UTICAJ ZELENOG KROVA NA KVALITET GRADSKOG VAZDUHA

THE IMPACT OF GREEN-ROOF ON URBAN AIR QUALITY

Žana STEVANOVIĆ[*], Danka KOSTADINOVIĆ, Marina JOVANOVIĆ, Vukman BAKIĆ, Nenad STEPANIĆ

Institut za nuklearne nauke „Vinča“, Nacionalni institut Republike Srbije, Univerzitet u Beogradu

Značaj kvaliteta vazduha direktno utiče na kvalitet života ljudi i vegetacije u urbanoj sredini, a primena zelenih krovova urbanih područja poslednjih godina postaje sve važnija u borbi protiv efekta staklene bašte. Da bi se definisali odgovarajući kapaciteti uticaja na mehanizam zelenog krova i pružila metodološka objašnjenja za postavljanje zelenog krova, potrebno je pridržavati se širokog okvira propisa o kvalitetu vazduha Republike Srbije koji su integrisali evropsku Direktivu 2008-50-EC. Poboljšanje metodologije održivog postavljanja zelenog krova zasnovano je na analizi intenziteta vektora disipacije koncentracije zagađivača u kritičnoj zoni emisije zagađujućih materija i u zoni postavljanja zelenog krova. Kriterijumi za izbor podataka zasnovani su na stacionarnim uslovima emisije koncentracije eksperimentalno izmerenih emisija CO, CO_2, NO_2 gasova. Pridržavajući se standardne matrice zagađenja, eksperimentalno poređenje podataka zasnovano je na analizi intenziteta dva vektora disipacije koncentracije zagađivača. Analiza prvog vektora zagađenja odnosi se na kontrolnu tačku SEPA Novi Beograd - Mostar, koja je postavljena kao kontrolna tačka u merenju zagađujućih materija. Analiza drugog intenziteta disipacionog vektora koncentracije zagađivača je merno mesto postavljeno iznad zelenog krova na školskoj zgradi u najgušće naseljenom urbanom području. U odnosu na vrstu zagađujućih materija prema Direktivi 2008-50-EC, Annex I A, definisan je vremenski kriterijum za period kontinuiranog uzorkovanja emisija CO, CO_2, NO_2, i kvalitet podataka uzetih u analizi. U analizama su uočene razlike u emisijama dva vektora u formi ΔCO, ΔCO_2, ΔNO_2, koje su direktne posledica delovanja zelenog krova kao pasivnog filtera za ovu vrstu izvora zagađenja. Dobijeni rezultati mogu se integrisati u strategiju šire primene zelenog krova, a kao jedna od dodatnih mera u cilju smanjenja i kontrole emisija gasova staklene bašte bilo bi i definisanje zelenog pasoša u okviru dokumentacije energetskog pasoša objekta.

Ključne reči: *zeleni krov; kvalitet ambijentalnog vazduha; zagađenje vazduha; urbana područja; Direktiva i politika EU*

The importance of air quality directly affects the quality of life of people and vegetation in the urban environment, and the application of green-roofs of urban areas in recent years has become increasingly important to the fight against the greenhouse effect. In order to define adequate capacities of the impact on the green-roof mechanism and provide methodological explanations for the installation of the green-roof, it is necessary to adhere to the broad framework of air quality regulations of the Republic of Serbia that integrated the European Directive 2008-50-EC. The improvement in methodology of sustainable green-roof installation is based on the analysis of the intensity of the pollutant concentration dissipation vector in the critical zone of pollutant emission and in the green-roof installation zone of interest. The data selection criteria are based on stationary emission conditions for the concentration of experimentally measured emissions of CO, CO_2, NO_2 gases. Adhering to the standard pollution matrix, the experimental comparison of the data is based on the analysis of the intensity of the two vectors of dissipation of the pollutant concentration. The analysis of the first vector of pollution refers to the SEPA control point New Belgrade - Mostar, which was set as a control point in measuring pollutants. The analysis of the second intensity of the dissipation vector of the pollutant concentration is a measuring point placed above the green-roof on the school building in the most density populated urban area. In relation to the type of pollutants according to the directive 2008-50-EC, Annex I A, where the criterion for the condition of time stationery is defined for the

[*] Corresponding author’s e-mail: zana_stevanovic@yahoo.com

period continuous sampling of CO, CO_2, NO_2 emissions, analyzes of concentration pollutants intensity was performed. In the analyzes, differences in emissions from ΔCO, ΔCO_2, ΔNO_2 were observed, which are direct consequences of the action of the green-roof as a filter for this type of pollution source. The obtained results can be integrated into the strategy of wider application of the green-roof as one of the measures in the development of the green passport as an additional measure in order to reduce and control GHG emissions.

Key words: *green-roof; ambient air quality; air pollution; urban areas; EU Directive and policy*

1 INTRODUCTION

The modern climate change and average global temperatures in the 20th century are higher than ever before in at least 1,300 years and the speed of global warming has never been as high as it is today. Man-made sources of greenhouse gases come mainly from the burning of various fossil fuels for power generation and transport use. The combustion products as carbon dioxide, methane, nitrous oxide, ozone, and various chlorofluorocarbons are human-emitted heat-trapping gases. Among these, carbon dioxide is of greatest concern to overall warming influence than the other gases combined. Humans emissions and activities have caused around 100% of the warming observed since 1950, according to the Intergovernmental Panel on Climate Change's (IPCC).

In recent years, green-roofs have played a significant role in sustainable construction as they can reduce the energy required to heat and cool buildings, absorb and store large amounts of heat and thus reduce temperature fluctuations. During the winter, such insulating effects mean less heat release from the building, which reduces the energy need for heating. In the summer, the vegetation of green-roofs reduces the temperature of the roof and the surrounding air and thus reduces the energy needs for cooling. In addition, they have the influence of mitigating the effect of a heat island in urban areas because, due to evapotranspiration, locally, above the area where the green-roof is placed, the air temperature decreases; then on efficient atmospheric water management, noise reduction, etc.[1,2].The green-roof is a type of roof that can be commonly used to reduce air pollution in a city. By helping to mitigate the urban heat island effect, green spaces and urban vegetation can improve the quality of the air. Their large surface area and low surface roughness make them natural sink or dehydrators for pollutants, so they help solve air pollution by reducing the effects on airborne pollutant concentrations [3,4].

The literature studying the impact of green-roofs on reducing air pollutant emissions agrees that green-roofs have a positive impact on reducing pollution [1,5]. The study of green-roofs in city Toronto, which was published in 2005, converting the city's roofs to green could help minimize air pollutants by around 58 metric tons, reducing air pollutants by almost 7 tons per year [6]. The air pollution removal from green-roofs in Chicago was estimated as an approximation [7,8]. This study approach shows the concentration of air pollutants in a form of a dissipation vector, which is defined by the intensity and time needed to move in stationary conditions. According to [3] decrease in ambient CO_2 concentration near urban green-roofs is significant. Data collected during a sunny day revealed that the concentration of CO_2 over the green-roof was 4.3 mg/m3 lower than that of the control roof and the author then measured the CO_2 concentration distribution around the green-roof using a chamber to construct an absorption/emission velocity curve [3]. Simulations revealed that the concentration of CO_2 around the green-roof fell noticeably when the wind was blowing. The wind speed reduced the concentration by around 9%. [1,9]. The results of the paper [9] present energy savings and ecological benefits of green-roofs in hot summer and cold winter areas in Wuxi, China. Experimental research and numerical simulation analysis show that a green stonecrop roof can absorb 1.79 kg of CO2 and release 1.3 kg of O2 per square meter per year. In addition, the annual carbon emission reduction per unit area of the green-roof in Wuxi was 9.35 kg m–2, and the emission reduction benefit of the green-roof was calculated to be USD $1.02 m–2 a–1.

This paper deals with lightweight green-roofs which installed on the school building roof in order to investigate their influence on energy saving and reducing air pollutants. The criterion for the condition of time stationery is defined for the period continuous sampling of CO, CO2, NO2 emissions, analyzes of concentration dissipation pollution intensity was performed by according to the directive 2008-50-EC, Annex I A [10,11,12].

However, most studies reported to influence green-roofs on decrease energy consumption in buildings and its effectiveness on air quality is not yet clear due to the limited number of studies on it.

Even with their high initial cost, green-roofs can be considered an attractive option for air pollution control and numerous studies have shown their long-term benefits.

2 SCOPE OF MEASURMENT

The data used for the field measurement analysis are evaluated in two parts. The first part is emission data analysis, which is used for determining the risks of air pollution. The second part of the absorption measurements data analysis is carried out on the roof of the school building located in the most densely populated urban area in the country, New Belgrade. Emissions data are observed in city Belgrade for air pollutants CO and NO_2 available from two SEPA field measurements stations. Unfortunately, the data CO2 measurements were not available due to the sensors not being installed on SEPA measurement site. CO2, CO and NO_2 sensors monitor emission field data are located above a green-roof on a school building in New Belgrade[10,11,12].

SEPA stations for automatic air quality monitoring that are used in data analysis are: Beograd_Novi Beograd RS1023A” (20° 24' 0" N,44° 48' 11" E, 74m) and Beograd_Mostar RS1025A” (20° 27' 0" N, 44° 47' 55" E, 83m). These two stations are located in an urban area with canyon sections. The altitude between them is 9 meters. The measuring station for monitor air quality above the green-roof over the reference building area in New Belgrade is placed near a busy intersection in the most highly urbanized area, and close to SEPA monitoring station[10,11,13].

The data collected during the analysis period covered 61 stationary environmental periods from September to October 2019. These include 39 periods over the day and 22 periods over the night.

Duration of one stationary environmental period is in the scope of 8 hours and it is defined by time stationary criteria by directive 2008-50-EC, Annex I A [11]. Furthermore, what is defined in directive 2008-50-EC, Annex I A is a data quality crieteria for gases CO, NO2, CO2, that is minimum period of 50% of one stationary environmental period in the scope of 8 hours. So minimum crieteria for quality measurements is minimum 4 hours of one stationary environmental period. Data quality measurements of the scope of 8 hour vector intensities of pollution V1 are in the based on directive crieteria, Figure 1 and 2. Figure 1 is a histogram of stationary periods daily data records for septembar and octobar 2019 wich includes 28 number of stationary periods for interval (4,6) hours, 7 number of stationary periods for interval for interval (6,8) hours, 3 number of stationary periods for interval for interval (8,10) hours and 1 number of stationary periods for interval for interval (10,12) hours.

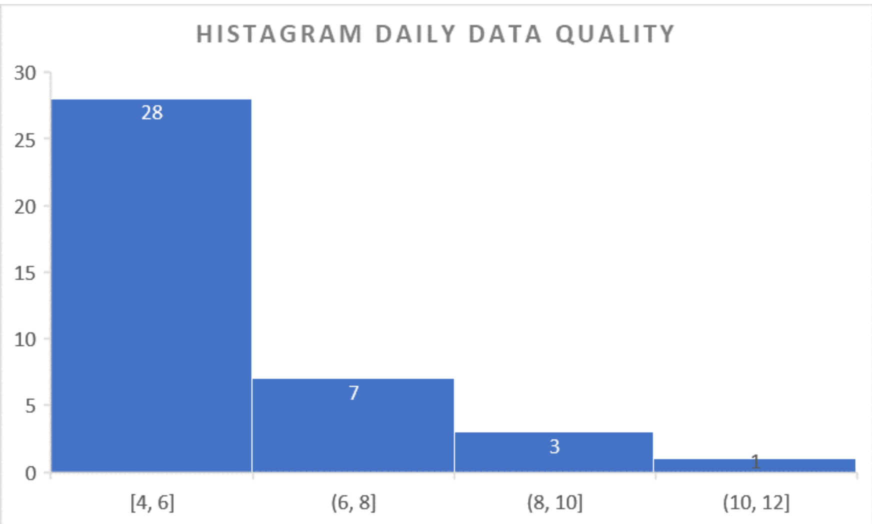

Figure1. Histagram daily stationary environmental data quality[12].

Figure 2 is a histogram of stationary periods data during the night records for septembar and octobar 2019 wich includes 15 number of stationary periods for interval (4,7) hours and 7 number of stationary periods for interval for interval (7,10) hours.

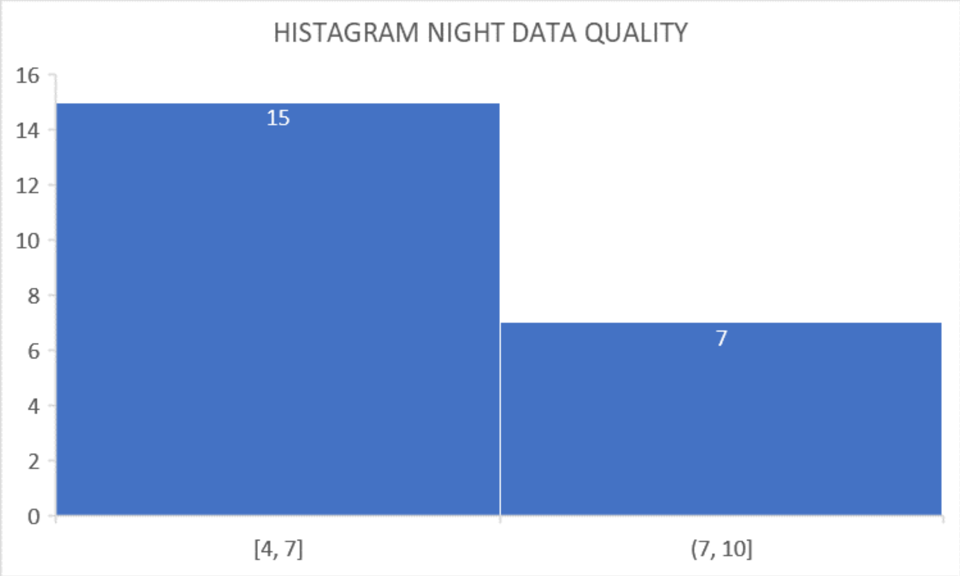

Figure2. Histagram night stationary environmental data quality[12].

There were 388 hours of recorded environmental stationary conditions in this database. It has 32 stationary periods, of which 86 hours are in the night period and 100 hours are in the day period during September 2019. For the period October 2019 in the day and night record, analyzed 29 stationary records of which 55 hours in the night period, 147 hours in the day period.

The first vector intensity of pollutants V1 is measured at the Beograd_Novi Beograd and Beograd_Mostar control points and represents CO and NO2 under stationary conditions. The pollution concentration V2 is obtained by measuring the concentration of pollutants on the green-roof of a school building. The second vector V2 above the green-roof can be treated as an absorption vector.

The analysis of the two vectors was carried out according to the Directive 2008-10-EC, which established the criterion for the time stationary condition of measuring CO, NO2, and CO2. The study revealed that the green-roof's filter effect (ΔCO, ΔCO2, ΔNO2) has a direct effect on the pollutants that enter the atmosphere. In addition, the temperature difference between the green-roof and the surrounding area was also observed [11].

3 RESULTS

The data analysis of the vector intensity of pollutants V1 for stationary conditions at the meteorological stations of Beograd_Novi Beograd and Beograd_Mostar was carried out. Under certain conditions, such as wind velocity of up to 1m per second and air temperature of 25°C, the steady flow was considered [14]. The time duration for a stationary period for measuring CO, NO_2 concentrations is eight hours. The calculation the vector intensity of pollutants of CO and NO_2 was performed in accordance with the conditions of the Directive 2008-50-EC, Annex I A. Stationary vectors was analyzed to obtain a environment stationary period of two month. The goal was to obtain a time sequence that could be compared with those of green-roof. In the observed period from September to October 2019, the minimum, maximum and average values of vector intensity V1 of pollutants CO and NO2 are shown in Tables 1 and 2.

The data analysis is performed regarding representative sequences of green-roof's filter effect for ΔCO, over the day, by taking into consideration the vector intensity of pollutant V1 for stationary conditions at the meteorological station of Beograd_Novi Beograd and Beograd_Mostar, and absorption vector V2. It was presented in figure 3 and table 3.

Table 1. The values of vector intensity V1 of pollutant CO (09-10/2019)

CO [mg.m-3]min (09-10/2019)	CO [mg.m-3]max (09-10/2019)	CO [mg.m-3]avg (09-10/2019)
0.359	0.569	0.453

Table 2. The values of vector intensity V1 of pollutant NO2 (09-10/2019)

NO2 [ug.m-3]min (09-10/2019)	NO2 [ug.m-3]max (09-10/2019)	NO2 [ug.m-3]avg (09-10/2019)
19.709	46.057	31.222

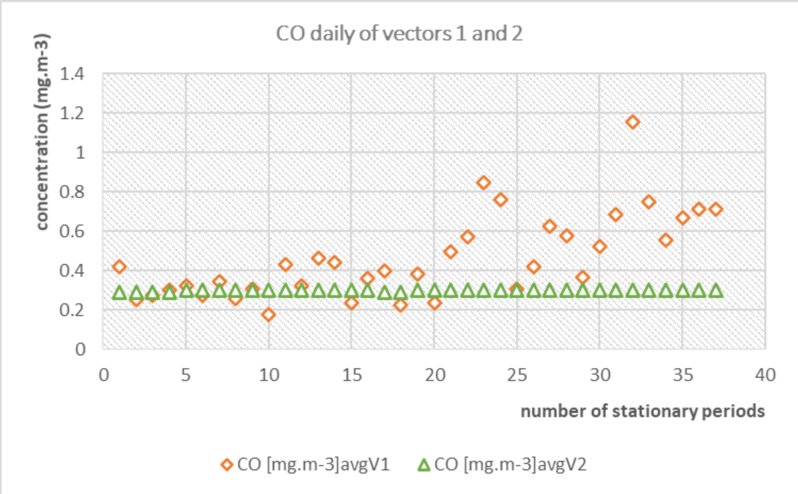

Figure 3. Representative sequences of CO in daily data recording mod of vectors 1 and 2 at stationary conditions for the period September - October 2019

Table 3. Percentage of green-roof efficiency as filter regarding CO in daily data recording mod

CO avg V1	CO avg V2	ΔCO daily	ΔCO daily
[mg.m-3]	[mg.m-3]	[mg.m-3]	%
0.465	0.299	0.166391494	35.78002672

The data analysis was performed in a form of time representative stationary environment sequences green-roof's filter effect for ΔCO, over a night, regarding vector intensity of pollutant V1 for stationary conditions at the meteorological station of Beograd_Novi Beograd and Beograd_Mostar, and absorption vector 2 was presented at figure 4 and table 4.

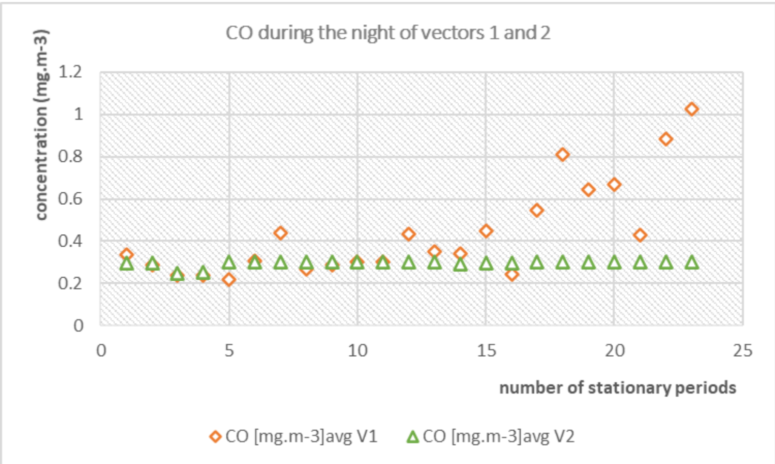

Figure 4. Representative sequences of CO in night data recording mod of vectors 1and 2 in stationary conditions for the period September - October 2019

Table 4. Percentage of green-roof efficiency as a filter in a night period regarding CO

CO avg V1	CO avg V2	ΔCO night ł	ΔCO night
[mg.m-3]	[mg.m-3]	[mg.m-3]	%
0.437	0.295	0.142	32.523

The data analysis performed regard to of time representative stationary environmment sequences for green-roof's filter effect for ΔNO2, over the day,-by taking into consideration vector intensity of pollutant V1 for stationary conditions at the meteorological station Beograd_Novi Beograd and Beograd_Mostar, and absorption vector 2 was presented at figure 5 and table 5.

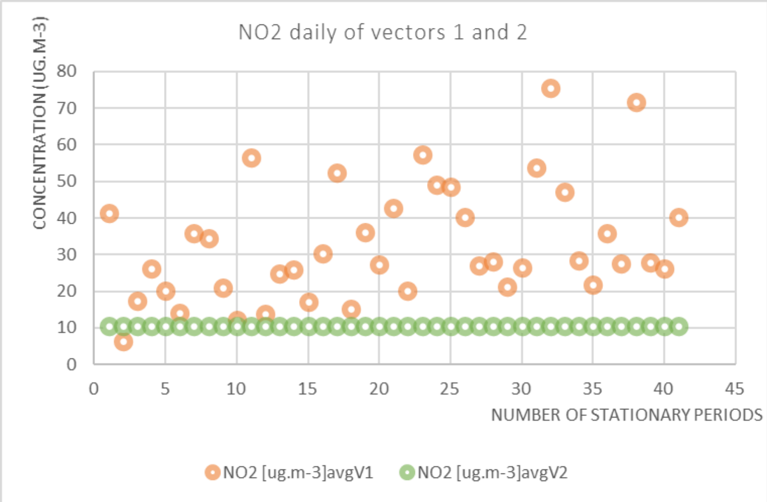

Figure 5. Representative sequences of NO2 in daily data recording mod of vectors 1and 2 in stationary conditions for the period September - October 2019

The data analysis performed in a form of representative time sequences for stationary environment periods green-roof's filter effect for NO2, over a night, regarding vector intensity of pollutant V1 for stationary conditions at the meteorological station of Beograd_Novi Beograd and Beograd_Mostar, and absorption vector 2 was presented at figure 6 and table 6.

Table 5. Percentage of green-roof efficiency as filter regarding to NO2 in daily data recording mod

NO2 avg V1	NO2 avg V2	Δ NO2 daily	Δ NO2 daily
[ug.m-3]	[ug.m-3]	[ug.m-3]	%
32.845	10.5	22.4	68.156

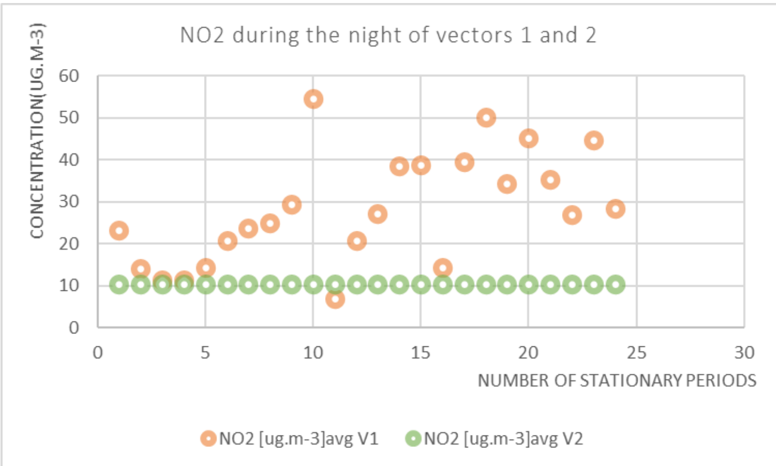

Figure 6. Representative sequences of NO2 in night data recording mode of vectors 1and 2 in stationary conditions for the period September - October 2019

Table 6. Percentage of green-roof efficiency as filter in a night period regarding to NO2

NO2 avg V1	NO2 avg V2	Δ NO2 night	Δ NO2 night
[ug.m-3]	[ug.m-3]	[ug.m-3]	%
28.328	10.5	17.9	63.1

The emission of CO2 is measured simultaneously on the green-roof and reference roof of school building. The results of average values of CO2 and air velocity for Septembre-October 2019 are placed in Table 7. It was shown that the above green-roof CO2 concentration was lower 1.59% and 9.08% than an above conventional roof in September and October, respectively.

Table 7. Percentage of green-roof efficiency as a filter, in September – October 2019 regarding CO2

SEPTEMBER 2019	CO2 avg. ppm	Wavg. (m/s)
Green-roof	845.30	0.33
Reference roof	859	0.11
difference	13.7	
difference (%)	1.59	
OCTOBER 2019		
(m/s)		
Green-roof	841.89	0.20
Reference roof	926	0.03
difference	84.11	
difference (%)	9.08	

3.1 DISCUSSION

The results of the paper show that the removal of air pollutants from green-roofs settled on the school building depended on different factors such as the weather conditions and the concentrations of pollutants. In the estimation of these various factors, an approach was made for a steady atmosphere for having stationary emission contrast repeated during September and October.

Based on the results presented in the paper, on the diagrams, a higher concentration of all considered pollutants of vector V1 is observed in October compared to September. This increase is a result of the beginning of the heating season. The intensity of absorption vector V2 was shown minor changes, particulate in September during day and night when the plants were fully grown. The measurement result for CO2 from sensors above reference and green-roofs show absorption effect of green-roof and possibility use the green-roof as a passive filter. For the green-roof, filter effects are 35.78% for the daily period and 32.52% for the night period for CO and, 68.16% for the daily period, and 63.1% for the night period for NO2 in a stationary condition. The average wind velocity above the green-roof was higher than the reference roof and it can be a reason to decrease od CO2 concentration above the green-roof. For this reason, it is necessary to provide additional continuous experimental campaigns.

4 CONCLUSION

Air pollution in urban areas is a major public health issue. There are various ways to reduce it, such as using green-roofs. The model was used to quantify the air pollutants that were removed by the green-roofs in Belgrade. The green-roof can be used as a stand alone measure to reduce air pollution. Its environmental benefits are numerous. Converting Belgrade’s roofs to green would remove a large amount of air pollutants. However, this method would require a high cost and lengthy construction. In addition, the cost of implementing green-roofs is very high. Even with their high cost, green-roofs are still considered an excellent alternative to trees for air pollution control. Numerous studies have shown that these roofs can provide long-term environmental benefits. Green-roofs can help reduce air pollutants and provide better ventilation. They can also be built with plant species that can tolerate high levels of VOC. The construction and maintenance of a green-roof should be standardized to lower its cost.

This paper analyzes the level of air pollution removal during day and night periods after the installation of a lightweight green-roof on a school building in an urban area. Further studies are needed to analyze many aspects regarding green-roofs effectiveness in improving air quality.

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