RETROFITTING OF BUILDINGS AT THE LEVEL OF THE ENTIRE TOWN: PLANNING, BENEFITS, THE EXAMPLE OF BELGRADE

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ABSTRACT
The paper presents a possible model used for determining the scope of retrofitting and the methods of improving energy performance of a group of buildings erected before the so called energy crisis, aimed at reducing the heating energy consumption. Statistical data on buildings constructed in specific time periods are used for the model, with basic data relating to the useful area of the buildings concerned. By comparing the old and the planned new conditions, achieved primarily by replacing windows and by subsequent insulation of outer walls, the reduction of annual energy consumption was calculated. The degree-day method was used with certain assumptions and introduction of correction factors from experience.

INTRODUCTION

Energy experts in the building sector, the city administration, the municipality administration, regional officials and even those from the state government – they all request and insist on the presentation of the final results and contributions of large-scale plans as well as the aims of decision-making and investment policies to be implemented. Today this situation often applies to the field of the highest energy consumption, the planning and implementation of energy use reduction measures in buildings, specifically in those buildings which were built a long ago and which are dominant in the building sector in all big cities. One of the decisions made by the European countries, defined by the EU directive, is based on the requirement to reduce energy consumption in the building sector by approx. 30%. The study was conducted for the city of Belgrade, a city with the population of 2 mil., for the purpose of analyzing the effects of retrofitting of old residential buildings with regard to energy saving, primarily by improving the building envelope's thermal performance, which specifically refers to improvement of windows and insulation of outer walls in all the buildings constructed before 1981. Herein the procedure applied to the example of Belgrade has been explained, the calculation methods have been presented, the assumptions and estimates have been described and the estimated results obtained by the energy comparison of the existing residential buildings have been presented.

THE PRESENT ENERGY CONSUMPTION

On the average, the annual final energy consumption in the highest number of the existing buildings in Serbia is 2 to 3 times higher than in new buildings, those buildings that have been constructed in the past several years. The consumption in new buildings is under 100 kWh/m2, which could be the upper limit value of the final energy consumption acceptable in Serbia.

According to the analyses of thermal energy consumption in the buildings which are connected with the district heating system in Serbian towns and according to the data from the largest district heating systems in Serbia, the average annual consumption in buildings is as follows: 171 kWh/m2 for heating and 58 kWh/m2 for domestic hot water, which makes the total amount of 229 kWh/m2 for the both purposes. In non-residential buildings, energy consumption for heating is slightly higher, amounting to 194 kWh/m2, while it is significantly lower for domestic hot water preparation.

According to the articles in relevant international journals, the average final energy consumption in residential buildings in the European Union for heating purpose (heating and domestic hot water) approximately amounts to 138 kWh/m2. In Denmark, heating accounts for 96 kWh/m2 in buildings connected with the district heating systems, while in buildings using fuel oil or gas, consumption is 131 and 106 kWh/2, respectively.

In the residential buildings in Poland, erected according to the new national regulations, consumption is between 90 and 120 kWh/m2. In Sweden, which has colder climate and longer heating season than Serbia, consumption is approx. 120 kWh. In the new buildings with the lowest energy demands, the so called low energy buildings, the annual final energy consumption is within the range of 60 to 80 kWh/m2.

In Serbia, 80% of all buildings were constructed before the 1980s. Belgrade accounts for one half of the buildings stock of the entire Serbia and, for that reason, the analysis will be based on the Belgrade building stock and climate characteristics of Belgrade, as the central geographical location in Serbia. It is estimated that Serbia could reduce energy demands by at least 30 to 40% by retrofitting the old buildings, by further development and expansion of the district heating systems and gas pipelines and by charging the thermal energy consumption in the district systems according to measured consumption rather than according to square meters of the heated area. Thereby, the tariffs according to measured amounts of consumed heat could contribute to the consumption reduction by approx. 10-13%.

HISTORICAL SURVEY OF THE GLOBAL USE OF ENERGY SOURCES

In future, buildings will be constructed according to new energy performance criteria and standards. But those buildings constructed in the pre-energy crisis must undergo “energy upgrading” according to the present requirements regarding energy consumption, regardless of the energy source they will continue to use. In such process of thermo-physical upgrading and harmonization with the requirements imposed by the present crisis and decreasing reserves of conventional energy sources, renewable energy sources should be used, wherever they are available. Fig. 1 shows a historical survey of energy sources percentage share in the total energy consumption at the global level since 1850. This survey shows that the predictions for the following fifty years are focused on wind, photovoltaic conversion of solar energy, geothermal heat, along with the remaining reserves of coal, gas and liquid fuels, and with 10% share of hydro and nuclear energy, which remains a possibility of energy generation, but with a constant concern regarding its sustainability. Needless to say, science is still in search for new energy sources. Therefore, from the today’s perspective, efforts are made regarding the use of renewable energy sources, not only for new buildings, but also for those constructed before the energy crisis and the period of enormous CO2 emissions. In any case, buildings should have minimum energy demands and, wherever it is possible, these minimum energy demands should be met by using the renewables.

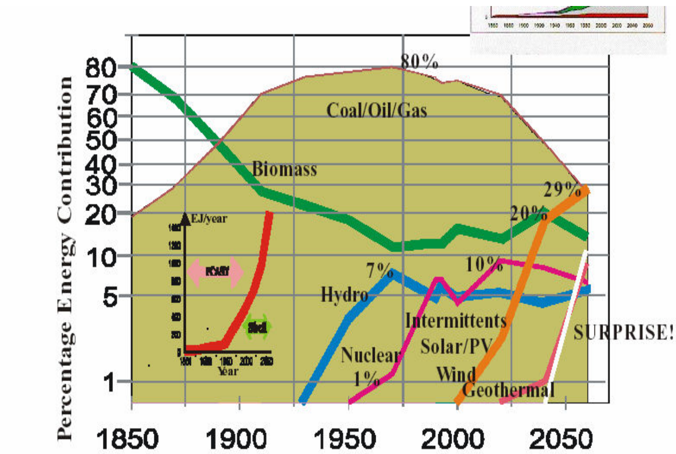

Fig.1. Specific energy sources in the global energy consumption – yesterday, today and tomorrow

ESTIMATES OF POSSIBLE SAVING AT THE CITY LEVEL – THE BELGRADE EXAMPLE

Possibilities of reducing energy consumption in residential buildings were analyzed for the city of Belgrade with regard to the retrofitting of all the buildings constructed before 1981. Such estimate is primarily based on good statistical data and evaluations of the buildings thermal performance. The procedure is based on the representative samples of buildings from specific periods of

construction and with similar characteristics, i.e. according to the norms in effect at the time of construction. This is a result of changes in construction styles and norms and their harmonization with the architectural trends, new materials and construction technology development.
Today, the building stock of Belgrade includes approx. 40.000.000 m2 of built residential area. The buildings erected during the 1960's and 1970s are dominant, making 67% share in the building stock of the city. That was the period of huge migrations to Belgrade, which was the capital of Yugoslavia. The housing shortage, even more intensified by the consequences of the Second World War devastation, was an aggravating factor. The then socialist government did not set priority in terms of high quality construction, but in terms of meeting the housing needs. New residential areas were built, mainly in the north area of Belgrade, across the two rivers Sava and Danube, in the district called Novi Beograd (New Belgrade). The buildings had wood windows, which were critical energy elements of these buildings, and inadequately sealed windows, since Belgrade is situated in the windy Danube region. This area of Belgrade was the first one with the centralized district heating, but with pipelines in the sandy soil of the dried up ancient Pannonian Sea, which used to cover the area from today's New Belgrade to Hungary at the north. Such conditions had a negative impact on the heat distribution efficiency of the system, requiring repeated drying of channels and improvements of insulation.

POSSIBLE REDUCTION IN ENERGY CONSUMPTION OF THE EXISTING BUILDINGS

For the analysis of possible savings in energy consumption of residential buildings, buildings were classified by construction periods with similar thermal performance. Accordingly, estimates were made regarding the scope of retrofitting and the current heating energy demands, and calculations were made for reduction of heating energy consumption that could be achieved after the retrofitting. It was assumed that interventions were possible on three façades of buildings, since buildings in towns usually lean on one another, while subsequent insulation of the ceiling was not taken into consideration, due to complications in obtaining consents from all building tenants.
The buildings in Belgrade were divided by the construction period into 9 groups. The buildings taken into consideration were those erected before 1981, those belonging to the group of the oldest buildings and those constructed to meet the acute housing needs of the increasing population of Belgrade. According to the representative samples of each group, specific heat losses per unit of useful area were obtained, and thus design rated power was obtained, which differed from one group to another, primarily due to the interfloor heights from the previous periods, old types of glazing and window framing and inadequate sealing. In older buildings, the room heights were bigger (max. 4.5 m), while today the room height is usually 2,8 or 3,0m . Energy consumption was

calculated according to the degree-day method, for the effective design outdoor temperatures and corresponding correction factors and temperature conditions in 1981.

The review of the present situation regarding buildings in Belgrade was made by systematized construction periods, with emphasis on the data relating to the housing stock, concluded with the year of 1981.

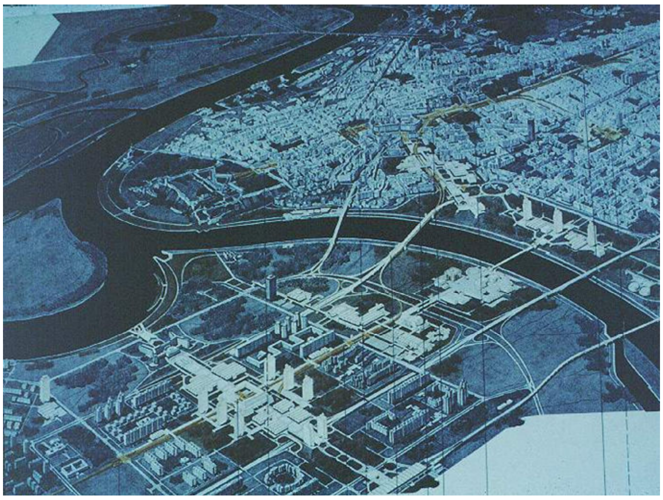

Figure 2. Belgrade with New Belgrade in the period
of its planning and construction (lower part of the figure)

TABLE I

Table I. Surface area of buildings classified by the period of erection

Buildings period	Floor area $.10^{3,}$	Design capacity	% the total floor area
Before 1918	692	232W/m^2	2 %
1919-1945	3.450	200	9 %
1946-1959	2.284	185	6 %
1960-1966	4.656	145	12 %
1967-1979	13.468	145	35 %
1980-1981	1.095	120	3 %
1982-1991	4.176		11 %
1992-2002	5.646		16 %
2003-2007	4.415		6 %
Total area 1981	25.645m^2	average 157W/ m^2	67%
Total area 2007	39.682 m^2		100%

In Belgrade, the floor area of the buildings erected before 1981 approx. amounts to 25.645.000 m^2. According to these data, energy consumption for heating in 1981 was calculated using the degree-day method and data on outdoor temperatures in 1981, for the heating period of 171 days and number of degree days DD =2527. The theoretical consumption in 1981 would be as follows:

$$Q= 24. \ 25645000. \ 157. \ 2527. \ 0,95 \ .0,63/ 34 = 4298,3 \text{ MWh}$$

According to this amount of energy, consumption per surface unit (m2) would be approx. 172 kWh/m^2 of final energy. Taking into account that the buildings erected at that time did not have the automatic control of heating and that indoor temperatures were not maintained within the control limits, the actual consumption was certainly higher, and therefore the correction coefficient 1/0,87 was introduced, based on the reduction in energy consumption for heating using thermostatic valves on radiators. The estimate of the actual consumption was as follows:

$$Q= 4.298,3 /0,87 = 4.940 \text{ MWh}$$

or 192 kWh/ m^2 on a yearly basis, exclusively for heating.

RETROFITTING OF WINDOWS

In the oldest buildings, the heat transfer coefficient of single-glazed windows was 5,7 W/m^2K. Later, windows with k=2,7 were built-in, and such windows prevail in the existing buildings erected before 1981. Therefore, the saving estimate has been made by using that coefficient. The present windows produced by domestic manufacturers have better coefficient k=1,2 W/m^2K. It was estimated that k_1=2,7 could be the average value of all windows that have been recently built-in.

It is difficult to determine the number of windows for the entire Belgrade area. However, with the data showing that the average surface of one room from that period was 21m^2, all the buildings in Belgrade from the period before 1981 have 1,333,333 rooms. According to the standard which was in effect in the central Europe at that time, by which there was one window per room, the number of windows would be equal to the number of rooms. Upon inspection of the older buildings in Belgrade, it was found that an average room had 1.3 windows. According to the European statistics, an average window has a surface of 1.69m2, and therefore the total surface of windows in the buildings erected before 1981 would be as follows:

$$Aw= 1.333.333 \times 1,3 \times 1,69 = 2.930.331 m^2$$

Taking into account that today windows used for buildings have the overall heat transfer coefficient k= 1,2 instead of old windows with k=2.8 W/m^2Km, and neglecting the reduction of outdoor air infiltration due to better sealing of new windows, reduction in energy consumption in 1981 by replacing windows, calculated by using the degree-day method, would have been as follows:

$$Qw = 24. Aw(k_2 - k_1) DD.e_1.e_2 =256 MWh$$

Extremely poor sealing of windows in the existing buildings in Belgrade would be significantly improved if the windows were replaced, which is especially important for Belgrade as a city in a windy area. That amount of the annual consumption has not been calculated.

(window surface A=2.930.331 m2. Heat transfer coefficient for old and new windows k_2= 2,8 W/m^2K k1= 1,2 W/m2K

Number of degree-days for 1981 DD= 2527, Coefficients for heating with night and Sunday interruptions

e1.e 2=0,9)

POTENTIAL SAVING BY IMPROVING INSULATION OF THE OLD BUILDINGS ENVELOPES

The ratio between the building A envelope surface, through which heat is lost and the volume of its heated space Ve represents a characteristic which defines the exposure of the heated space of the buildings to the outdoor environment. For the average ratio of A/Ve=0,5 and relations between the useful surface area of the indoor space Ak and volume Ve of:

$$Ak = 0,32Ve$$

The result is the volume which is approximately three times higher: Ve= Ak/0,32

And the envelope surface of all the buildings comprised in the analysis is as follows:

$$A = 0,5 \; 21500000 /0,32 = 33\;593\;750 \; m2$$

According to the previous calculation, windows account for 2.930.331 m2, while floors and roof account for 1/5 of the envelope surface. Therefore, insulation would cover the envelope surface of 23.943.419 m2. The outer walls of the buildings from the considered period have wall thickness of 56, 38 and 24 cm, and they are calculated by using the average improved coefficient of heat transfer, k_1–k_2=1,3. This would have contributed to the annual reduction of consumption in Belgrade in 1981:

Q= 24. 23 943.419. 1,3. 2527 .0,9=1700 MWh

New windows and building insulation certainly do have effect on the reduction of air infiltration. That share of reduction was calculated according to the ventilation rate in the present condition of 2.5 changes per hour, but to be 1chnge after improvements of both, windows and wall insulation,. which provided the saving of 175kWh.

TOTAL REDUCTION IN ENERGY CONSUMPTION

Total reduction in heating energy consumption in Belgrade, after retrofitting only the buildings built before 1981, would amount 1700 + 256+ 175= 2131 MWh

or reduction by 49,5%

and reduced to the unit of the building surface area, the annual reduction would be

2.131.000.000 kWh/ 25.645.000m2 = 83 kWh/m2

which means that the annual consumption per unit of residential surface area would be reduced from the present 192 to approx. 112 kWh/m2.

INSTEAD OF A CONCLUSION

Saving achieved by subsequent energy improvement in buildings in the entire city blocks and districts or large city areas, may be successfully predicted using the data on useful floor area considered and knowing the characteristics of the group of building, but also the scope of retrofitting and physical characteristics of buildings, which are to be improved in terms of energy use. When undertaking such generalized interventions, it is necessary to calculate the heating energy consumption before and after such retrofitting. The degree-day method for this type of prediction was entirely suitable. It is necessary to know what is included in the available data and to determine the value of corrections by experience, if this is required. Such estimate requires a broad experience in design, but also experience in the field of heating.

Such subsequent measures used for improving energy efficiency of buildings must include new insulation of the pipe network, if the central heating is installed in the building. And, in the buildings with their own boiler rooms, the German example should be followed – boilers built-in 30 years ago or earlier should be replaced, and the new boilers must meet specific efficiency levels. Additionally, overhaul and adjustment of all elements of the heating systems must be planned and defined. When retrofitting buildings, these measures should be implemented in the buildings which are huge energy consumers and in non-residential buildings (hospitals, hotels, sports halls and facilities, etc.). And, in order to achieve this, it is necessary to set and pass legal norms, regulations and other binding enactments. On the other hand, control and certification method for achieved quality, i.e. efficiency effect, must be practical, low-priced and without long administrative procedures.

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