ENERGY CONSUMPTION AND CO_2 EMISSION REDUCTIONS TROUGH REFURBISHMENT OF RESIDENTIAL BUILDINGS' ROOFS BY APPLYING THE GREEN ROOF SYSTEM – Case Study

by

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Climate changes which we are experiencing at the moment are affecting the entire globe. Serbia, as a developing country, is in the process of defining its own energy strategy and priorities when it comes to the problem of increased energy consumption in its building stock. Research shows that residential sector consumes the largest quantity of energy. The CO_2 emissions present another big problem which is in a direct correlation with energy consumption. Green roofs have multiple positive effects on buildings and their surroundings which make them a desirable option for retrofitting roofs. The aim of this paper is to investigate thermal properties of chosen green roof system and its potential to positively influence energy consumption for heating buildings and therefore CO_2 emissions trough refurbishing existing old flat roofs. The municipality of New Belgrade was chosen for this research for its unique urban characteristics – existence of large number of similar or identical buildings, which have same structural characteristics and similar surroundings. For the purpose of this paper, blocks 45 and 70 were chosen. Results of this research are applicable on all of the 132 buildings found at this location, which have total roof area of 90.990 m^2. By calculating energy quantity needed for heating the building with the existing roof and two hypothetical models, which have green roof, it was possible to quantify energy savings, which are in a direct correlation with CO_2 emissions. A control roof was introduced in order to examine if the proposed green roof possesses better characteristics than a traditional solution, most commonly used in Serbia. Apart from energy savings, overall impact of the green roof on the CO_2 reduction per building was calculated. By multiplying these results, we drew the conclusion that a project such as greening roofs of existing residential buildings in blocks 45 and 70 would have a noticeable effect on both the energy savings and CO_2 emissions.

Key words: *extensive green roof, refurbishment, residential buildings, CO_2 emission reduction, energy efficiency*

Introduction

Republic of Serbia has committed to European institutions to lower energy consumption by 9% in the period from 2010 to 2018. In order to define proper actions, the share of individual sectors in total energy consumption has been determined. Residential sector along with commercial and service sectors has spent around 38.5% of total energy in the Republic of Serbia in 2008. In 2011 this figure increased to 49.16% due to change in calculation

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methods in 2010 [1, 2]. It has been estimated that around 70% of this energy is spent in the residential sector. Average annual thermal energy consumption in most of the existing buildings is up to 2 to 3 times larger than in new buildings [1, 2]. Residential buildings built in the 20th century consume excessive amount of energy due to poor or non-existent thermal insulation and as they age, their envelope properties deteriorate. When we compare the number of existing buildings with new buildings which have proper thermal properties, it becomes clear that it is not possible to significantly influence energy consumption by applying energy regulations only on new buildings, but it is necessary to refurbish existing building stock.

According to statistical data, 98% of apartments in the Republic of Serbia were built before the 2004 (95% before 1992) [1, 2]. These numbers show not only how old buildings are, but the period of construction has a direct correlation to specific advances in building techniques and technology as well to the legislation related to construction industry. It is safe to assume that the same situation is characteristic for public and commercial sector. This indicates that there is a necessity to refurbish most of the existing buildings.

Energy refurbishment includes wide spectrum of actions among which improving thermal properties of building envelope takes the central spot. Applying green roof systems represents one way of improving energy properties of the roof since there are systems which are light in weight thus allowing for adding enough thermal insulation on the existing roof construction. While the thermal insulation affects thermal properties of the roof, the outer layer brings numerous additional benefits to the owners and users of the roof and surrounding space. Climate of Serbia can be described as moderate-continental with more or less pronounced local characteristics [3]. This climate is characterized by significant precipitation and green roofs have proven their efficiency in rainwater retention. On the other hand, very high temperatures that are characteristic for summer season are effectively alleviated due to existence of the sedum on the roof tops, thus preventing the creation of the urban heat island effect. Other benefits range from roof longevity, increasing biodiversity, rainwater filtration to psychological and social effects on their users.

Apart from the excessive energy consumption, air pollution has become a serious problem for the modern society and a big threat to human health. Accumulation of the harmful gases, especially CO_2, results in a phenomenon known as the green-house effect. As a consequence, the temperature of the entire ecosystem rises. In combination with the urban heat island effect, which occurs as a result of vast areas of non-porous surfaces such as asphalt, different pavements, and gravel, air pollution is creating urban microclimate which is damaging for human health and general wellbeing. More parks and gardens are needed to restore balance in the surrounding air. As the free space for new greenery is practically non-existent on the ground, the alternative would be placing them on the roofs of the existing buildings, based on the experience of big world cities such as Chicago, USA, or Toronto, Canada. For the purpose of this paper, stress will be put on the roof's impact on the CO_2 emissions and thermal properties of the roof.

Methodology

The main hypothesis of this research deals with determining if the chosen green roof system can contribute to the thermal properties of the existing roof, and consequently, influence reduction of the CO_2 emissions by lowering the primary fuel consumption needed for heating the building throughout the year. The starting premise is that the new solution would most certainly increase thermal properties of the existing roof due to adding more thermal insulation, but the true question lies in discovering if the chosen green roof system allows for enough thermal insulation to be added, due to weight limitations, while providing additional benefits unique to a green roof. Knauf TERM 2 PRO software solution was used to conduct calculations. The software offers static simulation and lacks certain criteria, characteristic for other, more complex, programs. The reason for using this program lies in the fact that it has been developed in compliance with current laws and ordinances, and it uses local climate data for more precise calculations. Current regulative relies on adopted European standards (EN ISO) and the software has been updated several times in order to fulfill latest requirements [4].

A specific type of extensive green roof produced and sold in the region was selected for this study, in order to obtain reliable data [4]. For characteristics of this roof solution, which are significant for this research, see tab. 4. As the polygon for the case study, New Belgrade was chosen primarily for its unique structure comprised of a vast number of identical or similar buildings, as well as for the building age factor (chosen buildings are 47 years old with no record of any roof refurbishment ever been conducted on them).

A set of requirements was constructed in order to verify that the chosen buildings' roofs were suitable to undergo a process of green roof retrofit. Special attention was paid to the bearing capacity of the existing construction.

To calculate the potential influence of the hypothetical green roof models (two models were suggested) as well as the properties of the existing roof and a standard well insulated roof (which was used as control roof), a software package available on Serbian market was used, since it complies with the current law and is widely used by professionals. The software calculates the heat transfer coefficient of the building elements U [$Wm^{-2}K^{-1}$], energy needed for heating $Q_{h.fin}$ [kWh], quantity of primary energy used in this process $Q_{h.prim}$ [kWh], and therefore the quantity of CO_2 released into the atmosphere on a yearly basis as a consequence of the energy consumption. This research is focused only on the energy needed for heating since the current law and the ordinance on the requirements and manner of issuing energy certificates rank buildings based on this parameter. In the future, the scope of this research will include the parameters related to the energy needed for cooling of the building stock.

Calculated values have been presented and compared to each other in order to draw relevant conclusions regarding the topic of the research. Summary of the research results and findings is given at the end of the paper. In addition to the summary, conclusions regarding refurbishing existing building stock by using green roof systems are offered.

New Belgrade's urban structure suitable for massive refurbishment undertaking

New Belgrade has 200 skyscrapers and 600 large residential buildings. These buildings house around 80.000 residential apartments. According to the last national survey from 2011, New Belgrade has 214.506 residents with permanent residency [5].

As early as 1923 plans were made to expand Belgrade across the Sava River. Historical conditions prevented this idea from realizing until three years after the World War II [5]. The period that followed World War II, known as the *period of renewal*, was characteristic for a substantial change of the approach in building, leading to highly intensive housing construction accompanied by a boom in building technology of prefabricated construction systems, thus defining an entirely novel architectural expression. This period was characterized by a dynamic urban growth, huge housing project developments, and creation of new neighborhoods and satellite communities [6]. These huge housing projects often meant building a vast number of identical or very similar buildings in order to lower the construction period and to ease the building process. Blocks 45 and 70 represent an obvious example of this ideology, fig. 1.

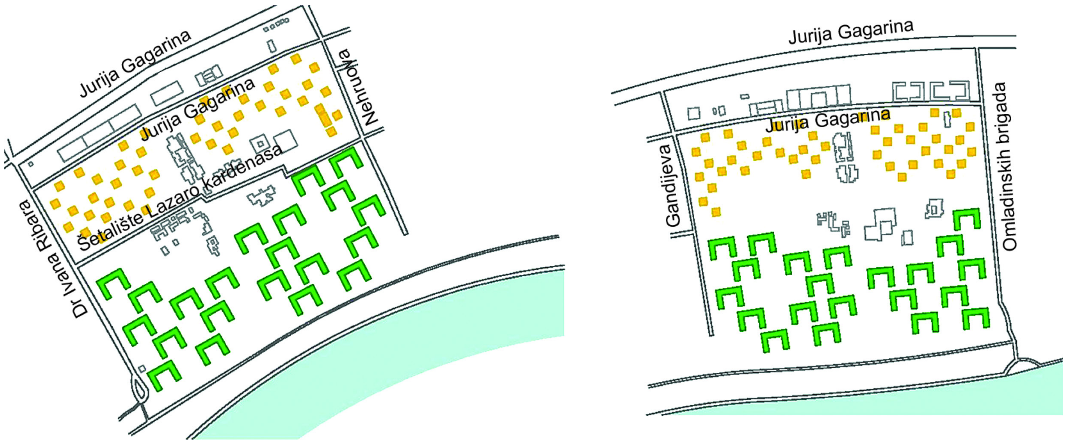

Figure 1. Structure of New Belgrade blocks 45 and 70

Determining if the chosen buildings are capable to retrofit a green roof

Two types of multistory buildings can be found in blocks 45 and 70. Free standing buildings with compact square floor plane with a recessed floor that range from 9-17 stories (from basement + ground floor + 6 stories + attic to basement + ground floor + 14 stories + attic) represent Type 1. Type 2 buildings have "U" shaped base with six lamellas and constant height – six stories (basement + ground floor + 4 stories). In city block 45 there are 45 buildings of Type 1 and 21 buildings of Type 2. The situation is the same in city block 70, tab. 1. For this case study, one building of each type located in block 45 was chosen. Representative building for Type 1 is located in Jurija Gagarina 263 Street, and for Type 2 in Dr Ivana Ribara 103-113.

Table 1. Number of same buildings in New Belgrade blocks 45 and 70

	Block 45		Block 70			
	Number of buildings	Free roof area of one building [m^2]	Number of buildings	Free roof area of one building [m^2]	Total number of buildings	Total roof area [m^2]
Type 1	45	311	45	311	90	27990
Type 2	21	1500	21	1500	42	63000
						90990

Concrete prefabricated panels were used to build plane and compact forms such as these. All floors (except basement – reinforced concrete, 20 cm, and the recessed floor in Type 1 – breeze block, 21 cm and 25 cm, plastered with lime-cement plaster) have triple-layered panels which consist of concrete (7.5 cm), styrofoam (4 cm), and concrete (3.5 cm). Windows are wooden, double frame, narrow box, double sash with single glazing with internal textile roller blind. Buildings use district heating system (hot water). All buildings are residential with multiple apartments which have natural ventilation.

In order to determine if the existing roof is suitable to undergo a process of green roof installation, it is necessary to verify if it meets following requirements, tab. 2:
– local climate,
– age of the building,
– load capacity of the existing construction,
– position of the building in the block matrix,
– roof orientation,
– building height,
– roof pitch,
– roof area under mechanical installations, and
– if the building is under any protection regime [7].

Table 2. Fulfillment of the listed criteria for determining if the building is suitable for the green roof installation

Criteria	Condition	Situation on the site
Local climate	Local climate should influence the need for additional heating and cooling of the building	Moderate continental climate is characteristic for large differences between maximum and minimum annual temperatures – in critical periods it is necessary to additionally cool/heat the building due to poor insulation of the building envelope
Age of the building	There has been no change or refurbishment of the roof in the last 20 years (estimated lifetime of conventional flat roofs is maximum 20 years)	The building dates from 1971, and it is 47 years old. There has been no proof of any refurbishment or roof replacement activity since it has been built
Height of the building, roof orientation and position of the building in the block matrix	The roof needs to be accessible to workers and machinery and should not be overshadowed by the surrounding buildings	Since the buildings are positioned 20 to 50 m away from the examined building, they have no influence on the overshadowing of the roof. And the roof is accessible to workers and the machinery
Area under mechanical installations	Roof area occupied by ventilation shafts, heating and cooling systems, lanterns and other such elements should not exceed 40% of the total roof area [6]	Around 90% of the total roof area on the examined buildings is unoccupied and therefore suitable for green roof.
Roof pitch	Roof pitch for flat green roofs varies between 0-5º (0-9%)	Roof pitch is 5º (special attention should be paid to connection between roof and the attica, mechanical installations, drains and revision openings)
Protection regime	Existing roof cannot be replaced with green roof if the building is being protected by the Heritage Protection Institute	The building is not under any protection regime at the present time

Bearing capacity of the existing construction. This criterion is being examined more thoroughly because it is the most important one since it determines type of the green roof and the depth of the substrate. If the existing construction is not able to bear the load of the preferred green roof, it is possible to reinforce the construction. However, this type of structural reinforcement is a complex process that requires a lot of additional work and substantial financial investment.

For this criterion, Type 1 building will be examined and it is safe to assume that obtained data applies to the Type 2 building. This building (like all residential buildings in blocks 45 and 70) has reinforced concrete skeletal structure. According to the static calculation, the roof construction can withstand 639.5 kg/m^2 [8]. Part of this load (111 kg/m^2) is reserved for snow and wind. Remaining 528.5 kg/m^2 are composed of construction layers shown in tab. 3.

Table 3. Construction layers of the existing roof, load, and heat conductivity coefficient

Layer	Layer thickness, d, [cm]	Load, Q, [kgm^{-2}]	Heat conduction, λ, [Wm^{-1}K^{-1}]
Mortar	0.5	8.5	0.85
Reinforced concrete slab	14.0	350.0	2.33
Perlite concrete	5.0-15.0	105.0	0.15
Verbit II, bitumen 75/75	1.0	11.0	0.17
Verbit, raw alu. foil	0.4	4.0	0.19
Gravel	3.0-13.0	50.0	0.81
Total	≈40.0	528.5	

Table 4. Construction layers of the green roof, load, and heat conductivity coefficient

Layer	Layer thickness, d, [cm]	Load, Q, [kgm^{-2}]	Heat conduction, λ, [Wm^{-1}K^{-1}]
Mortar	0.5	8.5	0.85
Reinforced concrete slab	14.0	350.0	2.33
Perlite concrete	5.0-15.0[1]	105.0	0.15
Knaufinsulation homeseal LD35	0.02	/	0.39
Knaufinsulation smart roof thermal	16.0[2]	20.0	0.036
Bitumen waterproofing	0.3	5.0	0.19
Urbanscape root membrane	0.05	0.5	0.19
Urbanscape drainage system	0.05	1.35	0.21
Urbanscape green roll multipurpose growing media	4.0	4.5[3]	2[4]
Urbanscape sedum-mix blanket	4.0	15.0-23.0	2.1
Total	≈54.0	517 .85	

[1] 5-8 cm of perlite concrete for the part of the roof above unheated area .
[2] 8 cm of thermal insulation for the part of the roof above unheated area.
[3] Weight of the saturated roof.
[4] 2.0 W/mK for soil with highest water saturation (0.04 W/mK is the λ value in dry state, but for the purpose of this paper, the worst case scenario has been examined since that is in compliance with current procedures for calculating U value).

The refurbishment of existing roof by implementing green roof solution requires freeing the construction of the excess layers in order to place the new ones. Since perlit concrete is a light material which is used to form slopes and it has thermal properties better than other materials used for this purpose (cement screed), it will not be removed but reused as the base for the new roof. Remaining layers weigh 65 kg/m^2 as shown in the tab. 3. Layers of examined green roof solution, with specified characteristics of importance for this research, are shown in the tab. 4 [4]. Additional roof layers comprised of thermal insulation (in order to fulfill requirements of the new Energy Efficiency Law), waterproofing/root membranes and growing media with sedum blanket would burden the construction with 54.35 kg/m^2 which is less than the load that would be removed from it. Therefore, the new solution would have a positive impact on the static system of the building.

In order to test if the green roof solution offers any advantages to traditional roofing solution which could be applied, a calculation has been made for a control roof which consists of layers presented in tab. 5. In order to meet requirements of the current law regarding thermal properties of the building envelope, some extra load should be put on the existing construction (new roof layers weigh 75 kg/m^2), which can also be seen in tab. 5. It can be concluded that traditional roofing solution would have a negative impact on the static system of the building.

Table 5. Construction layers of the control roof

Layer	Layer thickness, d, [cm]	Load, Q, [kgm^{-2}]	Heat conduction, λ, [Wm^{-1}K^{-1}]
Mortar	0.5	8.5	0.85
Reinforced concrete slab	14.0	350.0	2.33
Perlite concrete	5.0-15.0	105.0	0.15
Knaufinsulation homeseal LD35	0.02	/	0.39
Knaufinsulation smart roof thermal	17.0*	20.0	0.036
Bitumen waterproofing	0.3	5.0	0.15
Gravel	3.0-13.0	50.0	0.81
Total	≈50.0	538.5	

* 8 cm of thermal insulation for the part of the roof above unheated area.

Results and discussion

To calculate the impact of the hypothetical green roof model on the thermal properties and CO_2 emissions, a previously mentioned software package available on Serbian market has been used, since it complies with current law and is commercially available. In addition to structural layers of the building's envelope and heating system data (district heating system which burns fossil fuel, conversion factor 1.8), following climate parameters were used in order to obtain valid data:

– external design temperature for heating: –12.1 °C,
– internal design temperature: 20 °C,
– external average temperature in heating period: 5.6 °C,
– external design temperature for diffusion: 5.6 °C,

- number of heating days: 175 (from mid-October until mid-April),
- number of moisturizing days: 60,
- number of days for drying: 90, and
- temperature difference for heating: 14.4 °C.

By using these parameters, the heat transfer coefficient of the building elements U [Wm^{-2}K^{-1}], energy needed for heating $Q_{h.fin}$ [kWh], quantity of primary energy used in this process $Q_{h.prim}$ [kWh] and therefore the quantity of CO_2 released into the atmosphere on a yearly basis as a consequence of the energy consumption are calculated.

Improving thermal characteristics of the building roof

For the purpose of this research, Type 1 building will be closely examined since it was possible to obtain accurate plans from the Archive. The same methodology applies to Type 2 building, but in that case rough calculations will be used in terms of defining roof area.

Roof area on the examined building can be divided into two segments – part of the roof above heated area (in the following text it will be referred to as the Type A roof, measuring area of 288 m^2) and the other part above the unheated area (Type B roof, measuring area of 23 m^2). The heat transfer coefficient of the building element shows its thermal properties and it has been regulated by the law. The highest admissible value of the heat transfer coefficient of the refurbished flat roof is U_{max} = 0.20 W/m^{2}K for the elements above heated areas, and U_{max} = 0.40 W/m^{2}K for those elements above unheated areas [9]. These values must be taken into account in any new refurbishment undertaking.

The U coefficient for the existing roof has the value of 1.524 W/m^{2}K for the Type A roof, and almost the same for the Type B roof – 1.543 W/m^{2}K. When applying suggested green roof solution for Type A roof, the calculations show that 16 cm of thermal insulation is needed to fulfill the requirements, while only 8 cm of thermal insulation is needed for the Type B roof. For the control roof, obtained data shows that minimum 17 cm of thermal insulation is needed for the Type A roof, while 8 cm is enough for the Type B roof.

However, by looking at the bearing load of the construction, it can be concluded that it is capable to bear as much as 24 cm of the thermal insulation (30 kg/m^2 of thermal insulation, 527.85 kg/m^2 total roof load – see tabs. 3 and 4). Values for U coefficient and energy needed for heating, quantity of primary energy used in this process and the quantity of CO_2 released into the atmosphere on a yearly bases are shown in tab. 6.

Table 6. Calculated values for U, $Q_{h.fin}$, $Q_{h.prim}$, and CO_2 emission for Type 1 building

		Roof type	U [Wm^{-2}K^{-1}]	$Q_{h.fin}$ [kWh]	$Q_{h.prim}$ [kWh]	CO_2 emission, [kg]
Existing roof		Type A	1.524	30578.41	55041.14	18163.58
		Type B	1.543			
Scenario 1	New green roof with 8 cm/16 cm of thermal insulation	Type A	0.198	5434.51	9782.12	3228.10
		Type B	0.355			
Scenario 2	New green roof with 24 cm of thermal insulation	Type A	0.138	4087.56	7357.61	2428.01
		Type B	0.138			

Most of the scientific literature examines the influence of green roof on thermal properties of the roof. Many case studies show that green roof layers such as soil and sedum contribute to overall heat resistance of the roof. However, every research stresses that every green roof manufacturer has a specific soil composed of similar but different components, which influence its thermal conductivity. In order to find out if this specific roof solution offers any additional insulation capacity, a simulation was done for Scenario 3 applying green roof layers on the existing roof slab without additional thermal insulation. As a result, U value of Type A roof is 1.724 W/m^{2}K, and 1.748 W/m^{2}K for Type B roof. Compared to the original roof, thermal performance of Scenario 3 is even worst. This can be explained by high values of heat conductivity coefficient (2.0 W/mK for soil (0.04 W/mK in dry state) and 2.1 W/mK for sedum) [9].

By comparing these findings, it is possible to conclude that refurbishment of existing flat roof of the examined building would have a noticeable impact both in Scenario 1 and 2. Results which are obtained by applying control roof are very similar to those of the Scenario 1 roof, so they will not be presented separately.

Using the traditional roofing solution which complies with current legislation requirements (control roof) is only possible if the construction permits extra 10 kg/m^2 of load. On the other hand, this light type of green roof fits into structural limitation and offers numerous benefits compared to conventional flat roof, as mentioned before. In the first Scenario, by adding layers of green roof and minimal thermal insulation required by the law, it would be possible to save 25143.90 kWh per year, while Scenario 2, green roof layers and maximum thermal insulation allowed by the existing structure capacity, offers 26490.85 kWh in energy savings per year.

The same procedure can be applied on the Type 2 building found on examined locations. Results of the simulation are given in tab. 7.

Table 7. Calculated values for U, $Q_{h.fin}$, $Q_{h.prim}$, and CO_2 emission for Type 2 building

		m^2	U [Wm^{-2}K^{-1}]	$Q_{h.fin}$ [kWh]	$Q_{h.prim}$ [kWh]	CO_2 emission, [kg]
Existing roof		1550	1.524	154531.45	278156.61	91791.68
Scenario 1	New green roof with 16 cm of thermal insulation	1550	0.198	25816.89	46470.40	15335.23
Scenario 2	New green roof with 24 cm of thermal insulation	1550	0.138	20835.96	37504.73	12376.56

As previously mentioned, there are 90 buildings of Type 1 and 42 of Type 2. Total energy savings for blocks 45 and 70 would be 7668.96 MWh for Scenario 1 and 7999.39 MWh for Scenario 2 on an annual level.

Impact of the green roof on the buildings of various height located in blocks 45 and 70

As mentioned in the previous text, there are two types of buildings on the examined location and a several subtypes, which vary in height. Net areas of these building types and subtypes as well as energy savings per square meter of the heated area are shown in the tab. 8.

Impact of the new roof on the overall building energy consumption decreases as the number of floors increases, as shown in fig. 2.

Table 8. Net areas of different building subtypes found on the location and energy savings per square meter of heated area

Type	Subtype	Net heated area [m^2]	Energy savings – Scenario 1 [kWhm^{-2}]	Energy savings – Scenario 2 [kWhm^{-2}]
Type 1	Basement + ground floor + 6 stories + attic	2383.38	54.00	56.09
	Basement + ground floor + 8 stories + attic	2991.06	43.03	44.70
	Basement + ground floor + 10 stories + attic	3598.74	35.77	37.15
	Basement + ground floor + 12 stories + attic	4206.42	30.60	31.78
	Basement + ground floor + 14 stories + attic	4814.10	26.74	27.77
Type 2	Basement + ground floor + 3 stories	4800.00	26.81	27.85

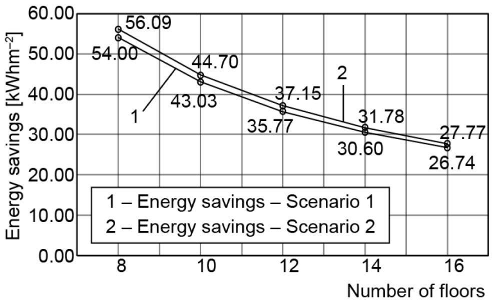

Figure 2. Correlation between number of floors and green roof impact on the building's overall energy consumption

Positive impact of the green roof on the CO_2 emissions and reduction from the surrounding air

Green roof influence on the CO_2 reductions can be direct and indirect. Two-year study conducted with the aim to determine the effect of extensive green roofs on the CO_2 reduction from the surrounding air resulted in conclusion that an extensive green roof absorbs and retains 189 g of CO_2 per m^2 per year [10].

Apart from the direct CO_2 reduction, they also have an indirect positive influence on building's envelope, which results in less energy spent and less CO_2 released in the atmosphere. District heating system, which burns fossil fuel, is used for heating the examined building. In tabs. 5 and 6, final energy, $Q_{\text{h.fin}}$, has been transformed into primary energy, $Q_{\text{h.prim}}$, and trough conversion CO_2 emissions have been quantified. In Scenario 1, CO_2 emission has been lowered from 18163.58 kg to 3228.10 kg on an annual level, and Scenario 2 shows CO_2 emission reduced to 2428.01 kg on an annual level for the Type 1 building, tab. 5. Total savings as well as savings per m^2 are presented in tab. 9. The CO_2 savings per m^2 are also applicable to Type 2 buildings.

It is also important to have in mind that a certain amount of CO_2 is being released into the air in the process of producing green roof and transportation of its elements from the factory to the construction site. Research shows that around 6.5 kg of CO_2 is released into the atmosphere for every m^2 of produced green roof [11]. Chosen green roof solution, without additional thermal insulation, would need around 35 years to neutralize its own polluting effect by absorbing and retaining 189 g CO_2 per year from the surrounding air. Even though this can look as a long period of time, it is necessary to keep in mind that most of human activities result in air pollution without any positive effect on the atmosphere. As green roof's life span is estimated to be between 40 and 55 years [9], it will keep filtering the air for minimum of 5 years after neutralizing its own polluting effect while providing its users with numerous additional benefits. However, by looking at CO_2 saving results for Scenarios 1 and 2 (tab. 9), it is clear that damaging effect of green roof production could be neutralized in the first 7 months or less.

Table 9. The CO_2 savings for building Types 1 and 2 in both scenarios

		Building type	Roof area [m^2]	Total CO_2 emission [kg]	CO_2 savings [kg]	CO_2 savings per m^2 roof [kgm^{-2}]
Scenario 1	New green roof with 8 cm/ /16 cm of thermal insulation	Type 1	311	3228.10	14935.48	48.02*
Scenario 2	New green roof with 24 cm of thermal insulation	Type 1	311	2428.01	15735.57	50.60

* Same CO_2 savings per m^2 are characteristic for the Type 2 buildings

Large scale projects such as refurbishing roofs in city blocks 45 and 70 by using roof layers defined in two examined scenarios would have a sizable effect on the CO_2 reduction, air quality and temperature. The total calculated area of 90990 m^2 under extensive green roofs could neutralize from 4369.34-4679.61 tonne of CO_2 on an annual level. Since CO_2 is notorious GHG, increased sequestration and reduced heating and cooling load due to these roofs would decrease the city's contribution to global warming.

Conclusions

The purpose of this research was to investigate the potential to positively influence energy consumption for heating buildings and CO_2 emissions trough refurbishment of the existing flat roof by using green roof. The energy needed for heating the buildings on an annual level has been taken into account since this parameter is the only one recognized by the current legislation as the relevant one for determining thermal properties of the building's envelope. New Belgrade, as a part of the city which is characteristic for its large number of same or similar buildings, was chosen for this research. Blocks 45 and 70 are the best example of the post war ideology which promoted fast building process trough multiplying same buildings over a vast free space. For this reason it is possible to examine influence of a new roof solution on one building but to multiply the results on other, same or similar, buildings since they share unified characteristics. Two types of buildings can be found in examined blocks and a representative building for each type was examined trough two possible scenarios. An additional scenario was introduced – control roof, which was used for comparing benefits of the proposed green roof systems to a traditional solution most commonly used in Serbia. As a result of this process, following conclusions were made:

- Roofs of chosen buildings fulfill all criteria concerning green roof installation. Special attention was paid to bearing load of the existing construction and it has been calculated that the new roof could have the same or better influence on the building's static system.
- Based on the bearing capacity of the building, it was established that it is possible to apply sufficient thermal insulation demanded by the current law (Scenario 1 – 8 cm/16 cm

of thermal insulation). Apart from that, it is possible to apply additional thermal insulation due to the low weight of the green roof layers (Scenario 2 – 24 cm of thermal insulation).

- It has been shown that a traditional roof solution would have negative impact on the static system of the building in order to fulfill the required parameters regarding thermal properties of the new roof.
- By using a software solution which is in accordance with the current law, it was calculated that proposed roof solution in Scenario 1 is able to save 7668.96 MWh per year for all 132 buildings on site, and 7999.39 MWh for Scenario 2. Thermal capacity of the control roof corresponds to those of the Scenario 1.
- Applying green roof layers on the existing concrete slab, without additional insulation (Scenario 3) proved to have even worst heat transfer coefficient than the original roof.
- It has been shown that for Type 1 buildings new roof solution has a higher effect on the overall building in the subtype with fewest floors. An increase in building height increases net heated area while the area of the roof remains the same, thus having a smaller influence on energy savings measured by m^2 of the building heated area.
- Proposed roof solutions have both direct and indirect influence on the CO_2 emission reduction. The total calculated area of 90990 m^2 under extensive green roofs could neutralize from 4369.34 t to 4679.61 t of CO_2 on an annual level.

Even though it has been proven that extensive green roof type chosen for this research has no positive impact on roof's thermal properties itself (without additional thermal insulation), it can be concluded that it presents a god solution for future refurbishment projects since it allows for enough thermal insulation to be added in order to fulfill the requirements of the current law. While the traditional solution had a negative impact on the static system of the building, it also had no capacity to directly influence CO_2 reductions from the surrounding air. Furthermore, the traditional roof displays poor properties when it comes to storm water retention, and it contributes to creating the urban heat island effect. Green roofs have proven to be suitable solution for climate conditions characteristic for Serbia (extremely warm summers and heavy precipitation periods) and they offer numerous additional ecological and psychological benefits. Since green roof systems are a more costly option than the traditional roof system, it is necessary to conduct a life cycle cost analysis to determine if this solution would be appropriate one for chosen buildings.

The future legislation should take some more parameters into account when it comes to calculating thermal properties of buildings' envelope and more precise tools for calculating these properties should be developed. Next phase of this research will examine the green roof influence on energy used for cooling buildings throughout the year and its impact on the lowering heat island effect, which has been a great problem for urban surroundings in Serbia in the past decade.

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