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# Feasibility on Upgrading Moscow Apartment Buildings for Energy Efficiency

**Satu H. Paiho, Mari A. Sepponen, Rinat Abdurafikov, Åsa E. Nystedt, Ilpo E.O. Kouhia, Malin C. Meinander & Ha M. Hoang**

**ABSTRACT**

*This paper describes the feasibility study of energy-efficient sustainable renovation and modernization of a limited selection of Moscow building stock. The developed sustainability requirements include the criteria for structural/functional planning, surrounding terrain, buildings, transport solutions, waste management and energy supply.*

*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. The energy consumption of a typical Russian building is 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. The typical energy production and distribution chain was analyzed. The efficiency of energy production and distribution were found interesting, as well as the data concerning primary energy sources. The most important question is which part of the energy production and delivery chain can have the biggest impact on energy efficiency of buildings and the entire building stock.*

*After the analysis of the present state energy efficiency of Moscow's buildings, the technical possibilities for building renovation and modernization were analyzed. The actual retrofit concepts could be composed after identifying the technical solutions. The energy analyses for the selected buildings energy renovation solutions are described in this paper.*

## INTRODUCTION

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 (Bashmakov et al. 2008). Residential buildings are evaluated to have the largest energy savings potential out of all building types. A largest part (67%) of the energy savings could be implemented through the reduction of district heating usage for space and water heating, resulting in more efficient utilization of district heating.

The majority of Moscow housing stock is built after World War II (Construction in Russia 2010) and need modernization. Sustainability should be taken to account when renovating these buildings. Thus, energy efficiency of buildings and districts is one of the core issues. Before deciding any renovation solutions, the energy consumption levels need to be estimated. After the estimation, different renovation concepts can be compared with the current situation. This paper describes the principles of the energy analysis process, estimates the present state energy consumptions of a typical Moscow apartment building and a typical district (neighborhood), and then analyses different building level energy renovation concepts.

## UTILIZED SUSTAINABILITY CRITERIA

All the authors work at VTT Technical Research Centre of Finland. Satu H. Paiho, Åsa E. Nystedt and Ilpo E.O. Kouhia work as Senior Scientists, Mari A. Sepponen and Rinat Abdurafikov work as Research Scientists and Ha M. Hoang as a Research Trainee in the knowledge center of Technologies and services for buildings. Malin C. Meinander work as a Research Scientist in the knowledge center of Advanced Materials.

In this paper, the sustainability requirements are developed based on the criteria of new residential districts in Saint Petersburg (Nystedt et al. 2010). The developed sustainability requirements include the criteria for structural/functional planning, surrounding terrain, buildings, transport solutions, waste management and energy supply.

Building type specific issues are focused on reduction of heating, electricity and water usage. Improved insulation and ventilation are top priorities. Regarding the water usage reduction, water meter technologies as well as water saving appliances in the apartments are in focus. Energy production and transmission systems are included on the list criteria in district level. The improved energy production should be based on low emissions and renewable energy. It is important that the heat leaks of the district heating network are minimized. Moreover, the water and waste management systems of the buildings are taken into account.

Consumption of energy can be reduced significantly on the district level by reducing the need for private cars. The number of residents in a district can be increased by infill-construction. Infill construction requires changes in city plans. Also changes in the usage of buildings (residential to service buildings) require changes in the city plan.

## THE MOSCOW HOUSING STOCK

Construction in Russia (2010) state that the total Russian housing stock in total residential floor area in 2009 was 3177 million $m^2$. Share of dilapidated and emergency-state housing was 3.1 % out of the total area of the housing stock. Total area of the housing stock per capita was 22.4 $m^2$.

According to the statistics from 2004, 95 % of the Moscow dwelling space is built after World War II, from which 52 % of the residential buildings were built during 1946-1975 and 43 % in 1976 or later. According to Rosstat (Construction in Russia 2010), there were 39.801 residential buildings in Moscow in 2009. The amount of residential buildings equals 3,835,000 apartments and the total floor area of 214 million $m^2$. The average floor area of an apartment in Moscow was 55.8 $m^2$ and the average number of residents per apartment was 2.8.

### Typical Apartment Buildings in Moscow

It is important to understand the general situation in the target place before energy analysis. United Nations published 2004 Country Profiles on the Housing Sector Russian Federation, which helps to form an overview of typical building solutions in Moscow and in Russia. First of all, the industrialization of construction begun 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 of today consists mainly of a few standard building types. (United Nations publications, 2004)

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. (United Nations publications, 2004)

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 (1994), 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 uncommon, and a lot of interesting information is simply unavailable to the public. The data used for this paper was gathered from several sources, and cross-checked when appropriate sources were found.

### The Selected Housing District

The selected area mostly represents 4-th Microrayon of Zelenograd, Moscow (longitude 37° East and latitude 55° North). It represents a typical residential district in Moscow and Moscow region with apartment buildings constructed for the most part in 1960s and 1970s. Renovation of such buildings and districts is 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 typical building design (Opitz et al, 1997). There are also other apartment buildings, schools, kindergartens, shops, and a bank in the area, but since this project concentrated on modernization of apartment buildings, these newer buildings from the 90's and from the beginning of 21st century were excluded from the energy calculations.

There are approximately 13,800 residents living in the buildings that are included in the calculations. The total floor area of the studied buildings is 327,600 $m^2$. The estimated number of residents is based on the assumption that the average occupancy rate per flat is 2.7 persons (United Nations publications, 2004).

## PRINCIPLES OF THE ENERGY ANALYSIS

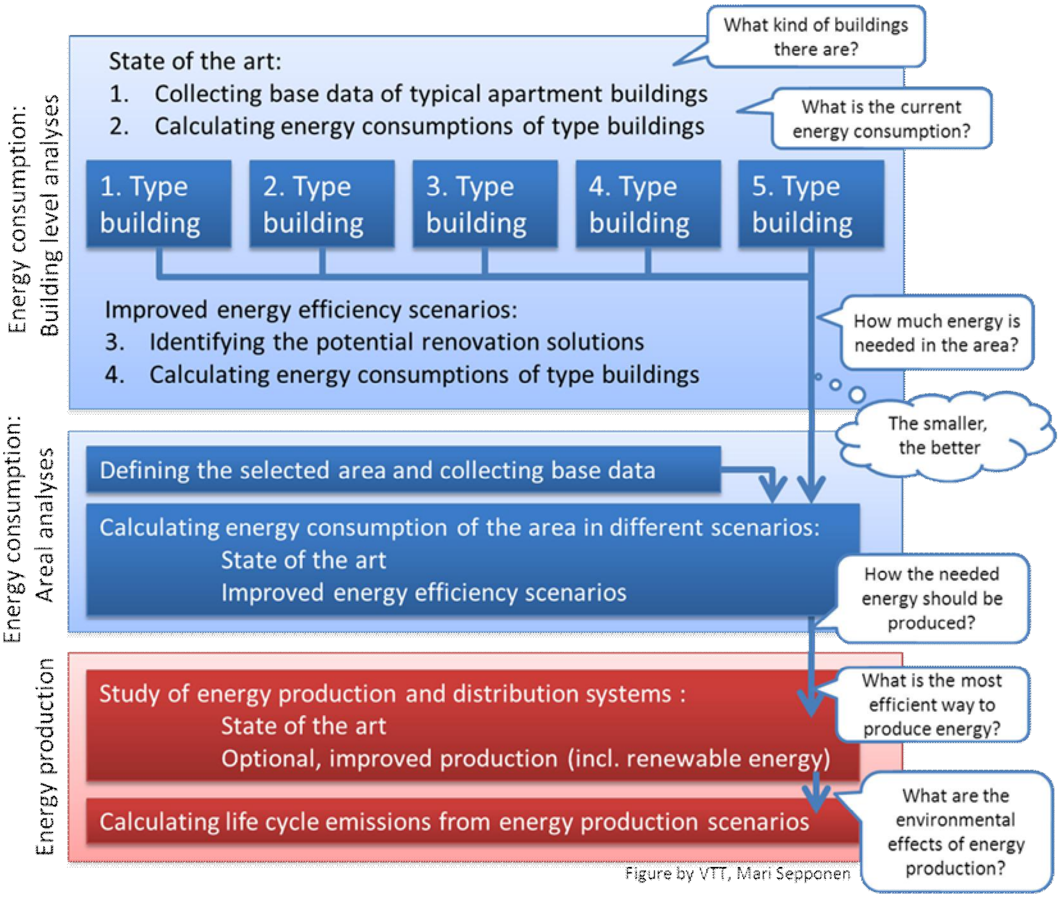


*Figure 1. The general principles of energy analysis.*

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 recognize the best ways of how to improve the energy efficiency of entire areas and energy systems. The key questions are: "What are the current means of energy production for buildings and districts?", "How the energy is currently produced?", "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?". The general principles of energy analysis were presented in Figure 1.

## THE STATE-OF-THE-ART ENERGY ANALYSIS

### The Energy Consumption of Buildings

The energy consumption of a typical Russian building is 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/modernized, were analyzed by means of typical buildings. The analysis takes into account structural solutions, heating, ventilation, water and drainage, electrical and other technical systems. These first analyses may be later revised based on walk-through audits inside the pilot buildings.

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 (U.S. Department of Energy).

Typical building parameters in Russia and in Moscow were used in the calculations. We used the value 18°C in our calculations as the default indoor temperature for living spaces in multi-family buildings located within the case districts. According to Russian construction norms on thermal performance of buildings, the value of building air tightness at 50 Pa pressure difference (n50) must not exceed 2 $h^{-1}$ for mechanical and 4 $h^{-1}$ for natural ventilation. However, based on the results of field measurements with blower door tests (Armstrong et al. 1996) 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-aluminum windows by residents of apartment buildings in Russia.

Natural ventilation is a typical ventilation solution in Russia (Opitz et al. 1997). Type of base floor in the buildings is assumed to be ground-supported slab. The typical U-values in Moscow buildings are approximately 1.1 W/$m^2$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 they are essentially the same among buildings even with different wall structures (except for recently constructed buildings with 3-layes panel walls).

Because Estonia was part of the Soviet Union, there still remain numerous apartment buildings built during the Soviet era. The typical annual Estonian water consumption is between 180-290 l/capita/day (The World Bank & IFC 2008). We estimated that the average water consumption in the selected buildings is 272 l/capita/day, of which hot domestic water consumption is 46 %, ergo 126 l/capita/day). The hot water consumption is based on expert estimations and average Finnish water consumption data.

The heat gain was assumed to be from hot water system 3.2 kWh/$m^3$/month (of which 30 % is utilized as in the Lithuania case [Luhanka, 1995]), from electrical equipments 1.42 kWh/$m^3$/month and from people 0.4 kWh/$m^3$/month. The electricity consumption of buildings was estimated based on assumed typical electrical equipment and their energy efficiency classes. Based on Finnish expert estimations it was assumed that the internal gains were: 1.4 kWh/$m^3$/month for hot domestic water (of which 65 % can be utilized), 1.62 kWh/$m^3$/month for electrical equipment (of which 74 % can be utilized) and people 0.4 kWh/$m^3$/month.

The general picture of energy flows going in and out of the building are presented in Figure 2. According to our calculations the heating energy consumption of typical old apartment buildings in Moscow is approximately 217 kWh/$m^2$,a and the electricity consumption 42 kWh/$m^2$,a. The result is quite well in line with some reference studies, e.g. The World Bank & IFC (2008). 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 "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.

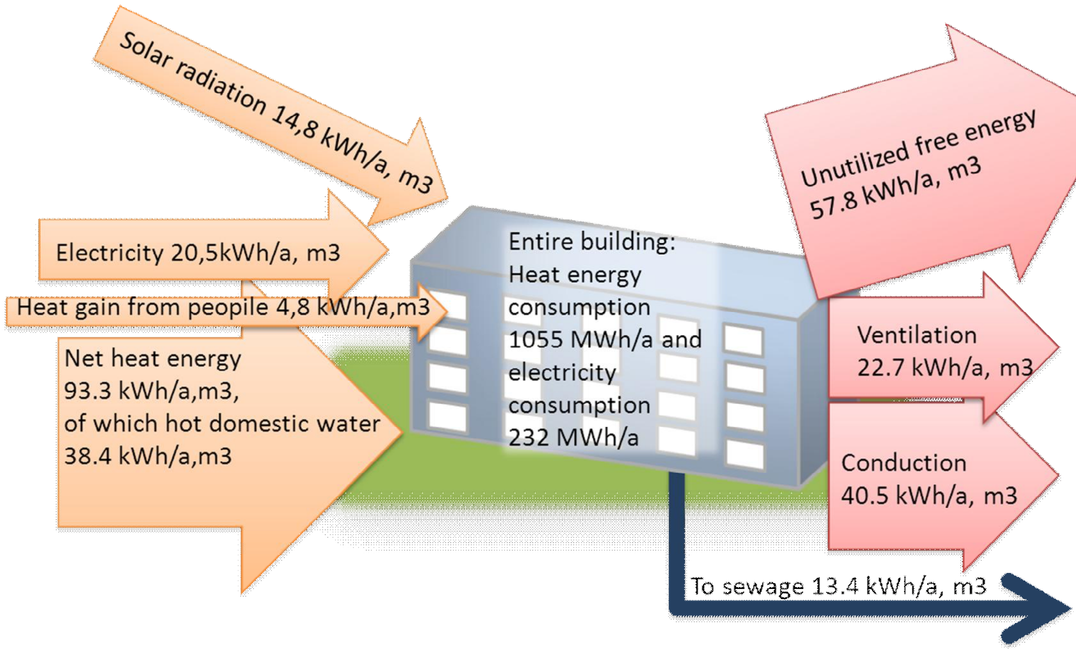


*Figure 2. An example of energy streams of an apartment building (II-18).*

### The District Level Energy Consumption

Energy consumption calculations of the selected building stock were based on the energy consumption of type buildings. Again, the present state was studied first on district level, including the energy chain analyses. The typical energy production and distribution chain was analyzed. The efficiency of energy production and distribution are found interesting, as well as the data concerning primary energy sources. The most important question is which part of the energy production and delivery chain can have the biggest impact on the energy efficiency of buildings and entire building stock. The analysis was made based on available literature.

The total heating energy consumption of apartment buildings in the selected area was 63.9 GWh/a, and the total electricity consumption was 12.8 GWh/a. Thus, the heat consumption is approximately 217 kWh/m$^2$,a or 4629 kWh/capita,a. Similarly, the average electricity consumption is 42 kWh/m$^2$,a, or 930 kWh/capita,a. Heat is distributed in the district through district heating network. It was assumed that the heat distribution loss in the network is 10 %. This means that the selected area needs heating energy production of 71 GWh/a. The same applies also for electricity systems: since the transmission loss of electricity is approximately 10 % (IEA 2008) the required electricity production for the area is 14.2 GWh/a.

## THE ENERGY ANALYSES OF ALTERNATIVE BUILDING RENOVATION CONCEPTS

Three alternative renovation concepts were selected for closer analysis (Table 1). 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 1. Building level retrofit solutions. 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 ($W/m^2K$)<br>- outer walls<br>- base floor<br>- roof<br>- windows and doors | <br><br>1.1<br>1.1<br>1.1<br>2.9 | <br><br>0.5<br>-<br>0.25<br>1.85 | <br><br>0.32<br>-<br>0.24<br>1.5 | <br><br>0.15<br>-<br>0.15<br>1.0 |
| Ventilation | Natural ventilation | Natural ventilation, repairing the existing system (ensuring sufficient air exchange rate)<br>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)<br>Energy efficient household appliances<br>Energy efficient lighting of staircases and public spaces | Energy efficient pumps and fans | Lifts – braking with recovering energy<br>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) |

Since the present state energy consumptions of the different apartment building types were really close to each other, only the most common apartment building type (II-18) was selected for further energy analysis. The results from the simulations are shown in Table 2 as annual energy consumption per floor area for each of the cases, from which results that each case consumes less total energy than the previous one. The same goes also for the heating consumption while the consumption of electricity is higher for the advanced case in comparison with the former improved case. This result was caused by the change of ventilation type into an automatically controlled ventilation in the advanced case. However, since the improved ventilation system made it possible to recover 60 % of the heat that otherwise would have been lost with the exhaust air, the ventilation type exchange resulted as energy savings in form of heat in the end.

**Table 2. Total annual heating energy and electricity consumptions.**

| Case | Current | Basic | Improved | Advanced |
|---|---|---|---|---|
| Total electricity consumption (kWh/m$^2$,a) & (share of the state of the art) | 47 (100 %) | 37 (79 %) | 35 (74 %) | 39 (82 %) |
| Total heating energy consumption (kWh/m$^2$,a) & (share of the state of the art) | 219 (100 %) | 134 (61 %) | 104 (47 %) | 71 (32 %) |

## CONCLUSION

The need to modernize and upgrade buildings in Moscow districts is evident, because many retrofits haven't been done since World War II. Indoor conditions are poor and the energy losses from buildings are big. 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 analyzing 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. 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. On the building level, the air tightness of the structures is one key issue that needs to be addressed in the retrofit solutions.

To achieve a universally efficient energy solution in Moscow, the entire energy chain needs to be analyzed and improvements made bearing in mind the whole energy chain. The results of this study showed that improved indoor conditions and reduced heating consumption often lead to increased electricity consumption. By analyzing 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 last part of the project includes technical, financial and business implementation plans for the renovations. The different renovation concepts are analyzed from technical and economical points of view. The last part of the prpject forms an understanding on what renovation solutions are feasible in Moscow apartment districts.


## ACKNOWLEDGEMENTS

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