Evaluacija mera za uštedu energije na postojećim stambenim zgradama na Novom Beogradu upotrebom modeliranja energetskih performansi zgrada

Evaluation of Energy Conservation Measures for Existing Residential Buildings in Novi Beograd Using Building Energy Modeling

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***Rezime* -** Objekti stare gradnje čine najveći deo postojećeg stambenog fonda u Republici Srbiji i po pravilu su energetski neefikasni, što ih svrstava među ključne činioce u procesu energetske tranzicije. Ovaj rad se bavi analizom mogućnosti za smanjenje potrošnje energije, emisija zagađujućih materija i gasova sa efektom staklene bašte, kod ovakvih objekata, kroz energetske sanacije i prelazak na grejanje hibridnim sistemima sa obnovljivim izvorima energije (OIE).

Prethodna istraživanja su na osnovu izmerene potrošnje na postojećim objektima, te korišćenjem proračuna baziranih na kvazi stacionarnim modelima za evaluaciju energetskih performansi zgrada (u skladu sa metodologijom iskazanom u Pravilniku o energetskoj efikasnosti zgrada), pružala procene o postojećim performansama i potencijalnim uštedama energije u slučaju energetske sanacije. Ti rezultati su prezentovani u okviru Nacionalne tipologije stambenih zgrada Srbije i Energetske mape Novog Beograda. Ovaj rad ide korak dalje u dva aspekta, najpre korišćenjem dinamičke simulacije energetskih performansi zgrada daje precizniju i detaljniju evaluaciju grupe mera za uštedu energije obrađene u prethodnim istraživanjima, a koje se odnose na građevinsku fiziku tj. energetsku sanaciju termičkog omotača objekta. Potom, u radu je prikazana i analiza dodatnih mera za uštedu energije, a koje se odnose na primenu hibridnih sistema za grejanje sa obnovljivim izvorima energije, kao i procena ušteda proisteklih iz implementacije takvih mera.

U radu su analizirana dva tipa objekta karakterističnih za Novi Beograd, a to su stambena zgrada tipa lamela (kategorija D4 prema Nacionalnoj topologiji) i stambena zgrada velike spratnosti – soliter (kategorija E6 prema Nacionalnoj tipologiji). Najpre je izrađen detaljan matematičko-fizički simulacioni model, na osnovu podataka o lokaciji, geometriji i građevinskoj fizici. Potom je na osnovu stvarno izmerene potrošnje za grejanje taj model kalibrisan prema ASHRAE-14 kriterijumima. Kalibrisani model je potom usklađen prema uslovima koji se očekuju u periodu nakon implementacije MUE, da bi na kraju takav usklađeni model bio korišćen za simulacije sa ciljem procene ušteda. Rezultati pokazuju da osim mera za uštedu energije koje se odnose na termički omotač objekta, moraju se razmatrati uzeti i mere koje se odnose na modernizaciju sistema grejanja, a koje u pojedinim slučajevima mogu imati i prioritet što se tiče redosleda implementacije.

***Ključne reči* -** Objekti stare gradnje, mere za uštedu energije, grejanje, modeliranje energetskih performansi zgrada

***Abstract* -** Old buildings make up the majority of the existing housing stock in the Republic of Serbia and are generally energy inefficient, giving them a critical role in the energy transition process. This paper analyzes the potential for reducing energy consumption, pollutant emissions, and greenhouse gases in such buildings, through energy retrofitting and transition to hybrid heating systems utilizing renewable energy sources (RES).

Previous research efforts were based on measured consumption in existing buildings and calculations using quasi-steady-state models for evaluating building energy performance (in line with the methodology outlined in the Energy Efficiency Regulation for Buildings), provided estimates of current performance and potential energy savings from retrofitting. These results have been presented in the National Typology of Residential Buildings in Serbia and the Energy Map of Novi Beograd.

This study advances the analysis in two aspects. First, by using dynamic simulations of building energy performance, it offers more accurate and detailed evaluations of energy-saving measures addressed in previous research, particularly those related to the building envelope thermal retrofitting. Second, the study also includes an analysis of additional energy-saving measures focused on implementing hybrid heating systems with renewable energy sources and assessment of the savings from such measures.

The study analyzes two types of buildings characteristic of Novi Beograd: a lamella-type residential building (category D4 according to the National Typology) and a high-rise residential building (category E6 according to the National Typology). A detailed software simulation models were developed based on location, geometry, and construction data. This model was

calibrated according to ASHRAE Guideline 14 criteria using actual heating consumption measurements. The calibrated model was then adjusted to reflect post-implementation conditions of energy conservation measures (ECMs), and this adjusted model was used for simulations to estimate savings.
The results show that in addition to energy-saving measures focused on the thermal envelope, modernization of heating systems must also be considered, as such measures can, in some cases, take precedence in the order of implementation.

Index Terms **-** Existing buildings stock, energy-saving measures, heating, building energy performance modeling.

I Introduction

The building sector is a cornerstone of global energy consumption and environmental impact, accounting for approximately 40% of total energy use and 30% of greenhouse gas emissions worldwide [1]. In the European Union, buildings contribute 40% of energy consumption and 36% of CO_2 emissions [2], a pattern mirrored in Serbia, where residential buildings drive significant energy demand [3]. With much of Serbia's housing stock constructed before modern energy efficiency standards—often during the post-World War II urbanization boom—these buildings exhibit poor thermal performance and outdated heating systems [4]. This inefficiency positions them as a critical target for Serbia's alignment with EU decarbonization goals, including the European Green Deal [5].

Novi Beograd, a planned urban district in Belgrade built largely between the 1960s and 1980s, exemplifies this challenge. Its residential buildings, characterized by concrete construction and minimal insulation, reflect the energy-intensive design of the era [6]. Retrofitting such structures offers a dual benefit: reducing energy consumption and supporting Serbia's commitments under the Energy Community Treaty to improve energy efficiency and integrate renewable energy [7].

Building energy modeling (BEM) is a powerful tool for assessing retrofit potential, simulating dynamic interactions between building systems, climate, and occupancy [8]. Unlike quasi-steady-state models used in prior studies (e.g., Serbia's National Typology of Residential Buildings [9]), dynamic BEM captures time-dependent effects, such as heat loss variations and system inefficiencies, with greater accuracy [10]. This study applies BEM to evaluate energy conservation measures (ECMs) in two Novi Beograd building types: a lamella-type residential building (D4) and a high-rise (E6). By analyzing thermal envelope upgrades and hybrid heating systems with renewable energy sources (RES), it aims to provide actionable insights for stakeholders in Serbia's energy transition.

II Methodology

This study employs a rigorous methodology for building energy modeling and ECM evaluation, adhering to ASHRAE 211-2018 and ISO 52000 standards [11, 12]. The process integrates empirical data, site assessments, and dynamic simulations to ensure robust results.

Data Collection and Audit **-** Baseline energy performance was established using technical documentation (e.g., architectural plans, utility data from Belgrade Power Plants) and site audits conducted in June–July 2024. These audits clarified operational patterns and validated energy consumption data [13]. Weather data were sourced from Typical Meteorological Year (TMY) records for Belgrade, enabling regional benchmarking [14].

Building Energy Modeling **-** Simulations were performed using IES VE software, compliant with ASHRAE 140 and CIBSE AM11 standards [15]. The process involved creating Calibrated Baseline Model and Adjusted Baseline Model

The Calibrated Baseline Model was constructed from architectural data and calibrated to ASHRAE Guideline 14 standards [16] using metered heating consumption from Novi Beograd's Energy Map.

The Adjusted Baseline Model provides modifications to the Calibrated Baseline Model to reflect post-ECM conditions, incorporating TMY weather data and a conservative 1% annual window replacement rate.

Infiltration rates, a significant factor in older buildings, were modeled as constant airflow per façade area ($l/(s \cdot m^2 fac)$) and fine-tuned during calibration.

Energy conservation measures (ECMs) **-** ECMs were selected based on prior studies [9] and practical feasibility in Serbia's retrofit market. Evaluated measures included thermal envelope upgrades, windows replacement, infiltration reduction, and hybrid heating systems.

Thermal insulation upgrade for external walls and roof include adding 10 cm (Improvement 1) or 20 cm (Improvement 2) of insulation to walls and roofs, reflecting common retrofit options [17].

Window replacement includes upgrading to double-pane low-e ($U=1.5\ W/m^2K$) or triple-pane ($U=1\ W/m^2K$) windows to reduce heat loss and improve airtightness [18].

Infiltration reduction was modeled separately from thermal insulation upgrade and windows replacement to clearly evaluate influence of convection heat losses on building energy performance. In practice, insulation reduction is achieved not just as a separate retrofit measure that includes caulking and air sealing, but also as a biproduct of windows replacement or walls insulation upgrade. However, analyzing infiltration losses separately is important for understanding energy performance of existing and retrofitted buildings, since infiltration is a key source of energy loss in aging structures [19].

Hybrid Heating Systems - Integrating heat pumps with district heating as a backup was modeled as a supplemental ECM to explore RES potential [20].

Analysis and simulation methodology is illustrated at Figure 1.

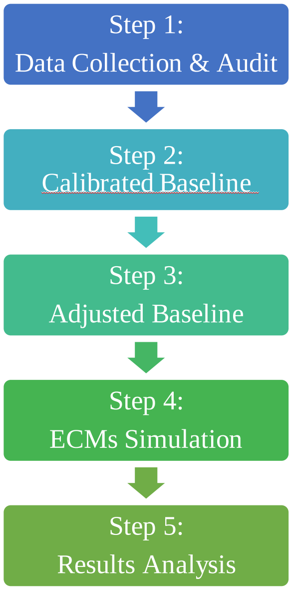

Figure 1: BEM Workflow.

III BASELINE MODEL

Two building types were analyzed: a lamella-type building (D4, Block 45) and a high-rise (E6, Block 70). These were chosen for their prevalence in Novi Beograd and distinct thermal characteristics—lamellas have larger exposed surface areas, while high-rises face greater wind-driven infiltration [21]. Baseline models were calibrated to ASHRAE-14 standards using 2014/15 heating data, with adjusted baselines reflecting standardized TMY conditions.

Figure 2 and Figure 3 show the high-rise residential building (category E6) and 3D model geometry while Figure 4 and Figure 5 show the lamella type residential building (category D4) and 3D model geometry

The model geometries were created using existing architectural drawings and site investigations, while envelope characteristics are modeled according to information provided in National Typology of Residential Buildings in Serbia [6].

Figure 2. High-rise residential building (category E6, Novi Beograd, Block 70)

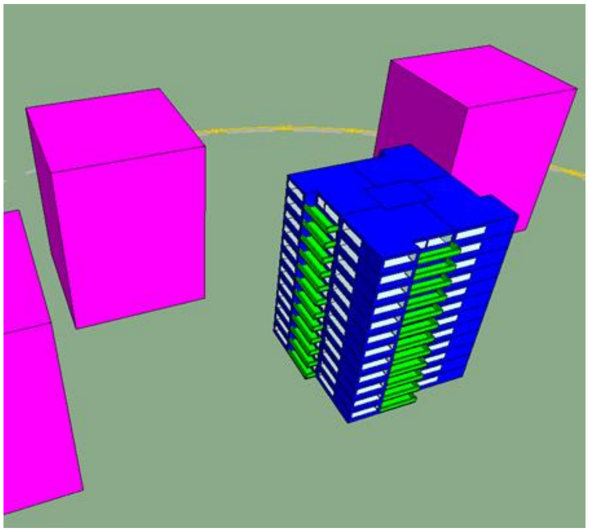

Figure 3. 3D Model of high rise building

Figure 4. Lamella-type residential building (category D4, Novi Beograd, Block 45)

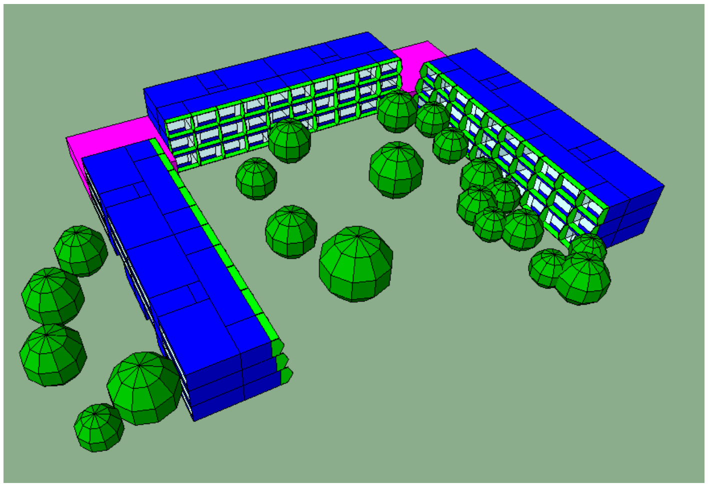

Figure 5. 3D Model of high rise building

IV Energy Conservation Measures

ECMs were evaluated individually and in packages to assess their combined impact. Envelope upgrades reduce conductive heat loss, window replacements enhance thermal resistance, and infiltration reduction targets uncontrolled air leakage **-** a critical issue in concrete-panel buildings [22]. The hybrid heating system, combining heat pumps with district heating system, was modeled to reflect Serbia's growing interest in RES under EU directives [23].

In addition to the building envelope retrofit measures, implementation of a central air source heat pump (ASHP) was evaluated. It is assumed that the new central heating system will be a hybrid system in which ASHP will operate and cover the heating load at outdoor air temperature equal or greater than 4 °C. Below that switchover temperature, the central heating will switch to district heating system as a source. The switchover temperature was selected based on existing outdoor air temperature reset curve for secondary heating loop and ASHPS maximum leaving hot water temperature for heat pumps using R134a or R410a refrigerants.

Depending on specific project goals, the switchover temperature should be optimized for each case, as lower switchover temperature means larger and more expensive ASHP but could also mean lower fossil fuel consumption on site.

The air-to-water heat pump performance was modeled using IES VE software and the following biquadratic function

$$fCOP_{\mathrm{tt}}(T_{\mathrm{elt}}, T_{\mathrm{odb}}) = \frac{C_{00} + C_{10}t_{\mathrm{elt}} + C_{20}t_{\mathrm{elt}}^2 + C_{00}t_{\mathrm{odb}} + C_{02}t_{\mathrm{odb}}^2 + C_{11}t_{\mathrm{elt}}t_{\mathrm{odb}}}{C_{\mathrm{norm}}}$$

Where:

$t_{elt}=T_{elt}-T_{datum}$

$t_{odb}=T_{odb}-T_{datum}$

T_{elt} is the entering load-side water temperature

T_{odb} is the entering source air dry-bulb temperature

T_{datum} is a datum temperature

C_{norm} is a normalization constant set such that $fCOP_{tt}(T_{eltref},T_{odbref})=1$ at reference conditions.

The selected reference conditions are COP_{href}=2.3 °C, $T_{odbhref}$=4 °C, and $T_{elthref}$=40 °C. The maximum value of *COP* is limited to 4.

This form of equation is not unique to IES VE but is a standard approach in heating, ventilation, and air conditioning (HVAC) performance modeling. Biquadratic curves are widely used in building energy simulation software, including IES VE, EnergyPlus etc., to represent how the performance (e.g., COP, capacity, or energy input ratio) of HVAC equipment, such as heat pumps, varies with operating conditions, typically temperatures.

V Results and Analysis

Energy savings are estimated as difference between the adjusted baseline energy consumption and the energy consumption after the implementation of specific ECM or ECM package:

Energy Savings = Adjusted Baseline Energy Consumption – Post Retrofit Energy Consumption.

The results are presented in Table 2 and Table 3 and illustrated on Figure 6 and Figure 7. On Figures 6 and 7 the annual energy need for heating per unit floor area for the adjusted baseline and for each retrofit option is shown as a blue bar and expressed in kWh highlight significant energy savings potential. Savings are expressed as a percentage of the adjusted baseline energy need for heating and illustrated as an orange bar. For the high-rise (E6), ECM packages achieve 59% (Improvement 1) and 75% (Improvement 2) reductions in heating energy, driven by its lower baseline consumption and higher infiltration losses. The lamella (D4) sees 48% and 57% savings, reflecting its larger surface area and initial energy intensity.

Adding the hybrid heating system boosts savings further, reducing energy consumption on site by additional 27% to 38% across both building types, consistent with studies on RES integration in Eastern Europe [24]. These findings align with research emphasizing the synergy between envelope upgrades and system improvements in older buildings [25].

VI Conclusions

This study demonstrates that integrated ECMs can reduce heating energy consumption by up to 75% in high-rise (E6) and 57% in lamella-type (D4) buildings in Novi Beograd. Dynamic BEM reveals that infiltration reduction and heating system modernization are as critical as envelope upgrades, challenging the traditional focus on insulation alone [26]. For Serbia, where district heating dominates but is often inefficient, hybrid systems with RES offer a scalable path to decarbonization [27].

These results provide a roadmap for policymakers and industry professionals, advocating retrofit strategies that prioritize comprehensive upgrades over isolated measures. Financial incentives, such as those in the EU’s Renovation Wave [2], could accelerate adoption in Serbia. Future research should investigate RES scalability (e.g., solar thermal and solar photovoltaic integration), occupant behavior impacts [28], and lifecycle cost analyses to refine retrofit prioritization.

ACKNOWLEDGEMENT

This research was supported by the Science Fund of the Republic of Serbia, Project No. 4344, Grant No. TF C1389YF, “Forward Looking Framework for Accelerating Households” Green Energy Transition – FF GreEN.

Table 1. Building Information and Energy Consumption (Metered, Calibrated Baseline, and Adjusted Baseline)

Block	Address	Year of Construction	Heated Area	Number of Heated Buildings	Metered Heating Energy Consumption for Season 2014/2015	Annual heating energy use per square meter	Calibrated Baseline Heating Energy Consumption for Season 2014/2015	Adjusted Baseline Heating Energy Consumption for TMY
			[m2]		[MWh]	[kWh/m2]	[MWh]	[MWh]
45	Dr. Ivana Ribara 191-193-195-197-199-201	1973	3086	6	674.569	210	673.9902	638.602
70	Jurija Gagarina 59	1975	4523	1	504.426	112	503.173	462.040

Table 2. Energy consumption and savings for Adjusted Baseline and ECMs – High Rise Building (E6)

		Envelope Insulation Upgrade		Windows Replacement		Reducing Infiltration		ECMs Package	
	Adj Bln	Imp. 1	Imp. 2	Imp. 1	Imp. 2	Imp. 1	Imp. 2	Imp. 1	Imp. 2
Annual heating kWh/m^2	102.2	77.8	74.3	90.8	86.1	77.2	67.9	41.5	25.2
Energy Savings	0%	24%	27%	11%	16%	24%	34%	59%	75%

Table 3. Energy consumption and savings for Adjusted Baseline and ECMs – Lamella Type Building (D4)

		Envelope Insulation Upgrade		Windows Replacement		Reducing Infiltration		ECMs Package	
	Adj Bln	Imp. 1	Imp. 2	Imp. 1	Imp. 2	Imp. 1	Imp. 2	Imp. 1	Imp. 2
Annual heating kWh/m^2	206.9	111.7	109.6	129.3	124.9	115.1	109.7	73.4	61.1
Energy Savings	0%	21%	22%	8%	12%	18%	22%	48%	57%

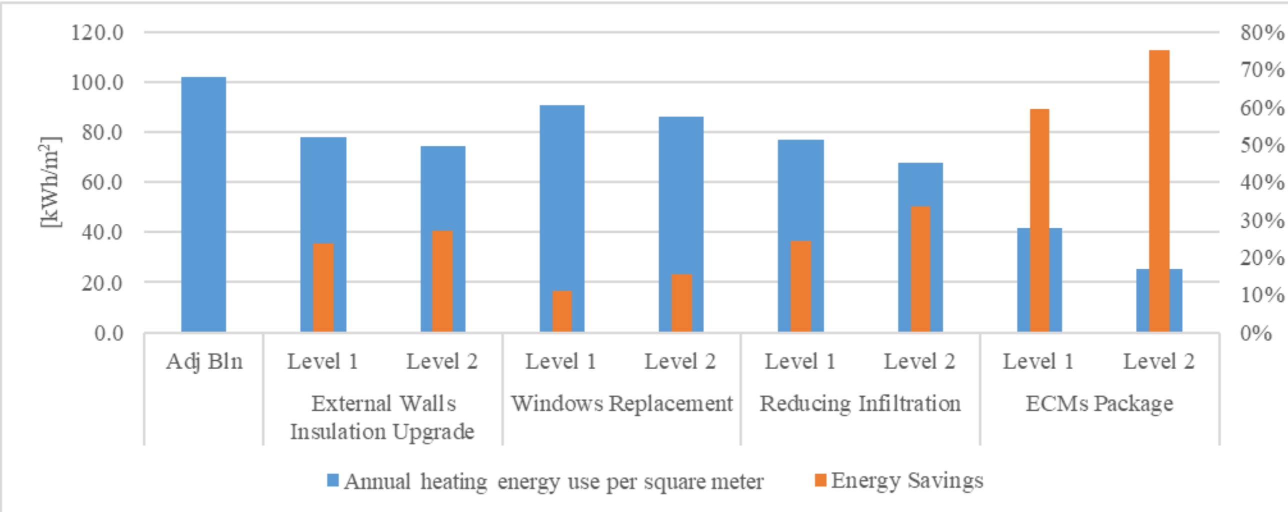

Figure 6. Energy consumption and savings for Adjusted Baseline and ECMs – High Rise Building (E6)

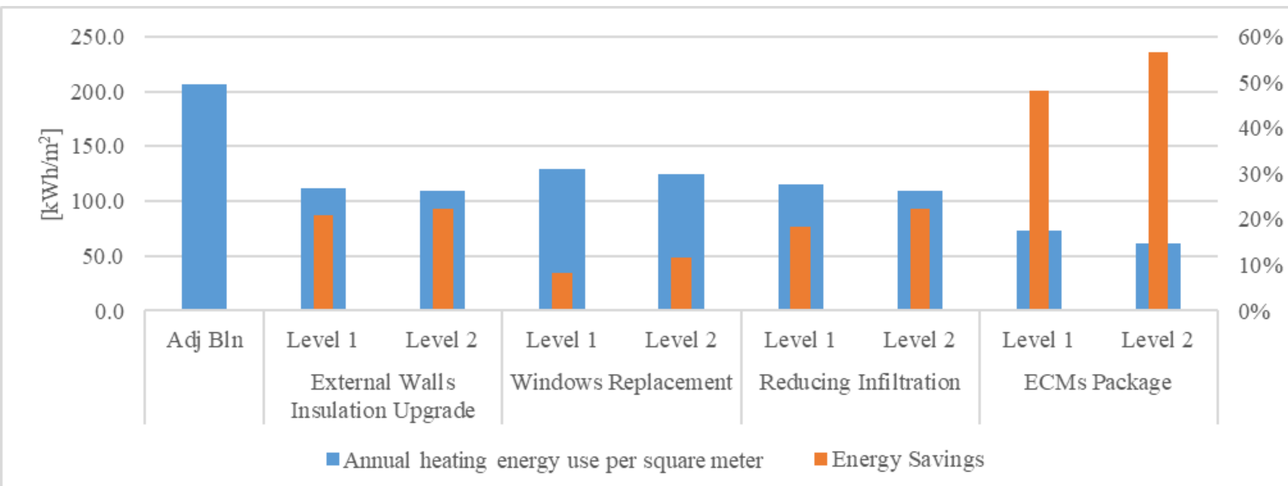

Figure 7. Energy consumption and savings for Adjusted Baseline and ECMs – High Rise Building (D4)

Table 4. ASHP hybrid system energy performance and savings

	High Rise Building		Lamella Type Buildings	
	Package 1	Package 2	Package 1	Package 2
Total Heating Energy [kWh]	187,546	114,189	331,804	276,228
District Heating Energy [kWh]	91,113	60,867	124,367	103,454
ASHP Heating [kWh]	96,433	53,322	207,437	172,775
ASHP Electricity [kWh]	39,450	22,259	80,428	67,364
Seasonal COP [kWh]	2.44	2.40	2.58	2.56
Final Energy Savings [kWh]	56,984	31,063	127,009	105,411
Final Energy Savings [%]	30%	27%	38%	38%

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