POTENTIALS FOR IMPROVING ENERGY PERFORMANCE OF MULTIFAMILY HOUSING BLOCKS CONNECTED TO THE DISTRICT HEATING SYSTEM

by

Nataša D. ĆUKOVIĆ IGNJATOVIĆ [*]***, Dušan M. IGNJATOVIĆ, and Budimir S. SUDIMAC***

Faculty of Architecture, University of Belgrade, Belgrade, Serbia

Original scientific paper
https://doi.org/10.2298/TSCI170612228C

Developments conceived following the principles of Athens Charter were typical form of urban answer to the post-war housing shortage and during the decades of intense construction activity that followed. In city of Belgrade, multifamily housing in open city blocks built between 1961 and 1990 account for about 40% of current housing stock. The current ownership and operation of these housing blocks derive from their socialist legacy: home-owners rights relate only to the buildings, excluding any open spaces, even the ones immediately along the building's perimeter. On the other hand, heating is supplied by district heating system. Management of open spaces as well as provision of district heating are subordinates to local municipality (the city of Belgrade). Energy efficiency related refurbishment options for these developments that would engage both the home-owners and the public companies may be the key for bringing ever-needed modernization, prolonged lifespan and a sustainable way of using this portion of housing stock. By applying simple architectural measures, energy demand for heating of these buildings can be reduced by 30-78%, which opens a pathway for effective use of renewable energy sources. Unlike solar energy, which can be managed at building level, geothermal energy can be exploited only at the district level due to the ownership rights. The presented research explores the effectiveness of using geothermal energy at a district level coupled with systematic approach to building refurbishment, taking the advantage of the repetitive use of the same building design and the formal and practical relations with local authorities.

Key words: *building refurbishment, energy efficiency, multifamily housing, open city blocks, district heating, renewable energy sources*

Introduction

Energy performance of building sector has been constantly improving during the last two decades, but this advancement remains much more notable in the domain of new construction while the existing building stock is being renovated at a rather slow pace – 1.4%, targeting 2% annually [1]. Consequently, the environmental impact from new buildings, with the share of 1.2% in residential building stock, is negligible compared to the impact of the existing buildings [2]. The problem was recognized in European Directive 2012/27/EU [3] that addresses both new construction and the existing building stock, but the effective implementation is facing numerous challenges.

* Corresponding author, e-mail: natasa@arh.bg.ac.rs

In Serbian urban settlements, multifamily housing occurs within two basic forms of urban blocks: traditional and open city blocks. According to the data from the 2011 Census [4], 31.7% of apartments are within the buildings of three and more dwelling units. As shown in fig. 1, the dwellings constructed in periods 1961-1980 and 1981-2000 have the major share in all regions. Having in mind turbulent political situation and unfavorable socio-economic context of the 1990s, the period 1961-1990 stands out as the decades of the most intensive housing construction, when the majority of current housing stock was built. Open city blocks were the dominant form for these new developments, so today some 40% of Belgrade's dwellings are placed in such structures, while in New Belgrade, a municipality of Belgrade, it is still the sole urban form when it comes to multifamily housing. Although often formalistic in concept, these open city blocks maintain very favorable ratio between the built and the open space, allowing high quality interaction with the immediate environment and providing abundance of green and recreational areas. Time has taken its toll, and, after decades of poor maintenance, these buildings, as well as their generous adjacent open spaces, yield refurbishment.

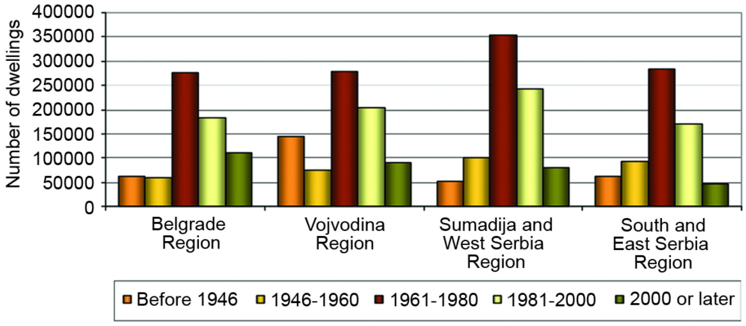
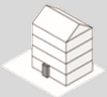
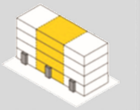
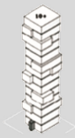


Figure 1. Dwellings by the period of construction, Serbia [4]

Energy performance of buildings constructed between 1961-1990 is very poor, as the first regulations in the domain of thermal properties of buildings were introduced in the late 1960s. It was not until the 1980s that a series of mandatory procedures and standards were introduced which resulted in notable improvements in energy efficiency [5, 6]. Table 1 depicts very high energy demands and corresponding poor energy class for typical multifamily buildings from this period. This portion of building stock also shows underperforming results regarding various aspects of indoor comfort [7], so thorough rehabilitation is crucial for sustainable exploitation of these buildings in the years to come. This opens the door for the effective use of the existing building fund as a precious resource [8] with significant potential for improvements of ecological characteristics of urban environments [2, 9].

The fact that the analysed buildings are 30-55 years old implies that the energy improvement measures can be successfully coupled with other works that occur in regular service and maintenance cycles that are estimated 30-40 years for most building elements and components [10]. Roofing (especially flat roofs, typical for this period), façade walls, joints in prefabricated buildings, or old windows often need repairs and refurbishments in order to maintain (or regain) their basic function, thus preserving building's functional, structural and material integrity. By coupling these two refurbishment drivers, a good share of construction costs, as well as incentives, credit options and other modalities of financial support could be shared to cover both these needs and energy upgrades, allowing for higher level of energy efficiency with rather low additional investment.

Table 1. Energy rating of multifamily housing representatives constructed 1961-1990

Building type	Freestanding		Lamella		High-rise	
						
D 1961–1970						
	F	172 kWh/(m^2a)	F	159 kWh/(m^2a)	E	118 kWh/(m^2a)
E 1971–1980						
	G	191 kWh/(m^2a)	E	137 kWh/(m^2a)	E	134 kWh/(m^2a)
F 1981–1991						
	E	126 kWh/(m^2a)	E	127 kWh/(m^2a)	E	125 kWh/(m^2a)

Energy class – as built
Energy needed for heating

Calculation methodology and energy classes according to Serbian national regulations [11, 12]

The main use of energy by households is for heating their homes – in EU it is 64.7% of final energy consumption in the residential sector [13]. In the observed multifamily housing blocks heating is charged at flat rate per heated area, regardless of actual consumption. This stresses the necessity to explore the scenarios that would provide the tangible benefits of energy upgrades for all stakeholders.

Open city blocks constructed during the socialist period* were greenfield developments in new, mainly suburban areas, with strong governmental control and a sense of collective property. This has been reflected on various levels that affect current options for energy efficiency upgrades that were considered in this research:

* 1963-1992, Socialist Federal Republic of Yugoslavia; 1946-1963 Federal People's Republic of Yugoslavia

– Building's lot equals its footprint and all free/open spaces belong to the local municipality (Belgrade); therefore, homeowners can intervene only within current building's envelope.
– Buildings are connected to district heating system which is provided by Public Utility Company (PUC) *District Heating Plants of Belgrade*, founded by the Belgrade city Government.
– Open spaces are owned by the city of Belgrade, management and maintenance is provided by PUC *Greenery Belgrade*, founded by the Belgrade city Government.

Several researches conducted at both national and local (municipality New Belgrade) level, as well as numerous case studies have shown that energy needed for heating of this portion of housing stock can be improved by 30-78% [14-17] by applying simple architectural measures, averaging around 60%, which is consistent with similar building types in other European countries [3, 18-20]. Such volume of estimated savings could reflect on wider energy picture on local and even national level. During the heating season, some 40% of total Serbian gas consumption is allocated to Belgrade's district heating plants, which shows the strategic importance of energy optimization of buildings supplied by such system as well as the importance of improvements of the district heating system itself. Reducing energy consumption and increasing the share of renewable energy sources implicates significant reductions of CO_2 emissions, but would also enable reduction of running costs and optimized management of PUC resources through enhanced capacity to connect new consumers, downsizing the equipment, *etc.*

The abundance of open spaces as well as the fact that they are managed by the city authorities, as is the case with the district heating system, indicated that use of renewable energy sources (RES) at district level could provide some valuable data on potential energy savings and reductions in CO_2 emissions related to the district heating system and point to solutions applicable in numerous socialist-era open city blocks.

Open spaces, conceived and designed in the spirit of Athens Charter, are currently in a rather poor condition, having been neglected and even partly losing their initial form, fig. 2. This is also the case with the buildings, where refurbishment of open/green spaces could be coupled with upgrades of infrastructure, including the district heating system.

Figure 2. Deteriorated open spaces within the Block 45 (a), (b) and in riverbank area (c)

The study was conducted for the case of New Belgrade's Block 45, fig. 3, in order to investigate the possibilities of coupling energy efficiency refurbishment with introducing on-site available RES, in particular geothermal. Built in the early 1970s, it remains as one of the finest examples of implementing modernist concepts in designing neighborhoods, with a strong base in the principles of the Athens Charter [21]. Both the master plan and building designs were selected through architectural competition, and its network of green and recreational spaces present one of the exceptional attributes of this urban structure. It is located at the very southern part of Novi Beograd, between the river Sava and Jurija Gagarina Str., covering an area of around 68 ha, with additional 13 ha along the Sava quay. Typologically, this neighborhood is largely uniform, fig. 3, – along the Jurija Gagarina Str. there are 45 skyscrapers, number of storeys Gf+8 up to Gf+16, and in the part closer to Sava there are 23 buildings (wings with 6 entrances each), number of storeys Gf+2 and Gf+4. Apart from the mentioned apartment buildings, housing around 18000 people, there is a set of buildings within the block with complementary amenities (primary school, two childcare institutions, municipality centre, craft centres, *etc.*).

Figure 3. Block 45 (*for color image see journal web site*)

Methodology

Methodology follows the general logic for energy refurbishments of housing stock, addressing the necessity of improving buildings' performance (reducing energy needs) in order to enable effective use of RES. In the first step, the current energy performance and possible retrofit options were assessed for the selected sample block in order to quantify the energy needed for heating at the scale that represents the basic organizational unit of local community. In the second phase, the options for use of RES were explored, by quantifying their capacity to contribute to the district heating system. Legislative and organizational residues from socialist era were taken into consideration as drivers for private homeowners and public sector.

Energy performance assessments

Since the research was focused on large housing blocks, developments constructed during 1961-1990, where similar models were used repeatedly within the same block (but also in numerous developments throughout Serbia and former Yugoslavia), building typology was used as a tool for assessment of current building performance as well as for assessment of estimated savings through different retrofit scenarios. The national building typology used in this paper was developed within the EU project TABULA*, that has been appointed as one of two official European methodologies for building stock energy performance assessment and only one that contains all the data needed for the energy performance calculation [22]. Na-

* TABULA – Typology Approach for Building Stock Energy Assessment. Project co-funded by the Intelligent Energy Europe program of the EU (2009-2012, predecessor of currently active project EPISCOPE). Detailed info available at http://episcope.eu/building-typology/

tional Typology of Residential Buildings in Serbia [14] was developed in two forms: one completely compliant to TABULA nomenclature, and a more elaborate one, with more building types in order to provide better sensitivity to assessment within local communities. The later was used for identification of building types within the sample block, as well as for the assessments related to energy needed for heating.

National Typology depicts four basic forms of multifamily housing: free standing buildings, lamellas, building in a row, and high-rise [14]. Except from buildings in a row, that are typical for traditional city blocks, all other building types occur in open city blocks, referring to the most frequent form of residential zones in urban environments.

An overview of basic energy features of residential buildings constructed from 1961 to 1990 depicted by National Typology is presented in tab. 1 (as built) and tab. 2 (two improvement scenarios). Energy performance is indicated by energy performance certificate rating and specific annual energy needed for heating, calculated using methodology and procedures stated in the current Serbian regulations on energy efficiency of buildings [11, 12] which includes only energy needed for heating and uses general calculation principles set in accordance with European standards and EN ISO 13790. Typical representatives were selected after cluster analysis of specialized residential buildings survey covering 20000 sample buildings nationwide. Energy rating was calculated based on the available technical documentation, while improvement models were defined by National Typology:

– The first level of improvement (*Improvement 1* in tab. 2) is defined as the result of applying *standard measures, typical for our market in case of refurbishment*.
– The second level of improvement (*Improvement 2* in tab. 2) is defined as the result of applying *advanced measures, requiring a large scope of investment*.

In case of the open city block buildings dated 1961-1991, the first scenario – *Improvement 1* – included the following measures:

– Window replacement, wooden frame windows, double insulated glazing, $U = 1.5$ W/m^{2}K.
– Addition 10 cm of thermal insulation to the most relevant façade walls, $U = 0.23$-0.31 W/m^{2}K, $U_{max} = 0.40$ W/m^{2}K.
– Rehabilitation of flat roofs with 16-20 cm of additional thermal insulation, up to achieving code-compliant U-values, $U = 0.16$-0.18 W/m^{2}K, $U_{max} = 0.20$ W/m^{2}K.

The second scenario – *Improvement 2* – included:

– Window replacement, the PVC frames, triple insulated glazing, U-value 1.0 W/m^{2}K.
– Addition of 20 cm of thermal insulation on all accessible façade walls, $U = 0.14$-0.22 W/m^{2}K.
– Rehabilitation of flat roofs with 25 cm of additional thermal insulation, $U = 0.13$-0.26 W/m^{2}K.
– Insulating the floor construction to the unheated areas, $U = 0.13$-0.28 W/m^{2}K.
– Replacing the apartments' entrance doors, metal, insulated, U-value 1.5 W/m^{2}K.

Energy rating class of E, F, and even G indicates that energy performance of all sample buildings shown in tab. 1 is notably below contemporary standards, but even the first level improvements shown in tab. 2 result in much better energy ratings – class D or C is achieved (mainly depending on surface-to-volume ratio). More ambitious refurbishment scenario with level 2 improvements led to achieving at least class C rating (36-70 kWh/m^{2}a), which indicates energy performance in compliance with the current requirements for new construction.

Table 2. Specific energy needed for heating for multifamily housing representatives for periods D, E and F (1961-1990) after proposed upgrades (data according to National typology)

		Specific energy needed for heating [kWh/m^{2}a] and corresponding energy rating		
Building type		Freestanding	Lamella	High-rise
D 1961-1970	Improvement 1	55 – C	77 – D	62 – C
	Improvement 2	37 – C	48 – C	30 – B
E 1971-1980	Improvement 1	72 – D	78 – D	52 – C
	Improvement 2	47 – C	60 – C	30 – B
F 1981-1991	Improvement 1	78 – D	86 – D	58 – C
	Improvement 2	42 – C	53 – C	38 – C

During the work on Energy Map of New Belgrade [23], the actual data on energy consumption measured at the district heating substations was collected for all residential buildings in the municipality of New Belgrade for the heating season 2014/2015. The research showed the great variety of measured consumption for identical buildings: 125-210 kWh/m^{2}a (averaging 154.35 kWh/m^{2}a) for lamellas and 84-166 kWh/m^{2}a (averaging 119.46 kWh/m^{2}a) for high-rise. However, these values correspond to the values from National typology (159 kWh/m^{2}a for lamellas and 118 kWh/m^{2}a for high-rise). For the calculations of existing energy consumption for heating, the actual measured data was used. The estimated post-refurbishment energy needs were determined using National typology.

Renewable energy assessments

Initially, two main RES were considered: solar and geothermal. Preliminary assessments of solar potential were done using PVGIS tool while geothermal capacities were established following the results of previous researches done within the national research project: *Research and Application of Underground Water Resources in Context of Upgrading Energy Efficiency of Buildings,* when the capacities were measured at relevant points of New Belgrade.

Solar potential was calculated having in mind three possible positions for photovoltaic panels: horizontal and optimal angle (for flat roofs and shading) and vertical (for available side walls with SE-SW orientation). As shown in fig. 4, capacities are the lowest during the heating season and solar power should be used much more effectively for production of

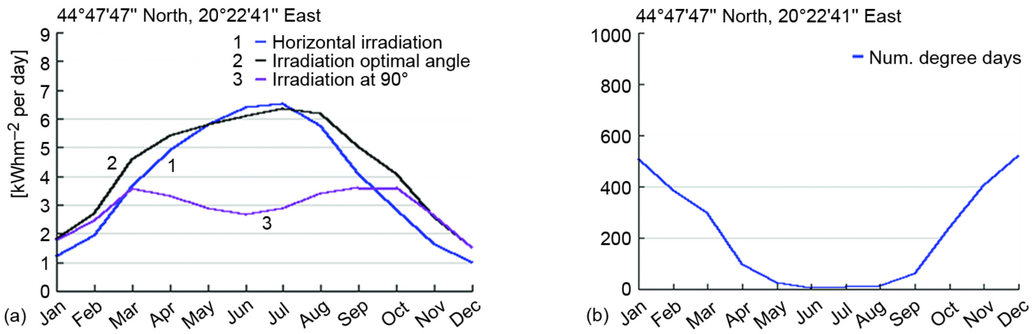


Figure 4. Solar irradiation (a) and heating degree days (b) for Block 45

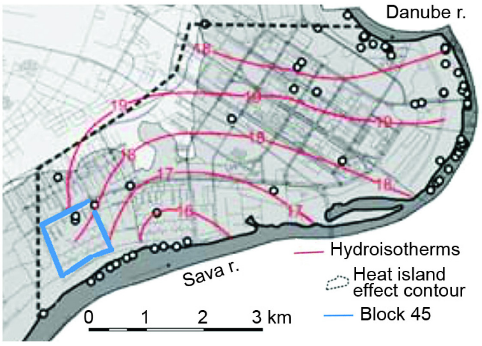


Figure 5. Simplified hydro-isotherm maps of New Belgrade area, winter season [24]

electrical energy and/or for hot water preparation, supplying the individual buildings rather than the district heating system.

Geothermal potential for Block 45 was quantified using the winter season data from hydro-isotherm maps of New Belgrade, fig. 5. The energy potential of the river Sava's water body was not included in this research.

Results and discussion

Potential reductions in energy needed for heating at district level

Based on the data on the geothermal potential of New Belgrade – 19.85 MW in the zone of 16 km^2 to which Block 45 belongs [24], it has been established that around 1.24 MW/km^{2}s can be expected in this area. The values calculated after this input, are given in tab. 3. Calculations for two different scenarios and the possibility of using geothermal energy are performed: the first scenario related to the territory without the riverbank area (around 68 ha), while the second scenario included the part along the river, total area of 13 ha.

Major savings in energy needed for heating derive from building refurbishment – 50.12% with Improvement 1 and 65.45% with *Improvement 2* scenario. The values for estimated post-refurbishment energy needs were taken from National typology and applied for each building in accordance to its building type. Typical lamella from Block 45 (Gf+4) and high-rise (Gf+14) were examined as case studies in previous researches, using various methodologies and refurbishment scenarios. The resulting energy savings regarding energy needed for heating were.

- Lamella Gf+4: 51.8% (improvements on thermal envelope) – World Bank tool [16].
- Lamella Gf+4: 51.6% (improvements on thermal envelope) – World Bank tool [15].
- High-rise Gf+14: 53.9% (improvements on thermal envelope) – World Bank tool [15].
- High-rise Gf+14 39.44% (improvements on thermal envelope) – conservative cost-optimal approach [6].
- High-rise Gf+14 50-55% (improvements on thermal envelope) – various calculation methods [25].
- High-rise Gf+14 68-70% (advanced architectural and technical improvements) – various calculation methods [25].
- High-rise Gf+14: 65.51% (improvements on thermal envelope, all accessible components covered) [16].

The values in tab. 3 show average for all buildings combined (lamellas and high-rise); respective energy savings also apply at total housing block level, reflecting the actual structure of its buildings. The impact of potential energy savings from building refurbishment is not only relevant for the tenants/homeowners, but it may affect the district heating system as well. This reduction in energy demand for current users enables PUC *District Heating Plants of Belgrade* to cover new developments while downsizing the equipment and running costs. The benefits for the PUC could be used to explore the incentives for building refurbishment.

While, according to the current use, the possibility of covering the energy needs for heating by using the geothermal potential is under 10% in both cases, by improving the energy

Table 3. Energy needed for heating of multifamily residential buildings in Block 45 – options of geothermal energy usage coupled with different building refurbishment scenarios

Block 45 – residential buildings (heated area 276057 m^2)		Existing	Improvement 1	Improvement 2
Energy needed for heating [MWh]		38459.04	19185.22	13287.30
Energy needed for heating [kWhm^{-2}a^{-1}]		130.22	64.96	44.99
Energy savings by building refurbishment [%]		–	50.12	65.45
Share of energy needed for heating that could be covered using geothermal energy [%]	Territory excluding the riverbank area	7.89	15.83	22.85
	Territory including the riverbank area	9.40	18.85	27.22
Reduction of fossil fuels use and reduction of CO_2 emission [%]	Territory excluding the riverbank area	7.89	58.01	73.35
	Territory including the riverbank area	9.40	59.52	74.85

characteristics of buildings through the implementation of standard measures (*Improvement 1*), this share increases to 15.83% for the net block area, *i. e.* 18.85% for the larger block area, whereas, after the more ambitions scenario of building renovation, 22.85% (for net block area), *i. e.* 27.22% (for the territory including riverbank area) of needs for heating energy would be covered in this manner. This information points to the strategic significance and large benefits of simultaneous improvement of buildings' energy efficiency and more intensive involvement of RES in the process of energy optimization at district level. In regard to nominal share of RES in district heating energy consumption, the option that includes the riverbank area is significantly better. However, the effects of including the riverbank area are minor in regard to fuel consumption and CO_2 emissions: only about 1.5%. This implies that the blocks along the riverbank area (Blocks 45, 44, 70, and 70a) are not in the advantageous position regarding the use of geothermal energy and that the same approach could be used in all similar developments in New Belgrade.

Challenges of implementation

The effective implementation would require harmonized actions by homeowners and relevant PUC but would also provide immediate benefits for all stakeholders. The homeowners would benefit from better comfort conditions, decrease in running costs and increase in property value. The PUC *District Heating Plants of Belgrade* would profit from the huge reductions in fuel consumption and other benefits described in the previous chapter, while the instalment costs are reduced when synchronized with PUC *Greenery Belgrade* operations. Since both PUC are subordinates to city authorities, the benefits reflect on that level as well and the city could offer some incentives for homeowners in order to intensify the refurbishment rate. Finally, the fact that same or similar models repeatedly occur throughout the territory managed by the same PUC, can also offer design documentation and implementation guidelines that would facilitate legal procedures for building refurbishment.

Conclusion

Space heating remains dominant component in energy use in households (64.7% of final energy consumption in the residential sector in the EU). Between 1961-1990 multifamily housing blocks in Serbia and all over Western Balkan countries heating is provided through district heating system. The paper has explored the potentials for improving energy efficiency through reducing energy needed for heating by combining building refurbishment and use of RES. Open city blocks, typical developments during 1961-1990 possess specific potential, both for energy upgrades as for favorable disposition regarding the use of RES. Energy needed for heating in this portion of housing stock can be reduced by 50-65% through building refurbishment, with reductions in fossil fuel use by 58-75% when combined with use of geothermal energy.

Based on the example of Block 45, it is theoretically calculated that, depending on the considered scenario, the participation of geothermal energy in the total energy balance of an apartment block can increase to 16%, and even to 27%, which gives this approach specific strategic significance. The research presented in the paper illustrates the potential for application of integrated approach of energy rehabilitation through building improvement and use of RES, having in mind the specific ownership rights in Belgrade regarding the housing, buildable land and PUC. By identifying the benefits for all stakeholders (tenants, PUC, city of Belgrade) in this process, the paper provides ground for future implementation of the method and possible activation of Public companies or city of Belgrade as the economical drivers through public-private partnership or energy service company models.

References

[1] ***, Communication from the Commission (COM) to the European Parliament and the Council, Energy Efficiency and its Contribution to Energy Security and the 2030 Framework for Climate and Energy Policy, 2014
[2] Nemry, F. *et al.*, Options to Reduce the Environmental Impacts of Residential Buildings in the European Union – Potential and Costs, *Energy and Buildings, 42* (2010), 7, pp. 976-984
[3] ***, Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union 14.11.2012. EN L 315 p. 1-56
[4] ***, Statistical Office of the Republic of Serbia. 2011 Census of Population, Households and Dwellings in the Republic of Serbia: Dwellings by the Type of Building (Data by Municipalities/Cities), Belgrade, 2013
[5] Radivojević, A., The Global and Local Experiences and Directions of Development of Thermal Protection Regulations, in: *Energy Optimisation of Buildings in Context of Sustainable Architecture – Part 1: Analysis of Building Fund's Structure* (in Serbian) (Ed. M. Jovanović Popović), Faculty of Architecture, University of Belgrade, Belgrade, 2003, pp. 99-124
[6] Ćuković Ignjatović, N., Optimisation of Refurbishment Measures for Residential Buildings in Order to Improve Energy Efficiency (in Serbian), Ph. D. thesis, Faculty of Architecture, University of Belgrade, Belgrade, 2016
[7] Đukanović, Lj., Typology and Valorisation of Belgrade's Multifamily Structures Regarding Living Comfort (in Serbian), Ph. D. thesis, Faculty of Architecture, University of Belgrade, Belgrade, 2015
[8] Rovers, R., Existing Buildings, a Hidden Resource, Ready for Mining, in: *Joint Workshop on Sustainable Buildings: Towards Sustainable Use of Building Stock.* OECD Public Governance and Territorial Development Directorate, OECD, Paris, 2004
[9] Petersdorff, C. *et al.*, Cost-Effective Climate Protection the Building Stock of the New EU Member States Beyond the EU Energy Performance of Buildings Directive, Report established by ECOFYS, EURIMA, Brussels, 2005
[10] Giebler, G., Planning Refurbishment Works, in: *Refurbishment Manual*, Birkhauser Verlag AG, Basel, Switzerland, 2009, pp. 22-31
[11] ***, Rulebook on Energy Efficiency of Buildings (in Serbian), *Official Gazette of the Republic of Serbia*, 61/2011 of 19.8.2011. Belgrade, Serbia, 2011, pp. 28-40

[12] ***, Rulebook on Conditions, Contents and Way of Issuing Certificates on Energy Characteristics of Buildings (in Serbian), *Official Gazette of the Republic of Serbia*, 69/2012, of 20.7.2012., Belgrade, Serbia, 2012, pp. 67-88
[13] ***, Eurostat – Energy consumption in households, http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households#Use_of_energy_products_in_households_ by_ purpose accessed March 2018
[14] Jovanović Popović, *et al.*, National Typology of Residential Buildings in Serbia, Faculty of Architecture, University of Belgrade and GIZ, Belgrade, 2015
[15] Ignjatović, D., Ćuković Ignjatović, N., Atlas of Energy Characteristics of Belgrade's Buildings (in Serbian), study by Faculty of Architecture, University of Belgrade on behalf of the city of Belgrade, Belgrade, 2012
[16] Ignjatović, D., Ćuković Ignjatović, N., Conserve Energy, Faculty of Architecture, University of Belgrade and GIZ, Belgrade, 2017
[17] Ćuković Ignjatović, N., Façade – Adaptations and Transformations (in Serbian), Zadužbina Andrejević, Belgrade, 2010
[18] Uihlein A., Eder, P., Policy Options Towards an Energy Efficient Residential Building Stock in the EU-27, *Energy and Buildings, 42* (2010), 6, pp. 791-798
[19] ***, BPIE, A Guide to Developing Strategies for Building Energy Renovation – Delivering Article 4 of the Energy Efficiency Directive, 2013
[20] Csoknyai, T., *et al.*, Building Stock Characteristics and Energy Performance of Residential Buildings in Eastern-European Countries, *Energy and Buildings, 132* (2016), Nov., pp. 39-52
[21] ***, Le Corbusier, Charte d'Athenes, 1957
[22] ***, EC, Guidelines Accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, C115, 2012, pp. 1-28
[23] Ćuković Ignjatović, N., Nedić, M., Energy Map of New Belgrade. Faculty of Architecture, University of Belgrade and GIZ, Belgrade, Serbia, 2016 (unpublished study material)
[24] Vranješ, A., *et al.*, Geothermal Concept for Energy Efficient Improvement of Space Heating and Cooling in Highly Urbanized Area, *Thermal Science, 19* (2015), 3, pp. 857-864
[25] Matic, D. *et al.*, Economically Feasible Energy Refurbishment of Prefabricated Building in Belgrade, Serbia, *Energy and Buildings, 98* (2015), July, pp. 74-81

Paper submitted: June 12, 2017
Paper revised: March 20, 2018
Paper accepted: May 2, 2018