

CONFERENCE
PROCEEDINGS

**5th INTERNATIONAL
ACADEMIC CONFERENCE ON
PLACES AND TECHNOLOGIES**

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PLACES AND TECHNOLOGIES 2018

THE 5TH INTERNATIONAL ACADEMIC CONFERENCE ON PLACES AND TECHNOLOGIES

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TABLE OF CONTENTS

IMAGE, IDENTITY AND QUALITY OF PLACE: URBAN ASPECTS

THE EFFECT OF BEHAVIOURAL SETTINGS ON THE REGENERATION OF URBAN DYNAMIC ARTS, CASE STUDY: TEHRAN AZADI SQUARE Yasaman NEKOU Ali Entezarinajafabadi	3
DEVELOPMENT SCENARIOS OF THE ZAGREB'S SATELLITE TOWN DUGOSELO - "THE CITY OF THE FUTURE" Lea Petrović Krajnik Damir Krajnik Ivan Mlinar	11
SUSTAINABILITY OF MODERN-DAY UTOPIAS AS SEEN IN MASS MEDIA Aleksandra Til	18
URBAN DENSIFICATION OF THE POST-SOCIALIST CITY AND ITS IMPLICATIONS UPON URBAN STRUCTURE: A STUDY OF NIS, SERBIA Milena Dinić Branković Ivana Bogdanović Protić Mihailo Mitković Jelena Đekić	25
MUSEUM QUARTERS VS CREATIVE CLUSTERS: FORMATION OF THE IDENTITY AND QUALITY OF THE URBAN ENVIRONMENT Ekaterina Kochergina	35
URBAN NON-MECHANICAL CODE AND PUBLIC SPACE Aleksandra Đukić Valentina Milovanović Dubravko Aleksić	43
ADDRESSING THE SOCIO-SANITARY EMERGENCY IN AFRICA: THEORIES AND TECHNIQUES FOR DESIGNING A COMMUNITY HEALTH CENTRE IN MALI Adolfo F. L. Baratta Laura Calcagnini Fabrizio Finucci Cecilia M. L. Luschi Antonio Magarò Massimo Mariani Alessandra Venturoli Alessandra Vezzi	50
THE NETWORK OF LOCAL CENTERS AS A TOOL FOR STRENGTHENING THE SUPER-BLOCK COMMUNITIES: BELGRADE VS. ROME Predrag Jovanović Aleksandra Stupar	58
TRANSFORMATION OF IDENTITY OF SAVAMALA DISTRICT IN BELGRADE Aleksandra Đukić Jelena Marić Tamara Radić	66
THE CULTURE OF MEMORY AND OPEN PUBLIC SPACE - BANJA LUKA Jelena Stankovic Milenko Stankovic	73

IMAGE, IDENTITY AND QUALITY OF PLACE: ARCHITECTURAL ASPECTS

IMPROVEMENT OF SOCIAL HOUSING THROUGH THE MIXING CONCEPT IMPLEMENTATION Nataša Petković Grozdanović Branislava Stojković Vladana Petrović Aleksandar Keković Goran Jovanović	83
---	----

IMPROVING THE IDENTITY OF NON – SURROUNDED COMMUNAL SPACES WITH USING ARCHITECTURAL PROGRAMING. CASE STUDY: NAJAF ABAD (ESFAHAN), IMAM KHOMEINI SQUARE 91
Ali Entezarinajafabadi YasamanNekoui

A CONTRIBUTION TO THE STUDY OF THE ARCHITECTURAL OPUS OF NATIONAL STYLE WITH MODELS IN FOLK ARCHITECTURE AND NEW INTERPOLATIONS 100
Katarina Stojanović

SHOPPING CENTRE AS A LEISURE SPACE: CASE STUDY OF BELGRADE 108
Marija Cvetković Jelena Živković Ksenija Lalović

ARCHITECTURAL CREATION AND ITS INFLUENCE ON HUMANS 119
Nikola Z. Furundžić Dijana P. Furundžić Aleksandra Krstić-Furundžić

INNOVATIVE METHODS AND TECHNOLOGIES FOR SMART(ER) CITIES

POTENTIAL OF ADAPTING SMART CULTURAL MODEL: THE CASE OF JEDDAH OPEN- SCULPTURE MUSEUM 131
Sema Refae Aida Nayer

AN INNOVATIVE PROTOCOL TO ASSESS AND PROMOTE SUSTAINABILITY IN RESPONSIBLE COMMUNITIES 140
Lucia Martincigh Marina Di Guida Giovanni Perrucci

GEOHERMAL DISTRICT HEATING SYSTEMS DESIGN: CASE STUDY OF ARMUTLU DISTRICT 148
Ayşe Fidan ALTUN Muhsin KILIC

DATA COLLECTION METHODS FOR ASSESSMENT OF PUBLIC BUILDING STOCK REFURBISHMENT POTENTIAL 157
Ljiljana Đukanović Nataša Čuković Ignjatović Milica Jovanović Popović

SMART HOSPITALS IN SMART CITIES 165
Maria Grazia Giardinelli Luca Marzi Arch. PhD Valentina Santi

INNOVATIVE METHODS AND TOOLS

PRIMARY AND SECONDARY USES IN CITIES – PRINCIPLES, PATTERNS AND INTERDEPENDENCE 175
Marina Čarević Tomić Milica Kostreš Darko Reba

MODELLING AND ANALYSING LAND USE CHANGES WITH DATA-DRIVEN MODELS: A REVIEW OF APPLICATION ON THE BELGRADE STUDY AREA 183
Mileva Samardžić-Petrović Branislav Bajat Miloš Kovačević Suzana Dragičević

INNOVATIVE DECISION SUPPORT SYSTEM 190
Mariella Annese Silvana Milella Nicola La Macchia Letizia Chiapperino

URBAN FACILITY MANAGEMENT ROLE	196
Alenka Temeljotov Salaj Svein Bjørberg Carmel Margaret Lindkvist Jardar Lohne	
ANALYSES OF PUBLIC SPACES IN BELGRADE USING GEO-REFERENCED TWITTER DATA	205
Nikola Džaković Nikola Dinkić Jugoslav Joković Leonid Stoimenov Aleksandra Djukić	
SENTIMENT ANALYSIS OF TWITTER DATA FOR EXPLORATION OF PUBLIC SPACE SENTIMENTS	212
Miroslava Raspopovic Milic Milena Vukmirovic	
CITIES AND SCREENS: ARCHITECTURE AND INFORMATION IN THE AGE OF TRANSDUCTIVE REPRODUCTION	217
Catarina Patricio	
CITIZEN EMPOWERMENT, PUBLIC PARTICIPATION AND DEMOCRATIC CITIES	
CITIES AS PLATFORMS FOR SOCIAL INNOVATION: AN INVESTIGATION INTO HOW DIGITAL PLATFORMS AND TOOLS ARE USED TO SUPPORT ENTREPRENEURSHIP IN URBAN ENVIRONMENTS	227
Margarita Angelidou	
PROBLEM ISSUES OF PUBLIC PARTICIPATION IN HERITAGE CONSERVATION: GEO-MINING PARKIN SARDINIA	235
Nađa Beretić Arnaldo Cecchini Zoran Đukanović	
A METHODOLOGY FOR STAKEHOLDER EMPOWERMENT AND BENEFIT ASSESSMENT OF MUNICIPAL LONG-TERM DEEP RENOVATION STRATEGIES: A SURVEY WITHIN SOUTH-EASTERN EUROPEAN MUNICIPALITIES	242
Sebastian Botzler	
THE OPPORTUNITIES OF MEDIATED PUBLIC SPACES: CO-CREATION PROCESS FOR MORE INCLUSIVE URBAN PUBLIC SPACES	249
Inês Almeida Joana Solipa Batista Carlos Smaniotta Costa Marluci Menezes	
ARCHITECTURE AS SOCIAL INNOVATION: EDUCATION FOR NEW FORMS OF PROFESSIONAL PRACTICE	255
Danijela Milovanović Rodić, Božena Stojčić Aleksandra Milovanović	
CITY AS A PRODUCT, PLANNING AS A SERVICE	262
Viktorija Prilenska Katrin Paadam Roode Liias	
RAJKA: CHANGING SOCIAL, ETHNIC AND ARCHITECTURAL CHARACTER OF THE "HUNGARIAN SUBURB" OF BRATISLAVA	269
Dániel Balizs Péter Bajmócy	
POSSIBLE IMPACT OF MIGRANT CRISIS ON THE CONCEPT OF URBAN PLANNING	279
Nataša Danilović Hristić Žaklina Gligorijević Nebojša Stefanović	

TOWARDS DIMINUISHING DISADVANTAGES IN MIGRATION ISSUES IN SERBIA
(FROM 2015) THROUGH PROPOSAL OF SOME MODELS 287

Eva Vaništa Lazarević Jelena Marić Dragan Komatina

ARCHITECTURAL DESIGN AND ENERGY PERFORMANCE OF BUILDINGS

APPLICATION OF ENERGY SIMULATION OF AN ARCHITECTURAL HERITAGE
BUILDING 303

Norbert Harmathy Zoltán Magyar

APPLICATION OF TRADITIONAL MATERIALS IN DESIGN OF ENERGY EFFI-
CIENT INTERIORS 311

Vladana Petrović Nataša Petković Grozdanović Branislava Stoiljković Aleksandar Keković
Goran Jovanović

DETERMINATION OF THE LIMIT VALUE OF PERMITTED ENERGY CLASS FOR
THE KINDERGARTENS IN THE NORTH REGION OF BOSNIA AND HERZEGOVI-
NA 318

Darija Gajić Biljana Antunović Aleksandar Janković

ARCHITECTURAL ASPECTS OF ENERGY AND ECOLOGICALLY RESPONSIBLE
DESIGN OF STUDENT HOUSE BUILDINGS 326

Malina Čvoro Saša B. Čvoro Aleksandar Janković

ENERGY EFFICIENCY ANALYSES OF RESIDENTIAL BUILDINGS THROUGH
TRANSIENT SIMULATION 332

Ayşe Fidan ALTUN Muhsin KILIC

INNOVATIVE TECHNOLOGIES FOR PLANNING AND DESIGN OF “ZERO-ENER-
GY BUILDINGS” 340

Kosa Golić Vesna Kosorić Suzana Koprivica

ENERGY REFURBISHMENT OF A PUBLIC BUILDING IN BELGRADE 348

Mirjana Miletić Aleksandra Krstić-Furundžić

TPOLOGY OF SCHOOL BUILDINGS IN SERBIA: A TOOL FOR SUSTAINABLE
ENERGY REFURBISHMENT 357

Nataša Čuković Ignjatović Dušan Ignjatović Ljiljana Đukanović

ARCHITECTURAL DESIGN AND NEW TECHNOLOGIES

EVALUATION OF ADVANCED NATURAL VENTILATION POTENTIAL IN THE
MEDITERRANEAN COASTAL REGION OF CATALONIA 367

Nikola Pestic Jaime Roset Calzada Adrian MurosAlcojor

TRENDS IN INTEGRATION OF PHOTOVOLTAIC FACILITIES INTO THE BUILT
ENVIRONMENT 375

Aleksandra Krstić-Furundžić Alessandra Scognamiglio, Mirjana Devetaković, Francesco
Frontini, Budimir Sudimac

INTEGRATION OF NEW TECHNOLOGIES INTO BUILDINGS MADE FROM CLT	389
Milica Petrović Isidora Ilić	
INTEGRATION OF SOLAR WATER HEATING SYSTEMS INTO GREEN BUILDINGS BY APPLYING GIS AND BIM TECHNOLOGIES	394
Kosa Golić Vesna Kosorić Dragana Mecanov	
IMPLEMENTING ADAPTIVE FAÇADES CONCEPT IN BUILDINGS DESIGN: A CASE STUDY OF A SPORTS HALL	402
Aleksandar Petrovski Lepa Petrovska-Hristovska	
SIMULATION AIDED ENERGY PERFORMANCE ASSESSMENT OF A COMPLEX OFFICE BUILDING PROJECT	409
Norbert Harmathy László Szerdahelyi	

ARCHITECTURAL DESIGN AND PROCESS

THE HABITABLE BRIDGE: EXPLORING AN ARCHITECTURAL PARADIGM THAT COMBINES CONNECTIVITY WITH HABITATION	421
Ioanna Symeonidou	
REFURBISHMENT OF POST-WAR PREFABRICATED MULTIFAMILY BUILDINGS	428
Aleksandra Krstić-Furundžić, Tatjana Kosić, PhD	
THE FUTURE (OF) BUILDING	438
Morana Pap, Roberto Vdović, Bojan Baletić	
COMPARISON OF ARCHITECTS' AND USERS' ATTITUDES TOWARD SPATIAL CHARACTERISTICS OF APARTMENTS	445
Ivana Brkanić	
DIGITAL VS. TRADITIONAL DESIGN PROCESS	453
Igor Svetel Tatjana Kosić Milica Pejanović	
CREATING THE EASTERN CAMPUS CONCEPT AT THE UNIVERSITY OF PÉCS - CONNECTED THE FACULTY OF BUSINESS AND ECONOMICS	461
Péter Paári Gabriella Medvegy Bálint Bachmann	

BUILDING STRUCTURES AND MATERIALS

SUSTAINABILITY BENEFITS OF FERROCEMENT APPLICATION IN COMPOSITE BUILDING STRUCTURES	471
Aleksandra Nenadović Žikica Tekić	
POSSIBILITIES OF ENERGY EFFICIENT REFURBISHMENT OF A FAMILY VILLA IN BELGRADE: A CASE STUDY	479
Nenad Šekularac Jasna Čikić Tovarović Jelena Ivanović-Šekularac	

ENHANCING THE BUILDING ENVELOPE PERFORMANCE OF EXISTING BUILDINGS USING HYBRID VENTILATED FAÇADE SYSTEMS	485
Katerina Tsikaloudaki Theodore Theodosiou Stella Tsoka Dimitrios Bikas	
STRUCTURAL ASPECTS OF ADAPTIVE FACADES	493
Marcin Kozłowski Chiara Bedon Klára Machalická Thomas Wüest Dániel Honfi	
STRATEGIZING FOR INFORMAL SETTLEMENTS: THE CASE OF BEIRUT	500
Hassan Zaiter Francesca Giofrè	
THE IMPACT OF USERS' BEHAVIOUR ON SOLAR GAINS IN RESIDENTIAL BUILDINGS	509
Rajčić Aleksandar Radivojević Ana Đukanović Ljiljana	
PRESERVATION OF ORIGINAL APPEARANCE OF EXPOSED CONCRETE FACADES, CASE STUDY: RESIDENTIAL BLOCK 23, NEW BELGRADE	517
Nikola Macut Ana Radivojević	

ADAPTIVE REUSE

CONVERSION AS MODEL OF SUSTAINABLE SOLUTION FOR DEVASTATED INDUSTRIAL COMPLEXES	529
Branko AJ Turnšek Aleksandra Kostić Milun Rancić	
SILO CONVERSION - POTENTIALS, FLEXIBILITY AND CONSTRAINTS	537
Branko AJ Turnsek Ljiljana Jevremovic Ana Stanojevic	
ARCHITECTURE OF MULTIPLE BEGINNINGS AS A TOOL OF SUSTAINABLE URBAN DEVELOPMENT	545
Milan Brzaković Petar Mitković Aleksandar Milojković Marko Nikolić	
INHABITING THE TOWER. THE PARADIGM OF THE FORTIFIED TOWERS OF MANI AND THE REUSE PROJECT	556
Rachele Lomurno	
ADAPTIVE REUSE THROUGH CREATIVE INDUSTRY TOOLS: CASE OF URAL-MASH, YEKATERINBURG, RUSSIA	564
Eva Vaništa Lazarević Timur Abdullaev, Larisa Bannikova	

URBAN MOBILITY, TRANSPORT AND TRAFFIC SOLUTIONS

POLICY FOR REDUCING EMISSIONS IN AIRCRAFT OPERATIONS IN URBAN AEREAS BASED ON REGULATORY AND FISCAL MEASURES	579
Marija Glogovac Olja Čokorilo	
SIMULATING PEDESTRIAN BEHAVIOUR IN SCHOOL ZONES – POSSIBILITIES AND CHALLENGES	586
Ljupko Šimunović Mario Ćosić Dino Šojat Božo Radulović Domagoj Dijanić	

MODEL OF SMART PEDESTRIAN NETWORK DEVELOPMENT USING AN EDGE-NODE SPACE SYNTAX ABSTRACTION FOR URBAN CENTRES 593

Bálint Kádár

THE ROLE OF SMART PASSENGER INTERCHANGES IN THE URBAN TRANSPORT NETWORK 604

Bia Mandžuka, Marinko Jurčević, Davor Brčić

CLIMATE CHANGE, RESILIENCE OF PLACES AND HAZARD RISK MANAGEMENT

THE IMPACT OF CLIMATE CHANGES ON THE DESIGN ELEMENTS OF CONTEMPORARY WINERIES - CASE STUDIES 617

Branko AJ Turnšek Ana Stanojević LjiljanaJevremović

DETERMINATION OF COMMUNITY DEVELOPMENT POLICIES USING URBAN RESILIENCE AND SYSTEM DYNAMICS SIMULATION APPROACH 626

Zoran Keković Ozren Džigurski Vladimir Ninković

QUALITIES OF RESILIENT CITY IN SYSTEMS OF PLANNING SUSTAINABLE URBAN DEVELOPMENT. AN INTRODUCTORY REVIEW. 634

Brankica Milojević Isidora Karan

PLACE-BASED URBAN DESIGN EDUCATION FOR ADAPTING CITIES TO CLIMATE CHANGE 641

Jelena Živković Ksenija Lalović

IMPROVING URBAN RESILIENCE, INCREASING ENVIRONMENTAL AWARENESS: NEW CHALLENGE OF ARCHITECTURAL AND PLANNING EDUCATION 652

Aleksandra Stupar Vladimir Mihajlov Ivan Simic

URBAN RESILIENCE AND INDUSTRIAL DESIGN: TECHNOLOGIES, MATERIALS AND FORMS OF THE NEW PUBLIC SPACE 659

Vincenzo Paolo Bagnato

THERMAL COMFORT OF NIŠFORTRESS PARK IN THE SUMMER PERIOD 666

Ivana Bogdanović Protić Milena Dinić Branković Petar Mitković Milica Ljubenović

LANDSCAPE ARCHITECTURE AND NATURAL BASED SOLUTIONS

SMALL ISLANDS IN THE FRAMEWORK OF THE U.E. MARINE STRATEGY – CHERADI'S ARCHIPELAGO IN TARANTO 679

Giuseppe d'Agostino Federica Montalto

LANDSCAPE AWARENESS AND RENEWABLE ENERGY PRODUCTION IN BOSNIA AND HERZEGOVINA 686

Isidora Karan Igor Kuvac Radovan Vukomanovic

SAVAPARK – A RESILIENT AND SUSTAINABLE NEW DEVELOPMENT FOR ŠABAC 692

Milena Zindović Ksenija Lukić Marović

ADRIATIC LIGHTHOUSES. STRATEGIC VISIONS AND DESIGN FEATURES 702

Michele Montemurro

LANDSCAPE ARCHITECTURE AND INFRASTRUCTURES: TYPOLOGICAL INVENTORY OF GREEK WATER RESERVOIRS' LANDSCAPE 710

Marianna Nana Maria Ananiadou-Tzimopoulou

THE BASIN OF THE MAR PICCOLO OF TARANTO AS URBAN AND LANDSCAPE "THEATRE" 717

Francesco Paolo Protomastro

INTERWEAVING AND COMPLEXITIES OF THE MAN-MADE ENVIRONMENT AND NATURE 725

Dženana Bijedić Senaida Halilović Rada Čahtarević

BUILT HERITAGE, NEW TECHNOLOGIES AND DANUBE CORRIDOR

DIGITAL TOOLS IN RESEARCHING HISTORICAL DEVELOPMENT OF CITIES 737

Milena Vukmirović Nikola Samardžić

APPLICATION OF BIM TECHNOLOGY IN THE PROCESSES OF DOCUMENTING HERITAGE BUILDINGS 751

Mirjana Devetaković Milan Radojević

GIS-BASED MAPPING OF DEVELOPMENT POTENTIALS OF UNDERVALUED REGIONS – A CASE STUDY OF BAČKA PALANKA MUNICIPALITY IN SERBIA 758

Ranka Medenica Milica Kostreš Darko Reba Marina Carević Tomić

MAPPING THE ATTRACTIVITY OF TOURIST SITES ALL ALONG THE DANUBE USING GEOTAGGED IMAGES FROM FLICKR.COM 766

Bálint Kádár Mátyás Gede

INVENTARISATION AND SYSTEMATIZATION OF INDUSTRIAL HERITAGE DOCUMENTATION: A CROATIAN MATCH FACTORY CASE STUDY 777

Lucija Lončar Zlatko Karač

CULTURAL LANDSCAPE OF ANCIENT VIMINACIUM AND MODERN KOSTOLAC – CREATION OF A NEW APPROACH TO THE PRESERVATION AND PRESENTATION OF ITS ARCHAEOLOGICAL AND INDUSTRIAL HERITAGE 785

Emilija Nikolić Mirjana Roter-Blagojević

ALTERNATIVE TERRITORIAL CHANGES OF HOUSING ESTATES TOWARDS A SUSTAINABLE CONCEPTION 793

Regina Balla

HERITAGE, TOURISM AND DANUBE CORRIDOR

- CULTURAL TOURISM IN THE BALKANS: TRENDS AND PERSPECTIVES. 807
Kleoniki Gkioufi
- CULTURAL TOURISM AS A NEW DRIVING FORCE FOR A SETTLEMENT REVIT-
ALISATION: THE CASE OF GOLUBAC MUNICIPALITY IN IRON GATES REGION,
SERBIA 814
Branislav Antonić Aleksandra Djukić
- CULTURAL AND HISTORICAL IDENTITY OF TWIN CITIES KOMÁR-
NO-KOMÁROM 823
Kristína Kalašová
- PLACE NETWORKS. EXPERIENCE THE CITY ON FOOT 830
Milena Vukmirovic Aleksandra Djukić Branislav Antonić
- STORIES WITH SOUP - CULTURAL HERITAGE MOMENTS ALONG THE DAN-
UBE RIVER 837
Heidi Dumreicher Bettina Kolb Michael Anranter
- ETHNIC AND TOPONYMIC BACKGROUND OF THE SERBIAN CULTURAL HERI-
TAGE ALONG THE DANUBE 844
Dániel Balizs Béla Zsolt Gergely

SPATIAL AND RURAL DEVELOPMENT

- BEAUTIFUL VILLAGE PROJECT: AN ARCHITECTURAL AND LANDSCAPE DESIGN
STRATEGY FOR NON-HERITAGE VILLAGES IN HEBEI PROVINCE 859
Dapeng Zhao Bálint Bachmann Tie Wang
- CHANGES IN DEVELOPMENT OF NORTHERN CROATIA CITIES AND MUNICI-
PALITIES FROM 1991 TO 2011: MULTIVARIABLE ANALYTICAL APPROACH 869
Valentina Valjak
- SPECIFICS OF DYNAMICS OF SHRINKING SMALL TOWNS IN SERBIA 879
Milica Ljubenović Milica Igić Jelena Đekić Ivana Bogdanović-Protić Ana Momčilović-Petroni-
jević
- BALANCED REGIONAL DEVELOPMENT OF RURAL AREAS IN THE LIGHT OF
CLIMATE CHANGE IN SERBIA– OPPORTUNITIES AND CHALLENGES 888
Milicalgić MilicaLjubenović Jelena Đekić Mihailo Mitković
- COLLABORATIVE RESEARCH FOR SUSTAINABLE REGIONALDEVELOPMENT:
EXPERIENCES FROM “LEARNING ECONOMIES” ITALY-SERBIA BILATERAL
PROJECT 899
Jelena Živković Ksenija Lalović Elena Battaglini Zoran Đukanović Vladan Đokić

ASSESSMENT OF VALUE OF BIOMASS ENERGY POTENTIAL FROM AGRICULTURAL WASTE IN LESKOVAC FIELD AND ITS IMPORTANCE IN THE SETTLEMENT DEVELOPMENT PLANNING 908

Mihailo Mitković Dragoljub Živković Petar Mitković Milena Dinić Branković Milica Igić

MULTIFUNCTIONAL FACILITIES – FROM PRIMARY FUNCTIONS TO SPATIAL LANDMARKS (STUDY OF TWO CASES IN SERBIA AND BOSNIA AND HERZEGOVINA) 918

Aleksandar Videnovic Milos Arandjelovic

THE IMPACT OF USERS' BEHAVIOUR ON SOLAR GAINS IN RESIDENTIAL BUILDINGS

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ABSTRACT

Regulations governing the relevant procedures for the energy certification of buildings in Serbia do not consider the impact of users' behaviour on the level of heat loss or gain. In the case of solar heat gains, the gains are calculated both through transparent, as well as through non-transparent thermal envelope positions. Solar gains through transparent parts - windows and balcony doors are dominant, and depend on thermal properties of windows, orientation, shadings. In this regard, the regulation stipulates that all transparent (and semi-transparent) surfaces in the residential areas, other than those oriented to the north, northeast and northwest, must have non-transparent protection from direct solar radiation in the summer period. Shading elements can be permanent and movable, and their shading effect is defined by the standard EN 13790.

Users express different attitude towards the possibilities of solar gains provided through the glazed parts. This is mainly determined by the dynamics of moving (lifting) the shadings, which depends on their presence and, to a large extent, on the heating system (with the assumption that in buildings connected to the district heating system and the lump sum of heat consumption per m², users are not motivated to contribute actively to the heat gains).

The paper analyses the ratio of lifted / lowered (outer) shadings at different times of the day in the winter period on several examples of collective housing in Belgrade, with the aim of establishing the effective calculated area of the window for solar gains. The comparison of the obtained results with the parameters of the reduction due to sun protection equipment defined by the standard EN 13790, aims to establish and promote the design values that are realistic for use in the energy certification procedure of residential buildings.

Keywords: Residential buildings, Solar gains, Windows, Shadings, Users' behaviour

Introduction

Estimations and calculations of energy performance of buildings consider definition of certain scenarios regarding building characteristics, climatic conditions and the use of a building. Such presumptions also predefine a typical model of users' behaviour, which is usually understood as inalterable. However, in practice, the way some space is used is a subject of a change that happens either due to the change in time (diurnal or seasonal changes), or as a result of a change of behaviour of the occupants, which might have an impact on the amount of energy that the building consumes. This situation is confirmed by several recent researches that study

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the relationship between the users' behaviour and energy efficiency of buildings (Ben and Steemers, 2014; Guerra-Santin et al., 2018; Guerra-Santin and Iard, 2010). Regarding the correlation between the users' behaviour and energy consumption, windows, i.e. transparent parts of façade tend to be especially sensitive and conditioned by the applied operation mode and consequent potential for solar gains.

According to the regulations in Serbia that govern the relevant procedures for the energy certification of buildings (Rulebook on energy efficiency of buildings, 2011), the solar heat gains are calculated both through transparent and non-transparent parts of thermal envelope. Solar gains through transparent parts, which represent dominant heat gains in general, depend on thermal properties of windows, their orientation and the existence of shadings. With respect to the significant impact that solar heat gains through windows might have in the summer period, the need for non-transparent protection from direct solar radiation for all the windows except those oriented to the north, northeast and northwest has been declared by the regulations. The presence and type of shadings is especially in conjunction with the way users use them, influencing the energy performance of the building, but the calculation procedure does not consider the influence of occupants' behaviour. It has been shown that, in research, there is always a dilemma when defining the model and method of calculating the energy performance of buildings in terms of elements of the building whose application is susceptible to user influence, such as are the shading devices (Đukanović, 2015). The unpredictability of the way of using external shading devices may be best seen by observing large multi-storey residential buildings, in which there is a repetition of identical rooms, both in width and in height of the building (Figure 1).

Erection of the multifamily housing was typical for the post WWII period. The mass construction in this building sector was especially present in the period from 1970 till 1990. Hence, according to the research of the building typology of housing stock in Serbia (Jovanović Popović et al., 2013), buildings dating from this period today represent about 22% of the total housing stock. In 1973, the requirements and technical norms for the design of residential buildings and apartments were introduced, which imposed the obligation to install effective external protection in the form of blinds made of wood, metal or plastic, with the exception of openings in the loggias that could remain unprotected. Consequently blinds are normally present on the buildings from the mentioned period. It is noteworthy that on buildings, regardless of the time of day or weather (sunny or cloudy) or orientation, the outer blinds are in the most cases slightly lowered and the impression is that in average, they cover about 50% of the window surface. There are few rooms where the blinds descend all the way to the end. In the case of Belgrade, the most of such buildings are connected to the district heating system that is dominantly charged per square meter. This system of charging does not stimulate users to behave rationally, i.e. to regulate the temperature in the rooms using thermostatic valves, to raise the outside blinds during the day due to solar operation, and to lower them at night due to the reduction of thermal losses. Therefore, even opening of windows in the winter period for the purpose of thermoregulation in the room is not uncommon.



Figure 1: View of typical multi-storey residential buildings in Belgrade showing different ways of using external blinders along the façade

Since the method of the use of elements of external window protection together with users' habits in their exploitation, reflect on the energy balance of the rooms, i.e. on the need for thermal energy for heating in the winter, this complex problem is the particular subject of this paper.

Definition of model and research methodology

In order to examine and quantify the particular impact of user's behaviour on energy consumption, a theoretical model-building has been created followed by different scenarios of the use of shading devices.

Volumetric and material properties of the analysed model-building

Having in mind basic characteristics, volumetric and structural, of the multifamily housing from the period of the mass construction, theoretical model has been created (Figure 2).

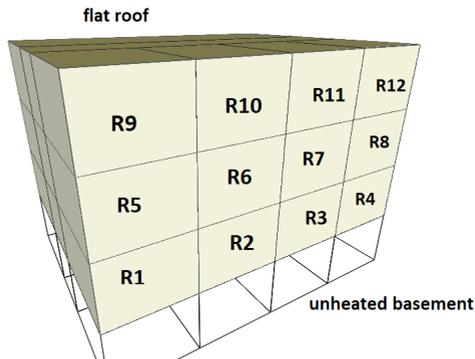


Figure 2: Theoretical model - building

The model has the following volumetric characteristics:

- Three above ground levels with heated rooms,
- One underground level with unheated rooms,

- Floor height $H = 2.8\text{m}$,
- Width of the room (R1-R12) $b = 4\text{m}$,
- Depth of the room (R1-R12) $d = 5\text{m}$.

In the continuation of the previous research on influence of disposition and orientation on energy performance, selection of typical rooms has been made and investigated (Rajčić et al., 2016). Hence, the rooms R1, R2, R5, R6, R9 and R10 were analysed, while the others were considered symmetrical. The analysed rooms have different sizes of the thermal envelope and, accordingly, different energy demand for heating.

Taking into account different structures and materials that were in use during the reference period of construction (1970-1990), typical structures of the time were assumed as elements of the thermal envelope of the model-building and presented in the Table 1.

Table 1: Relevant elements of model-building thermal elements

ELEMENT OF BUILDING THERMAL ENVELOPE	U VALUE [$\text{W}/\text{m}^2\text{K}$]	DESCRIPTION
MAIN FAÇADE WALL	0.816	CONCRETE WALL+THERMAL INSULATION+CONCRETE CLADDING
LATERAL FAÇADE WALL	0.816	CONCRETE WALL+THERMAL INSULATION+CONCRETE CLADDING
FLOOR ABOVE UNHEATED BASEMENT	0.948	WOODEN FLOORING+CEMENT SCREED+THERMAL INSULATION+CONCRETE SLAB
FLAT ROOF	0.655	CONCRETE SLAB+THERMAL INSULATION+HYDRO INSULATION+CEMENT SCREED

Since the buildings were built decades ago, their window characteristics were presumed in three typical variations that might be actually present in reality (Table 2):

- Present, i.e. original state,
- Improvement 1 (windows were replaced before the adoption of the Rulebook on energy efficiency in buildings in 2012, usually with 3 chamber PVC windows), and
- Improvement 2 (windows were replaced after 2012 with high performance windows in accordance with the Rulebook).

Table 2: Thermal properties of different types of windows regarding the assumed state of improvement

LABEL	State of the window	U [$\text{W}/\text{m}^2\text{K}$]	GLAZING FACTOR g [-]	FRAMING FACTOR F_f	AIR TIGHTNESS CLASS	NUMBER OF AIR EXCHANGES PER HOUR
PS	Presentstate	3.3	0.8	0.25	MEDIUM	0.7
I1	Improvement 1	2.5	0.6	0.25	MEDIUM	0.7
I2	Improvement 2	1.3	0.35	0.25	GOOD	0.5

Apart from the window type, paper analyses another variable related to the window characteristics, in particular the size of a window, i.e. the share of openings in the façade wall, which is analysed as 60%, 50% and 40%.

Assumed climatic conditions

Calculations of solar heat gains were conducted considering Belgrade as a geographical location of the analysed buildings. Relevant data regarding the mean sum of the solar radiation has been adopted from the *Rulebook* (Figure 3).

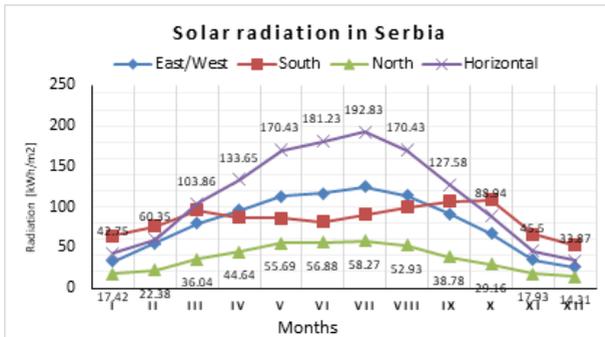


Figure 3: The mean sum of the solar radiation for Belgrade by months
Constant location parameters that were applied in this research are:

- HDD(Heating Day Degrees)=2520,
- Building is exposed to wind, with more than one façade,
- $F_s=0.9$ (position shading factor - unshaded position),
- $F_w=0.9$ (reduction factor for non-perpendicular position).

Unlike the constant parameters, F_c - reduction factor due to sun protection equipment (type of curtains) was assumed as variable, in accordance with standard EN 13790:

- $F_c=0.9$ (internal curtains, white),
- $F_c=0.6$ (the assumed medium condition that is not stated in the standard),
- $F_c=0.3$ (external blinds).

Results

Calculations of energy demands for heating were conducted for number of scenarios obtained by a combination of different variables, which reflect the effects of different ways of using window blinds by users (Table 3).

Table 3: Review of different types of variables used for various scenarios

Type of variables	VARIATIONS		
Vertical room position	ABOVE UNHEATED SPACE	MIDDLE FLOOR	BELLOW THE ROOF
Horizontal room position	MIDDLE	CORNER	
Room orientation	north	east/ west	south
Window condition	original state (PS)	improvement 1 (I1)	improvement 2 (I2)
Window/wall ratio	60%	50%	40%
F_c (reduction factor)	0.9	0.6	0.3

All calculations were conducted using non-commercial software KnaufTERM 2 Pro as the calculation tool. Two of the analysed scenarios are presented.

Scenario 1

The first scenario refers to the combination of the following variables:

- Different window condition (PS/ I1/ I2),
- Different position of a room in the building (R1/ R2/ R5/ R6/ R9/ R10),
- Different share of the windows in the main façade wall (60% / 50% / 40%),
- Different values of reduction factor F_c (0.9/ 0.6/ 0.3).

The focus of the scenario is on the window characteristics, i.e. its condition, as well as the combined impact of the window/wall ratio and different level of protection against solar radiation on the energy demand for heating of a room.

This scenario was performed on different cases of orientation of the rooms: north, east/west and south, and results that refer to the north and the south orientation are presented (Figures 4 and 5). For each of the analysed rooms, horizontal bars in a diagram present window/wall ratio (40-60%), with variations in values of specific annual energy for heating as a result of different values of reduction factor (0.9-0.3). Colours of the bars match the colours of the appropriate energy class.

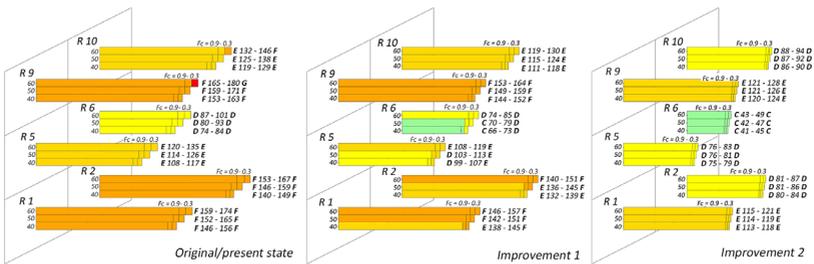


Figure 4: Specific annual energy for heating $Q_{h,an}$ [kWh/m²] and energy class of rooms for north orientation of the main façade

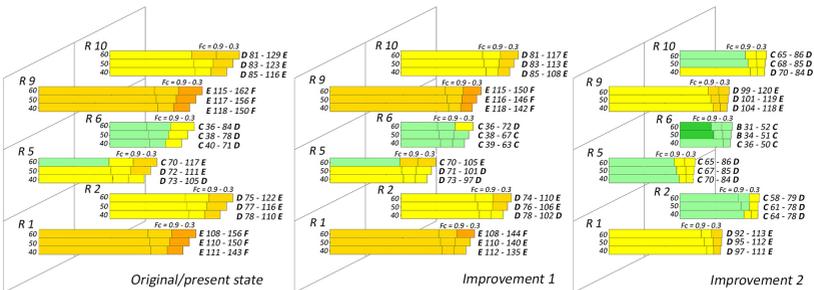


Figure 5: Specific annual energy for heating $Q_{h,an}$ [kWh/m²] and energy class of rooms for south orientation of the main façade

In the case of the north oriented main façade, the results indicate that more exposed rooms,

need more energy for heating - Room 9 is the most exposed, while Room 6 is the least exposed (Figure 4). Regarding the specific annual energy for heating and energy class of analysed room, rooms express different energy classes. Depending on the combination of the size of the window and the type of window protection, the differences in the energy classes are within 4 classes for original windows (D-G), as well as for the improvement 1 (C-F), while for the improvement 2, the energy classes vary in the range of 3 classes (C-E). In the same room, the energy class does not generally vary due to the size of the window.

A similar trend is evident in the case of the south-oriented main façade (Figure 5). Energy requirements vary among the four energy classes regardless of the condition in which they are, but less heating energy is needed compared to the north orientation. In the same room, the energy class varies in the range of two classes, depending on the window size (larger windows - the lower class).

Scenario 2

The second scenario refers to the combination of the following variables, with a constant average window size adopted (50% of the share in the main façade):

1. Different window condition (Present/ Intervention 1/ Intervention 2),
2. Different correction factor F_c (0.9/ 0.6/ 0.3),
3. Different rooms (R1/ R2/ R5/ R6/ R9/ R10),
4. Different orientation (north/ east/west/ south).

The focus of this scenario is on the influence of orientation. Hence it was performed on different cases of orientation (north, east/west, south), with reference to the influence of the state of the window (Figure 6). For each of the analysed rooms, horizontal bars in a diagram present window condition, with variations in values of specific annual energy for heating as a result of different values of reduction factor (0,9-0,3). Colours of the bars match the colours of the appropriate energy class.

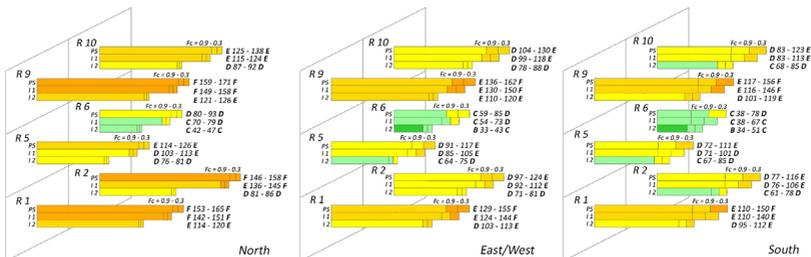


Figure 6: Specific annual energy for heating $Q_{n,an}$ [kWh/m^2] and energy class of rooms regarding the orientation of themain façade

The results indicate that the most exposed room need more energy for heating - Room 9 is the most exposed, while Room 6 is the least exposed. Energy class of a room vary in the range of four classes in the north orientation (C-F), i.e., five in the east/west orientation (B-F) and in the south orientation (B-F).

In the same room, the energy class varies within 2-3 classes depending on the condition of the window (original/present state - poorer class, intervention 1 - better class, intervention 2 - the best grade).

Conclusions

The complex scenarios of the conducted research have enabled the following conclusion to be drawn:

1. Energy required for heating is directly proportional to the size of the window openings, and inversely proportional to the factor F_c .
2. With the increase of the quality of the window (intervention 1 and 2), decreases the energy needed for heating, although g factor also decreases.
3. The required energy for heating is inversely proportional to the factor F_c .
4. The most energy is needed for north-oriented rooms, less for east/west oriented, and least for south-oriented rooms.

Finally, all of the conclusions undoubtedly confirm the importance and the impact that the user's behaviour might have on the energy performance of a building.

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