing water use. Improved insulation and ventilation are top priorities. Regarding reducing water use, meter technology is in focus as well as water-saving appliances in the apartments.

At a district level, also energy production and transmission systems are included in the criteria. The energy production should be mainly based on low emission, renewable energy production. It is also important that the losses of district heating network are minimised. Moreover, the water and waste systems of buildings are also taken into account.

At a district level, energy demand can be reduced significantly by reducing the need for using private cars. This is achieved by placing daily services close to residents and offering functional public transportation. Norms in Moscow require many daily services close to residents already, so this criterion is quite easy to fulfil successfully. Public transportation in Moscow is a major challenge, since its capacity is already in full use and huge infrastructural investments are needed to increase the capacity.

By using infill-construction, the number of residents in a district can be increased. This prevents urban sprawl and improves the level of services available in the district. However, the city plan is already quite dense in Moscow. The architectural aspects of a district can also be significantly improved by wise infill construction. Infill construction requires changes in city plans. Also, changes in the use of buildings (residential to service buildings) require changes in the city plan. The process needs to be flexible enough that there will not be unnecessary administrational obstacles to improving the energy-efficiency of districts. It should also be noted that infill construction activities have so usually far been unpopular on the part of the population, and therefore overall success of such projects highly depends on strong involvement of the residents as well as the openness and transparency of the district planning process, rather than only traditional public hearings.

Table 8. Sustainability criteria for district renovation activities adapted to Moscow region.

Sustainability criteria	**District assessment**	**Building assessment**	**Level of technical challenge +++ very challenging, ++ challenging + low level of challenge**	**Cost estimations (€ low; €€€ expensive) * low improvement cost if energy-efficiency is improved together with other renovation**	**Special notes and issues affecting to the criteria**
Building renovations					
Energy-efficiency of a building	x	x	++	€–€€	Energy-efficiency consists of criteria presented below this line
The use of safe and ecological materials	x	x	++	€	Depends on how much material is renewed → improvement possible
Efficient air conditioning with efficient heat recovery	x	x	+(+)	€€*	Mechanical ventilation could be an efficient option. Russian building norms do not yet support mechanical ventilation.
Highly insulated and air-tight structures	x	x	++	€*	Can be improved, and then ventilation should also be improved to avoid bad indoor air-quality and risk for moisture problems in the constructions. A cost efficient option for adding mechanical ventilation (if the facade is also renovated) to use element wall units, which already have channel for supply air, as well as good insulation. In practise: choose

					structures with low U-values. Building surface should be air-tight.
Energy-efficient windows and doors	x	x	+	€*	Easy to improve, ventilation should then also be improved
Passive cooling systems; reducing the cooling demand	x	x	++	€*	Minimisation of cooling energy demand, passive solar cooling; In practise: choosing windows with good solar energy transmittance (G value: the smaller the better, as long as it does not affect to the visible light penetration through the window, recommended g 0.3-0.35). Also shading with blinds and curtains.
Energy-efficient electrical equipment		x	+	€*	Energy class A or better as a target
Energy-efficient lighting		x	++	€*	Energy saving bulbs, LED technology, utilization of natural light, controlling lighting
Energy (electricity and heat) meters in the apartments		x	+	€*	Individual meters in the apartments help residents to pay attention to the energy consumption and therefore reduce it.
Water consumption meters in the apartments		x	+	€	Note: maintenance costs of the meters are important to take into account
Water-saving appliances		x	+	€*	Especially hot water, i.e. in the shower, bath tubs, washing dishes…

The availability of building maintenance and safety services	x	x	+	€	The adequate maintenance level of buildings should be ensured; The better the design, the lower the maintenance costs.
Flexible multifunctional use of public spaces	x	x	+	€€	High utilisation rate of public spaces
The embedded energy in construction materials and greenhouse gases (CO_2) related to the materials	x	x	+	€	Some materials can be difficult to replace, there might be a lack of information about used material and their energy and emission data
Planning of structure and functionality of districts					
Dense city planning	x		++	€	Existing blocks can be improved with infill-construction of new buildings
Energy-efficiency enabled through architectural planning	x	x	++	€	Take microclimatic issues into consideration, utilise shading efficiently etc.
Short distances to places visited daily, such as offices and services	x		++	€	When adding new buildings into an existing area this can easily be improved, in some cases this can be improved also in existing buildings, if the use of the buildings are changed (residential => service/offices). Require changes in the city plan. Increase in number of inhabitants leads to better availability of services. This aspect is well addressed in the Russian building norms that require certain services close to residential buildings.

Flexible multi functionality of public spaces	x	x	+	€€	High utilisation rate of public spaces, enough public space close to residents
Area reservations for renewable energy production in the city plan	x		++	€	Important, if local energy production is wanted in the area
Length of district heating network	x		+	€	Minimisation of the length of the district heating pipes -> smaller losses. Can be influenced by correct placing of the buildings.
Green zones and other recreational areas	x		++	€	
Contaminated soil treatment	x		+++	€€€	
Surrounding terrain					
Surrounding terrain taken into account (topography etc.)	x		+++	€	Might be difficult to influence in renovation.
Waste, rain, surface and subterranean waters considered	x	x	+++	€	Some building specific solutions can be made, but can be difficult to make new solutions for whole district (existing)
Ability to grow food locally	x	x	+	€	Bad air-quality in big cities like Moscow can be an obstacle to local food production.
Transport solutions in the area					
Safe and high quality transportation routes	x		+++	€€	Space need
Centralized parking facilities	x		++	€€	Space need, centralised parking require less space than building specific parking, but space can be difficult to re-adjust in existing areas.

Easy-to-use public transportation	x		+	€	Depending on the current state of the public transportation in the area and how much it is used. Challenge in Moscow is that public transportation is used to its full capacity today.
Improved pedestrian and cycle routes (separately)	x		+	€€	Bicycle routes need to be separated both from cars and pedestrians. Especially in Moscow with heavy traffic own cycle routes are essential.
Safe and secure cycle parking facilities	x	x	+	€	Especially needed close to metro-bus and train stations.
Waste management					
The territory has waste collection points near residents for several different waste fractions	x	x	+	€	Encourages waste source separation and enables recycling
Underground collection system	x	x	+/+++	€€€/€€	The investment costs for a vacuum collection system is very high. But deep collection containers (with or without compacter) do not require much earthworks (in comparison to vacuum collection) and improve the aesthetics significantly.
The waste collection transport routes are reduced	x		+	€€	Significantly reduces the local air pollution

Water management					
Sustainable waste water treatment	x		++	€–€€	Can be even integrated into bio-gas production (for energy production, or transportation) Additional village scale waste water treatment plant can be constructed in the area.
Safe drinking water	x	x	++	€–€€	Implementation of extra water treatment facilities in the area/buildings, e.g. active carbon filters and uv / ozone treatment in order to guarantee safe potable water
Water saving appliances and installation of water meters in all apartments		x	+	€	Significantly reduces the water consumption
Energy production and distribution					
The maximization of the use of renewable energy sources for heating	x	x	++	€€	Depending on the current heat production plants, how much improvements / changes are needed
The maximization of the use of renewable energy sources for electricity	x	x	++	€€–€€€	In cities, some technologies are hard to implement, like large scale wind power. Solar electricity is easy to fit into the built environment. District biogas CHP plant can also be an option as well as fuel cell plants in the future. Wood chips as energy source might be non-feasible in ventral districts due to a large amount of transport need.

Energy-saving solution for street and outdoor lighting	x		++	€€	For example changing of light bulbs, LED solutions
The minimisation of district heating energy transmission losses	x		++	€	Increasing density of the area (infill-construction) and minimisation of the length of the pipes
The minimisation of emissions of energy production (particulates, CO_2, SO_2 etc.)	x		++	€€	Depends on current energy productions systems and energy sources, filters etc.

4. Renovation solutions for energy-efficiency

4.1 Renovation principles

4.1.1 Building level renovation principles

A starting point for energy-efficient renovation is always the building itself and the activities in it (Hekkanen et al. 1993). Renovation measures are always building- or building type-specific. But some basic renovation principles include: maximization of the operating efficiency of the heating system, maximization of the use of internal energy sources in the building, maximization of the energy-efficiency of sanitary equipment, and optimization of the thermal insulation capacity of the structures of the outside shell.

General energy renovation principles:

1. Reduce the energy demand.
2. Utilize renewable energy sources.
3. Make fossil fuel use as clean as possible.

Other renovation principles in the building level include:

- improving energy-efficiency
- improving and upgrading living conditions
- extending building life time
- reducing building operation costs.

It is important to look at the building as a whole when planning renovations. For example, if the windows are renovated, but the heating system of a building is not re-adjusted, the temperature in the apartments will rise. Then residents open windows to lower the temperature and no energy savings are achieved. Another example is that, if the ventilation is insufficient at the moment and the ventilation system is improved, energy consumption can rise.

4.1.2 District level renovation principles

It is often important also to examine the impacts of building level renovation solutions in a wider perspective, since energy renovation at a building level, for example, reduces the energy demand from the grid or from the network. So this also has an effect on primary energy consumption. In order to achieve the most eco-efficient results, the districts also need renovation. In this report, both building level and district level energy renovation solutions are considered.

Some general principles for energy-efficient renovations in the district level:

- improving the energy-efficiency of buildings (see Chapter 4.1.1)
- improving the energy-efficiency of outdoor lighting
- improving energy networks and grids, especially by reducing distribution and transmission losses
- replacing fossil fuels with renewable energy sources
- increasing the energy-efficiency of energy supply processes
- improving the energy-efficiency of waste and water management systems
- reduction of emissions (e.g. change of fuel or flue gas treatment)
- energy-efficient transportation: high quality of public transportation as well as pedestrian and cycle routes to encourage people to reduce the usage of private cars.

From the previous list, transportation was not in scope of this study.

4.2 Building level renovation solutions

In this chapter, the most relevant building level energy renovation solutions for Moscow apartment buildings are introduced in brief. There are several references that describe building level energy renovation solutions in greater detail, such as Häkkinen et al. 2012, Vares et al. 2012, SHC 2010. The renovation solutions for water management systems are described in Chapter 6.2.1 and for waste management systems in Chapter 7.2.1.

4.2.1 Renovation solutions for building envelopes and structures

Improving the thermal properties and thus the energy-efficiency *of the building envelope* is usually cost-effective if other repairs to the building envelope are also needed. Then improvement of the thermal properties may form only a marginal share of the costs, and the heating energy demand is reduced considerably.

Renovation of the building envelope also makes it possible to change or modernize the architectural image of the building. Among other things, renewal of balconies may also increase usability of apartments. Using different façade materials may give the building a modern image.

Extra insulation of the roof is often easy to do (Kouhia et al. 2010). But the heat losses through the roofs in apartment buildings are quite small, about 10% of the total losses in Finland (Holopainen et al. 2007). In addition, the leaks in roofs should also be repaired. *Extra insulation of base floors* is not usually cost-effective. It often leads to too extensive and too expensive construction work.

Changing the windows to more efficient ones is often profitable. Demolishing the old windows and installation of new ones forms a considerable share of the costs (in Finland around 50%), and the price of the high quality windows is a maximum 50% (usually around 20%) more expensive than the standard product. Also passive cooling solutions, such as shading the windows, could be considered, which reduces solar gains and overheating of apartments in the summertime.

Improving the airtightness is also a key issue in envelope renovations. For example, the window and door joints in construction elements should be airtight. But then it should always be noticed that enough ventilation is assured.

4.2.2 Renovation solutions for heating systems

Typically, buildings in Moscow are heated with district heating (DH) . The heating system of a building is commonly connected directly to the building, which does not allow controlling the heat load on the heating system of a building. Thermal control is provided by the heat production facility. Therefore, it is necessary to *add a manual readjustment of a jet pump or heat exchanger in the heating system of a building*. This will enable transmitting a lower heating load to the district heating grid. Without this improvement, energy-efficient buildings will be overheated and the benefits of energy-efficiency renovations are lost. (Opitz 1994)

In buildings connected to the district heating system, improvements in the system can be achieved by renewing or if these do not already exist (as is usual in Russia), adding heat exchangers to the system, i.e. passing from the central substation system to a system with *individual substations*. By installing a completely automatic individual substation in every building it is possible to change from a four-pipe to two-pipe DH system (Eliseev 2011). With heat exchangers the management of the system is easier and energy-efficiency is also improved. Modern heat exchangers have an efficiency of around 95%, while older ones can be as low as 75%.

The *upgrading of radiator systems* is one way to improve the efficiency of the heating system. The change of the radiators brings better adjustability of the indoor temperature and savings in heating energy consumption if *thermostats are installed* as well. Another cheap improvement is to *adjust the pressure level* in the radiator system in the building.

The hot water boiler (if it exists) might be in need of renewal and its renewal will bring advantages in terms of energy-efficiency.

It is also important to *install heat consumption meters* in buildings or perhaps even in apartments as required by the legislation (Korppoo & Korobova 2012). However, flat level heat metering is quite problematic if it is the basis for heat billing, since it is difficult to bill each apartment fairly.

4.2.3 Renovation solutions for cooling

In regard to cooling, the cheapest way to increase energy-efficiency is to *reduce cooling demand*. There are some easy and cheap ways to do this. By adding solar shading to windows you can decrease the cooling needs significantly. Investments are not high for these. They might, however, raise some discussion regarding the architectonic influence of the shadings. Better windows (better U-values) also reduce cooling demand in the summer.

Centralised cooling systems are more energy-efficient than apartment-wise systems, but they require huge infrastructural investments, and some cooling source, like seawater.

Heat pump systems can be utilised for very energy-efficient cooling. By utilising the cold medium pumped from the ground directly, you get effective cooling almost for free. The same system can be used for heating during heating seasons.

A *green roof* is a roof of a building that is partially or completely covered with vegetation, planted on a waterproof surface. Green roofs serve several technical purposes for a building, such as absorbing rainwater, providing insulation, and helping to lower urban air temperatures and combat the heat island effect. Green roofs are sometimes used to reduce cooling energy demand (by evaporating rainwater).

4.2.4 Renovation solutions for ventilation systems

A building's ventilation system can be improved either *by updating the existing system or by renewing the whole system*. In the case of ventilation it is important whether there are existing ventilation ducts or not. In many older buildings there is only natural ventilation where the consumed air is removed from the building by natural forces, pressure and temperature differences. In these cases, all of the heat goes out to the outside air leading to higher heating consumption. The positive side is that the system does not consume any electricity.

To improve such a system the installation of ventilation ducts is needed. By *installing supply and exhaust ducts and a mechanical ventilation unit with efficient heat recovery*, indoor air comfort is improved and heat consumption reduced. These systems, however, use electricity in order to function. The electricity amount is, however, much less than the heating energy saved . In addition, mechanical ventilation improvements may also require upgrading of non-tight air ducts.

It is also possible to *add only mechanical exhaust to the system*. This improves the air change in the building, resulting in a better indoor environment. Since no heat is recovered, this does not lead to any energy savings though. The exhaust air can, however, be treated with an exhaust air heat pump, where the heat in the exhaust air is utilised to heat hot water for the domestic hot water consumption and the radiator network.

There is also a “non-mechanical” ventilation system with heat recovery. This “wind cowl” system

utilises natural forces to extract the air from the building and recovers the heat to the inlet air. The system uses no electricity at all. It has, however, not been tested in many different climate conditions, and user feedback is not widely available. Since the climatic conditions influence functionality a great deal, it would be of the greatest importance to have it tested in the right conditions before taking into use.

4.2.5 Renovation solutions for electricity

Reduction of the electricity demand in buildings can be achieved by *replacement of old home appliances* with ones with higher energy-efficiency ratings and by upgrading building equipment such as pumps, elevators, etc. Renewable energy sources, such as wind or solar energy, can be utilized for the generation of electricity in buildings through installation of photovoltaic panels or small-scale wind turbines. The energy produced by these installations is, however, according to some discussions, seen by Moscow officials as suitable for the illumination of staircases and yards. Wide-scale installation of solar panels and wind turbines other than on rooftops and in some cases facades, is unlikely due to shortage of space and inappropriate conditions in densely built neighbourhoods with high-rise residential buildings (wind speed, shade).

Usage of fossil fuels can be made cleaner and monetary savings can be achieved through *efficient demand response*. Demand response means a reduction of electricity consumption during those periods when electricity consumption is most expensive. In normal conditions these periods coincide with power system peaks, when less efficient and most polluting power plants are committed or increase their production levels. At a building level demand response can be facilitated with *energy monitoring and management systems*, which would manage flexible loads, such as electrical boilers with storage tanks, heat pumps and ventilation systems (within acceptable ranges from a thermal comfort and indoor air quality point of view). A building level system can also control apartment-specific units (smart boxes), which can in their turn manage remotely-controlled household appliances, preselected by tenants. The technology for remote control management of regular home appliances, utilizing so-called smart tags, is being developed and tested. Timely communication of electricity price levels to the energy management systems is crucial for efficient demand response. This, as the state-of-play in the ICT sector suggests, should not be seen as major technical challenge.

At least until 2014, the electricity prices for households in Russia will remain regulated. However, the management system can still be set up to account for the currently available time-of-the-day tariffs (three periods).

In addition, electricity distribution networks/wires/systems in buildings may need renovation. Since electricity for lighting is an important part of the building energy consumption, renovation solutions for lighting are discussed in their own Chapter, 4.2.6.

4.2.6 Renovation solutions for lighting

The electricity saving potential of indoor lighting depends mainly on two issues: the type of light bulbs and the control of the lighting. First of all, the type of a light bulb is crucial. For example, filament lamps are typical bulbs used in indoor lighting. If those filament lambs are replaced with bulbs that have better energy-efficiency (e.g. with LED, or other type of *energy saving lamps*), the electricity consumption of lighting will drop by more than 70%. Typically these kinds of lamps are more expensive, but the profitability of the investment in lighting solutions will reduce electricity consumption, and therefore, electricity bills.

In addition, the electricity consumption of indoor lighting can be reduced by improving the *control of lighting*. The influence of control of lighting is especially useful in public spaces, such as halls and stairways, etc. Are the lights on all the time, and is that really necessary? Or could lights be controlled by an automatic timing control, for example. With these kind of lighting control solutions the electricity consumption of indoor lighting in public spaces could be reduced by 20–30%.

4.3 District level renovation solutions

In this chapter, the most relevant district level energy renovation solutions for Moscow apartment buildings are briefly introduced. The renovation solutions for water management systems are described in Chapter 6.2.2 and for waste management systems in Chapter 7.2.2.

4.3.1 Renovating heating energy supply

The heating energy supply system can be renovated with three main environmental improvements: increasing the energy-efficiency of heating energy production and transmission, reducing emissions, and replacing fossil fuel with renewable energy sources. *Improvements in energy-efficiency* of energy production plants will increase the energy yield from fuels and thereby reduce emissions. For the very same reason, combined heat and power production (CHP) technology should also be favoured.

The second renovation principle is to replace fossil fuels with *renewable energy sources*. Usually, this means decentralised energy production and that energy is produced close to its end users. This already improves the overall energy systems, because the distribution lengths are short. In principle, the shorter the distribution lengths, the fewer distribution losses. Suitable renewable energy sources in Moscow could be biomass-based fuels, such as *wood* chip district heating boilers. *Solar heat* energy production with solar collectors is also possible in Moscow, especially in heating domestic hot water (a yield potential to heat 50% of annual domestic hot water demand). However, the challenge of solar collectors is that the heat is produced in the summer time; and a parallel heat energy production system is also needed. It could, for example, be a district heating system, which would be closed in the summer. This would bring benefits, because the heat demand is really low in the summer, meaning that the share of relative distribution losses is larger than in the winter; and the heat energy production system will operate at a low power level, which reduces the efficiency of the process significantly. Particle emissions from wood chip boilers are also significantly higher when the plant is running on low power; this problem can be reduced by utilizing solar heat during low peak times. *Ground/rock/water source heat pumps* are also one suitable option, even for groups of buildings, but they are more commonly used in single buildings. Heat pumps consume electricity, depending on their annual performance of coefficient (COP) factor.

In addition to improving energy-efficiency, emissions caused by the energy production plant should also be minimised. The *emission reductions* can be realised in heat energy boilers in many different ways, such as:

- improving the quality and purity of a fuel
- improving/controlling the combustion process in the boiler
- flue gas treatments (reduction of nitrogen oxides, small particulates, sulphur etc.), such as filters and flue gas scrubbers
- improving energy-efficiency of boiler and heat transmission processes.

4.3.2 Renovation of district heating networks

The main requirements for the renovation of Russian district heating systems are the modernization of heating energy sources, the introduction of combined heat and power production according to European standards of optimization, and the improvement of means of conveyance and distribution of heat energy (Eliseev 2011).

The state of the current district heating networks from the 1970s is estimated to be quite low, which causes high distribution losses and significant leakages. It may be necessary to replace the current district heating pipes with new ones. As an example, replacing the network with new pipes has helped to reduce the distribution losses in Tallinn, Estonia[8]. The total renewal of the piping is costly but might be in place if the pipes are old. Connection points are most likely causing big losses, as well as connection points between buildings and the pipes. These can be assessed and repaired, if there is no possibility of a total renewal of the piping.

The district heating network should be planned so that the heat loads to buildings can be controlled according to the heat demand of a building. According to Opitz (1994), the control of district heating network may also be improved by adding and adjusting control equipment at group heating substations.

4.3.3 Renovation solutions for electricity supply and distribution

The electricity supply, including that produced at some local and district heating plants, is centralized. The utilization rate of renewable energy produced by building-integrated solar panels and wind turbines could be better if the installations operated in a "must run" mode instead of being used for illumination purposes only. In this case, integration with a power supply network is needed. Such a parallel operation, even though implemented via a power electronics interface, would require changes in the distribution network's protection and regulation systems. The same applies to other types of distributed generation[9].

Installation of reactive power compensators in buildings, which is not required by existing power supply design norms[10], brings a reduction in resistive losses in distribution networks (but it does not reduce the consumption of energy in buildings). These savings are usually insignificant (Misakian et al. 2009), but in some cases, when the power factor proves to be very low (which may happen, for instance, after installation of powerful mechanical ventilation system), the measure might be considered[11]. Renovation of electricity distribution network and upgrading voltage levels also leads to energy savings in the network. For instance, for a wider distribution network voltage the level can be raised (from current use of 6 or 10 up to 20 kV[12]). Replacement of distribution transformers may lead to a reduction of no-load losses.

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[8] Opening speech of Mr. Tiit Rahkema from the Estonian Power and Heat Association at the 12th International Symposium on DHC in Tallinn, Estonia in the autumn of 2010.

[9] For instance, biofuel powered micro CHP plants, fuel cells, etc. Installation of these types of facilities is not considered in this study due to the necessity for fuel storage, transportation and lack of space. However, this option is not completely excluded in the case of underground installation.

[10] http://base.consultant.ru/cons/cgi/online.cgi?req=doc;base=EXP;n=422519;dst=0;ts=5CC9F544A373664428F32F4D1391F087 at distribution substation the design value of power factor is 0.92 (gas stoves are in use in the district) or 0.96 (electric stoves).

[11] According to similar calculations performed for the largest building in the pilot district the possible annual savings are below 1% of total supplied energy in 0.4 kV network.

[12] This is the main strategy for the electricity distribution systems of Moscow for the next decade.

Contrary to the case of specific heating energy consumption in buildings, which has remained stable or even fallen over time, specific consumption of electricity has been increasing and is expected constantly to rise due to rising living standards. Therefore, upgrading and strengthening of existing networks is important to ensure sufficiency of power supply, integrate renewable energy generation and realize energy-efficiency at district or larger scale. Where the existing infrastructure is approaching the end of its service life or operational limits, it is advisable not only to replace the existing infrastructure but at the same time to make the (district) energy system smarter through integration of information and communication technologies.

Smart Grids can be described as an upgraded electricity network enabling two-way information and power exchange between suppliers and consumers, thanks to the pervasive incorporation of intelligent communication monitoring and management systems (Giordano et al. 2011). The smart grid concept could be deployed locally at a district scale (e.g. the borders of it could be on the low-voltage side of a distribution substation supplying electricity to a group of residential buildings). Deployment does not necessarily need to be full-scale, rather only those parts of a concept that would be found feasible will be suggested for implementation.

The building-level energy management systems can be integrated into a district level intelligent system, which can, for example, facilitate demand response at a district level based on the electricity price signals available, fault detection, consumption metering and monitoring, and fraud detection. The demand response control actions of the proposed solution should envisage a possibility for management based on hourly or dynamic electricity pricing. Deployment of a smart system may lead to operational costs savings for a local electricity distribution company mainly from network remote control and automation, optimized work force management and internal processes, e.g. billing, provided the deployment covers sufficiently large area. Another benefit is improved customer satisfaction, as such a system allows for very flexible pricing policies (Lama 2010). With time, the functionality of the district level system could be extended to include management of distribution generation, energy storage and charging of electrical vehicles to become a part of a full-scale smart grid, which could in the future be scaled further to cover a larger area.

4.3.4 Renovation solutions for outdoor lighting

Electricity consumption of lighting can be reduced by replacing current light bulbs with new energy-efficient bulbs. It is assumed that the outdoor lighting solutions of renovated areas from the 1960s and 1970s in Moscow are similar to Finnish districts built in the 1960s, which means typically mercury lamps. Then the electricity saving potential of public outdoor areas is estimated to be 50–70%. In addition, the planning of lighting areas and controlling the timing of the lighting is also important.

4.4 Selected renovation concepts

The following renovation concepts were selected for further studies. The concept is here defined as a set of measures to be carried out. Three alternatives are given for renovations. 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. If not otherwise stated, the improved and advanced solutions always include the solutions mentioned in the previous renovation.

4.4.1 Building level renovation concepts

Table 9 shows the renovation solutions for the building level.

Table 9. Building level renovation solutions 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
Structures: U-values (W/m^2K) • outer walls • base floor • roof • windows and doors	 1.1 1.1 1.1 2.9	 0.5 – 0.25 1.85	 0.32 – 0.24 1.5	 0.15 – 0.15 1.0
Ventilation	Natural 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	2	
Passive cooling		Static solar shading above windows Shading: manual blinds between the window glasses	Selective windows	Green roofs
Lighting (indoor)	Incandescent lamps	Energy efficient lights to stair cases	+ presence sensors	

Electricity consumption / electrical equipment		Car parking places in case preheating of cars is used nowadays (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
Electricity production (on site)				Photovoltaic panels integrated on roofs and facades.
Heating system, including hot domestic water • radiators • controlling/adjusting temperature	Hardly any control to regulate radiators' heat output No district heating substation in buildings	Replace radiators and pipes Insulated pipes Adding control valves and adjustment of insulated heating network of a building.	Installation of prefabricated building-specific heat distribution substation with automatic regulation system, thermostat valves on radiators (including control equipment and expansion tank, hot water preparation)	Two-pipe system (Eliseev 2011)
Water distribution/piping system	Water meters being installed but not in use Water appliances old	Replacing of pipes if needed Insulation of water pipes Utilisation of water meters (separate for cold and hot water)	Installation of remote readable water meters (separate for cold and hot water)	Prefabricated, innovative piping solutions (may include also electricity wires and ventilation ducts)
Water consumption	Water consumption: 272 l/day/occupant, of which hot water: 126 l/day/occupant	Installation of modern fixtures and appliances (Water consumption 160 l/day/occupant)	Installation of water saving fixtures and appliances (water consumption 120 l/cap/d)	+ separate metering in each apartment (water consumption 100 l/cap/d)

Waste sorting	No existing site sorting of household waste	If districal solutions enables recycling of site sorted waste: site sorting facilities in kitchen and waste collection area		
Knowledge sharing to residents and maintenance personnel		Information to residents about energy efficiency (recommendations on energy-efficient household appliances and lighting equipment) and water savings. Usage and living patterns. Training of persons responsible for operation and maintenance.	Suggestions for decreasing energy consumption for example based on real time monitoring data	
Monitoring and operation		Automatic outdoor closers Apartment-specific heat, electricity and water consumption meters	Communication equipment/channels Real time monitoring of energy. Possibility to benchmark energy use to similar buildings.	Smart meters Installation of remote readable water meters Building automation and monitoring systems

Quality of materials used. The embedded energy in construction materials	Embedded energy not taken into account.	Indoor spaces: materials of high level according to emissions classifications M1 (in Finland). Low/no toxic emissions into indoor air.	Renewable building materials preferred, mainly wood. Transport of wood material needs to be assessed and the harvesting conditions of the wood needs also to be handled in a sustainable manner. Other materials can be ok if produced nearby and in a sustainable way.	Thorough LCA analysis performed for all building materials and choices made based on best LCA performance.

4.4.2 District level renovation concepts

Table 10 shows the renovation solutions for the district level.

Table 10. District level renovation solutions 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 supply 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.) or with more efficient plants, such as 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 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 (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. Sewage treatment efficiency vary between plants (Zelenograd ok)	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)	Separate waste collection Reduced landfilling Increased recycling		Increased recycling and energy utilisation
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.

5. Energy analyses of the renovation concepts

The district selected that is described in Chapter 1.2.2 was utilized in the following analyses.

5.1 Principles of the energy analyses

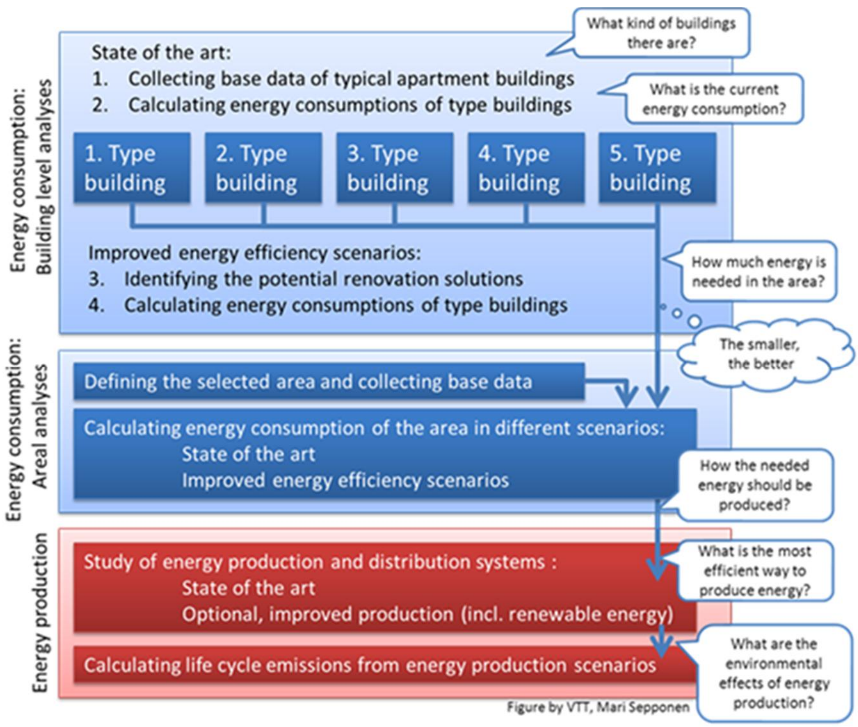

Figure 4. Methodology of the energy analyses.

The main objective of the energy analyses was to form an overview of average energy consumption, energy production quantities, and energy-efficiency in Moscow, Russia. These kind of analyses are important for recognizing the best ways of improving the energy-efficiency of energy systems and entire areas. The key questions were: “How is the energy 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 to achieve lower emission levels?”. The general methodology of the energy analysis used in this chapter is presented in Figure 4.

The renovation concepts presented in Chapter 4.4 were assessed from the perspective of energy demand and emissions generated . This began by making a “Current” energy and water demand model of the typical II-18 building. From this model, other “renovated” models were generated, containing the renovation solutions presented in Table 9. A similar current demand model was also created for each of the other building types in the case district. However, since a comparison of these showed minor differences between the demands of the buildings[13], the most common building type, II-18, was selected to represent the average building in further studies.

In all, four models of the type II-18 building were created and analysed. These were given names according to the concept on which they were based: Current, Basic, Improved and Advanced. These building models were later used in the energy demand analyses of their corresponding district concepts. Each district concept was further studied in different scenarios of energy production from which the resulting emission levels were examined. See Figure 5 for further clarification of the different steps of the energy analysis process.

[13] The annual heating and electricity consumption per floor area differed at most with respectively 3 and 17%.

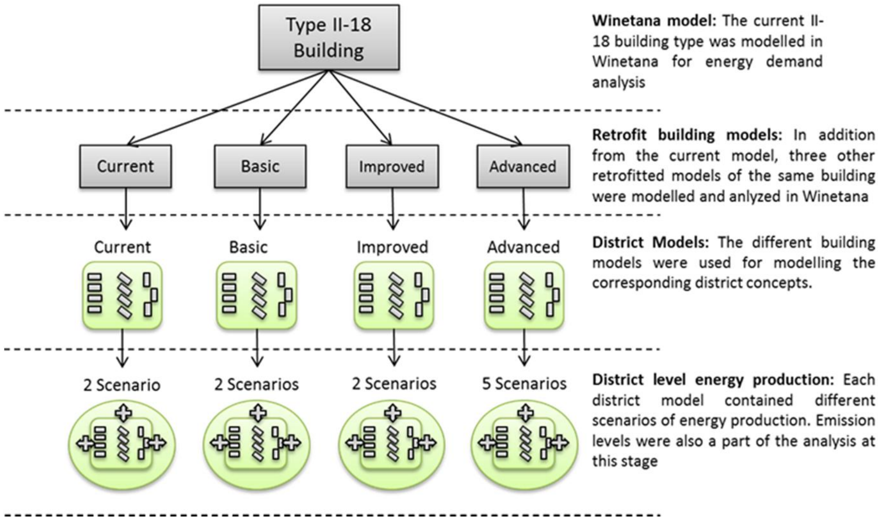

Figure 5. Overview of the process of conducting the energy analyses. (WinEtana is a computer software for making building energy analyses developed by VTT Technical Research Centre of Finland.)

5.2 Building level energy analysis

5.2.1 Energy model of the current II-18 building before renovation

The energy and water demand of the II-18 building was modelled on Winetana, which is a computer software for conducting building energy analyses developed by VTT Technical Research Centre of Finland. Energy flow calculations were made, based on the structural properties, heating, ventilation, water use and drainage, and electrical appliances of the building. To match the simulated model to the real scenario, the following input data was used.

Typical U-values in Moscow buildings are approximately 1.1 W/m^{2}C° for wall constructions and 2.9 W/m^{2}C° for fenestration (converted from transmission R-values by Matrosov et al. 1997). Opitz et al. (1997) point out that the design R values differ minimally among older buildings built between 1954 and 1979, and that they are essentially the same among buildings even with different wall structures (except for recently constructed buildings with 3-layes panel walls).

The indoor temperature was set at 18°C for the multi-storey building model. An estimated air density factor of n50 of 6.5 h^{-1} was used in order to account for the recent improvements of air tightness of windows in Russian apartment buildings. Besides, natural ventilation is a typical ventilation solution in Russia (Opitz et al. 1997).

Because Estonia was part of the Soviet Union, there are still numerous apartment buildings built during the Soviet Union era. It was, therefore, considered that the following data from Estonia are comparable to those in Moscow and could be used for the energy analysis. The typical annual water consumption in Estonia is 180–290 l/capita/day (The World Bank & IFC 2008). Based on this, an average water demand of 272 l/capita/day was used for modelling the Current model. The share of domestic hot water was 46% of the water demand, thus 126 l/capita/day).

As for the internal heat gains, the following values were used based on the experiences of Finnish experts (Shemeikka 2011): 0.96 kWh/m^3/month from domestic hot water (30% of the heat demand for hot water [Nyman et al. 1995]), 1.42 kWh/m^3/month from electrical equipment and 0.4 kWh/m^3/month from people.

The simulated energy balance of the II-18 building is presented in Figure 6. According to our calculations, the heating energy demand of typical old apartment buildings in Moscow is approximately 219 kWh/m^2,a and the electricity demand 47 kWh/m^2, a. The result is well in line with the study of The World Bank & IFC (2008). The differences in energy consumption calculations might have resulted from divergences in the initial data used. For example, the structures and building technical systems may vary between different buildings in Russia (even for those within same building series) or might even be different within a single building. Moreover, according to the Moscow city programme “Energy Conservation in Construction in the City of Moscow During 2010–2014 and Until 2020”, the thermal insulation of buildings complies with norms only ‘on paper’, which may also explain the differences in the results. Also, the air tightness of the building has a great significance, and a different value might have been used in this study.

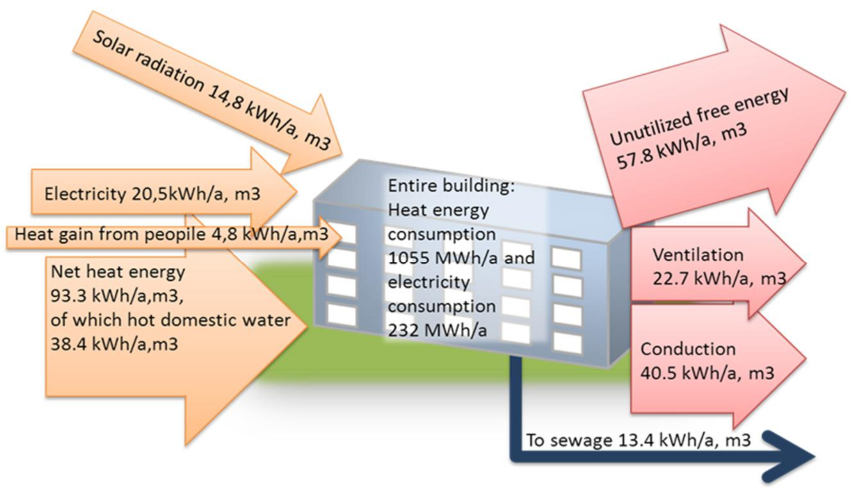

Figure 6. An example of the annual energy balance of an apartment building (II-18).

5.2.2 Renovation models of the II-18 building

In addition to the current state of building II-18, the Basic, Improved and Advanced renovation models were generated according to the corresponding renovation concepts described in Table 9 in Chapter 4.4.1. Results from energy simulations show that the heating demand of the building is significantly reduced for each degree of improvement. The same also goes for the electricity demand except for in the Advanced renovation model, where mechanical ventilation was implemented. Mechanical ventilation enables better indoor air quality and heat recovery from the outgoing air, but increases electricity consumption as a trade-off. The energy demands of the different models of the II-18 building are shown in Table 11.

Table 11. Energy demand of the current and renovation models of the II-18 building.

	Current	Basic	Improved	Advanced
Total energy demand (kWh)	**1,308,003**	**840,731**	**675,755**	**518,897**
Heat (kWh)	**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%)	6936 (2%)
Electricity (kWh)	**231,630**	**183,510**	**172,000**	**190,460**

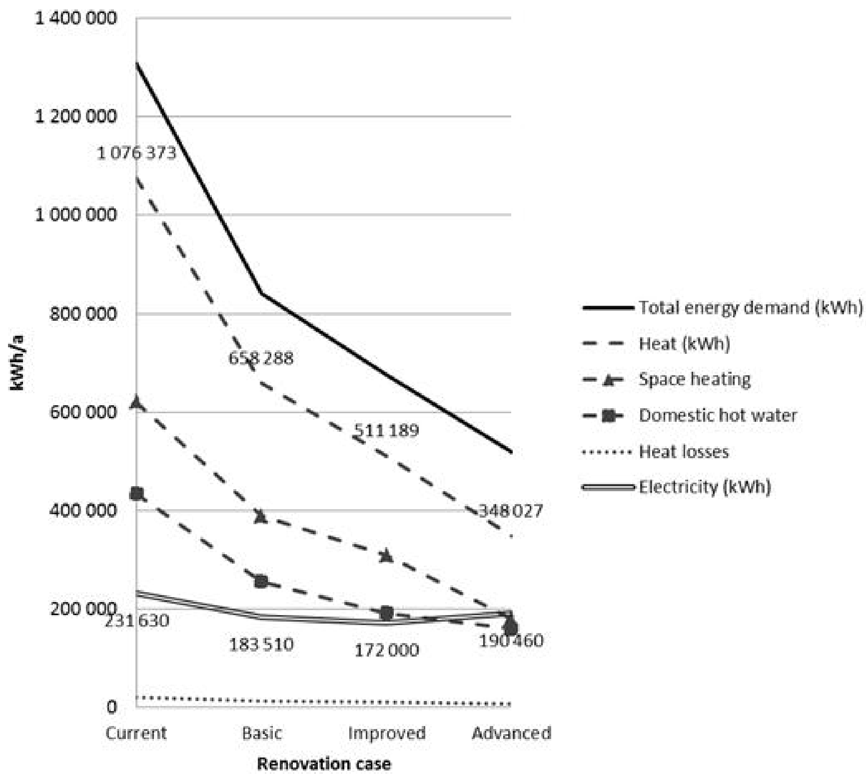

Figure 7. Energy demand comparison between the II-18 building renovation concepts.

By implementing the Basic renovation concept, heat and electricity demand could be reduced to respectively 61% and 79% of the current situation. Corresponding numbers for the Improved concept were 47% and 74%, and for the Advanced 40% and 82% (see Figure 7). The energy demands were further converted into units of energy per floor surface (kWh/m^2) in order to model the energy demand of all the buildings in the corresponding district energy model (see Table 12).

Table 12. Annual energy demand per square meter of floor area for renovation models of the II-18 building.

	Current	Basic	Improved	Advanced
Heat demand/m^2 (kWh/m^2)	219	134	104	71
Electricity demand/m^2 (kWh/m^2)	47	37	33	35

5.3 Energy and emission analyses of renovated district concepts

5.3.1 Initial data and energy analysis results of the district concepts

The energy demands of several renovated district concepts were also analysed 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 10 in Chapter 4.4.2.

The case district was estimated to have 13,813 inhabitants in all, which is about 0.12% of the total population of Moscow. The total building floor area in the district was 327,581 m^2 and the total roof area 31,230 m^2. These values remained the same in each district model.

In the Current district, the annual energy demands per floor area were 219 kWh and 47.2 kWh for heating and electricity respectively. The heating demand of the buildings was estimated to be fully covered by district heating with 20% heat distribution losses, while transfer losses of the electrical grid were estimated to be 10%. 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. Outdoor lighting was estimated to consume 350 kWh per lamp per annum, while a factor of 0.167 lamps per inhabitant was used (Echelon 2007, Radocha & Baumgartner 2006).

The Basic district consisted of buildings where the annual demand of heating was 134 kWh and electricity was 37 kWh per square metre of floor area. 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 of heating and 33 kWh 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 were

48% less than for the Current district, while the outdoor lighting electricity demand was reduced by 70% due to the implementations of advanced technologies.

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 level analyses. The annual energy demands per square meter of floor area in the Advanced district were 71 kWh and 35 kWh for heating and electricity respectively. An exception of the Advanced district from the others is that smart meters are used in the buildings, which lowers their electricity demand by 5%. 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 IEA (2008) & Paiho et al. 2012. The works of Echelon (2007) and Radocha & Baumgartner (2006) were consulted for estimating electricity consumption of the different district concepts. Corresponding values for water and wastewater consumption have been obtained from Chapter 6 and from Sepponen (2010).

Calculations show that the energy need is mostly affected by the improvement measures in the Basic and Advanced concepts. This has mostly to do with the fact that the renovated building resulted in the same manner, and that buildings are accounting for close to all the energy demand of the case district. The calculation results are shown in Table 13 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. The energy reduction potential of each concept can be better differentiated in Figure 8. Looking at electricity and heating demand separately, it is notable that the potential for reduction of these are 34% and 72%, respectively.

Table 13. Resulting annual energy demand for the district concepts presented in Chapter 4.4.2.

	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	1 533	414	981	265	797	215	675	182
Total	19 507	90 167	14 879	51 957	13 164	40 410	12 816	25 146

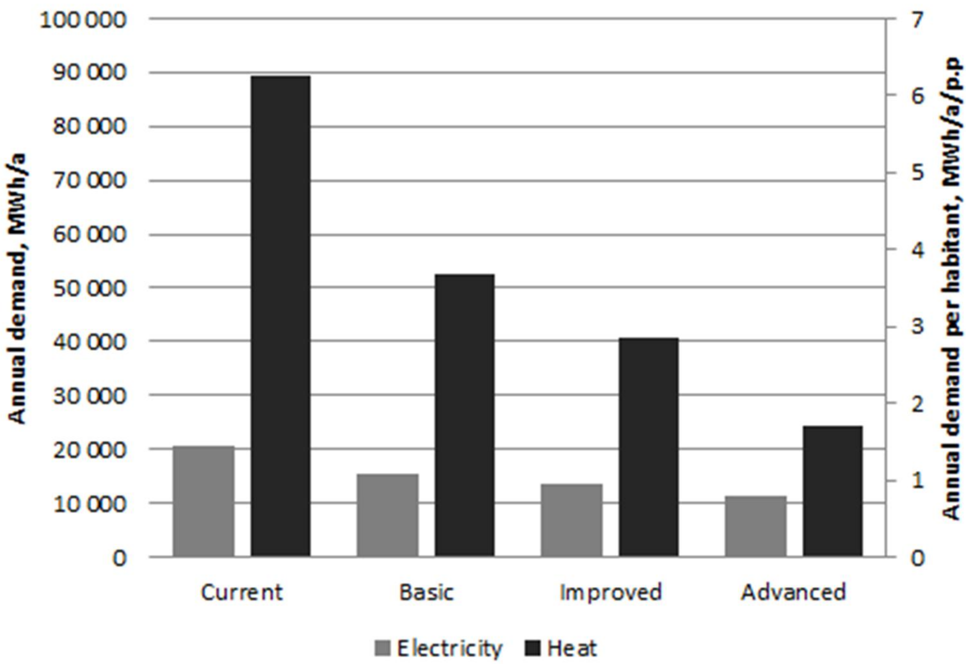

Figure 8. The annual energy demand for the different district concepts. The total demand on the left and per habitant on the right.

It has to be said 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 the Table 10 in Chapter 4.4.2 are directly related to pollution or the comfort level of the inhabitants, and would not be notable in the results from the energy analyses.

5.3.2 Emission levels for different energy production scenarios

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. Since almost all energy produced in the Moscow area comes from natural gas, 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. All the district concepts had two scenarios, except the Advanced, which had five in total. Table 14 summarizes the scenarios analysed.

Table 14. Analysed energy production scenarios.

Energy production scenarios of the different district concepts				
	Current	Basic	Improved	Advanced
CHP natural gas scenario	x	x	x	x
CHP biogas scenario	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

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 would cover 7.5% of the total electricity demand, while the rest would be bought from the Moscow grid (this affects emissions). 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 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. See Appendix A for further information about how the renewable energy production was calculated.

The scenarios where analysed in terms of generated CO_2-equivalents, SO_2-equivalents, TOPP-equivalents (mass-based equivalent of the ozone formation rate from precursors, measured as ozone precursor equivalents) and particulates. These values have been retrieved for each of the energy production technologies involved in the scenarios, and account also for the life cycle of the production unit. More information about the emission calculations is also found in Appendix A. Generated emissions from the different scenarios are compared to each other and the value for the Moscow area (Moscow ref.) in Figure 9 (CO_2-equivalents), in Figure 10 (SO_2-equivalents), in Figure 11 (particulates) and in Figure 12 (TOPP-equivalents). The Moscow reference values are average emission values from energy production for the whole of Moscow. In order to be comparable, these have been converted to emissions per inhabitant and thereafter multiplied by the number of inhabitants of the case district.

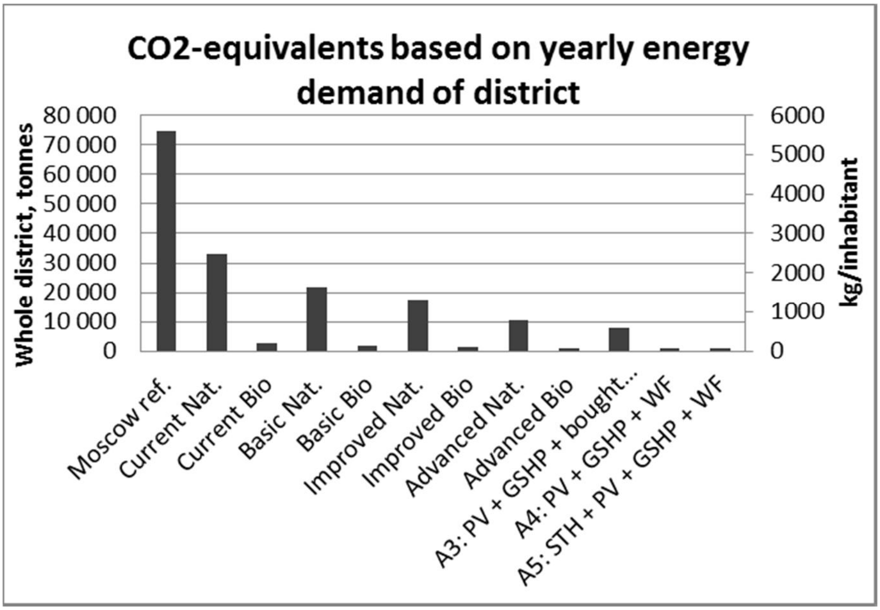

Figure 9. Level of CO_2-equivalents of the district energy production scenarios.

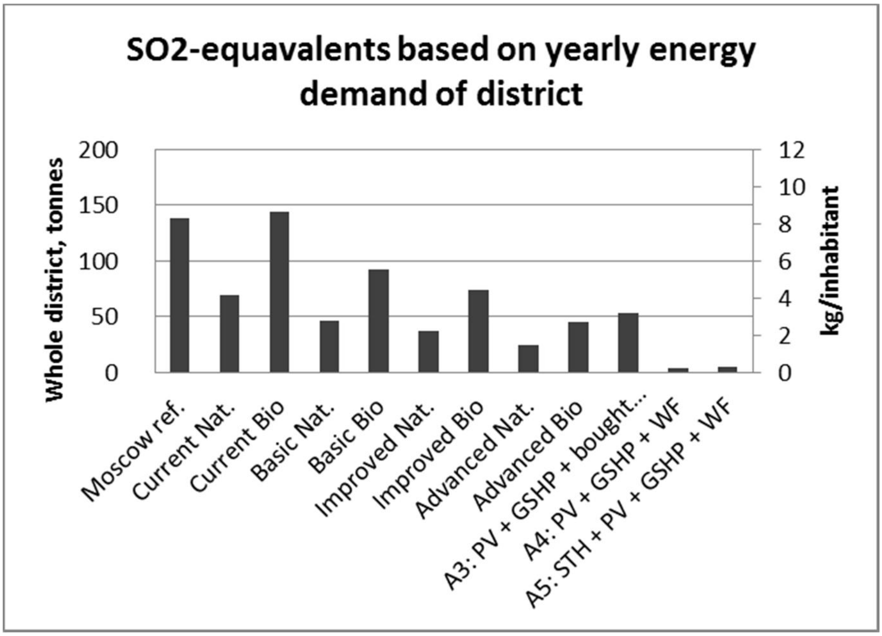

Figure 10. Level of SO_2-equivalents of the district energy production scenarios.

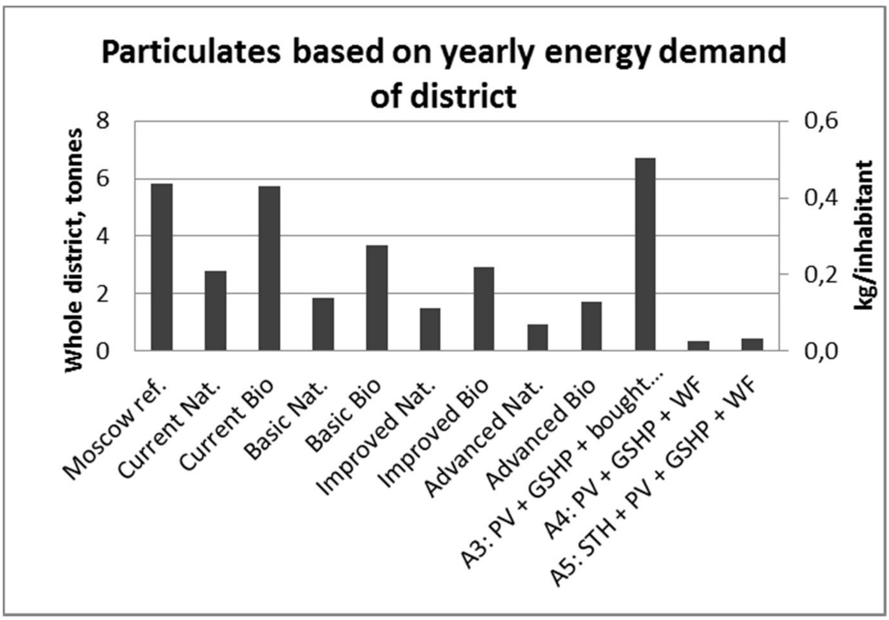

Figure 11. Level of particulates of the district energy production scenarios.

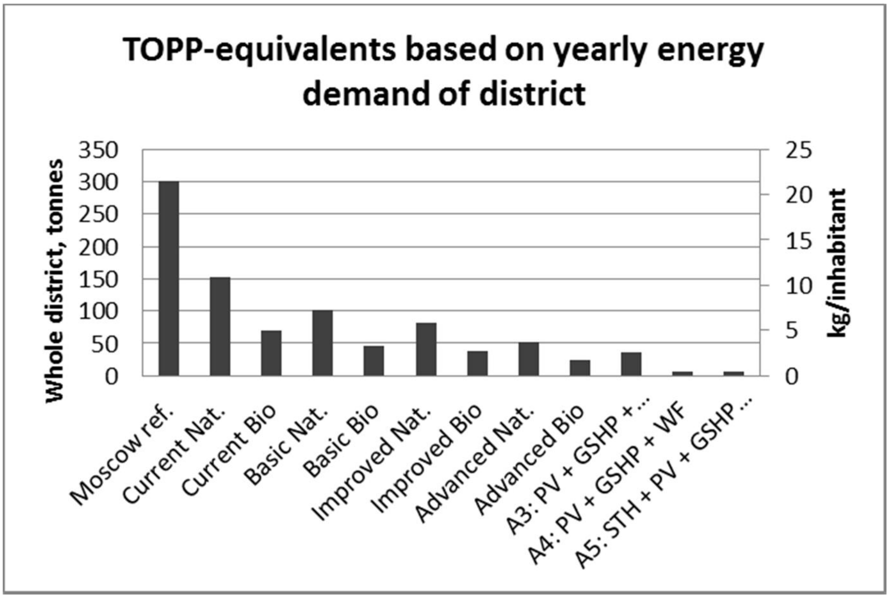

Figure 12. Level of TOPP-equivalents of the district energy production scenarios.

The results from 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 a good choice of reduction. The same also goes for TOPP-equivalents, where it can be noted that changing fuel type would result in better 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 from the results, producing energy from renewable technologies as in A4 and A5, would be a better solution than switching to biogas when it comes to reduced emission levels compared to the current situation.

6. Modernization of water management systems

The selected district described in Chapter 1.2.2 was utilized in the following analyses.

6.1 Current water management systems

6.1.1 Fresh water production and distribution

The freshwater of the city of Moscow is mainly supplied by surface water from the Moskvoretsky-Vazuza and Volga systems, which have a catchment area of 55,000 sq. km in the Moscow, Smolensk and Tver regions. The net capacity of these water bodies is approx. 2,262 million cubic meters. The renewal rate (i.e. sustainable capacity) of these reservoirs is 10.9 million m^3/d. The total capacity of the water purification plants is 6.7 million m^3/d, with a back-up capacity of 38.5%. Current actual water offtake and potable water production is 4–5 million m^3/d (City of Moscow 2010).

Currently, the fresh water distribution network of Moscow is in poor condition and the tap water not always safe to drink. According to a resident survey, only 11% of the residents drink the tap water without any pre-treatment (8% drink bottled water and the remainder filters or boil the water before drinking). The quality of the drinking water can be improved through improving the processes at the purification plant and by ensuring safe distribution of the water (Resident survey 2010).

The water supply of the city of Moscow was approx. 4.1 million m^3/d in 2008, and the leakage rate of the water distribution network was 9.2%[14]. Of the water supply, 5.3% was delivered to inner suburbs; of the remaining water supply 81% was used for household needs (City of Moscow 2010). With the Moscow popula-

[14] The reported leakage rate in Moscow was 9.2 % in 2008 and the target for 2020 is 5% (City of Moscow 2010). This is extremely low, much lower than in most western cities; in Helsinki the leakage rate was 19% in 2008 (Helsingin Vesi 2009).

tion of 10.5 million, this makes the average daily household water consumption of a Muscovite an estimated 272 litres (Table 15). As a comparison to the Muscovite water consumption, the current Finnish average daily water consumption is 155 litres (Motiva 2011).

Table 15. Muscovite water distribution and consumption (City of Moscow 2010).

Category		m3/d	l/cap/d
Water supply, total		4,100,000	
Leakage	9%	377,200	36
Water supply, City of Moscow	95%	3,525,492	336
Household water consumption	81%	2,855,648	272

Household water consumption includes drinking water, bathing, cooking, sanitation, and gardening. The water consumption per inhabitant varies a lot depending on various factors, such as the price and quality of water, the metering and billing system, as well as the standard of living and consumption habits. The water efficiency of fixtures and appliances affect the total water consumption. Figure 13 shows the average household water consumption in Helsinki, on which the calculations for the Muscovite household water consumption is based.

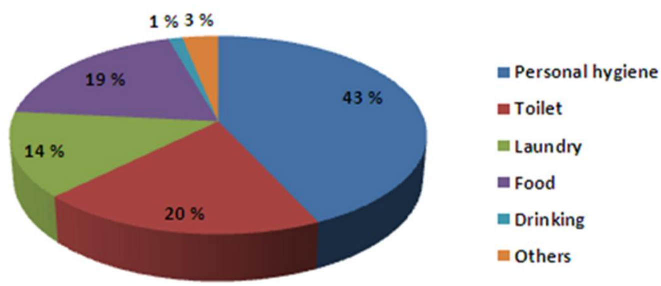

Figure 13. Household water consumption in Helsinki, Finland (Helsingin Vesi 2009).

6.1.2 Wastewater collection and treatment

The Muscovite sewage collection network system comprises more than 8.1 thousand km of pipes of which about 45–70% have exceeded their service life. The poor condition of the wastewater network allows wastewater leakages to contaminate soil and groundwater. There are 4 wastewater treatment plants (WWTP) in Moscow – Kuryanovo, Lyubertsy, Zelenograd and South Butovo, with a total capacity of 6.3 million m^3/d (City of Moscow 2010). In total the WWTPs in Moscow daily processes approx. 4.1 million m^3 of wastewater, of which 80% does not get sufficient treatment.

The selected area 4-y Microrayon (see Chapter 1.2.2) is located within the operational area of the Zelenograd WWTP, a very small plant with a capacity of 140,000 m^3 daily. As the WWTP of Zelenograd is very efficient, the emissions to the environment are very low and there is no need to alter the treatment processes at all. The majority of the pollutants are removed and the water is disinfected using UV light. The emissions and functional parameters of the Zelenograd WWTP are displayed in Table 16. It is assumed that, as one of the most efficient in the Moscow region, the Zelenograd WWTP constantly works at full capacity, and further that the plant serves approx. 300,000 people. (Mosvodokanal 2012)

Table 16. Functional parameters and emissions of the Zelenograd WWTP; increasing nitrate concentration due to the transformation of ammonia to nitrite and nitrate in the nitrification process and less efficient denitrification process for nitrogen removal (Mosvodokanal 2012).

Parameters	Incoming wastewater [mg/l]	Incoming wastewater [kg/d]	Incoming wastewater [g/cap/d]	Treated wastewater [mg/l]	Treated wastewater [kg/d]	Treated wastewater [g/cap/d]	Efficiency [%]
Suspended matter	236	33 040	110	1,10	154	0,51	99,53 %
BOD 5	156	21 840	73	1,40	196	0,65	99,10 %
Nitrogen ammonium	27	3 808	13	0,14	20	0,07	99,49 %
Nitrite nitrogen	0,04	5,60	0,02	0,01	1,40	0,00	75,00 %
Nitrate Nitrogen	0,21	29	0,10	3,60	504	1,68	-
Tot-N	27	3 842	13	3,75	525	1,75	86,34 %
Phosphates (as P)	3,73	522	1,74	0,10	14	0,05	97,32 %
Chromium 3	0,03	3,64	0,01	0,00	0,42	0,00	88,46 %
Nickel	0,04	5,74	0,02	0,01	1,68	0,01	70,73 %
Zinc	0,25	35	0,12	0,03	3,92	0,01	88,93 %
Copper	0,16	23	0,08	0,01	0,70	0,00	96,93 %
Cadmium	0,002	0,21	0,00	-	-	-	100,00 %

The sludge from the Zelenograd WWTP is treated at the Kurjanovo WWTP. There the sludge is stabilised through anaerobic digestion, forming biogas, and then dehydrated and deposited at landfills. (Mosvodokanal 2012) In anaerobic sludge treatment, part of the carbon is transformed into biogas; every tonne of sludge creates approx. 180 m^3 of biogas, consisting of approx. 30% CO_2 and 70% CH_4. The landfilled sludge creates approx. 190 m^3/t of LFG (60% CO_2 and 40% CH_4), generating approx. 200 kg of CO_2e per capita annually.

6.2 Renovation solutions

6.2.1 Building technical systems

When the water and wastewater pipes reach a certain age, the leakage risks start increasing; the estimated life expectancy of the pipes is approx. 35–60 years. There are several alternative techniques for the renovation of the water pipes; traditionally it is common to install new pipes, either replacing the old pipes, or leaving the old pipes and installing new ones as surface installation. Surface installations generally enable shorter renovation times than changing the pipes.

Contemporary renovation systems also enable the provision of a new coating in the existing pipes, giving them extended life expectancy. The new coating requires the old pipes to be in quite good condition, as the pipes need to be mechanically cleaned before the coating is installed.

With quite easy solutions for buildings, water consumption can be reduced. In Russia, the majority of fixtures and appliances are quite old and water is squandered. By installing water saving fixtures and appliances, water consumption can be reduced without reducing living standard and habits. By influencing people's habits, water consumption can also be reduced. For example, installing water meters in all apartments together with billing based on consumption will result in people consciously trying to reduce water consumption to minimize the water bill. Alternative water saving solutions are e.g. (Motiva 2011 & Vesiverto 2011):

- Removal of bath tubs; bath tubs takes an estimated up to 150 litres of water per bath, while an 8 min. shower consumes approx. 80 litres.
- Water saving taps and showers have a capacity of as little as 5 l/min, while traditional taps use approx. 10–15 l/min, thus reducing water consumption by two thirds.
- Water saving washing machines use less than 50 l/wash, while traditional ones use approx. 100 l/wash, thus reducing this water consumption by 50%.
- Dishwashers consume less water than washing dishes by hand; water saving machines use less than 20 l/wash, while washing dishes by hand consumes approx. 50–150 litres.
- Water saving dual flush toilets use 2.5 or 4 l/flush, while traditional use approx. 7–15 l/flush; through the installation of water saving toilets the daily water consumption can be reduced to approx. 20 l/cap/day.

According to Motiva (2011) water consumption is reduced by 15–20% when installing meters; the change comes from people's attitudes and habits.

6.2.2 District level solutions

The main objective of improving the water distribution network is to reduce leakage and the threat of failing function. Leakage can never be eliminated, only reduced; leakage rates are dependent on many external factors, such as seismic activity and climate, but mainly on the state and maintenance of the network. Smart networks enable the introduction of automatic network surveillance and leaking detection systems, where water towers and booster stations as well as valve grids are remotely monitored and controlled. Leakage is rapidly located and can be stopped, and the pressure can be optimised at all times. The implementation of a smart network could reduce the leakage to as little as 3% (depending on circumstances and maintenance), which would result in a reduced water supply demand of 123,000 m^3/day for the city of Moscow, i.e. 12 l/cap/day.

6.3 Technical analyses of renovation concepts

Currently, the average water consumption in Moscow is 272 l/cap/day; the proportion of different household activities is estimated to be the same as in Helsinki, presented in Figure 13. The fixtures and appliances are old and water is being squandered. Three renovation alternatives with the following reductions in water consumption are presented in Table 17. The water savings estimations are based on estimated current consumption and the saving solutions presented earlier[15].

- The installation of modern fixtures and appliances, reducing the water consumption to 160 l/day/occupant.
- Installation of water-saving fixtures and appliances, reducing the water consumption to 120 l/cap/d.
- Installation of apartment-specific water meters and billing based on consumption, reducing the water consumption to 100 l/cap/d.

Table 17. Estimate of the current average water consumption in Moscow as well as the saving potentials.

Category	Moscow, current	Savnings 1	Savings 2	Savnings 3
Personal hygiene	120	68	52	39
Toilet	50	27	20	20
Laundry	33	13	13	13
Food	60	46	30	23
Drinking	2	2	2	2
Others	7	4	4	4
Total	**272**	160	120	**100**

6.4 Environmental impact analysis

Water consumption rates together with waste water treatment efficiencies affect the environmental impacts of the water management sector. Reduced consumption rates also reduce the stress on water bodies, improving the hydrology of the area. The main environmental impacts from the water management sector commonly come from emissions of the waste water treatment plants, which may result in algae blooms. This is because in water bodies with excess nitrogen and phosphorous, the plants can grow without hindrance, causing “blooms”.

[15] Due to the very low reported leakage rate of Moscow, reduction in leakage is excluded from the calculations.

The chemical use for the water purification is based on the total water consumption rates, thus, when reducing the water consumption rate, the chemical demand is also reduced. Chemicals are used in the water purification process for removing pollution, including suspended particles, parasites, bacteria, algae, viruses, fungi, as well as a range of dissolved and particulate material.

The waste water treatment efficiency determines the concentration and total amounts of various pollutants emitted to the environment. The pollution originating from the wastewater is not dependent on water volume, but on population, which is why the environmental impacts from the wastewater sector is only reduced minimally due to reductions in the water consumption.

Another major environmental impact comes from the energy consumption of the water management sector. Energy is used for the pumping of water at the purification and treatment plant and in the network, as well as for heating hot water in buildings; through a reduction in the water consumption, the energy consumption will fall as well. Tukiainen (2009) has estimated the average energy consumption rates for the water management sector in some Northern European countries. The results are displayed in Table 18. The energy reductions based on reduced consumption rates are presented in Table 19.

Table 18. Average energy consumption of the water management services (Tukiainen 2009).

	Electricity [kWh/cap/a]	Heat energy [kWh/cap/a]
WWTP and sewage system	62	23
Water purification plant and distribution network	49	7
Total	**111**	**30**

Table 19. Reductions in energy demand of the treatment plants and distribution networks due to reduced water consumption.

Category	Moscow, current	Savnings 1	Savings 2	Savnings 3
kWh/cap/a	141	90	73	61
GWh/a	1 479	944	763	644

7. Modernization of waste management systems

The selected district described in Chapter 1.2.2 was utilized in the following analyses.

7.1 Current waste management systems

The annual municipal solid waste (MSW) generation in Moscow is approx. 5.5 million tonnes(Department of housing utilities and beautification of Moscow 2013, Rianovosti 2009). Moscow generates 25% of all municipal waste in Russia (REC 2007). Current Municipal Solid Waste (MSW) generation per capita in Russia is 445 kg annually (OECD 2010); it has grown from 252 kg in 1996 (Kalyuzhnyi et al. 2003). According to The Regional Environmental Center for Central and Eastern Europe (REC) the Muscovite MSW generation is approx. 10% higher than the Russian average and could, thus, be estimated at 500 kg/cap annually[16]. The waste composition in Russian urban areas is continuously becoming more similar to that of European countries, where packaging and biowaste make up for the majority of the household waste.

Of the Muscovite MSW, the majority is collected and treated as mixed MSW. The majority of this waste is landfilled (63%), about 27%[17] is incinerated (Rianovosti 2009), and 10% is recycled (Russian Heat Engineering Institute 2008). Due to lack of Muscovite waste statistics, the Finnish waste composition will be used in this study. Table 20 is based on the content of the household waste in Helsinki, Finland in 2007 and presents the estimated generation and treatment of the Muscovite waste.

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[16] This is also supported by Rianovosti (2009) estimating the total MSW generation in Moscow to 5.5 million tonnes and by REC (2007) estimating the MSW generation to 5 million tonnes; with a population of approx. 11 million this makes the annual per capita waste generation to 500 kg.

[17] Department of housing utilities and beautification of Moscow (2013) claims the incineration capacity of the city's three incineration plants to only 740 tonnes, allowing for incineration of 14% of the MSW.

Table 20. Estimation of the municipal solid waste generation and current treatment in Moscow (Statistics Finland 2008, YTV 2008).

		Total waste		Treatment	
Waste fraction	**Content**	**[kg/cap/a]**	**landfilled**	**recycled**	**incinerated**
Paper and cardboard	25 %	125	79	32	14
Bio waste	35 %	173	109		64
Glass	7 %	37	23	12	2
Metals	3 %	15	10	5	1
Wood	3 %	16	10		6
Plastics	10 %	52	33		19
Electrical & electronic equipment	2 %	12	7	1	3
Others	14 %	70	44		26
Total	**100 %**	**500**	**315**	**50**	**135**

The Muscovite waste is disposed mainly at three landfills; Timokhovo, Khmetyevo and Iksha (REC 2007). In 2008 the Russian Heat Engineering Institute estimated the number of landfills in the Moscow area to 58 legal and 109 illegal sites. The capacity of the landfills is continuously declining, and estimates of the landfills being full within 5 years are quite common (e.g. Russian Heat Engineering Institute 2008, REC 2007).

7.2 Renovation solutions

The City Programme of Moscow presents a goal of reducing the landfilled amounts of MSW from 3.2 Mt in 2010 to 1.2 Mt in 2016 (including the rejects from recycling) (City of Moscow 2011). This is a reduction of the landfilling rate from the current 63% to a staggering 22%. In order to reduce the landfilling, sorting must be increased; this can be done either by introducing on-site sorting or by increasing the mechanical sorting capacity. On-site sorting is in its infancy in Russia, which is why the successful on-site sorting of many fractions is not very feasible. However, Modern Moscow can be seen as suitable for implementing on-site sorting due to the emphasis on environmental awareness. Table 21 presents the fractions considered as recyclable and combustible.

Table 21. Recoverable waste fractions; recyclable and combustible.

Waste fraction	recyclable	combustible
Paper and cardboard	x	x
Bio waste	x	
Glass	x	
Metals	x	
Wood		x
Plastics	x	x
Electrical & electronic equipment	x	x
Others		x

As Moscow currently has neither an on-site sorting culture nor capacity at the mechanical sorting plants, sorting and recycling has to be implemented according to local circumstances. Treatment facilities for all fractions should not be built in Moscow before the sorting and collection system has proved to be able to cover the capacity of such facilities. Especially on-site sorting requires information and customisation; it takes time for people to learn and adopt. When introducing on-site sorting, people can always choose not to sort their waste if the settings are not suitable for them.

7.2.1 Building technical systems

Currently Moscow utilises mixed waste collection and the sorting of waste is done at a sorting plant. In mixed waste collection the waste fractions are quite contaminated. By introducing on-site sorting the sorting and recycling rates could be increased, allowing for local recycling, as well as recycling abroad. On-site sorting makes it possible to keep the waste fractions clean before recycling, preserving the material quality and enabling a higher recycling rate. On-site sorting requires both the facilities for sorting, such as adequate bins in the kitchen as well as containers at the collection point. In the case area, on-site sorting could be implemented as one of the first areas in Moscow.

When implementing on-site sorting, it is advisable to start with only a few easily separable fractions, preferably high value fractions such as metals and/or paper and cardboard, which already have a market demand. When increasing the number of fractions, the following order could be an alternative for Moscow:

1. metals: easily separable, high market value
2. paper and cardboard: easily separable, high market value
3. energy waste (wood, plastics, some papers and cardboard): easily separable, high market value
4. glass: easily separable, inert waste without any emissions from landfilling

5. biowaste: easily separable, but unpleasant (dirty & smelly), significant GHG emissions from landfilling
6. plastics: difficult to separate due to many different types, some homogeneous fractions easily separable (mainly PET-bottles), high energy content (can be sorted as energy waste as well)
7. WEEE: partly hazardous (should have suitable treatment), easily separable, high market value. The small waste volumes may make on-site sorting relatively expensive.

7.2.2 District level solutions

In traditional mixed waste collection, a specialised vehicle collects the mixed household waste as kerbside collection. Waste collection vehicles have high fuel consumption per kilometre; with increasing waste collection demand, the collection traffic is increased, impacting the air quality, safety and comfort of the area. The introduction of underground collection of waste leads to a drastic reduction of road transportation of waste. The system encourages source separation and supports recycling, as there can be separate inlets for several fractions of waste. The investment costs, required to build the infrastructure, are quite high, but the maintenance costs are lower than for kerbside collection. However, the energy demand tends to be higher for the automated system.

The main environmental benefit of waste recovery is the reduction of LFG emissions due to reduced landfilled waste volumes. Incineration is seen as a recovery method if the energy is utilised. Incineration of waste reduces the GHG emissions, but may well have other negative side-effects, like odour and particle emissions. Recycling, again, reduces the environmental impacts from virgin raw material production but may increase the transport distances.

Currently there are no waste recycling facilities in Moscow, but the waste is taken to other regions – Cherepovets, Kiev, Naberezhnie Chelni, Nizhniy Novgorod, Kursk, Vologda and Saint-Petersburg. However, the volumes of recyclables should be able to cover the capacity of treatment facilities in Moscow, if the recyclables are separated from the waste stream. Of course, the creation of a recycling system takes time; more sorting plants are needed while also introducing site sorting.

7.3 Technical analyses of renovation concepts

Waste sorting and treatment generates plenty of rejects, which are disposed of. In order to reach the landfilling target of 22%, all waste must be sorted, the recyclables removed and the rejects incinerated in a mass burn plant. Then the ash from the incineration would comprise approx. 22% of the generated MSW. However, mass incineration is neither the most efficient nor environmentally-friendly waste treatment method. Another alternative is to aim at sorting 78% of the waste for recovery (this is the most common way of reporting waste recovery rates in the EU, including Finland). In practise, this means a higher than 22% landfilling rate, as ash and rejects from the treatment processes are landfilled as well.

Based on the current recycling and recovery rates of Moscow (Table 20), Table 22 presents a suggested solution for reaching the target of 78% recovery of waste. In order to reach these recovery rates, the waste should be on-site sorted into at least recyclables (paper and cardboard, glass, metals and WEEE), energy waste (non-recyclable paper, some biowaste, wood, plastics and others), and landfill waste; the recyclables can be separated at a specific sorting facility.

Table 22. Estimation on the MSW treatment to reach the 22% landfilling goal of the City of Moscow. This is further referred to as “Case 2” presenting future scenario after the renovation.

	Total waste		Treatment	
Waste fraction	[kg/cap/a]	landfilled	recycled	incinerated
Paper and cardboard	125	28	74	24
Bio waste	173	36		136
Glass	37	10	27	
Metals	15	4	11	
Wood	16	3		13
Plastics	52	11		41
Electrical & electronic equipment	12	3	6	3
Others	70	15		55
Total	**500**	**110**	**118**	**272**
Total	**100 %**	**22 %**	**24 %**	**54 %**

7.4 Environmental impact analysis

The main environmental impact from the waste management sector is the GHG emissions from the final treatment of the waste, especially landfilling of organic waste. The Muscovite waste is collected as mixed waste, and taken either to a sorting plant, an incineration plant or directly to the landfill. The majority of this waste is landfilled; in order to reduce the environmental impacts, a larger share of the waste should be recovered as material or energy. Table 23 and Table 24 present the estimated emissions from the current system and the increased recovery (Case 2 as presented in Table 22). In total, the annual emissions savings from the increased recovery are approx. 382 kg CO_2e/cap.

Table 23. Emissions from landfilling; current case, increased recovery and savings from reduced landfilling (= case 2), and the difference between the current and the renovation case (case 2).

	Current		Case2		Decrease	
GHG emissions	**annual per capita**		**annual per capita**		**annual per capita**	
CO2	94	kg	33	kg	-61	kg
CH4	23	kg	8	kg	-15	kg
Total CO2e	**661**	**kg**	**231**	**kg**	**-430**	**kg**
VOC	1,535	g	0,536	g	-0,999	g
Percolation water	0,732	m^3	0,256	m^3	-0,477	m^3
BOD	0,172	kg	0,060	kg	-0,112	kg
COD	0,833	kg	0,291	kg	-0,542	kg
Cd	1,386	mg	0,484	mg	-0,902	mg
Cl	236,250	g	82,500	g	-153,750	g
Cu	0,020	g	0,007	g	-0,013	g
Cr	0,013	g	0,005	g	-0,008	g
Hg	0,044	mg	0,015	mg	-0,029	mg
Pb	1,922	mg	0,671	mg	-1,251	mg
Zn	0,230	g	0,080	g	-0,150	g

Table 24. Emissions from incineration; current case, case 2 with increased incineration and increased emissions due to increased incineration, and the increased emission rates due to incineration after the renovation (case 2) compared to the current situation.

	Current		Case2		Increase	
GHG emissions	**annual per capita**		**annual per capita**		**annual per capita**	
CO2	47	kg	95	kg	48	kg
CH4	0,000135	kg	0,000272	kg	0,000137	kg
N2O	0,000135	kg	0,000272	kg	0,000137	kg
Total CO2e	**47**	**kg**	**95**	**kg**	**48**	**kg**
SO2	0,081	kg	0,163	kg	0,082	kg
NOx	0,054	kg	0,109	kg	0,055	kg
particles <2.5 ppm[6]	5,400	mg	10,880	mg	5,480	mg
Particles, tot	16,200	mg	32,640	mg	16,440	mg
Cadmium	0,002	mg	0,004	mg	0,002	mg
Lead	0,014	mg	0,027	mg	0,014	mg
Mercury	0,149	mg	0,299	mg	0,151	mg
Dioxines	0,000	mg	0,000	mg	0,000	mg
Bottom ash	25,380	kg	51,136	kg	25,756	kg
Fly ash	9,585	kg	19,312	kg	9,727	kg

Recycling of materials aims at reducing the total environmental impacts from waste management through reduction of the landfilling rate while utilising the recovered materials. Recycling eliminates the energy demand of the production processes of virgin raw materials, which reduces the life-cycle energy demand and environmental impacts of materials and products. There are numerous estimations on the energy savings gained through recycling; dependent on e.g. technologies, efficiencies and transport distances. In Table 25 some estimates are presented combined with the energy savings possible with increased recovery (Case 2 as presented in Table 22).

- Incineration of e.g. plastics creates plenty of energy, while recycling of plastics is a very difficult process and the recovered plastic is seldom of the same quality as virgin plastic.
- Metals are inert and cannot be incinerated; on the other hand, metals are easy to recycle; the quality of the recovered material is equally good to the virgin, and the energy consumption of the recycling process is far less than that of virgin metal production.
- Paper and carton are easy to recycle, but quite heavy to transport. The energy savings from utilisation of recovered paper are quite large. Thus, the profitability is dependent on the transport distances.[18]

Glass can be recycled without reducing the quality of the material; however, the energy demand is reduced. Thus, the profitability is again dependent on the transport distances.

Table 25. Estimations on energy savings from material recycling, current and increased annual energy savings based on previously presented recycling rates.

Recyclable material	Energy savings [MWh/t]	Current [GWh/a]	Case 2 [GWh/a]
Plastics	2,5	17	81
paper	5	851	1 940
carton	3	511	1 164
glass	0,6	73	167
ferrous metals	2	94	247
non-ferrous metals	12	120	274
Total		**1 666**	**3 873**

The number of fractions highly affects the transport and energy demand, but the energy savings from recycling should easily cover this increased transport demand. Although increased recovery reduces the environmental impacts, the treatment capacities will need to be increased. If the waste cannot be treated locally, it must be transported to a treatment facility. When transporting the waste by road with modern freight trucks (25 t capacity), the energy consumption is approx. 0.17 kWh/tkm (Mäkelä 2010).

[18] As organic materials, paper and carton also generate LFG during the decomposition at the landfill, thus, it is better to find alternative treatment methods for paper and cardboard than landfilling unless LFG collection is used.

8. Cases

8.1 Pilots in Zelenograd

Some of the buildings in the selected housing district (see Chapter 1.2.2) were visited. The visit was organized by the City of Moscow and facilitated by the local municipal facility management company GUP DEZ-1, which operates most of the buildings in the district.

The purpose of the visit was to receive information about typical buildings and materials, current renovations practices as well as collect information about district energy systems. The objective was to collect information primarily about typical buildings II-18 and II-49 so as to propose renovation concepts. For this reason, brief visits were organized to see the current condition of the external walls and more thorough visits to the renovated typical buildings.

8.1.1 Buildings maintenance practices

In the district, the organization of maintenance is conducted in a typical for Moscow manner. The responsibility for buildings in terms of their maintenance, cleaning, etc. lies with the management company; the majority of the buildings are operated by a municipal company GUP DEZ-1 (state enterprise “single buyer directorate”), although some buildings are operated by privately owned management companies. The residents may choose the management company, but in practice such cases have been very rare. The area of the management companies’ responsibility is limited by the 0.5-meter wide waterproofing pavement encircling the buildings. The management companies tend to have own personnel to implement everyday routine repair services (e.g. plumbers), while more demanding works are outsourced to third-party providers. Unfortunately the competition between the third-party providers is in practice restricted.

The territories of the district are mostly managed by a specialized public company owned by the City of Moscow, the so called “single buyer directorate for communal services”. This territory-company is the main one for organizing all the beautification work in the district, cleaning the streets, renovation of sports grounds and playgrounds, repair and marking of municipal roads and pavements, animal control, channelling housing subsidies from the budget of Moscow to building management companies, construction and renovation of childcare and education facilities.

8.1.2 Building structures

The following description of the basic structures (based on renovation documentation) of the building series “II-49-04/Ю variant Д” is based on renovation documents. The II-49 is a nine-storey building with 4 design blocks and 4 apartments per floor. The floor-to-floor height is 2.7 meters. The structural scheme of the building is cross-sectional walls with “frequent” intervals of 2.7 and 3.3 meters. The expansion joint and settlement joint are combined into one.

The “cellar” is something between a basement and a crawl space, and it was about 160 cm high in the visited buildings. Basement structures for II-49 are based on precast concrete units for dry-type and non-frost-susceptible soil. The basement is intended for technical systems including transit pipelines (Figure 14). The documentation says that the household use of basements (e.g. storage) is strictly prohibited. The same apparently applies to building II-18. Some of the basements may have a concrete slab on the ground, but in most of them the floor is soil. The basement insulation is not known, but the space was not cold.

Figure 14. Pipelines in a basement.

The walls of II-49 are three-layer concrete sandwich panels (elements) with fibrolite (concrete fibreboard) insulation 350 kg/m^3 (total wall thickness – 280 mm and 320 mm for end-walls). The elements, however, differ from the Finnish concrete sandwich panels in such a way that the window and door openings, as well as the edges of the element to the outer edges of concrete and the inner and outer shells are moulded together. In other words, in the joints and in the edges of the openings there is concrete from inside to outside. These sections form very strong thermal bridges to external walls, which perhaps causes the high U-values of the external walls. The external walls of II-18 are blocks of expanded clay concrete.

An exterior wall surface (Figure 15) is either plain concrete or ceramic tiles. The outer wall elements are sealed with grout, but the seams on the outside are not covered by anything. In other words, the elements in the blocks of flats can be seen clearly.

Figure 15. Exteriors of a II-18 (on the left) and of a II-49 (on the right).

Roof structures (Figure 16) are either ventilated or unventilated ceilings. Unventilated ones are flat-roofed or gently inward-sloping roofs with heat insulation and a concrete slab over a load-bearing roof structure. A bituminous membrane is used for water isolation, but also asphalt is sometimes used according to the received information. Ventilated roofs are ridge roofs heat insulation above the ceiling. Then the rooftops are made of wood or of concrete and over that is the actual water isolation. The roof of II-49 is attic-less, so-called “open roof” with a gap of 450 mm with openings. The second option is that there is a “cold” attic with the lower flat concrete slab and an upper ribbed slab.

Figure 16. Visited roofs.

8.1.3 Building technical systems

Apartment buildings in Zelenograd are connected to the district heating system. District heating comes to the so-called distribution centres, from which heat is distributed to 4-6 adjacent buildings. There are no heat exchangers in the apartment buildings nor in the distribution centres, but the district heating water circulates in the heat distribution network of a building. Domestic hot water is heated in the distribution centres from where hot water is delivered to the buildings in single pipe systems. Typically, there are no hot water circulation systems. The cold water pipe also comes via the same distribution station.

Every “section” (a typical design element, which usually covers the layout of one entrance) has its own heat distribution installation with a jet-pump (Figure 17). Each “section” has a ring of supply and return pipes in the basement along the external parts, from which standpipes (Figure 18) rise the whole height of the building to supply the radiators placed on external walls. A return pipe collects water from several risers.

Figure 17. Heat distribution pipes in a building.

Figure 18. Standpipes rising from the cellar.

The buildings have natural ventilation systems. The exhausts are located in kitchens and in bathrooms. One exhaust unit (Figure 19) is connected to exhaust ducts on several storeys.

Figure 19. An exhaust unit in a roof.

There are also newer buildings in the district that include modern building technical systems. These buildings have mechanical ventilation with heat recovery and district heating with heat exchangers in the building. These buildings also have hot water circulation systems, and domestic hot water is produced by the heat exchangers in the building.

8.1.4 District systems

General information about district technical infrastructure was collected, although no sites were visited.

The district is supplied from local heating-only plants burning gas. There are no electricity generation facilities in the district. All the electricity is delivered. Some production will be there after renovation of the Local Heat Plants.

The water is supplied from the city of Moscow centralized water supply system .

8.1.5 Implemented renovations in buildings

There were two types of facade renovation solutions used, with ceramic tiles and with plastering. In case of façade renovations, windows are typically replaced with double-glass units.

The building II-49 featured plastered façade system “Thermomax E” (Thermomax 2013). A principle of the system is shown in Figure 20. This method is quite similar to a method also in use in Finland where extra insulation is installed on an existing exterior structure, and a new exterior surface is made after that. In Figure 21, there is shown how a II-49 type building looks after this renovation.

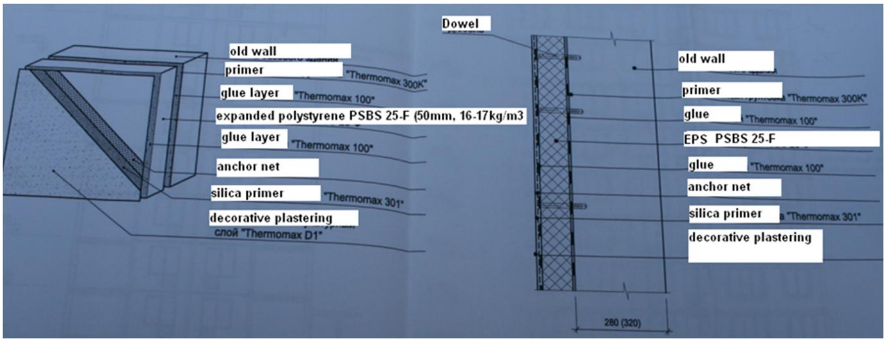

Figure 20. Thermomax-E method (Thermomax 2013).

Figure 21. A renovated II-49 building.

Another renovation solution, a ventilated façade system (Figure 22) with tiles, is widely used for buildings II-18 (Figure 23). Total insulation thickness is 120 mm of basalt fibre. Insulation consists of two layers: the density of the inner layer is 30kg/m^3 and of the outer layer 80 kg/m^3 (thickness of the outer layer 50 mm). Air permeability of the outer mineral wool layer is $30 \cdot 10^{-6}$ m^3/m·s·Pa.

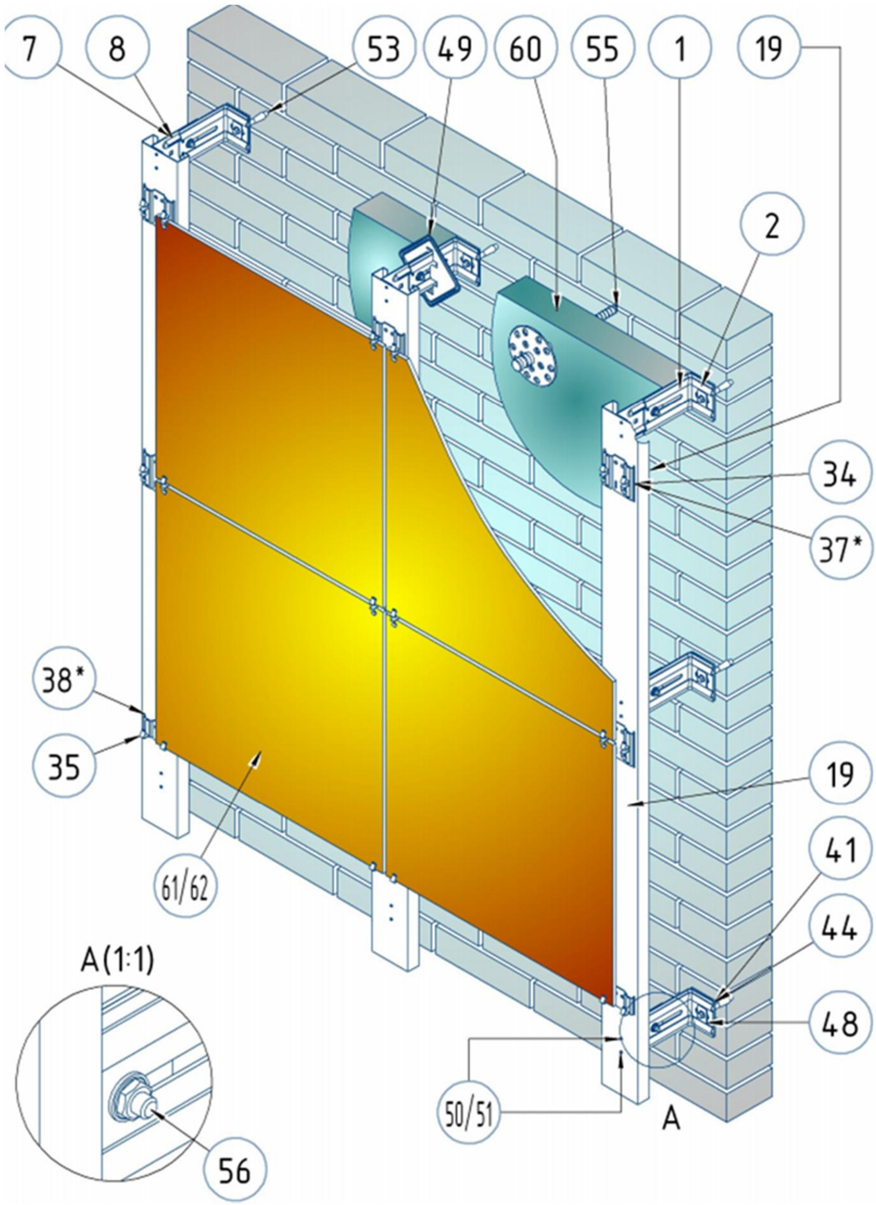

Figure 22. The principle of the ventilated facade system (Gradochist 2013).

Figure 23. A II-18 building renovated with the ventilated façade renovation system “Gradochist” (“city cleaner” in English).

Extra insulation of unventilated roof structures is achieved in a pretty much the same way as in Finland. The extra insulation is installed above the existing water insulation and the new water insulation is installed above the new structure (Figure 24). An exception to Finnish practices is that no wood is used in the structure, because it is thought that wood decays rapidly in such applications. Another significant difference is that in the centre of the inwardly inclined roofs, a “ditch” is made for the removal of water (see Figure 16 in Chapter 8.1.2).

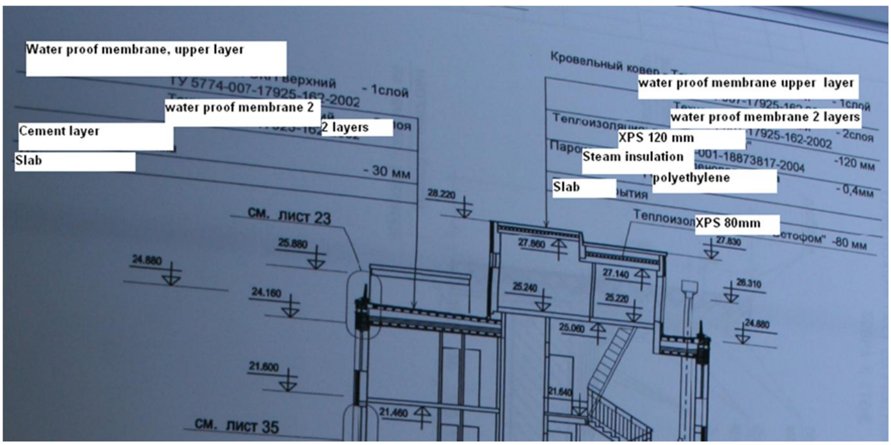

Figure 24. Renovation of the roof II-49.

Extra insulation of ventilated roof structures is achieved so that in the "attic" additional thermal insulation is installed on top of the existing roof slab (see Figure 25). The method is more or less the same as in Finland.

Figure 25. In building II-18, the floor of an attic was also insulated with XPS-based plates.

8.1.6 Possible energy-efficiency improvements for buildings

Building-specific temperature control would bring energy savings, especially if the energy renovations progress in stages. However, reducing heat losses in buildings does not bring significant savings, if the heating power cannot be reduced simultaneously. So, heat exchangers for district heating are required for each building. Then, domestic hot water can also be produced in each building. Domestic hot water consumption is also affected by a one-pipe system with hot water temperature that drops when there is no consumption. For example, in the morning the inhabitants often need to run lots of water before getting hot water. This increases both the water consumption and the heating energy used to heat domestic hot water. An alternative solution could be the installation of heat exchangers in the district heating distribution centres serving more than one building. However, this solution would require building-specific temperature control.

Changing natural ventilation into a mechanical supply/exhaust ventilation system with heat recovery may turn out to be unprofitable in terms of costs. But installing mechanical exhaust systems could be energy-efficient, if heat were recovered from the exhaust air and transferred for heating the hot water in the building.

However, the solution would require building-specific storage tanks where heat from the heat pumps would be condensed.

The façade renovation project is good to link to renovation of windows. This makes it possible to install the windows with insulation properties appropriate to those of additional thermal insulation of the facades. It would help reduce the cold bridge effect in the areas around windows. Solutions seem adequate, however, greater insulation thickness should be considered.

The applied roof renovation practices were at a good level, although greater insulation thickness should be considered.

8.2 District heating system renovation in Tallinn

There still exist numerous buildings and energy systems from the Soviet era in Tallinn, the capital of Estonia. These are similar in type to those buildings and districts in Moscow. Experiences from renovated district heating systems in Tallinn were examined and sites visited in 2011.

The district heating (DH) networks of Tallinn by dimension, i.e. by maximum/connected heat load are comparable to those of Zelenograd or to a part of it, e.g. to the part, where the hot water connection scheme is open-type (Eliseev 2011). The maximum heat load of the three largest networks of Tallinn, serving ca. 280,000 residents (Dalkia 2013) is 740 MW (Trumsi 2012), while the total connected capacity of MOEK's Zelenograd networks, serving about 201,500 residents is slightly over 1,500 MW (1299.4 Gcal/h) (Moscow Unified Energy Company 2013). This case does not aim to compare the above mentioned networks; rather the aim is to demonstrate the real energy savings achievable with major rehabilitation within a certain service area. Experiences of Tallinn DH rehabilitation are to a large extent applicable in Moscow, where the service areas presently operate quite independently from one another, which allows for a phased implementation of system transformation.

The need for rehabilitation of Tallinn DH arose in the early 1990s, when the pricing principles of the primary fuels had been changed into market-based, which unveiled significant inefficiencies in the DH chain (World Bank 2000). Raising tariffs and increasing cross-subsidization prompted some industries to build their own heat production facilities and to disconnect from the DH system, which adds to inefficiencies, as heat load density decreases.

The improvements achieved as a result of network renovation and transformation of the system from constant flow into variable flow has led to significant energy savings. The number of water changes in the DH system has been reduced substantially by switching from an open scheme of hot water connection to a closed one, which besides improved water quality contributes to elimination of internal corrosion and thus improves the reliability of network components (Hlebnikov et al. 2010). The corresponding values by years are presented in Figure 26. In addition, it was estimated that the heat consumption in buildings equipped with renovated substations was typically reduced by about 24 per cent, mostly through more accurate control (World Bank 2000).

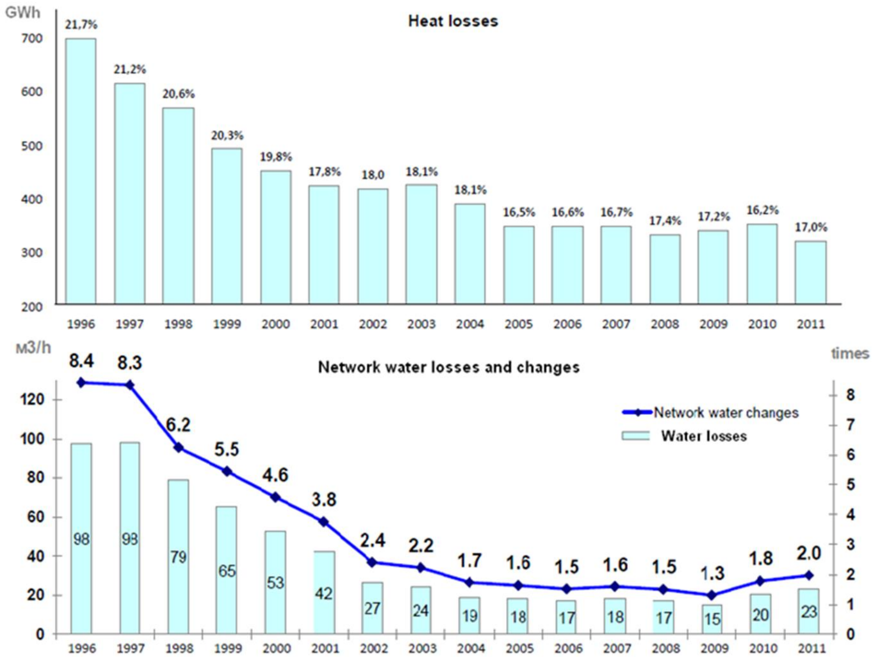

Figure 26. Heat losses, water losses and network water changes in Tallinn DH network.

Traditionally, Russian and East European district heating systems were designed for centralized temperature regulation at heat production plants, meaning that their heat output followed a pre-defined regulation curve and depended heavily on outdoor temperature, while the pumps were designed to run at constant speed to maintain constant flow of water in the DH network. Even if the temperature schedules are calculated and observed perfectly throughout the entire DH network and heat distribution substations, deployment of such a system limits possibilities for demand-side regulation (e.g. during periods when the flat is unoccupied in most cases it is impossible to switch the heating off), as the flow is required to remain constant. In case of the indirect DH connection scheme (Moscow), the typical solution is to install the heat exchangers at central (district) heat distribution substations serving a group of neighbouring buildings. In such a case, the connection between each building served and the central substation is represented by two sets of supply/return pipes (heating and hot water), which increases losses and the probability of failures.

Proponents of the East-European constant flow (Figure 27) system point out that in case of direct DH connection the equipment installed in buildings' distribution substations is simple and consumes no electricity for pumping (electricity is consumed at production plants instead), which keeps investment and maintenance costs low. Maintenance is easier also in the case of indirect DH connection with central heat distribution substations. However, proper feasibility assessment should take into account total operating costs, which include the costs of primary energy in estimating costs of losses.

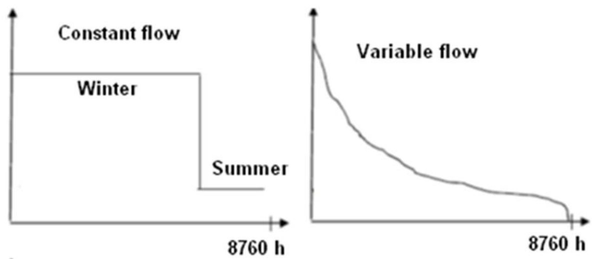

Figure 27. Duration curves for constant and variable flow designs.

In order to implement the change to variable flow, variable speed networks and circulation pumps were introduced at major production plants. In parallel, a huge number of consumer substations were replaced with modern ones (similar to those presented on **Figure 28**), equipped with heat meters, variable speed pumps and control systems. In the case of a variable flow system, where flows and pressures frequently change, there is a need for hydraulic tools and real-time control (SCADA) systems. An integrated system deployed in the Tallinn DH control centre (Figure 29), coupled with a GIS system allows for precise demand forecasting (accuracy 1%), heat losses calculations and maintenance optimization (Cowi 2013). The most critical parts of the district heating network were renovated with pre-insulated pipes.

Figure 28. Modern heat distribution substations with plate heat exchangers.

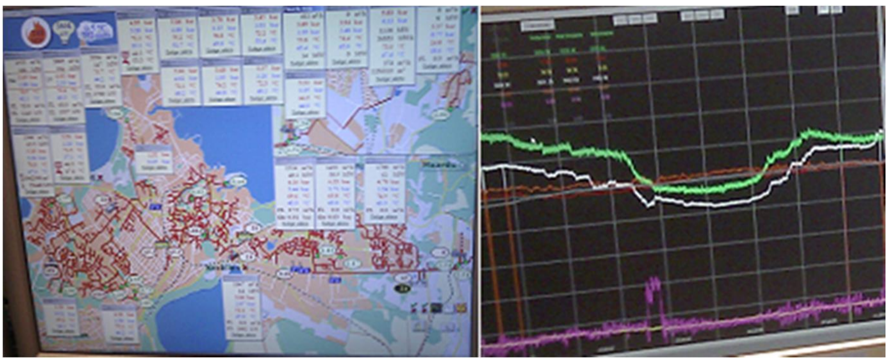

Figure 29. TERMIS system interface in control room of Tallinna Kute (right – variable flow).

The DH system of Tallinn consists of three main networks – Western, Central and Eastern. In order to improve utilization of a large-scale CHP plant located in the Eastern networks, a pumping station was built to connect Eastern and Central networks. There are six heat exchangers GX-325P (Figure 30) which allows for a total heat transfer capacity of 200 MW while keeping the networks hydraulically isolated (there is a difference in elevation between parts of the city).

Figure 30. Heat exchangers at Laagna pumping station.

According to a customer survey conducted by the Tallinn DH-network operator in 2011, the quality of products and service was good (score 4.6 out of 6).

9. Conclusions and recommendations

The need for modernization of Moscow multi-family apartment buildings is evident. Their technical condition is generally bad and their energy-efficiency usually poor. In addition, the energy losses in all phases of the energy chain (from production through distribution to usage) are big. What is more, the water consumption is high. Sustainabilty should be considered when upgrading the buildings and districts.

This publication mainly concentrates on the technical principles and alternatives of different renovation solutions for the Moscow apartment buildings. The analyses are focused on energy analyses and environmental impacts both in the building and at the district level. A typical Moscow housing district was selected to be analysed.

Besides the technical analyses a brief analysis of non-technical obstacles was done. Through stakeholder workshops it was found out that there are several challenges in terms of ownership of apartments, bank systems, regulations etc. that need to be thoroughly understood before one is able to enter the market.

Energy analyses of the selected renovation concepts were conducted by first developing a building model in Winetana program. This model was the starting point for generating different renovation models of the same building. The different building models were subsequently used for modelling their equivalent district concepts. Each district concept was further used in different scenarios of energy production for measuring emission outcomes. The following discoveries emerged from the energy and emission analyses.

At the building model level, the most common apartment building type (II-18) was selected for the energy analysis. Three alternative renovation concepts were selected for closer analysis, named Basic, Improved and Advanced renovations. The renovation cases were manipulated in such a way that each of them became an improvement on the previous one in terms of total annual energy consumption. The basic renovation refers to minimum, low-cost or easy-to-do renovation measures. The improved renovation solutions outputs better energy or eco-efficiency. The advanced renovation suggests the most progressive solutions. The building level energy saving potential would be up to 68% for heating energy and 26% for electricity based on the calculations.

Energy chain optimizations of various technology combinations (including utilization of renewable energy) with different energy renovation scenarios of building stock were carried out. Different improvement scenarios in terms of energy demand and emissions were analysed. The district scenarios which have also (as at the building level) been named Current, Basic, Improved and Advanced comprise the corresponding buildings from the II-18 building renovation cases. 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.

Considerable energy savings could be achieved in the district considered with different district modernization scenarios. Even with the basic district concept, the total annual electricity demand would become 23.7% less, and the total annual heating demand 42.4%. With the improved district concept, the corresponding reductions would be 32.5% and 55.2 %. With the advanced district concept, potential reductions would be 34.3% for electricity demand and 72.1% for heating demand.

Buildings are significant energy consumers in the district, which means that they also have the greatest potential for reducing energy consumption and emissions. As the calculations showed, by merely a basic renovation of the building, heating demand would be reduced to almost a half, which would have direct economic and ecological consequences.

As for the emission analyses, switching from natural gas to biogas would result in lowering the levels of generated CO_2- and TOPP-equivalents but increasing the generation of SO_2-equivalents and particulates. A better solution would then be to produce energy from renewable technologies such as ground source heat pumps, solar panels, solar collectors or wind turbines.

Currently the average water demand in Moscow is 272 l/cap/day. With different solutions, this could be reduced even to 100 l/cap/day. By reducing the water demand, the hot water consumption will fall as well, thus reducing the energy demand for water heating. The energy demand of the water plants and distribution networks will also fall due to a lower pumping volume. Currently the energy demand of water treatment plants and distribution networks in Moscow is 141 kWh/cap/a (1479 GWh/a). There the savings could be between 36% and 56% depending on the technical renovation solution.

Based on the current recycling and recovery rates of Moscow, a proposed solution for reaching the target of 78% recovery of waste was presented. In order to reach these recovery rates. the waste should be on-site sorted into at least recyclables, energy waste, and landfill waste; the recyclables can be separated at a specific sorting facility. As Moscow currently has neither an on-site sorting culture nor the capacity at the mechanical sorting plants, the sorting and recycling should be implemented according to the local circumstances.

The main environmental impact from the waste management sector is the GHG (greenhouse gas) emissions from the final treatment of the waste. The waste is collected as mixed waste, and taken to either a sorting plant, an incineration plant or directly to the landfill. The majority of this waste is landfilled (63%), 10% is sorted for recycling, and 27% incinerated. In order to reduce the environmental impacts, a larger share of the waste should be recovered as material or energy.

In order to analyse fully the renovation solutions' real energy efficiency potential, in-depth financial analyses are needed. This will be the next step in this research.

9.1 Target setting from the technical point of view

The results of the project could be used for setting targets in the process of making Moscow environmentally friendly and raising the comfort of its habitants. Despite the absence of economic evaluations in the proposed solutions, a rough expert evaluation of the realistically achievable measures has been taken into account when setting the following targets:

The proposed targets at the building level:

- reduction of heating consumption by 60%
- reduction of electricity consumption by 20%
- reduction of water use by 60%
- sorted waste for recycling and incineration 75%.

In order to achieve overall improvements, the following improvements are needed at a district level:

- improvement of water pipes, to reduce leakages in pipes
- improvement of waste systems for recycling and recovering (waste infrastructure)
- improvement of district heating network in order to reduce heat losses.

As can be seen from the study on energy consumption evaluation, the potential for reducing heating demand is enormous, and, according to our estimates, could equal one third of the original value. This can be greatly affected by the reduction in heat losses. Practically, this means improving insulation, installing heat recovery to ventilation and improving water appliances and domestic water equipment in buildings. We therefore suggest that, by the use of these measures, the heating demand in buildings and improve water savings can be reduced by 60%. Furthermore, reducing heat demand would directly affect the primary fuel consumption, which in turn would reduce emissions. Water savings would affect the water and wastewater treatment plants in terms of lower operational requirements.

The main part of the heat in Moscow is produced in CHP plants. The suggested improvements listed above would mean a major shift in the current demand ratio between heat and electricity, which might influence the optimal utilization of the existing CHP plants.

The growing amount of waste has been a worldwide problem for long. It is, therefore, suggested that improved waste management is to be introduced as quickly as possible. Better waste management would lead to rare or hazardous materials being recycled or treated. There is a great potential in influencing the waste management in Moscow. It is important to note that actions are required simultaneously both on the infrastructural level and individual level. People will need to know that their recycling efforts lead to recycling in the end.

Consumers need to be involved in the process of creating a more environmental friendly Moscow by giving them responsibilities for and information on how to reduce their energy and water consumption, and how to be part of reducing waste going to landfill.

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Appendix A: Renewable energy and emission calculations

Renewable energy calculations

As regards generating energy from solar radiation, the photovoltaic potential estimation utility PVGIS was used for estimating solar irradiation in Moscow. According to this, the average annual solar radiation on a horizontally inclined surface is 986 kWh/m^2 and 1 154 kWh/m^2 for an optimal surface in Moscow. The optimal surface has an inclination angle of 39° and is south-oriented. (JRC 2012)

The annual electricity generation of the solar photovoltaic (PV) system was calculated as follows. The CIS system that was used would result in an annual generation of 1060 kWh/kWp (temperature and reflectance losses included), which means that for every kW-peak power installed we get 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 (JRC 2012, Gregg et al. 2005). The peak power per square metre ratio for the system was presumed to be 0.125 kWp/m^2 (EPIA 2011). The same number was multiplied with half of the roof surface area of the buildings in the district for estimating the total yearly generation of electricity. Half of the roof area of the district was accounted for by 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 production from the PV system is 1,655 MWh in a year.

Solar collectors are estimated to cover 30% of the energy for heating domestic water, which is a rough estimate based on the results from the Ekoviikki report (Solpros 2004). The performance of solar thermal heat (STH) systems 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 annual demand for domestic water heating for an Advanced building will fall 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 be 20,011 MWh/a, which is a more than 14% overall decrease when including solar thermal heating. The total surface of solar collectors needed will then be 8,011 m^2, which was calculated by assuming that one square metre of collector produces 400 kWh in a year. This surface would be around 26% of the total roof area of the district (the tilting of the collectors is not accounted for). 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 fact that solar panels are covering half of the roof area in the district has to be taken into account in this case.

The ground source heat pumps (GSHP) were assumed 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 number of boreholes needed for the ground source heating pumps. The number of boreholes was calculated by calculating the total pipe length needed and dividing this by twice the maximum depth of a borehole (200 m). Based on the heating energy Dh demanded, the length L of the pipe is calculated by equation 1:

$$\mathrm{L} = \mathrm{Dh}/\mathrm{G} \times 0{,}67 \qquad (1)$$

The term G denotes the extractable amount of energy from the 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 comes from the ration of heat production for a GSHP with a COP value of 3. The pipe length can be twice the length of a borehole, since it is supposed a make a loop at the end and return back to the surface again. This means that the total amount of boreholes was calculated by dividing the total pipe-length for the whole district by 400.

Each borehole is to be placed 15 metres from the next one, which means that one borehole occupies at most 177 m^2 of ground surface. It has been considered that each II-18 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 report were, for convenience, considered to contain only II-18 buildings, which means that the number of buildings in each scenario is 67. This number was later used for calculating how large an area is required around each building for the installation of boreholes. (SULPU 2012.)

Emission calculations

The values for emissions per produced energy (kg/MWh) in this study were retrieved from GEMIS (Global Emission Model for Integrated Systems software) 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 heating 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:

$$\varepsilon'_{\mathrm{hi}} = \frac{\mathrm{E_h}}{\mathrm{n_h}} \qquad (2)$$

$$\varepsilon_{hi} = \frac{\varepsilon'_{hi}}{\varepsilon'_{hi}+\varepsilon'_{ei}} \times \varepsilon_i \qquad (3)$$

$$\varepsilon'_{ei} = \frac{E_e}{n_e} \qquad (4)$$

$$\varepsilon_{ei} = \frac{\varepsilon'_{ei}}{\varepsilon'_{hi}+\varepsilon'_{ei}} \times \varepsilon_i \qquad (5).$$

In equation 2, 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 equation 4. In equation 3, 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 (from Table A1-3). The corresponding value for the partial fraction of a certain emission type coming from electricity generation is calculated according to equation 5.

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 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 A-1 to Table A-3.

Values for the other energy technologies are found in Table A-4.

Table A-1. Corresponding emissions for heat and electricity generation based on the partial substitution method for a 1 heat/0,85 electricity natural gas CHP plant.

Partial emissions natural gas CHP		
Emissions into air	Heat (kg/MWh)	Electricity (kg/MWh)
SO_2-equivalent	0.592	1.160
TOPP-equivalent	1.303	2.556
Particulates	0.024	0.047
Greenhouse gases		
CO_2-equivalent	285.192	559.415

Table A-2. Corresponding emissions for heat and electricity generation based on the partial substitution method for a 1.5 heat/1 electricity natural gas CHP plant.

Partial emissions biogas CHP		
Emissions into air	Heat (kg/MWh)	Electricity (kg/MWh)
SO_2-equivalent	1.313	2.020
TOPP-equivalent	0.630	0.969
Particulates	0.052	0.081
Greenhouse gases		
CO_2-equivalent	25.716	39.564

Table A-3. Corresponding emissions for heat and electricity generation based on the partial substitution method for a 1 heat/0.345 electricity waste incineration CHP plant.

Partial emissions waste incineration CHP		
Emissions into air	Heat (kg/MWh)	Electricity (kg/MWh)
SO_2-equivalent	0.4	0.3
TOPP-equivalent	0.68	0.54
Particulates	0.006	0.004
Greenhouse gases		
CO_2-equivalent	36	29

Table A-4. Emission coefficients according to produced energy for the different types of facilities or technologies.

Emissions (kg/MWh) (GEMIS)	Russia electricity 0-level; IEA numbers	Natural gas CHP plant, 1 heat/0,85 electricity (MWh)	Solar photovoltaic (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

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Series title and number

VTT Technology 82

Title	**Energy-efficient renovation of Moscow apartment buildings and residential districts**
Author(s)	Satu Paiho, Rinat Abdurafikov, Åsa Hedman, Ha Hoang, Ilpo Kouhia, Malin Meinander & Mari Sepponen
Abstract	The majority of Moscow housing stock has been built after World War II and needs modernization. This publication concentrates on energy-efficient and sustainable renovation and modernization of selected Moscow housing stock. The emphasis is on technical solutions and their energy-saving potentials and possible reduction in emissions. In addition, the publication includes an analysis of the non-technical issues and obstacles to building renovation in Moscow. Relevant pilot visits are also presented. During building renovation, existing and future criteria for sustainability should be taken into account. Sustainability criteria for energy-efficient renovations of Moscow apartment buildings and districts were developed based on criteria developed for new residential districts in Saint Petersburg. The criteria setting includes criteria for planning structure/functional planning, the surrounding terrain, buildings, transport solutions, waste disposal and energy supply. A typical Moscow residential district was selected for analysis. The pilot district was estimated to contain about 13,800 inhabitants in total, which is about 0.12 % of the total number for Moscow. The total building floor area of the district is about 327,600 m2, and the total roof area about 31,000 m2. First, a state-of-the-art was produced of energy performance, and water and waste management of the buildings and of the district. Then alternative energy renovation concepts reducing the environmental impacts of the buildings and the district were developed and analysed. The building renovation concepts, named Basic, Improved and Advanced, were adjusted in such a way that each of them becomes an improvement on a previous one as regards the total annual energy demand. The basic concept refers to minimum, low-cost or easy-to-do renovation measures. The improved renovation concept outputs better energy or eco-efficiency. The advanced renovation concept suggested the most progressive solutions. Based on the calculations, the building level energy saving potential was up to 68% for heating energy and 26% for electricity. At the district level, different energy renovation scenarios were analysed in terms of energy demand and emissions. The district scenarios were also called Current, Basic, Improved and Advanced. Considerable energy savings could be achieved in the district considered using different district modernization scenarios, of up to 37% of the electricity demand and up to 72 % of the heating demand. As for the emission analyses, switching from natural gas to biogas would result in lower CO2-equivalent emissions while increasing SO2-equivalent emissions and particulates. A better solution would then be to produce energy from renewable technologies such as ground source heat pumps, solar panels, solar collectors or wind turbines which, in comparison, would result in fewer emissions overall. Currently, the average water demand in Moscow is 272 l/cap/day. With different solutions, this could be reduced even to 100 l/cap/day. Based on the current recycling and recovery rates of Moscow, the target of 78% recovery of waste was suggested. The main environmental impact from the waste manage-ment sector is the greenhouse gas emissions from the final treatment of the waste. In order to reduce the environmental impact, a larger proportion of the waste should be recovered as material or energy.
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Julkaisun sarja ja numero

VTT Technology 82

Nimeke	**Energiatehokkaat korjausratkaisut Moskovan asuinrakennuksille ja -alueille**
Tekijä(t)	Satu Paiho, Rinat Abdurafikov, Åsa Hedman, Ha Hoang, Ilpo Kouhia, Malin Meinander & Mari Sepponen
Tiivistelmä	Valtaosa Moskovan asuinrakennukannasta on rakennettu toisen maailmansodan jälkeen ja tarvitsee modernisointia. Tämä julkaisu keskittyy valitun Moskovan asuinalueen energiatehokkaaseen ja kestävän kehityksen mukaiseen korjaamiseen ja modernisointiin. Pääpaino on teknisissä ratkaisuissa ja niiden energiansäästöpotentiaaleissa ja päästöjen vähentämismahdollisuuksissa. Lisäksi julkaisussa analysoidaan Moskovan rakennusten korjaamiseen liittyviä muita näkökulmia. Julkaisussa esitellään myös vierailukäynneillä tehtyjä havaintoja samantyyppisistä rakennuksista. Korjausrakentamisessa tulisi ottaa huomioon olemassa olevat ja tulevat kestävän kehityksen mukaiset kriteerit. Kestävän kehityksen kriteeristö Moskovan asuinkerrostalojen ja asuinalueiden energiatehokkaaseen korjaamiseen kehitettiin Pietarin uudisrakennusalueille tehdyn kriteeristön pohjalta. Kriteeristö sisältää rakennus- ja aluetason kriteerit rakennusten korjaamiselle, ympäröivälle maastolle, alueen liikenneratkaisuille, jäte- ja vesihuollolle sekä energian tuotannolle ja jakelulle. Analysoitavaksi valittiin tyypillinen asuinalue Moskovasta. Tällä alueella asuu arviolta 13 800 asukasta (noin 0,12 % Moskovan koko väestöstä). Alueen rakennusten kokonaiskerrosala on noin 327 600 m2 ja kokonaiskattopinta-ala noin 31 000 m2. Ensiksi muodostettiin käsitys alueen ja sen rakennusten nykyisestä energiatehokkudesta sekä vesi- ja jätehuollosta. Sitten kehitettiin ja analysoitiin vaihtoehtoisia energiakorjauskonsepteja, jotka vähentävät rakennusten ja alueen ympäristövaikutuksia. Rakennustason korjauskonseptit nimettiin peruskonseptiksi sekä parannelluksi ja ke-hittyneeksi konseptiksi. Ne valittiin siten, että seuraava taso vähentää aina vuositason kokonaisenergiantarvetta. Peruskonsepti viittaa edullisiin ja helposti toteutettavissa oleviin minimikorjaustoimenpiteisiin. Paranneltu korjauskonsepti johtaa parempaan energia- tai ekotehokkuuteen. Kehittynyt korjauskonsepti on vaihtoehdoista edistyksellisin. Tehtyjen laskelmien perusteella rakennustason energiansäästöpotentiaali on lämmitysenergialle jopa 68 % ja sähköenergialle 26 %. Aluetasolla eri energiakorjausskenaariot analysoitiin energiantarpeen ja päästöjen perusteella. Alueskenaariot nimettiin rakennustasoa vastaavasti: “nykyinen”, “perus”, “paranneltu” ja “kehittynyt”. Merkittäviä energiansäästöjä voidaan saavuttaa myös aluetasolla eri korjausskenaarioilla. Energiansäästö voi olla sähköntarpeessa jopa 37 % ja lämmöntarpeessa jopa 72 %. Päästöanalyysien perusteella siirtyminen energiantuontannossa maakaasusta biokaasuun johtaisi alempaan tasoon hiilidioksidipäästöjen osalta, mutta kasvattaisi rikkidioksidi- ja pienhiukkaspäästöjä. Tätä parempi ratkaisu olisi tuottaa energiaa uusiutuvia energialähteitä hyödyntävillä teknologioilla, kuten maalämpöpumpuilla, aurinkopaneeleilla, aurinkokeräimillä tai tuuliturbiineilla, jotka aiheuttaisivat pienemmät kokonaispäästöt. Nykyään keskimääräinen vedentarve Moskovassa on 272 litraa asukasta kohden vuorokaudessa. Eri ratkaisuilla tämä voitaisiin pudottaa jopa sataan litraan. Moskovan nykyisten jätteiden kierrätys- ja hyötykäyttömäärien perusteella projektissa asetettiin jätteiden hyödyntämisen tavoitteeksi 78 %. Jätehuollon tärkeimmät ympäristövaikutukset ovat kasvihuonekaasut jätteiden loppukäsittelystä. Jotta näitä ympäristövaikutuksia voitaisiin vähentää, nykyistä suurempi osa jätteistä olisi hyödynnettävä materiaalina tai energiana.
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