

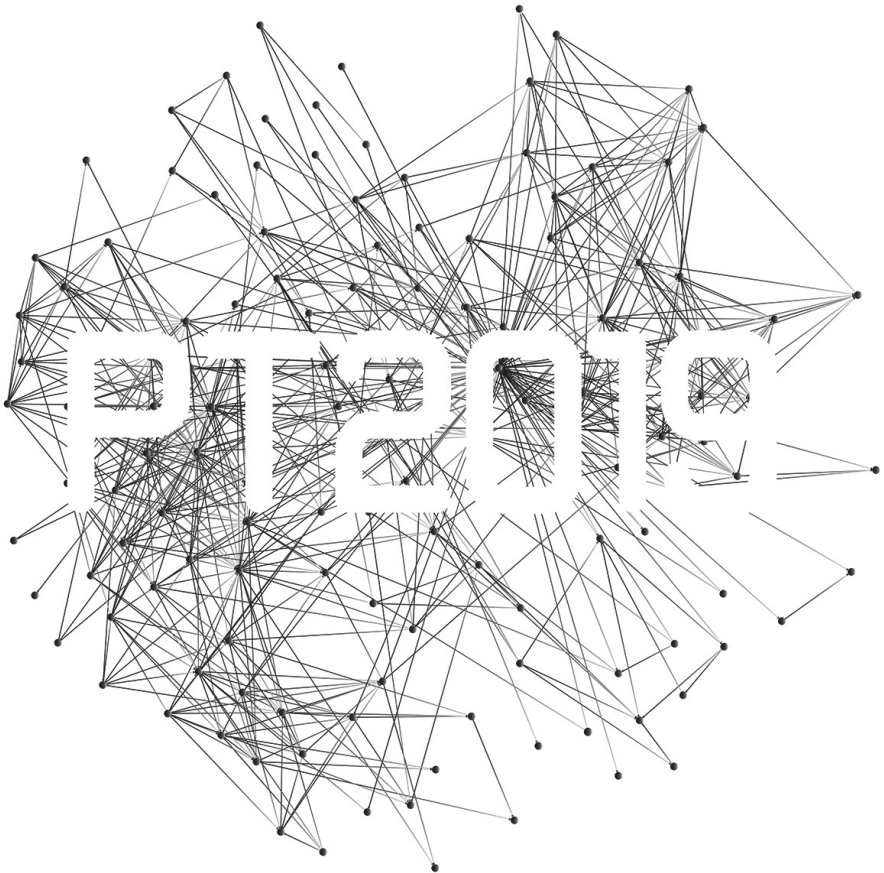
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6th INTERNATIONAL
ACADEMIC CONFERENCE ON
PLACES AND TECHNOLOGIES

PLACES AND TECHNOLOGIES 2019

THE 6th INTERNATIONAL ACADEMIC CONFERENCE ON
PLACES AND TECHNOLOGIES

EDITORS: Dr Tamás Molnár, Dr Aleksandra Krstić-Furundžić, Dr Eva Vaništa Lazarević, Dr Aleksandra Djukić, Dr Gabriella Medvegy, Dr Bálint Bachmann, Dr Milena Vukmirović
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PLACES AND TECHNOLOGIES 2019

**KEEPING UP WITH TECHNOLOGIES TO TURN BUILT HERITAGE INTO
THE PLACES OF FUTURE GENERATIONS**

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Technical Supporting Staff, University of Pécs Faculty of Engineering and Information Technology, Pécs, Hungary

TABLE OF CONTENTS

PLENARY LECTURE**44**

HERITAGE AND TECHNOLOGY - GENERATING A SENSE OF PLACE	45
Demeter Nóra, BA UC B, MYU, DLA UP	
FORM AND ENERGY: INNOVATIONS IN METAL BUILDING FAÇADES	53
Hachul, Helmut	
ASSESSMENT AND REHABILITATION OF HERITAGE STRUCTURES HELPED BY COMBINED NON-DESTRUCTIVE TESTS	64
Orbán Zoltán; Török Brigitta; Dormány András	
SEARCHING THE RIGHT DISTANCE BETWEEN THE OBJECTIVITY OF THE HISTORY AND THE NEED OF THE CONTEMPORARY	72
Stella, Antonello	

PAPER**89**

HUMAN MIGRATION CRISIS	90
Alwani, Omar; Borsos Ágnes	
THE MULTIPLEX TYPOLOGIES OF SHRINKING CITIES	100
Antonić, Branislav; Djukić, Aleksandra; Lojanica, Vladimir	
MONASTERY CRKVINA AND MONASTERY TVRDOŠ, TREBINJE, FEDERATION BOSNIA AND HERZEGOVINA - COMPLEX RECONSTRUCTION AND DEVELOPMENT	109
Arsić, Petar	
COLLECTIVE REUSE – CO-HOUSING DEVELOPMENTS IN THE SERVICE OF PRESERVATION THE BUILT HERITAGE	117
Babos Annamária	
TEENAGERS' PERCEPTIONS OF PUBLIC OPEN SPACES: EXPERIENCES FROM A LIVING LAB IN LISBON, PORTUGAL	124
Solipa Batista, Joana; Menezes, Marluci; Smaniotto Costa, Carlos; Almeida, Inês	
THE PERCEPTION OF PUBLIC SPACE: IMAGES AND REPRESENTATIONS OF STREET FURNITURE	132
Ben Dhaou, Ons; Vasváry-Nádor Norbert	
THE DESIGN CONCEPT OF A PRE-FABRICATED APARTMENT BUILDING	138
Borsos Ágnes; Kokas Balázs	

PROTECTION AND TOURISM DEVELOPMENT OF ANCIENT VILLAGES FROM A SUSTAINABLE PERSPECTIVE - HOUGOU ANCIENT VILLAGE AS AN EXAMPLE	146
Cao Hui	
POP(O)S OF SHOPPING CENTRE - A NEW APPROACH TOWARDS URBAN DESIGN.....	154
Cvetković, Marija; Radić, Tamara	
TRANSCRIPTION OF FORMER ARCHITECTURE	163
Zinoski, Mihajlo; Dimitrievski, Tome	
THE LOCAL LEVEL OF GOVERNANCE IN THE EUROPEAN PROCESS OF ENERGY TRANSFORMATION: CHALLENGES AND EMPOWERMENT CHANCES IN BULGARIA.....	171
Dimitrova, Elena; Tasheva – Petrova, Milena; Burov, Angel; Mutafchiiska, Irina	
URBAN GROWTH PATTERNS AND ENVIRONMENTAL PERFORMANCE: A COMPARISON OF LATE 20TH CENTURY AMERICAN SUBURBAN PATTERNS TO THOSE OF LATE 19TH CENTURY CENTRAL EUROPEAN URBAN FABRIC.....	180
Dougherty, James, AICP, CNU-A, ASAI	
ENERGY CONSUMPTION INDICATORS DUE TO APPLIANCES USED IN RESIDENTIAL BUILDING, A CASE STUDY NEW MINIA, EGYPT	188
Elhadad, Sara; Baranyai Bálint; Gyergyák János; Kistelegdi István	
MANAGEMENT APPROACH FOR SUSTAINABLE URBAN OF EXISTING NEW CITIES IN THE DIFFERENT REGIONS OF EGYPT (COMPARATIVE STUDY).....	194
Elhadad, Sara; Baranyai Bálint; Gyergyák János; Kistelegdi István	
INVESTMENT LOCATIONS MAPING: KIKINDA CITY CASE STUDY	202
Furundžić, Danilo S.; Furundžić, Božidar S.; Borko Lj, Drašković	
“VISIBLE” AND “INVISIBLE” TECHNOLOGIES FOR THE INCLUSION OF VULNERABLE USERS AND THE ENHANCEMENT OF MINOR ARCHITECTURAL HERITAGE	211
Finucci, Fabrizio; Baratta, Adolfo F. L.; Calcagnini, Laura; Magarò, Antonio	
DETAIL ASSEMBLAGES.....	219
Gourdoukis, Dimitris	
CONVERTIBLE UMBRELLA PT2016.....	227
Halada Miklós	

BUILT HERITAGE PROTECTION STRATEGY OF GUANGZHOU HISTORIC DISTRICT BASED ON PUBLIC SPACE UPDATE	235
He Honghao	
THE FRENCH LEGACY IN ALGERIA : THE ARCHITECTURE OF A SHARED IDENTITY, THE CASE OF THE KASBAH: ALGIERS, AND THE COLONIAL CHECK BOARD: BISKRA	244
Hiba, Barbara; Molnár Tamás	
COMPLEX REHABILITATION OF BUILDINGS BUILT WITH INDUSTRIALIZED TECHNOLOGY	253
Horkai András; Kiss Gyula	
PRESERVING ARCHAEOLOGICAL ELEMENTS IN URBAN HERITAGE DYNAMIC STREET - THE MAKING OF PUBLIC STREET OPEN MUSEUM - CASE STUDY: THE STRAIGHT STREET OF THE ANCIENT CITY OF DAMASCUS	261
Ibrahim, Sonia	
FLUIDITY OF CONTEMPORARY CONTEXT AND THE POST-INDUSTRIAL PHASE OF THE FIRST INDUSTRIAL ZONE IN BELGRADE	271
Jerković-Babović, Bojana; Fotirić, Nebojša	
SEARCHING FOR THE CODE OF NEW BELGRADE'S OPEN SPACE: CASE STUDY OF BLOCK 37	279
Jovanović, Predrag; Vuković, Tamara; Mitrović, Biserka	
HUNGARIAN ENERGY+ CUBE	287
Kondor Tamás; Kósa Balázs; Baranyai Bálint; Kistelegdi István; Juhász Hajnalka; Szigony János; Zrena Zoltán	
ACTIVITY BASED-MODELLING AS BASIS FOR SUSTAINABLE TRANSPORT POLICIES	293
Jurak, Julijan; Šimunović, Ljupko; Radulović, Božo; Sikirić, Matija	
THE ARCHITECT'S DESIGN IN THE RURAL STIMULATES THE VITALITY OF RURAL— XIAMUTANG CHILDREN'S LIBRARY.....	299
Kang Xue; Medvegy Gabriella	
THE TRANSFORMATION OF URBAN FORM BETWEEN MODERNITY AND TRADITION, WITH REFERENCE TO ERBIL CITY	307
Khoshnaw, Rebaz	
NEW FORMS OF TOWNSCAPE REGULATION IN HUNGARY	315
Füleky Zsolt; Kolossa József	

THE ISSUE OF PRESERVATION OF TRADITIONAL RAMMED EARTH HOUSES: CURRENT PRACTICE OF PRESENTATION IN SERBIA AND REGION.....	322
Kontić Ana; Lukić, Nevena	
APPLICATION OF MULTI-CRITERIA ANALYSIS IN THE PROCESS OF ENERGY RENEWAL OF RESIDENTIAL BUILDINGS.....	331
Krstić-Furundžić, Aleksandra; Kosić, Tatjana	
SUSTAINABLE DEVELOPMENT OF THE TOWN CENTER OF VISEGRÁD.....	340
Kovács-Andor Krisztián; Tamás Anna Mária	
SPECIAL REQUIREMENTS OF EDUCATIONAL BUILDINGS	345
Kovács Péter; Kósa Balázs; Molnár Tamás	
ASPECTS OF THE RELATIONSHIP BETWEEN THE ARCHITECTURAL HERITAGE AND NATURE FOR BETTER PLACES IN FUTURE	353
Furundžić, Nikola Z.; Furundžić, Dijana P.; Krstić-Furundžić, Aleksandra	
URBAN REGENERATION OF OPEN PUBLIC SPACES AS A TOOL FOR THE STRENGTHENING OF CULTURAL TOURISM: THE EXAMPLE OF THE HISTORIC CORE OF SMEDEREVO	361
Lazarević, Milica; Djukić, Aleksandra; Antonić, Branislav	
THE STATUS QUO OF HERITAGE BUILDING PROTECTION IN CONTEMPORARY CHINA	371
Liu Sha Sha; Kovács-Andor Krisztián	
RESIDENTIAL DESIGN PATTERNS UNDER HUTONG CULTRE.....	379
Lu Chang	
THE CONTRIBUTION OF INTERMODAL TRANSPORT NODES TO THE VITALITY OF PUBLIC SPACE	386
Madzhirski, Vasil	
POST-DISASTER URBAN PLANNING STRATEGIES DEVELOPMENT OVERVIEW	395
Maiteh, Shaha Mazen; Zoltán Erzsébet Szeréna	
FLOATING BUILDINGS AS NEW CONCEPT OF RESIDENCE IN BELGRADE FOR FUTURE SOCIAL REQUIREMENTS	402
Jacovic Maksimovic, Tijana	
VALORISATION AND REVITALIZATION OF HERITAGE ALONGSIDE DANUBE RIVER: CASE STUDY OF SMEDEREVO CASTLE	410
Vanista Lazarevic, Eva; Komatina, Dragan; Maric, Jelena; Vucur, Aleksandar	

PARTICIPATORY PROCESSES AND DESIGN METHODOLOGIES FOR IMPROVING LIVEABILITY: A COMBINATION USED IN SOME HISTORICAL DISTRICTS IN ROME	420
Martincigh, Lucia; Di Guida, Marina	
ANALYSING THE HOSPITAL PATIENT ROOM THROUGH SOCIAL REPRESENTATIONS.....	429
Marx, Fernanda	
CEBU PROVINCIAL CAPITOL: BALANCING URBAN CONSERVATION AND DEVELOPMENT RIGHTS.....	437
Menjares, Neil Andrew Uy; Solis, Carmencita Mahinay	
INCLUSIVE AND DEMOCRATIC METHODS FOR THE APPRAISAL AND THE EVALUATION OF URBAN INFRASTRUCTURES.....	446
Miccoli, Saverio; Finucci, Fabrizio; Murro, Rocco	
THE INFLUENCE OF AN ELECTRONIC PAYMENT SYSTEM ON PASSENGER COMFORT IN VEHICLES OF URBAN PUBLIC PASSENGER TRANSPORT	455
Milenković, Ivana; Pitka, Pavle; Simeunović, Milan; Miličić, Milica; Savković, Tatjana	
SENTIMENT ANALYSIS OF TWITTER DATA OF HISTORICAL SITES	463
Raspopovic Milic, Miroslava; Banovic, Katarina; Vukmirovic, Milena	
UPGRADING URBAN MOBILITY: THE APPLICABILITY OF CYCLING APPS IN BANJALUKA	472
Milaković, Mladen; Stupar, Aleksandra	
DESIGN PRINCIPLES FOR BETTER OPEN SPACES AT UNIVERSITIES, DESIGN APPROACHES FOR UNIVERSITY OF PÉCS	479
Paári Péter; Gyergyák János; Sebestyén Péter	
THE IMPORTANCE OF STRATEGY IN THE DEVELOPMENT OF HUMANE CITY IN THE 21ST CENTURY – SYNERGIC ACTION FOR LOCAL IDENTITY IN THE GLOBAL CONTEXT: CASE OF NIKSIC (MONTENEGRO)	488
Perović, Svetlana K.	
CONCEPTUALIZING AN ACTIVE LEARNING TAXONOMY IN AN ARCHITECTURAL COURSE FOCUSED ON EVALUATION OF CLIMATE CHANGE EFFECTS	495
Pesic, Nikola	
MECHATRONICS IN ARCHITECTURE: DESIGN RESEARCH METHODOLOGY	507
Petrović, Milica; Stojanović, Djordje	

ANALYSIS OF THE WAITING TIME OF PASSENGERS ON PUBLIC TRANSPORT IN THE PERIOD MORNING PEAK HOURS.....	516
Radivojević, Dejan; Simeunović, Milan; Pitka, Pavle; Lazarević, Milan	
THE RELATIONSHIP BETWEEN SPACE QUALITY OF ADDICTION CENTRES AND PATIENT BEHAVIOUR.....	524
Sadoud, Nesma; Zoltán Erzsébet Szeréna	
HISTORICAL PRELUDES OF PARAMETRIC DESIGN TECHNIQUES	533
Sárközi Réka; Iványi Péter; Széll Attila Béla	
TEXTILE MEMBRANE STRUCTURES IN REFURBISHMENT OF BUILT HERITAGE	538
Savanović, Dijana; Krstić-Furundžić, Aleksandra; Josifovski, Andrej	
REBUILDING RURAL PUBLIC SPACE BY VERNACULAR AND ART METHOD IN CHONGQING CHINA.....	547
Shi Yongting	
IDENTIFYING PRIORITY INDICATORS FOR REUSE OF INDUSTRIAL BUILDINGS USING AHP METHOD - CASE STUDY OF ELECTRONIC INDUSTRY IN NIS, SERBIA	555
Stanojević, Ana; Jevremović, Ljiljana; Milošević, Mimica; Turnšek, Branko AJ; Milošević, Dušan	
ENERGETIC RETROFIT OF THE TRADITIONAL APARTMENT HOUSES	564
Sugár Viktória	
„UNITY IN THE MULTITUDE”	572
Šutović, Anastasija	
PARAMETRIC CURTAIN WALLS	578
Katalin Szommer; Sárközi Réka	
ALTERNATIVE COMMUNITY – PROMOTOR OR INHIBITOR OF SUSTAINABLE DEVELOPMENT	582
Temeljotov Salaj, Alenka; Leuraers, Cato; van Dooren, Amber; Bjørberg, Svein	
THE EFFECTS OF THE POPULATION DECLINE ON THE BUILT ENVIRONMENT AND DEVELOPMENT POSSIBILITIES FOR SMALL SETTLEMENTS – A CASE STUDY OF BARANYA COUNTY IN HUNGARY.....	591
Tőke Máté	
URBAN PARTICIPATION AS A TOOL ALL OVER THE WORLD	598
Tommasoli, Lavinia; Luciani, Francesca Romana	
EXPLORING THE SYMBOLISMS AND TECHNIQUES OF DAYLIGHT MANAGEMENT IN HISTORIC GREEK CONSTRUCTIONS	605
Tsikaloudaki, Katerina; Tsoka, Stella; Theodosiou, Theodore; Tsirigoti, Dimitra	

TECHNOLOGICAL SOLUTIONS FOR COVERING ARCHAEOLOGICAL SITES IN ORDER TO PRESENT MOSAICS IN SITU – CASE STUDIES	613
Ugrinović, Aleksandra; Krstić-Furundžić, Aleksandra	
THE RECONSTRUCTION OF TRADITIONAL PITCHED ROOF IN MOUNTAINOUS BUILDING	621
Wu Mengyang; Bachmann Bálint	
RETURN TO THE LOCALISM – TWO PROJECTS BASED ON LOCAL TRADITIONS	628
Zhang Qian; Hutter Ákos	
MEIXIAO VILLAGE YONGXING TOWN HAIKOU CITY PROTECTIVE RECONSTRUCTION DESIGN	635
Zhao Liangyu; Kertész András Tibor	
RELATIONSHIP BETWEEN URBAN REHABILITATION OF BUILT HERITAGE AND LOCAL INHABITANTS, CASE STUDY ON CHONGQING ROAD, TIANJIN	644
Zhao Tianyu; Gyergyák János	
LIVEABLE, MODULAR AND FLEXIBLE – NEW WAYS OF UPDATING AND UPGRADING POST WORLD WAR HOUSING ESTATES	652
Zoltán Erzsébet Szeréna; Gyergyák János	

APPLICATION OF MULTI-CRITERIA ANALYSIS IN THE PROCESS OF ENERGY RENEWAL OF RESIDENTIAL BUILDINGS

Krstić-Furundžić, Aleksandra

Full Professor, Faculty of Architecture, University of Belgrade, Bulevar kralja Aleksandra 73/II, 11000 Belgrade, Serbia, akrstic@arh.bg.ac.rs

Kosić, Tatjana¹

Research Associate, Innovation Center, Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16., 11000 Belgrade, Serbia, tkosic@mas.bg.ac.rs

ABSTRACT

The subject of this paper is multi-criteria analysis of the selection of the best group of measures for energy efficiency improvement of multifamily housing. Selection of the optimal sets of measures for energy efficiency improvement is made on the basis of multi-criteria optimization using the method of multi-criteria compromise ranking of alternative solutions - AHP method (Analytical Hierarchical Process). The goal of the analysis is to select the best combination of measures for energy renewal of the existing building, or the best variant of a series of offered favourable variants in terms of adopted criteria and defined limitations. For the purpose of energy renewal of the existing building and according to recommendations of national regulations, five measures for energy efficiency improvement was adopted. The measures include the thermal performances improvement of non-transparent and transparent parts of the thermal envelope of the building and the use of renewable energy sources, respectively integration of solar thermal collectors into the building envelope. For multi-criteria optimization, a set of the following five criteria is adopted, according to which alternatives are evaluated: annual final energy consumption for heating; annual primary energy consumption for heating; annual CO₂ emissions; investment costs for energy renovation of buildings and return period of investment means. The aim of this study is to demonstrate the efficacy of AHP method in practice when is necessary to reach an optimal decision in selecting the best measures for improving the energy performance of buildings. Finally, ranking of alternatives is done according to selected scenarios of different combinations of criteria weight.

Keywords: decision-making, multi-criteria optimization, measures for improving the energy performance of buildings

¹Corresponding author

INTRODUCTION

Many suburban settlements had been built in Belgrade after the World War II. In that time, a few prefabricated systems were mostly in use in our country resulting in housing settlements which consisted of numerous buildings with the same or similar layouts. Belgrade's building stock has a significant number of buildings whose energy performance has to be improved. One of the examples is the housing settlement Konjarnik which has been selected as a case study in which possibilities for improving energy performance are analyzed. The subject of the analyses is typical 8-storey building (ground floor, 6 floors and attic) which consists of 5 lamellas. For the analyses one of the central lamellas is selected (Fig. 1). The building is located in a semi-closed block, on the south oriented hillside. Its longer, east-west axis is parallel to the isohypses. Methodological approach includes the presentation of measures for energy renovation, indication of energy consumption and selection of the optimal sets of measures for energy efficiency improvement using AHP method.



Figure 1: Location (left) and appearance (right) of the building in Konjarnik settlement

For the purpose of energy renewal of the existing building and according to recommendations of national regulations, 5 measures for energy efficiency improvement were adopted. The measures include the thermal performances improvement of non-transparent and transparent parts of the thermal envelope of the building and the use of renewable energy sources, respectively integration of solar thermal collectors into the building envelope. The following measures of energy performance improvement of envelope are selected: increasing the thickness of thermal insulation (on parapet wall and attic slab) including thermal bridges break, completely replacement of the windows by modern one with improved thermal and solar features, and glazing of loggias. Two models (M1 and M2) of building envelope improvement are selected and shown in Table 1.

Table 1: Models of thermal performance improvement of the building envelope

Models of thermal performance improvement	PARAPET WALL		ATTIC SLAB		GLAZING				Predicted exchanges of the air flow
	Wall structure	U-val. [W/m ² K]	TI thickness	U-val. [W/m ² K]	Windows		Loggias		
					Glazing Type	U-val. [W/m ² K]	Glazing Type	U-val. [W/m ² K]	
Model M1	int.concrete 10cm, therm.insul. 5cm, ext.concrete 5cm, + 5cm added exp. polystyrene, total TI thickness = 10cm	0.371	10cm of added min.wool, total TI thickness = 22cm	0.171	double glazing (4+12+4), five-chamber PVC profiles	2.30	double glazing (4+12+4), five-chamber PVC profiles	2.30	2 - 3
Model M2	int.concrete 10cm, therm.insul. 5cm, ext.concrete 5cm, + 5cm added exp. polystyrene, total TI thickness = 15cm	0.255	10cm of added min.wool, total TI thickness = 22cm	0.171	low-emiss. glazing, argon fill., five-chamber PVC profiles	0.90	double glazing (4+12+4), five-chamber PVC profiles	2.30	0.8 - 1

Four distinctive variants of position of solar thermal collectors on building envelope are selected and shown in Fig. 2 (Krstić-Furundžić and Kosorić, 2009):

- I Design Variant: solar panels mounted on the roof and tilted at 40°, area of 100 m² (Fig. 2-a),
- II Design Variant: solar panels integrated in parapets (vertical position-90°), area of 90 m² (Fig. 2-b),
- III Design Variant: solar panels integrated in parapets and tilted at 45°, area of 120 m² (Fig. 2-c),
- IV Design Variant: solar panels integrated as sun shadings (horizontal position-0°), area of 55 m² (Fig. 2-d).



Figure 2: (a) I Design Variant: roof 40° (roof and facade layouts), (b) II Design Variant: parapet 90°, (c) III Design Variant: parapet 45° and (d) IV Design Variant: sun shading 0°

Considering that all of the proposed measures for energy efficiency improvement of the building can be simultaneously applied, 4 combinations of possible measures for each Model (M1 and M2), done on the basis of engineering experience, were adopted and defined as alternatives:

- Model 1/2 + Roof collectors 40°;
- Model 1/2 + Roof collectors 40° and facade collectors 90°;
- Model 1/2 + Roof collectors 40° and facade collectors 45°;
- Model 1/2 + Roof collectors 40° and facade collectors 90° + sun shading 0°.

THEORY AND RESULTS

Selection of the optimal sets of measures for energy efficiency improvement is made on the basis of multi-criteria optimization using the method of multi-criteria compromise ranking of

alternative solutions - AHP method (Analytical Hierarchical Process). AHP method is one of the most popular methods of scientific analysis of scenarios and decision-making through the process of evaluating alternatives in the hierarchy which consists of goal, criteria, sub-criteria and alternatives. This method is suitable for use in optimization of procedures for the selection of energy renewal measures in the case of more diverse criteria that are often mutually opposed, and a number of alternatives where each alternative can be accurately evaluated according to each criterion. Also, based on the calculation by AHP method, the consistency of decisions is usually achieved and hierarchy of alternatives is clearly defined according to set goal (Pohekar and Ramachandran, 2004). Multi-criteria analysis in this paper, is based on the results of previous research related to energy savings for space heating achieved by improving the building envelope (Krstić-Furundžić et al., 2013), and energy savings for water heating achieved by the application of solar thermal collectors (Krstić-Furundžić and Kosorić, 2009). Indicators of energy savings are obtained through numerical simulation.

Results of numerical simulations

Based on the official data of the Belgrade heating plant energy consumption for heating was estimated, while the electricity consumption for water heating was calculated according to the actual water consumption. The results of all the proposed measures for energy performances improvement of the building envelope were calculated on the basis of thermodynamic simulation of 3D mathematical models in a specialized software package TAS, according to Serbian Regulations on energy efficiency of buildings.

The results of thermal energy production of the proposed variants of solar thermal systems' application and monthly thermal energy demands satisfaction were calculated on the basis of simulations in the program Polysan. Thermal energy demands for water heating is calculated regarding number of occupants and hot water consumption per person per day. Consumption of hot water amounts 7,200ℓ (20-50°C) per day for one block. In terms of energy consumption it is 251 kWh per day, i.e. 91,618.3 kWh per year for one block.

Eight possible combinations of proposed measures for improving energy efficiency of the building are defined as alternatives. Their contribution to annual energy savings for space and water heating is shown in Tables 2 and 3.

Table 2: Annual energy consumptions and savings for space and water heating for the Model 1 and different variants of STC application (Alternatives 1, 2, 3 and 4)

Alternatives	Model of the building	Annual energy consumption (kWh)			Energy savings (kWh)	Reduction of energy consump. (%)
		For space heating	For hot water	Total		
	Model of the existing building	424,572	91,618	516,190		
1	Model 1 + Roof collectors 40°	44,690	42,349	87,039	429,151	83
2	Model 1 + Roof collectors 40° and facade collectors 90°	44,690	10,234	54,924	461,266	89
3	Model 1 + Roof collectors 40° and facade collectors 45°	44,690	energy surplus (+5,060)	44,690	471,500	91
4	Model 1 + Roof collectors 40° and facade collectors 90° +sun shading 0°	44,690	energy surplus (+11,242)	44,690	471,500	91

Table 3: Annual energy consumptions and savings for space and water heating for the Model 2 and different variants of STC application (Alternatives 5, 6, 7 and 8)

Alternatives	Model of the building	Annual energy consumption (kWh)			Energy savings (kWh)	Reduction of energy consump. (%)
		For space heating	For hot water	Total		
	Model of the existing building	424,572	91,618	516,190		
5	Model 1 + Roof collectors 40°	22,135	42,349	64,484	451,706	88
6	Model 1 + Roof collectors 40° and facade collectors 90°	22,135	10,234	32,369	483,821	94
7	Model 1 + Roof collectors 40° and facade collectors 45°	22,135	energy surplus (+5,060)	22,135	494,055	96
8	Model 1 + Roof collectors 40° and facade collectors 90° +sun shading 0°	22,135	energy surplus (+11,242)	22,135	494,055	96

Results of Multicriteria Analysis

AHP Method- Analytical Hierarchy Process

AHP- Analytic Hierarchy Process (or Analytical Hierarchy Process) is a mathematical method and represents a strong and flexible decision making technique which helps in setting priorities and reaching optimal decisions in situations when quantitative and qualitative aspects have already been taken into consideration. By reducing complex decision making to comparisons between pairs of alternatives and by synthesizing results, AHP helps not only in decision making but leads to a rational decision and showing the complete order of the importance of alternatives in the model. Created in a way to reflect the way people think, AHP was developed by Professor Thomas Saaty in the 1970s of the last century. Model for multicriteria decision making is usually implemented through the following four phases:

- Structuring of the problem; Goal definition; Defining criteria and alternatives;
- Data collection for alternatives according to defined criteria;
- Analysis of possible alternatives for the goal achievement (relative weights evaluation);
- Selection of the optimal alternative of problem solution.

The first phase- structuring of the problem consists of decomposing a specific complex problem of decision making in series of hierarchy, where each level represents a smaller number of controlled attributes. The graphics of structuring problem that consider selection of the best measures for improvement of energy performances of the multifamily housing in Belgrade is shown in Fig. 3.

The first level of the structure is defining the goal. The second level of the structure for multicriteria optimization represents a set of 4 criteria which is adopted and according to which alternatives are evaluated. These four criteria are:

- Annual energy consumption for space and water heating (Criterion C1),
- Annual CO₂ emissions (Criterion C2),
- Investment costs of energy renovation of the building (Criterion C3),
- Return period of investment means (Criteria C4).

The third level implies defining alternatives.

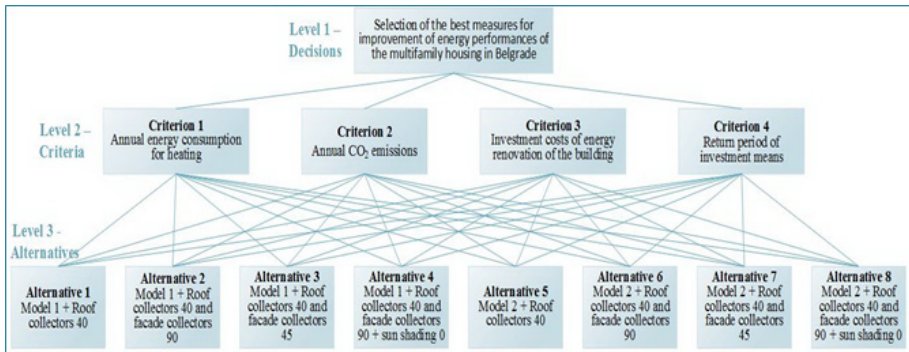


Figure 3: Problem structuring of the selection the best measures and technologies for envelope energy renewal of the multifamily housing in Belgrade

The second phase - refers to collecting data. Data for alternatives are specified according to defined criteria, as shown in Table 4.

Table 4: Data for alternatives specified according to defined criteria

Alternatives	Model of the building (combinations of proposed measures)	Annual primary energy consumption (kWh)	Annual CO ₂ emissions (kg)	Investment costs of energy renovation of the building (€)	Return period of investment means (years)
1	Model 1 + Roof collectors 40°	87,039	34,064	187,180	7.96
2	Model 1 + Roof collectors 40° and facade collectors 90°	54,924	17,043	250,180	9.16
3	Model 1 + Roof collectors 40° and facade collectors 45°	44,690	11,620	271,180	8.55
4	Model 1 + Roof collectors 40° and facade collectors 90° + sun shading 0°	44,690	11,620	288,680	10.34
5	Model 2 + Roof collectors 40°	64,484	28,200	211,910	9.03
6	Model 2 + Roof collectors 40° and facade collectors 90°	32,369	11,179	274,910	10.10
7	Model 2 + Roof collectors 40° and facade collectors 45°	22,135	5,755	295,910	9.35
8	Model 2 + Roof collectors 40° and facade collectors 90° + sun shading 0°	22,135	5,755	313,410	11.25

After data collection, their evaluation is performed in the third phase. By using the Saaty’s scale in pairs, the importance is given to the ratio of two criteria when their values are expressed quantitatively, qualitatively and in different measurement units. Saaty’s scale is the ratio scale with five intensity degrees and four intermediate stage (Table 5) which corresponds to a value evaluation about how many times one criterion is more important than another. The same scale is used in comparison of two alternatives, but in this case the values are interpreted as an assessment of how many times the higher priority is given to one alternative over another relative to their respective values.

Assessment of the relative weight is also part of the third phase of AHP method implementation. Matrix of pairwise comparisons is converted into the problem of determining their own values in order to obtain their own unique and normalized vectors, as well as the weight of all attributes at each level of the hierarchy.

Table 5: Format for pairwise comparisons, according to Saaty's scale

Intensity of importance	Definition	Explication
1	Equal importance	Two criteria or alternatives equally contribute to the objective
3	Moderate importance	Based on experience (estimation), it is given moderate priority to one criteria or alternative over another
5	Strong importance	Based on experience (estimation), it is given strong priority to one criteria or alternative over another
7	Very strong, demonstrated importance	Based on experience (estimation), it is given vary strong priority to one criteria or alternative over another
9	Extreme importance	The evidence on which it is based favors for one criteria or alternative have been confirmed with the highest conviction
2, 4, 6, 8	Intermediate values	

AHP method is one of the most popular methods due its possibility to identify and analyze the consistency of decision-makers in the process of comparing the elements of the hierarchy (Saaty, 1980). Monitoring the consistency of assessments at any time in the process of comparison of attributes pairs is performed using the index of consistency:

$$C.I. = (\lambda_{\max} - n) / (n - 1) \quad (1)$$

by which the ratio of consistency ($C.R=C.I./R.I.$) is calculated, where R.I. is random index, for which table (Table 6) with theoretical values is used. The coefficient λ_{\max} is a maximum feature of the value of comparisons matrix, while n is matrix size. Assessment of the relative importance of criteria (priorities of alternatives) is acceptable if $C.R. \leq 0.10$.

Table 6: Values of the random index (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.52	0.90	1.11	1.25	1.35	1.40	1.45	1.49

One of the major problems in the implementation of AHP method is to define the attributes of decision-making on the second level (decision making criteria) and evaluation of their relative weight. The authors have defined criteria and assess the value of their relative weights based on experience from previous scientific research giving a slight dominance to economic criterion – investment costs (Table 7). In accordance with the foregoing and considering that the criteria comparison is based on subjective assessment of decision-maker, the comparison of attributes on the second level (decision making criteria) is carried out by constant checking of their consistency (Table 7).

Table 7: Comparison of attributes on the second level (decision making criteria)

	C1	C2	C3	C4	Weights
C1	1	1	0.5	4	0.2545
C2	1	1	0.5	4	0.2545
C3	2	2	1	3	0.4069
C4	0.25	0.25	0.33	1	0.0842

Comparing the alternatives on the third level was enabled by converting the values of all criteria functions shown in Table 4 in values of Saaty's scale. The appropriate matrices of comparing the alternatives on the third level for each attribute (decision making criteria) and their priorities are shown in Table 8. By using MychoiceMydecision software the relative weight of the alternatives in the model is calculated. In order to rank the alternatives, all the intensity values were inserted in the software rating model.

Table 8: Matrix of relevant weights of alternatives in relation to the criteria C1-C4

Alternative	Weights in relation to criterion C1	Weights in relation to criterion C2	Weights in relation to criterion C3	Weights in relation to criterion C4
A1	0.0148	0.0178	0.3549	0.3301
A2	0.0497	0.0414	0.1348	0.1181
A3	0.0845	0.1054	0.0699	0.2109
A4	0.0845	0.1054	0.0376	0.0830
A5	0.0280	0.0237	0.2613	0.0888
A6	0.1631	0.1130	0.0826	0.0406
A7	0.2962	0.2967	0.0349	0.1078
A8	0.2793	0.2967	0.0241	0.0207

Selection the best measures for envelope energy renewal of the multifamily housing
 The overall synthesis of the problem of selection the best measures for improvement of energy performances is the forth phase - final procedure implementing AHP method (Table 9). It is carried out in such way that all alternatives are multiplied by the weights of individual decision-making criteria, and the results are summarized.

Table 9: Selection of the optimal alternative

Criteria	Criteria weight	C.weight X A1	C.weight X A2	C.weight X A3	C.weight X A4	C.weight X A5	C.weight X A6	C.weight X A7	C.weight X A8
C1	0.2545	0.0038	0.0126	0.0215	0.0215	0.0071	0.0415	0.0754	0.0711
C2	0.2545	0.0045	0.0105	0.0268	0.0268	0.0060	0.0288	0.0755	0.0755
C3	0.4069	0.1444	0.0549	0.0284	0.0153	0.1063	0.0336	0.0142	0.0098
C4	0.0842	0.0278	0.0099	0.0178	0.0070	0.0755	0.0034	0.0091	0.0017
		0.1805	0.0880	0.0945	0.0706	0.1270	0.1073	0.1742	0.1581

CONCLUSIONS

By accurately procedure implementation of AHP method alternatives ranking was carried out, as shown in Fig. 4. It is estimated that the alternative A1 has the greatest total value of 0.1805, and therefore is the most appropriate or optimal alternative according to determined criteria priorities. Alternative A7 also has slightly lower total value of 0.1742. It can be noted that the best ranked alternative, Alternative 1 is the best individually by two criteria (investment costs and return period of investment means), as well as Alternative 7 (annual energy consumption and CO2 emissions), as shown in Fig. 5. The index of consistency is 0.0847 (less than tolerant limit of 0.1), meaning consistency of result.

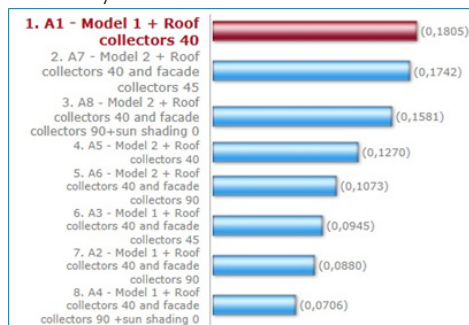


Figure 4: Ranking of alternatives in order of priority

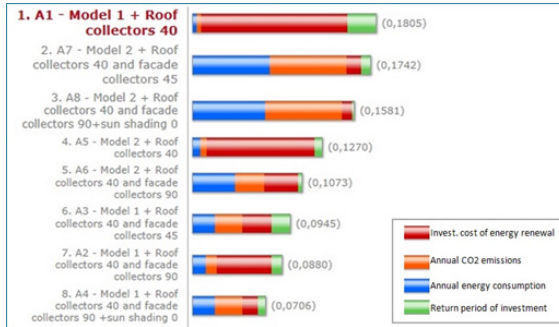


Figure 5: Ranking and the structure of the alternatives in relation to the set criteria

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