UNIVERSITY OF NIS
FACULTY OF CIVIL ENGINEERING AND ARCHITECTURE

in cooperation with
UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF CIVIL ENGINEERING AND GEODESY

UNIVERZITET U NIŠU
GRAĐEVINSKO-ARHITEKTONSKI FAKULTET

u saradnji sa
FAKULTETOM TEHNIČKIH NAUKA U NOVOM SADU
DEPARTMAN ZA GRAĐEVINARSTVO I GEODEZIJU

PhIDAC 2019 PhIDAC

V INTERNATIONAL SYMPOSIUM FOR STUDENTS OF DOCTORAL STUDIES IN THE FIELDS OF CIVIL ENGINEERING, ARCHITECTURE AND ENVIRONMENTAL PROTECTION

V MEĐUNARODNI SIMPOZIJUM STUDENATA DOKTORSKIH STUDIJA IZ OBLASTI GRAĐEVINARSTVA, ARHITEKTURE I ZAŠTITE ŽIVOTNE SREDINE

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Prof. Zoran Grdic
Assoc. Prof. Gordana Toplicic-Curcic
Assis. Prof. Nenad Ristic
Assis. Prof. Vuk Milosevic

TECHNICAL EDITOR:

Assis. Prof. Nenad Ristic

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EDITORAL NOTE:

The Faculty of Civil engineering and Architecture of University of Nis organizes the Fifth International Symposium of Doctoral Studies' Students in the fields of Civil Engineering, Architecture and Environmental Protection "PhIDAC 2019".

The first Symposium of the Doctoral Studies' Students "PhIDAC 2009", held in September 2009 in Nis, confirmed the expectations of Prof. Slavisa Trajkovic and Professor emeritus Radomir Folic, the founders of this symposium, that the two-day meetings of the students of Doctoral studies and their professors would be of invaluable use both for young researchers and their tutors. Namely, a great number of published and presented papers, as well as open discussion on the quality of paper, directions in further researches and relationships between doctoral students and tutors demonstrated that the Symposium fulfilled the expectations of the participants and that the organization of new meetings should be continued.

At the Second Symposium "PhIDAC 2010" held in Novi Sad, the symposium programme was expanded, i.e. the field of environmental protection was also introduced as the third thematic field with the expectation that this multidisciplinary area should be more closely introduced to young researches in the fields of civil engineering and architecture.

The organizers of the Third Symposium "PhIDAC 2011", also held in Novi Sad, decided that the symposium should be international and thus they opened new possibilities for affirmation and development of young researches from Serbia, as well as of their colleagues from the Balkans.

There were 66 papers dealing with topics in the fields of civil engineering, architecture and environment protection that were submitted for the fourth international symposium of students of doctoral studies "PhIDAC 2012". The papers covered a wide range of scientific topics. All the papers were reviewed. On the basis of the reviews, it was concluded that the young researchers provided a significant contribution to the development of scientific thinking.

Members of the international scientific committee actively participated in the preparation of the symposium and reviewing of the papers. For this symposium too, the proceedings including papers in English and Serbian were included, which provides better and more productive communication and exchange of experience with the colleagues from abroad.

We would like to thank all the authors and co-authors of the papers and their mentors, and it is our wish that the young researchers would continue their successful careers and persist in realization of the goals they have set.

Nis, October 2019 Editors

THE CONTENT:

SESSION CIVIL ENGINEERING AND ENVIRONMENTAL PROTECTION / OBLAST GRAĐEVINARSTVO I ZAŠTITA ŽIVOTNE SREDINE

RADOVI NA SRPSKOM JEZIKU / PAPERS IN SERBIAN LANGUAGE

OBLAST ARHITEKTURA / SESSION ARCHITECTURE

OBLAST GRAĐEVINARSTVO I ZAŠTITA ŽIVOTNE SREDINE / SESSION CIVIL ENGINEERING AND ENVIRONMENTAL PROTECTION

Dušan Ranđelović [1]
Miomir Vasov [2]
Jelena Savić [3]
Aleksandra Ćurčić [4]

APPLICATION OF GREEN ROOF AS A MODEL FOR IMPROVING THE ENERGY PERFORMANCE OF ELEMENTARY SCHOOLS

Abstract: *The building sector is considered the biggest single contributor to world energy consumption and greenhouse gas emissions with around 40% of total energy consumption. Numerous parameters such as climatic characteristics and urban conditions, location and purpose of the facility, affect the architecture of the designed object. The rationality, functionality, economy, and aesthetics are the criteria that each designer should integrate into their design in order to achieve an energy-efficient solution. Interventions on the existing construction fund represent enormous potential. Public facilities have great importance in the promotion of green construction, and as such, they can greatly affect the awareness of people about the importance of energy savings. Passive solar design involves the use of passive measures in order to reduce power consumption through the use of solar energy for the production of other forms of energy, or thermal energy transport by means of natural convection, conduction or radiation. Unlike active solar design, this technology does not require additional devices. It does not require particularly high costs and is usually the investment worth over a period of several years. Green roofs as a representative of passive solar design, in addition to a number of environmental and economic benefits, can contribute to the reduction of energy consumption. The subject of this paper is an analysis of the application of the green roof system at the existing primary schools in Niš. The methods of analysis, synthesis, and modeling methods were used, as well as energy simulation in EnergyPlus software. The aim of this research is to examine the potential for improving the energy performance of primary schools using the green roof system.*

Key words: *green roof, energy simulation, energy savings, primary schools*

1. INTRODUCTION

In the European Union, the construction sector represents one of the largest consumers of energy, with a share of almost 40% of the total energy produced [1]. Public buildings have a large share of the total building stock. If every designer responsibly approaches the design and understanding of energy losses and gains in local climatic conditions, the environment will be much healthier and of better quality. Architects, therefore, must pay more attention to the quality of the space they are designing in order to make the design of passive solar objects more attractive to the general public [2]. Designing sustainable buildings with thermal comfort and the low energy consumption is of great importance. Gvozdenac-Urosevic [3] indicates the need to simultaneously analyze energy intensity and other energy and economic indicators. Otherwise very unreliable conclusions can be drawn. It is also necessary to use only

[1] Dušan Ranđelović, PhD Student, Teaching Assistant, Faculty of Civil Engineering and Architecture, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, e-mail: randjelovic.dusan.88@gmail.com
[2] Miomir Vasov, PhD, Associate Professor, Faculty of Civil Engineering and Architecture, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, e-mail: miomir.vasov@gaf.ni.ac.rs
[3] Jelena Savić, PhD, Teaching Assistant, Faculty of Civil Engineering and Architecture, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, e-mail: jelena.savic@gaf.ni.ac.rs:
[4] Aleksandra Ćurčić, PhD Student, Faculty of Civil Engineering and Architecture, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, e-mail: ajacurcic@hotmail.com

verified data obtained through known methodologies. Such analyses can be very useful for energy policymakers.

The use of mechanical systems such as HVAC (heating, cooling, air conditioning) has greatly changed the approach to design. In the past, traditional construction methods had a much greater variety. They gave a kind of stamp to every built object, while today it is all different. Despite the highest quality mechanization, application of modern materials and the use of numerous systems for improving human comfort, there is a great lack of newly constructed buildings. The advantage of using passive solar systems is that the initial costs are lower than active solar systems, as they are part of the building itself. Perhaps the best definition of Passive Solar Design might be: "Systems that collect, store and redistribute solar energy without applying mechanical systems."

While designing buildings according to passive solar principles architects should pay attention to many things such as: glazing characteristics (which contributes to direct solar gains), the orientation of the thermal mass (regarding high storage capacity) and windows (orientation towards the south is recommended), consistent implementation of the principle of zoning (correct allocation of space in the northern and southern areas of the building), thermal protection of areas that require less heat (kitchens, auxiliary rooms…), a stable microclimate (energy balance combination with a variety of walls, glass surfaces, roofs, green areas), use of solar panels on the roof (heat water and/or produce electricity), as well as additional green roofs (an impenetrable roof that protect the building, and also reduces the level of Urban Heat Island Effect) [4]. It is possible to improve the energy performance of elementary schools " by applying passive solar design strategies [5]. The subject of this paper is an analysis of the application of the green roof system, as a representative of passive solar design strategies, at the existing primary school in Niš. The methods of analysis, synthesis, and modeling methods were used, as well as energy simulation in EnergyPlus software. The aim of this research is to examine the potential for improving the energy performance of primary schools using the green roof system.

2. ENERGY CONSUMPTION IN SERBIA

Of the total final energy consumption in the Republic of Serbia in 2008, the construction sector has a share of about 38%, of which 70% is used in the residential sector and 30% is made up of commercial and public buildings [6]. Oka, Sedmak, and Đurović-Petrović [7] give a brief overview of the current energy situation in Serbia, with particular reference to energy efficiency, the use of renewable energy sources and dependence on energy imports. Most of the implemented projects gave very applicable results, but unfortunately, the implementation of those results was not successful. The main reasons are that most industrial enterprises are in transition, that energy and fuel prices are not yet stimulating, and that the Serbian government and line ministries have not yet created a favorable environment for rational and efficient behavior of people and companies.

Šumarac et al. [8] In the case study of the energy efficiency of residential buildings in Serbia, particular attention is paid to the energy efficiency of existing buildings. The average energy consumption in residential buildings in Serbia is about 3 times higher than in developed European countries. The average annual thermal energy consumption in most existing buildings in urban areas in the Republic of Serbia is significantly higher than in new buildings (Existing buildings consume 2 to 3 times more heat). Buildings built in the '70s and' 80s of the twentieth century, during a period of intense construction fund growth, are characterized by excessive consumption of final energy. As these buildings are constructed with an inadequate thickness of thermal insulation or without any thermal insulation, they represent the biggest problem related to energy consumption in the Republic of Serbia. [6]. Considering that the Regulations on the thermal protection of buildings first appeared after 1980, it is not surprising that almost 80% of Serbia's family facilities do not have thermal insulation installed, and that only 1/5 are built in accordance with any regulation. The current construction fund in Serbia as the largest energy consumer does not meet new global trends in environmental protection and carbon dioxide emissions [9]. The building stock, especially facilities built before 1980, should be a priority in energy renovation strategies. These facilities have great potential for improvement, thus reducing energy consumption and improving thermal comfort [10].

The modern approach to building renovation provides numerous and varied improvement opportunities that can be realized in this way. In view of the context in which construction practices operate in developed countries, it is possible to make unnecessary adaptations to an existing building stock because there is a great potential for energy savings [11]. Renovation of the existing building stock is a great untapped potential for energy savings and the implementation of adequate measures contributes to the increase of energy efficiency. Over 75% of buildings were built before 1980. Buildings and flats built before 1970 have almost no thermal insulation, while buildings built before 1980 have poor thermal insulation. These facilities have the highest energy savings (up to 80%). The public sector should play a leading role in the renovation of existing buildings [12].

Taking into account the fact that public buildings do not represent an energy-efficient segment of the construction fund, we conclude that their renovation can save considerable amounts of energy. Based on the analysis of types of public buildings and their share in total energy consumption, we obtain that educational buildings consume about 17% of energy [1]. So, if we want to change something, buildings are the best place to start, and primary schools are the best potential for investing and raising the environmental awareness of future generations. The category of educational buildings owned by the City of Niš has 128 facilities, with a total area of 191.074 [m^2]. This sub-sector consumed 5,795,186 [kWh] of electricity in 2010, which gives a specific consumption of 30,33 [kWh/m^2].

3. DEFINITION AND STRUCTURE OF THE GREEN ROOFS

A green roof (also known as the eco-roof, natural or living roof) is a roof structure that has a layer of substrate and vegetation on its outside. There are several types of these systems, but the general structure could be reduced to a geotextile filter layer, drainage layer, barrier layer, and waterproofing layer (*Figure 1*).

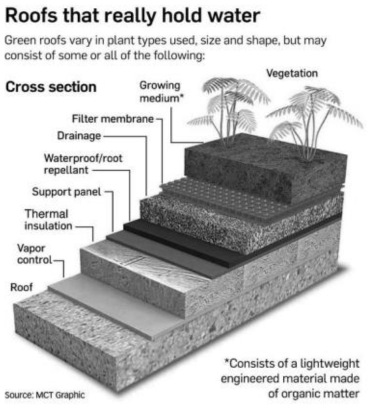


Figure. 1. 3D view of green roof (Source: https://s-media-cache-ak0.pinimg.com/564x/57/bc/e3/57bce36b2ddb7f8b77acf721b37219f1.jpg)

In addition to improving energy efficiency [13], green roofs also contribute to the reduction of urban heat islands (UHI effect) [14], reduced the accumulation of solar radiation in the roof structure [15], reducing rainwater runoff but also purifying water and air. In addition to improving the acoustic and aesthetic characteristics of the roof, the implementation of the green roof has a beneficial effect on increased biodiversity. They contribute to the improvement of thermal stability in warm climates [16]. The percentage of solar radiation that reaches the roof structure is much lower when building a green roof [17].

Elizabeth Joyce Grant in his doctoral thesis *A decision-making framework for vegetated roofing system selection* [18] divides the mechanisms related to the thermal properties of green roofs into four segments and provides an overview of the literature of thermal properties of green roofs. In addition to the basic four physical processes that occur (evaporation, radiation, convection, and conduction), Elizabeth Joyce Grant points out the fifth aspect as a very important component for a comprehensive understanding of green roofs, which are *other biological processes*. Plants under the influence of photosynthesis absorb the sun's energy. In this way the plants keep the temperature of the earth higher than the surrounding air, thus preventing the roots of the plants from freezing. This process is called "Root Respiration" [17].

The heat flux through the roof is calculated by the influence of the external absorption coefficient in combination with the influence of solar radiation on the inside air temperature (sol-air temperature). The lower roof surface temperatures contribute to reducing heat gain inside the building. In summer, when there is significantly less precipitation and when the soil layer is predominantly dry, the input heat flux from green roofs is significantly reduced compared to traditional roofs. Alcazar and Bass [19] indicate a direct relationship between soil moisture and thermal conductivity. Namely, the more moisture-saturated the earth, the easier it is for thermal energy to pass through it. Due to the fact that moist soil provides very little thermal resistance, the thermal insulation properties of the earth in winter are almost insignificant. [17]. Composition of green roof soils and Thermophysical properties of green roof soils for 0% of moisture level, as well as the correlation between soil thermal conductivity (λg) and soil density per specific heat, are among the most important parameters for considering the energy characteristics of a green roof [20].

Green roofs, in comparison to light conventional roofs, reduce the temperature of the roof surface and therefore the extreme temperature of the waterproofing membrane, thereby extending its life span. The delay in the amplitude of the oscillation of the roof temperature is extremely important in cases of maximum outside temperature [21]. This significantly reduces the heat flow through the structure during the summer day, which contributes to the reduction of temperature fluctuations within the roof structure. [22]. Based on research [23] Lazzarin et al. state that from the total incident solar radiation, the dry green roof absorbs 39%, 24% represents external adduction, 23% dissipates due to reflection, 12% makes evapotranspiration, 1.3% heat accumulates, and just under 2% penetrates through the roof structure inside the building, compared to about 4.5% penetration in the case of a traditional roof structure. Eumorfopoulou and Aravantinos [17] state that of the total amount of solar energy that falls on the green roof, 27% is reflected, 60% is consumed in the evaporation process, while only 13% goes through construction.

The process of evaporation and transpiration are correlated with each other and it is impossible to exclude one of these two processes, so the term evapotranspiration is very common in the literature. Quantifying the evapotranspiration process is complicated. Zhang and others [24] and Alexandri and Jones [25], considered the thermal exchange between the leaves and the surrounding air. On the other hand Takakura, Kitade, & Goto [26] In order to simplify the model, they considered the vegetation layer as a uniform material consisting of greenery (leaves) and air.

4. ENERGY SIMULATION OF GREEN ROOFS

Understanding the complexity of thermal properties and the energy impact of green roof systems involves a detailed analysis of physical phenomena and an interdisciplinary approach [17]. This complexity has for many years been the biggest problem and obstacle for computer modeling and simulation of these systems. The influence of different typologies and configurations of the green roof on its thermal characteristics depends primarily on the properties of the vegetation and soil layers [27].

Currently, there are several mathematical models for calculating the impact of green roofs on energy consumption. Sailor [28] analyzed the energy balance of green roofs taking into account longwave and shortwave radiation, the influence of the canopy on convective heat transfer, the influence of evapotraspiration of the vegetation layer and substrate, as well as the thermal conduction and storage of heat in the substrate layer. Feng, Meng, and Zhang [29] have included the process of photosynthesis in the mathematical model. [27] performed an analysis based on the Fast All Season Soil STrength (FASST) model developed by Frankenstein and Koenig [30] for purposes of the U.S. Army Corps of Engineers. This model was implemented in an EnergyPlus simulation program that used to perform numerical analysis. In the model, the green roof is represented as vegetation on the soil layer. The vegetation layer is characterized by emissivity, albedo, green height, leaf area index, while the soil layer is a homogeneous structure through which sensible and latent heat flux passes. The obtained results make it possible to determine the heat flow through the structure.

The green roof model assumes the following phenomena:

- Exchange of longwave and shortwave radiation within the vegetation layer, including the effect of multiple reflections between vegetation and soil layers;
- influence of vegetation layer on convection heat transfer;
- the process of evapotraspiration from plants and soil;
- thermal conductivity (and storage) in the soil layer.

Complexities of this problem are reflected in a large number of variables such as different purposes of buildings, different degrees of insulation, different climates, and different behaviors green roof in summer and winter [13]. The unpredictability of meteorological changes (temperature, wind speed, humidity, cloudiness and sunshine, precipitation, etc.) indicates that the analysis of these systems is extremely complex and it is impossible to exclude any of the above parameters. The complexity of analyzing the thermal properties of a green roof also depends on the characteristics of the building on which it is located (not only physical characteristics but also the purpose and usage of the building)[21]. The efficiency of green roofs is more significant in old buildings, ie those with modest insulation or those without thermal insulation [31].

5. ENERGY MODELS OF PRIMARY SCHOOLS - CASE STUDY

In order to analyze the influence of thermal characteristics of a flat green roof, a numerical model of Primary school “Car Konstantin“ was formed (*Table 1*). Characteristics of Thermal Envelope of analyzed Primary School is shown in *Table 2*. The conducted research used the climate parameters for the city of Niš. The entire building envelope, except the green roof, is represented by structures whose layers are fixed and not varied in the parametric study. Ventilation gains and losses have not been considered, while internal gains from lighting, techniques, and people have been taken into account. The indoor temperature is 26° C in summer, and 20° C in winter.

Table 1- 3D view (Photo documentation and Energy model) of analyzed Primary School

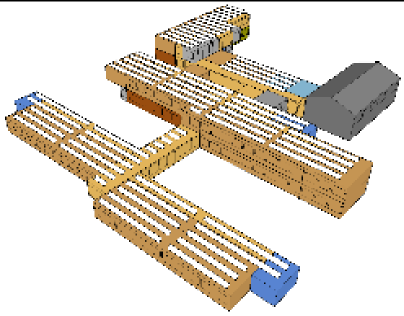
	Photo documentation	3D Energy models
Primary school “Car Konstantin“		

Table 2- Characteristics of Thermal Envelope of analyzed Primary School

Thermal envelope	PS "Car Konstantin"	
FLOORS - SUM	4612 m^2	100.0%
WALL-North	1165 m^2	30.7%
WALL-East	731 m^2	19.3%
WALL-South	1165 m^2	30.7%
WALL-West	731 m^2	19.3%
WALLS - SUM	3793 m^2	100.0%
GLAZ-North	358 m^2	28.3%
GLAZ-East	209 m^2	16.6%
GLAZ-South	416 m^2	32.9%
GLAZ-West	281 m^2	22.2%
GLAZING - SUM	1266 m^2	100.0%
ROOFS - SUM	3381.11 m^2	
WWR-North	30.8%	
WWR-East	28.7%	
WWR-South	35.8%	
WWR-West	38.5%	
Overall WWR	33.4%	
Thermal Envelope	11727 m^2	
Volume	19822 m3	
Form Factor	0.59 m^2	
Overall WWR	33.4%	

By varying the different values of green roof parameters, it is possible to evaluate the energy consumption needed for heating and cooling. For each green roof configuration, the heat flux through the interior surface is calculated and the corresponding equivalent dynamic thermal parameter is obtained. The conducted analysis contributes to the identification of the most important parameters for designing a green roof. Research on the most dominant parameter for improving the efficiency of green roofs has been the topic of many research [27], therefore, the LAI - Leaf Area Index is listed as one of the most important parameters for reducing energy consumption [32], which is confirmed by practical measurements. [33]. While some authors claim that a green roof can contribute to significant savings in heating and cooling energy consumption even when the roof structure is not thermally insulated [31], others claim that this type of construction cannot replace the thermal insulation layer [17].

Only variants with the extensive green roof are analyzed in the conducted research. The thickness of the thermal insulation of the roof varies from 0 cm (uninsulated); 25 cm (medium insulated) to 35 cm (super-insulated). The values of plant height, leaf area index is set to default, while the same assumption has been made for leaf reflectivity, leaf emissivity, and stomatal resistance (which is the resistance of plants to moisture transport). Different ranges of the soil thickness have been varying from 15 to 20 cm. So, the baseline Energy Model (M_0) is made. After that the Baseline Model is improved by applying thermal insulation (M_1, M_2), green roof structure (M_3, M_4), as well as the combination of thermal insulation and green roof structure (M_5, M_6, M_7, M_8). The descriptions of models with implemented alternatives as well as heating and cooling energy savings compared to the baseline model are shown in *Table 3*.

Table 3- Model descriptions with implemented alternatives and percentage savings for heating and cooling compared to the baseline model

MODEL	ALTERNATIVE	ROOF_INS_THICK	SOIL_THICK	FINAL_HEATING [KWH/M²]	FINAL_COOLING [KWH/M²]	SAVINGS_HEATING [%]	SAVINGS_COOLING [%]
M_0	BASELINE	-	-	173.50	8.94		
M_1	+Thermal Insulation	0.25	-	143.06	8.89	17.54%	0.60%
M_2	+Thermal Insulation	0.35	-	142.18	8.90	18.05%	0.52%
M_3	+GreenRoof	-	0.15	151.92	9.52	12.43%	-6.46%
M_4	+GreenRoof	-	0.2	150.75	9.38	13.11%	-4.83%
M_5	Therm.Ins.+GreenRoof	0.25	0.15	141.96	8.96	18.18%	-0.21%
M_6	Therm.Ins.+GreenRoof	0.25	0.2	141.72	8.92	18.31%	0.31%
M_7	Therm.Ins.+GreenRoof	0.35	0.15	141.43	8.92	18.48%	0.29%
M_8	Therm.Ins.+GreenRoof	0.35	0.2	141.19	8.90	18.62%	0.49%

6. RESULTS AND DISCUSSION

The applied measures lead to a decrease in heating energy consumption in all models (from 12,43% to 18,62%) compared to the baseline model (*Figure 2*). On the other hand, cooling energy consumption compared to a baseline model decrease in models with thermal insulation (M_1, M_2, M_6, M_7, M_8), while for models with only green roof implemented, as well as with green roof and 25cm thick thermal insulation layer (M_3, M_4, M_5) cooling energy consumption increase compared to a baseline model.

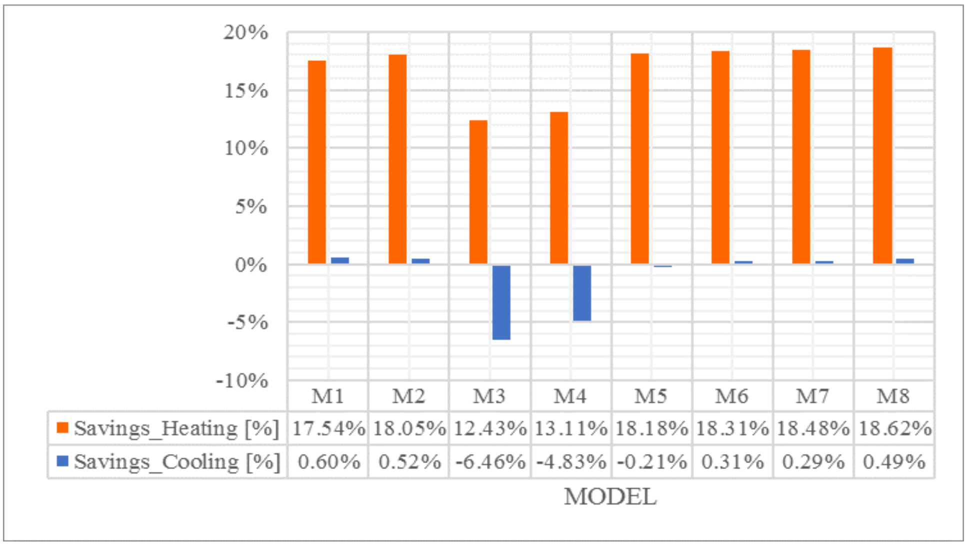


Figure. 2. Percentage savings for heating and cooling compared to the baseline model

Although energy savings for heating are recorded for all alternatives, we can conclude that the combination of thermal insulation with green roof structure is the best alternative to reduce heating energy consumption. Namely, the contribution of green roof applications is more significant in buildings that do not have thermal insulation. With the addition of the thermal insulation layer, the importance of the green roof in reducing energy consumption for heating and cooling is much smaller. It is also interesting to note that by applying green roof, energy savings for cooling are lower compared to models with only thermal insulation added.

7. CONCLUSION

By performing dynamic simulations, numerous authors have sought to predict the energy performance of buildings depending on the change in the thermal envelope or the HVAC systems used. The proposed methodology allows designers to try different variants of green roof implementation. Based on the conducted dynamic simulation, we can conclude that the application of green roofs can improve the energy performance of elementary schools. As the thickness of thermal insulation increases, the significance of the green roof structure decreases.

Although quantifying all the benefits of green roofing is very difficult (some of which are not measurable - in addition to energy benefits, there are environmental and social benefits), this research confirms that the application of these structures is a justifiable measure for saving energy for heating and cooling.

Since the very little research has been done related to the thermophysical characteristics of substrates and vegetation in Serbia (which mostly influence the energy consumption and thermal stability of buildings with the implemented green roof system), as well as cost-benefit analysis, the future research should take these aspects into account.

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