

Title Energy saving potentials of Moscow apartment
buildings in residential districts

Author(s) Paiho, Satu; Hedman, Åsa; Abdurafikov, Rinat;
Hoang, Ha; Sepponen, Mari; Kouhia, Ilpo;
Meinander, Malin

Citation Energy and Buildings. Elsevier.
Vol. 66 (2013) November issue, pages 706 - 713

Date 2013

URL <http://dx.doi.org/10.1016/j.enbuild.2013.07.084>

Rights Post print version of the article. This article may be
downloaded for personal use only.

<p>VTT http://www.vtt.fi P.O. box 1000 FI-02044 VTT Finland</p>	<p>By using VTT Digital Open Access Repository you are bound by the following Terms & Conditions.</p> <p>I have read and I understand the following statement:</p> <p>This document is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of this document is not permitted, except duplication for research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered for sale.</p>
---	---

Energy saving potentials of Moscow apartment buildings in residential districts

Satu Paiho¹, Åsa Hedman, Rinat Abdurafikov, Ha Hoang, Mari Sepponen, Ilpo Kouhia,
Malin Meinander

VTT

VTT Technical Research Centre of Finland, P.O. Box 1000, FI-02044 VTT, Finland

¹ Corresponding author, Satu.Paiho@vtt.fi, +358-50-3315160

Abstract

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

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

potentials for three different renovations concepts were estimated. In addition, non-technical barriers to energy efficient renovations are discussed.

Keywords: Apartment buildings, energy savings, building renovations

1. Introduction

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

According to national statistics service the share of dilapidated and emergency-state housing is around 3% of the total area of the Russian housing stock [2]. However, it is estimated that more than 290 million m² or 11% of the Russian housing stock needs urgent renovation and re-equipment, 250 million m² or 9% should be demolished and reconstructed [3]. Some 58-60% of the country's total multi-family apartment buildings are in need of extensive capital repair [4].

In 2005; the Russian residential, public, and commercial buildings were responsible for 144.5 Mtoe (million 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 [5]. Residential buildings are evaluated to have the largest

energy savings potential out of all building types. The largest part (67%) of the energy savings could be implemented through the more efficient utilization of district heating in space and water heating. An estimated 60% of the Russian district heating network is in need of major repair or replacement [6]. The investment needs for rehabilitating the district heating systems in Russia are estimated at US\$ 70 billion by year 2030 [7].

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

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

2. The Moscow Housing Stock

Construction in Russia [2] state that the total Russian housing stock in terms of total residential floor area was 3177 million m² in 2009. Total area of the housing stock per capita was 22.4 m².

According to the statistics from 2004, 95% of the Moscow dwelling space is built after World War II, from which 52% of the residential buildings were built during 1946-1975 and 43% in 1976 or later. According to Rosstat [2], there were 39.801 residential buildings in

Moscow in 2009. The amount of residential buildings equals 3,835,000 apartments and the total floor area of 214 million m². The average floor area of an apartment in Moscow was 55.8 m² and the average number of residents per apartment was 2.8. The figures do not account for administrative expansion of Moscow implemented in summer 2012.

2.1. Typical apartment buildings in Moscow

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

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

- First generation is five-storey buildings often called *khrushchevky*. Khrushchevky have been built between 1959 and 1969 and about 10% of residential buildings belong to this category. Typically their state is quite poor nowadays and they are situated in fairly attractive areas, not far from city centres.
- Second generation buildings were constructed between 1961 and 1975. The number of storeys varies but nine-storey buildings are the most common. The buildings are long and there are usually five to nine staircases in each. The external walls are different lightweight concrete structures without separate thermal insulation material. The housing norms of 1963 regulated their design and construction. The dwellings in this category are more comfortable than those in the first-generation buildings.

- Third generation buildings were built mainly after 1975 in the suburbs. Large elements and prefabricated modules were used. These buildings are nine-storey or higher, tower type blocks of flats or long, narrow buildings with four to seven staircases. The external walls are usually 32-35 cm thick expanded-clay lightweight concrete.

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

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

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

2.2. The selected housing district

A typical residential district was selected to be analyzed in the project. The selected district mostly represents 4-th Microrayon of Zelenograd, Moscow (longitude 37° east and latitude 55° north). Zelenograd is located about 35 km to the North-West from Moscow City centre. The district dimensions are approximately 1x0.5 km. It represents a typical residential district of Moscow and Moscow region with high-rise apartment buildings constructed for the most part in 1960's and 1970's. The district is heated with district heating. Renovation of such buildings and districts may be needed in the near future.

The apartment buildings in the area can be divided into groups according to the building series: II-57, II-49, AK-1-8, II-18 and Mr-60, which are apartment buildings build between 1966 and 1972. Each building series represents a specific building design [8]. There are also other apartment buildings, schools, kindergartens, shops, a bank in the area, but since this project concentrates on modernisation of buildings, these newer buildings from the 90's and from the beginning of 2000 are excluded from these energy calculations. The more detailed data about the older apartment buildings is presented in Table 1 and these buildings were the main target of the first calculations of this study. After the initial analysis the most common building type II-18 was selected for further analyses.

[Table 1]

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 m². The number of residents is estimated based on the assumption that the average occupancy rate per flat is 2.7 persons [3].

3. Principles of the energy analyses

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

The general methodology of energy analyses is presented in Figure 1. At first the state of the art was studied for both old apartment buildings and the entire residential district in the Moscow region. This means that the typical apartment building parameters were identified, and an example district was selected for the calculations. Most of the buildings in the example district are built between 1966 and 1972. A few different typical apartment building types was studied: their monthly energy consumption levels were calculated, and then from those results the energy demand of the entire district was calculated including also the energy demands for waste and water management and street lighting. The next step was to evaluate the energy saving potentials that can be achieved with renovating these old apartment buildings. This was done by calculating different scenarios for renovated apartment buildings. As a result knowledge of total energy consumption levels in different scenarios in the typical Moscow residential district was achieved.

[Figure1]

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

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

4.1. The energy consumption of buildings

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

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

Typical building parameters in Russia and in Moscow were used in the calculations. We used the value 18°C in our calculations as the default indoor temperature for living spaces in multi-family buildings located within the case districts. According to Russian construction norms on thermal performance of buildings, the value of building air tightness at 50 Pa pressure difference (n_{50}) must not exceed 2 h⁻¹ for mechanical and 4 h⁻¹ for natural ventilation. However, based on the results of field measurements with blower door tests

[11] for a 9-storey building, which represents closest to the buildings in the case district – the average values were 7.5 h^{-1} (vents sealed) and 6 h^{-1} (vents and windows sealed). In our calculations we used a rather conservative estimate of air density factor n_{50} , 6.5 h^{-1} so that it represented recent improvements in air tightness of windows due to massive installation of plastic-aluminium windows by residents of apartment buildings in Russia.

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

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

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

As for the part of internal heat gains, the following values were used based on the experiences of Finnish experts [14]: 0.96 kWh/m³/month from domestic hot water (30% of the heat demand [15] for hot water), 1.42 kWh/m³/month from electrical equipment and 0.4 kWh/m³/month from people.

The calculated energy consumptions per building floor area are presented in Table 2. According to the calculations the average heating energy consumption of typical old apartment buildings in Moscow was 217 kWh/m²,a and the average electricity consumption 42 kWh/m²,a. The result is quite well in line with some reference studies, e.g. [13]. The differences in energy consumption calculations may result from the divergence of the base data. Russian structures and used system solutions of buildings may vary in different buildings (even within same building series) or even within single buildings. Moreover, according to the Moscow city program [16] “Energy Conservation in Construction in the City of Moscow During 2010-2014 and Until 2020” the thermal insulation of buildings comply with norms only ‘on the paper’, which may also explain the differences in results. Also the air tightness of the building has a big significance.

[Table 2]

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

[Figure 2]

4.2. The district level energy consumption

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

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 [17]. Outdoor lighting was estimated to consume 350 kWh per lamp in a year, while a quote of $0,167$ lamps per inhabitant was used [19], [20]. Taking these into account the total annual heating energy demand without distribution losses for the district is 72.2 GWh and the total annual electricity demand without transmission losses 17.8 GWh , respectively. Adding the losses mentioned above will result in the total annual heating demand of 90.2 GWh and the total annual electricity demand of 19.5 GWh .

Heating energy in Moscow is up to 70% generated by large scale combined heat and power (CHP) plants and they are usually using natural gas [16]. Assuming that the heat and the power for the examined district are produced by a natural gas CHP plant, the related annual CO_2 -equivalents are for the heating $24.3 * 10^6 \text{ kg/a}$ and for the electricity $9.9 * 10^6 \text{ kg/a}$ (Table 7), respectively. These equal to the annual total CO_2 -equivalent of

$34.2 * 10^6$ kg/a and the total per person of $2.5 * 10^3$ kg/a/p.p. As a comparison, the heating of buildings in Finland accounted for $3.97 * 10^9$ kg of CO₂-equivalents in 2009 which per citizen would correspond to 0.74 kg in a year. This would be less than half of the corresponding values for case district (1,77 kg/a/p.p).

5. The energy analyses of alternative building renovation concepts

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

[Table 3]

The annual results from the simulations are shown in Table 4, from which emerges that each case consumes less energy than the previous one. The same goes also for heat consumption while the consumption of electricity is higher for the Advanced-case in comparison with the former Improved-case. The cause of this was the change of the ventilation system to a mechanical one consuming more electricity. However, since the improved ventilation system recovered 60% of the heat of the exhaust air that otherwise would have been lost it resulted in energy savings in the end in form of heat. In Table 5,

there are the results presented as percentages by comparing each value of the cases to the same value of the State of the art-case (the current case). Table 6 represents the yearly energy consumption per floor area for each of the cases.

[Table 4]

[Table 5]

[Table 6]

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

[Figure 3]

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

The space heating is showing a steep decrease again between the Improved- and the Advanced-case, partially because of changes in the U-value and partially since the losses

are being recovered by the ventilation system (not the same losses as in Figure 3).

However, the water heating curve between the same cases is behaving oppositely which results in only a smaller change in the total heat curve.

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

Grouping all the energy consumption together the curve is steep from the Current to the basic case, while the development is less steep and constant for the rest of the cases.

What can be observed from these results is that space and water heating is consuming the larger part of the total energy. A considered amount of the consumption can therefore be reduced through improving insulation (U-values) and reducing water consumption habits. Also, heat recovery from the exhaust air is proven to be a way of saving energy significantly but results in increased electricity consumption.

In Table 7, there are listed the CO₂-equivalent greenhouse gases for different renovation concepts assuming that the energy is produced by natural gas CHP plant. Even the Basic renovation concept reduces the total CO₂-equivalents by 36%. The reduction with the Improved concept is 48% and with the Advanced concept 66%, respectively.

[Table 7]

6. Non-technical barriers to energy efficient renovations

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

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

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

In residential buildings mechanical ventilation is neither allowed nor prohibited, and the officials in charge of issuing building permits or parties approving renovation plans refrain from assuming responsibility in the absence of clear official guidance as to how the connection capacity of space heating system should be dimensioned and mechanical

ventilation systems designed, installed and maintained, even when there is an understanding that natural ventilation is less energy-efficient especially in high-rise residential buildings than a mechanical system with heat recovery.

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

6.1. Political and administrative obstacles

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

administrations to conduct the renovation of the apartment building and hence- society expects that the state will conduct (finance) the renovations of the formerly privatized apartment buildings [24].

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

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

6.2. Social aspects

In the renovation business, social aspects are vital and need to be considered in advance. The distrust of apartment owners is the first obstacle an investor will face at the beginning of the project. A possible solution is to partner with local authorities to keep the residents informed, similar to the current budget co-funded renovation practice in Moscow and, ideally, involve the residents into the planning process. This way, different kind of rumours

and disinformation of residents can be efficiently managed, despite the fact that it is common for Russians not to trust the authorities, institutions, builders, etc. This distrust is also one of the causes of passivity on the part of people in joint planning activities (e.g. public hearings of renovation projects). Therefore, the involvement of residents, openness, transparency and the possibility of the residents influencing the decision making is important for success.

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

7. Discussion

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

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

The district heating network has a big potential for improving the energy efficiency of Moscow, because there are lots of heat losses in the heating network present day. One important renovation target is to install completely automatic individual substations in every building and so pass from the old four-pipe to new two-pipe district heating systems [27] with heat exchangers enabling control of heat distribution into buildings and apartments based on the actual heat demand. On the building level, the air tightness of the structures is one key issue that needs to be addressed in the retrofit solutions. Based on this study, the building level energy savings potential for the heating energy is up to 68% and for the electrical energy up to 30% based on these calculations. In addition, the CO₂-equivalent greenhouse gases may be reduced up to 65%.

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

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

Acknowledgements

The authors wish to thank the Finnish ministry of foreign affairs for funding this research.

References

- [1] Ministry of Energy of the Russian Federation, Energy strategy of Russia for the period up to 2030, 2010, 172 p. ISBN 978-5-98420-054-7 [Accessed Jan. 21st, 2013: [http://www.energystrategy.ru/projects/docs/ES-2030_\(Eng\).pdf](http://www.energystrategy.ru/projects/docs/ES-2030_(Eng).pdf)]
- [2] Construction in Russia, 2010. Rosstat. (in Russian) [Accessed June 1st, 2011: http://www.gks.ru/bgd/regl/b10_46/lssWWW.exe/Stg/05-09.htm]
- [3] United Nations, Country profiles on the housing sector. Russian Federation. New York and Geneva, 2004. 123 p., ISBN 92-1-116917-8. [Accessed Jan. 10th, 2013: http://www.unece.org/fileadmin/DAM/hlm/documents/2005/ECE/hbp/ECE_HBP_131.e.pdf]
- [4] International Finance Corporation (IFC) & European Bank for Reconstruction and Development, Financing Capital Repairs and Energy Efficiency Improvements in Russian Multi-family Apartment Buildings, Key Conclusions and Recommendations, 2012, 32 p. [Accessed Jan. 24th, 2013: http://www1.ifc.org/wps/wcm/connect/3f9bbb804cc01dfeadd0edf81ee631cc/Publication_RussiaRREP-AppartmentBuildings-2012.pdf?MOD=AJPERES]
- [5] I. Bashmakov, K. Borisov, M. Dzedzichuk, I. Gritsevich, A. Lunin, Resource of energy efficiency in Russia: scale, costs and benefits. CENEf - Center for Energy Efficiency. Developed for the World Bank, Moscow, 2008. 102 p. [Accessed Feb. 5th, 2013: <http://www.cenef.ru/file/Energy%20balances-final.pdf>]
- [6] The International CHP/DHC Collaborative, CHP/DH Country Profile: Russia., 2009, 12 p. [Accessed Feb. 5th, 2013: http://dbdh.dk/images/uploads/pdf-abroad/IEA_Russia_16pp_A4_web.pdf]
- [7] A. Nuorkivi, To the Rehabilitation Strategy of District Heating in Economies in Transition, Helsinki University of Technology, No. A13, 2005, 70 pp. + apps. 69 pp. ISBN 951-22-7542-2. [Accessed Jan. 8th, 2013: <http://lib.tkk.fi/Diss/2005/isbn9512275422/isbn9512275422.pdf>]
- [8] M.W. Opitz, L.K. Norford, Y.A. Matrosov, I.N. Butovsky, Energy consumption and conservation in the Russian apartment building stock, Energy and Buildings 25 (1997): 75-92.
- [9] M.W. Opitz, Potential Space-Heating Energy Efficiency Improvements in District-Heated Russian Apartment Buildings. Master's Thesis, Mechanical Engineering, University of Oklahoma (1991) and at the Massachusetts Institute of Technology (1994), 1994, 200 p.
- [10] U.S. Department of Energy, EnergyPlus Energy Simulation Software – Weather Data: All Regions: Asia WMO Region 2: Russian Federation. [Accessed August 5th, 2011: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata/6_europe_wmo_region_6/RUS_Moscow.276120_IWEC.stat]

- [11] P. Armstrong, J. Dirks, L. Klevgard, Y. Matrosov, J. Olkinuora, D. Saum, Infiltration and Ventilation in Russian Multi-Family Buildings, 1996. [Accessed Feb. 8th, 2013: <http://eec.ucdavis.edu/ACEEE/1994-96/1996/VOL01/031.PDF>]
- [12] Y. Matrosov, L. Norford, M. Opitz, I. Butovsky, Standards for heating energy use in Russian buildings: a review and a report of recent progress, *Energy and Buildings* 25 (1997) 207-222.
- [13] The World Bank & IFC (International Finance Corporation), *Energy Efficiency in Russia: Untapped Reserves*, 2008, 134 p. [Accessed Jan 22nd, 2013: http://www1.ifc.org/wps/wcm/connect/400e24004b5f69148d21bd6eac26e1c2/Final_EE_report_engl.pdf?MOD=AJPERES]
- [14] J. Shemeikka, Discussions with the WinEtana software developer at VTT, 2011.
- [15] M. Nyman, P. Hoving, K. Klobut, R. Kosonen, J. Laine, J. Määttä, *Hansa Renovation HARE 94-96, Teolliset korjaustekniikat ja mallisuunnitelmat – 5.1. Talotekniikka ja Energiakorjaukset*, VTT Rakennustekniikka & RTT Rakennustuoteteollisuus 30.1.1995, 1995, 109 p. + app. (in Finnish)
- [16] City of Moscow, 2009. The City programme “energy conservation in construction in the City of Moscow during 2010-2014 and until 2020”. Decree of Moscow government from June 9, 2009 N536 (version from October 10th, 2010). (in Russian) [Accessed August 14th, 2011: <http://base.consultant.ru/cons/cgi/online.cgi?req=doc;base=MLAW;n=120043>]
- [17] IEA - International Energy Agency, *Electricity/Heat in Russian Federation in 2008*, 2008. [Accessed Sept. 26th, 2011: <http://www.iea.org/stats/>]
- [18] T. Tukiainen, *Greenhouse Gas Emissions of Finnish Water and Wastewater Utilities*. Master’s thesis, Helsinki University of Technology, Faculty of Engineering and Architecture, 2009, 150 p. (in Finnish) [Accessed Jan. 14th, 2013: <http://civil.aalto.fi/fi/tutkimus/vesi/opinnaytteet/tukiainen2009.pdf>]
- [19] Echelon, *Monitored Outdoor Lighting: Market, Challenges, Solutions and Next steps*, 2007, 19 p. [Accessed Oct. 30th, 2009: http://www.echelon.com/support/documentation/papers/EchelonCorporation_Streetlight_Whitepaper.pdf]
- [20] M., Radocha, B. Baumgartner, *Energy efficiency in streetlighting and transport infrastructure, Reference material for competence*, 2006. [Accessed Oct. 30th, 2009: http://www.transportlearning.net/docs/Competence_reference%20material_urbandesign_en.pdf]
- [21] A. Korppoo, N. Korobova, *Modernizing residential heating in Russia: End-use practices, legal developments, and future perspectives*. *Energy Policy* 42 (2012), pp. 213–320.
- [22] Russian Ministry of Regional Development, *The state programme “On affordable and comfortable housing and communal services for citizens of the Russian Federation”*, (in

Russian), 2012. [Accessed on Feb. 8th, 2013
<http://minregion.ru/upload/documents/2013/02/8881010213-progr-5.pdf>]

- [23] Institute of Urban Economics, Administrative obstacles to implementation of construction projects (in Russian), 2012. [Accessed Feb. 8th, 2013:
http://www.urbaneconomics.ru/download.php?dl_id=3715]
- [24] EBRD - The European Bank for Reconstruction and Development, Russian Urban Housing Energy Efficiency Programme – Model Development, 2011. [Accessed Feb. 8th, 2013: <http://www.ebrd.com/downloads/sector/sei/report2.pdf>]
- [25] World Economic Forum, Scenarios for the Russian Federation. January 2013 (p. 18). [Accessed Feb. 8th, 2013:
http://www3.weforum.org/docs/WEF_Scenarios_RussianFederation_Report_2013.pdf]
- [26] S. Paiho, R. Abdurafikov, Å. Hedman, H. Hoang, I. Kouhia, M. Meinander, M. Sepponen, Energy-efficient renovation of Moscow apartment buildings and residential districts, VTT Technology 82, VTT, Espoo, 2013, 114 p. + app. 5 p., ISBN 978-951-38-7921-1 [Accessed March 28th, 2013: <http://www.vtt.fi/inf/pdf/technology/2013/T82.pdf>]
- [27] K. Eliseev, District heating systems in Finland and Russia, Mikkeli University of Applied Science, Bachelor's thesis, 2011, 39 p. [Accessed Jan. 8th, 2013:
http://publications.theseus.fi/bitstream/handle/10024/25777/DISTRICT_HEATING_SYSTEMS_IN_FINLAND_AND_RUSSIA.pdf?sequence=1]

List of Figures captions

Figure 1. The general methodology of the energy analyses.

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

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

Figures

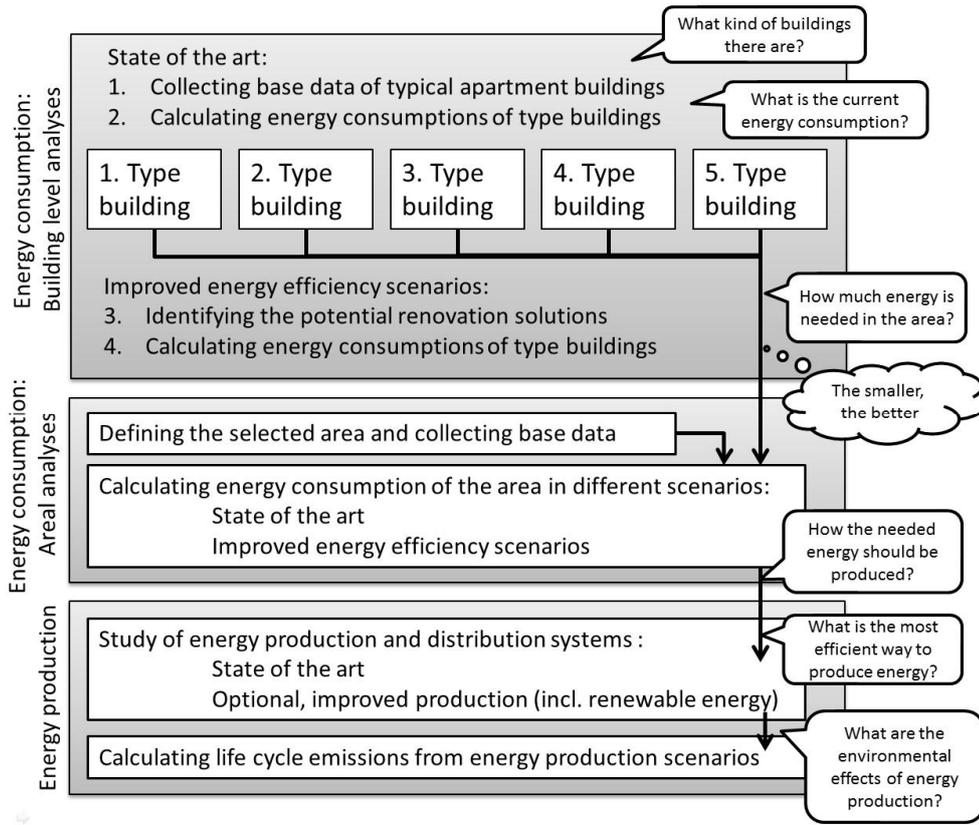


Figure 1.

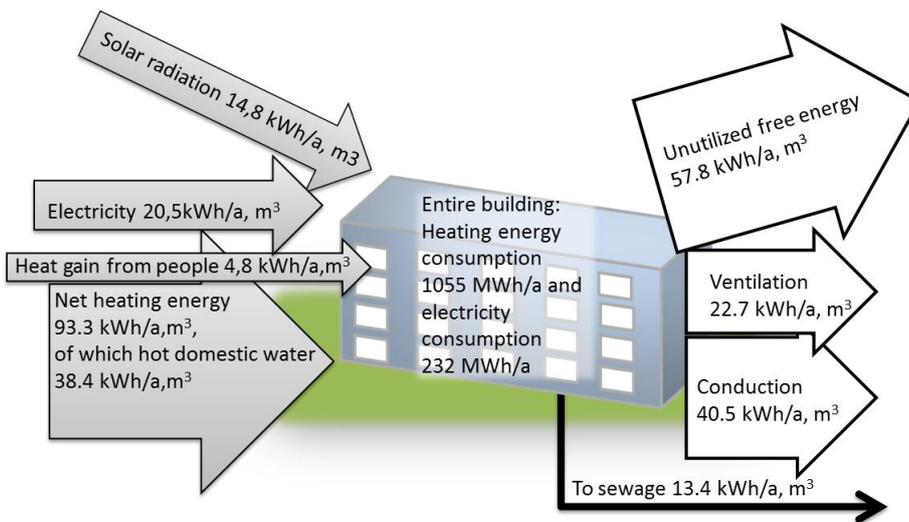


Figure 2.

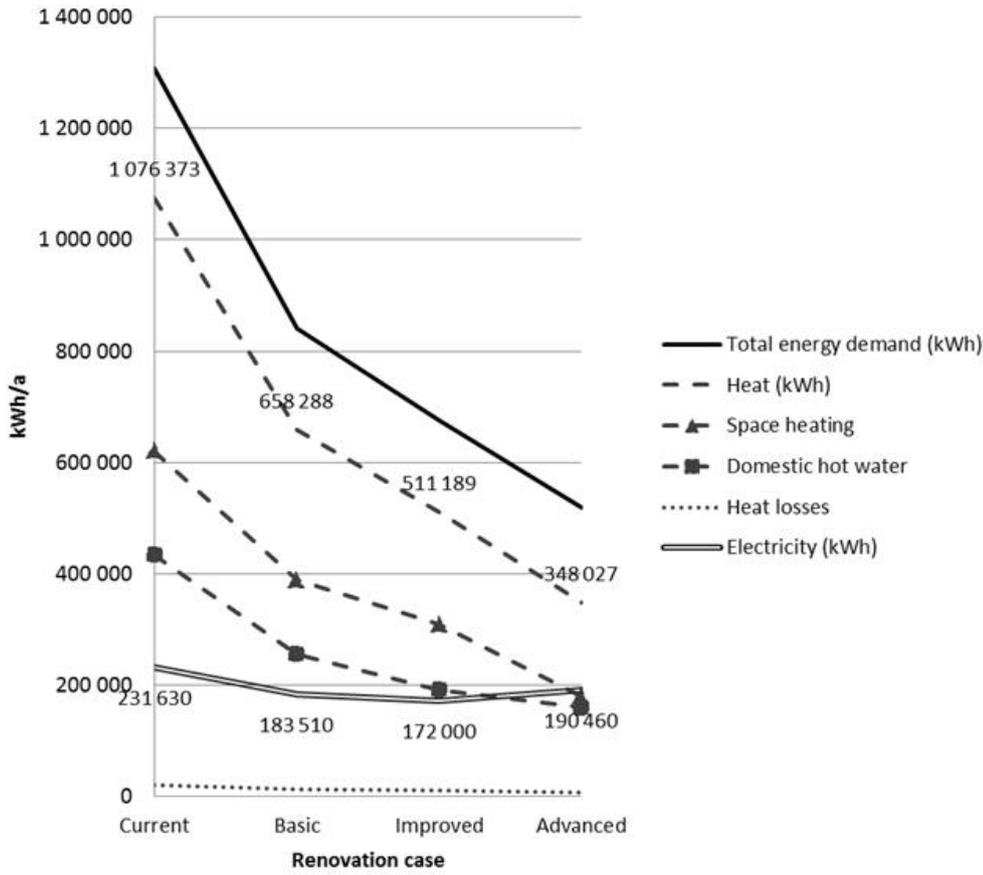


Figure 3.

Tables

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

Description	Long apartment building	Long apartment building	Higher apartment building	Apartment building	Apartment building
Series	II-57	II-49	AK-1-8	II-18	Mr-60
Construction year	1967-1968	1966-1969	1971-1972	1965-1966	1967-1968
Number of buildings*	4.6	11	6	10	4
Apartments per building	358	143	102	84	111
Residents per 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: an average flat has 2.7 residents (United Nations 2004)
*** Shape of the building: X is width of the building and Y is length of the building

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

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

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

Technology/ system	Current status	Basic renovation	Improved renovation	Advanced renovation
Structures: U-values (W/m ² K)				
• outer walls	1.1	0.5	0.32	0.15
• base floor	1.1	-	-	-
• roof	1.1	0.25	0.24	0.15
• windows and doors	2.9	1.85	1.5	1.0
Ventilation	Natural ventilation	Natural ventilation, repairing the existing system (ensuring sufficient air exchange rate) Installing outdoor valves	Enhanced mechanical exhaust	Mechanical ventilation (supply and exhaust air) with annual heat recovery efficiency 60 %
Air tightness factor n50 (1/h)	6.5	4.0	2.0	
Electricity consumption / electrical equipment		Car parking places (electricity: max two hour control) Energy efficient household appliances Energy efficient lighting of staircases and public spaces	Energy efficient pumps and fans	Lifts – braking with recovering energy Demand based control of lighting of staircases and public spaces
Water consumption (l/day/occupant)	272 / of which hot water 126	Installation of modern fixtures and appliances (160)	Installation of water saving fixtures and appliances (120)	Separate metering (100)

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

	Current	Basic	Improved	Advanced
Total energy consumption (kWh)/building,a	1.308.003	840.731	675.755	518.897
Heating consumption (kWh)/building,a	1.076.373	658.288	511.189	348.027
Space heating	620.766 (58 %)	388.946 (59 %)	308.833 (60 %)	180.245 (52 %)
Domestic hot water	434.076 (40 %)	256.176 (39 %)	192.132 (38 %)	160.104 (46 %)
Losses	21.516 (2 %)	13.164 (2 %)	10.212 (2 %)	6.936 (2 %)
Electricity consumption (kWh)/building,a	231.630	183.510	172.000	190.460

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

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

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

	Current	Basic	Improved	Advanced
Heating consumption (kWh/m ² ,a)	219	134	104	71
Electricity consumption (kWh/m ² ,a)	47	37	35	39

Table 7. CO₂-equivalents from natural gas CHP energy generation for different concepts.

	Current	Basic	Improved	Advanced
Heat (kg/ a)	24 296 019	14 060 219	10 767 202	5 656 596
Electricity (kg/a)	9 913 875	7 811 025	6 851 705	6 144 183
Total (kg/a)	34 209 894	21 871 245	17 618 907	11 800 779
Total per person (kg/a/p.p)	2 477	1 583	1 276	854

Highlights

- The energy consumptions of typical Moscow apartment buildings are estimated.
- Three different building renovation concepts are proposed and analysed also in the district level.
- There is a huge energy savings potential when renovating the buildings.
- Non-technical barriers to energy efficient renovations are also discusses.