INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

No IV/2/2017, POLISH ACADEMY OF SCIENCES, Cracow Branch, pp. 1649–1658
Commission of Technical Rural Infrastructure

DOI: http://dx.medra.org/10.14597/infraeco.2017.4.2.124

WATER RETENTION ON THE EXTENSIVE GREEN ROOF MODELS

Anna Baryła[1], Agnieszka Karczmarczyk[1], Michał Wróbel[2], Paweł Kożuchowski[3]
[1]Warsaw University of Life Sciences –SGGW, Faculty of Civil and Environmental Engineering,
[2]Forest Research Institute,
[3]Green Roofs Laboratory

Abstract

One of the main problems of urbanization is the continuous growth of sealed surfaces. Impermeable surfaces i.e. roofs, roads or pavements have dominated land cover, increasing surface runoff and limiting groundwater runoff, often contributing to increased flood risk. The practice of many countries has shown that green roofs are one of the solutions to the problem of rainwaters on the urban areas. The aim of the study was to assess the retention ability of three green roofs of extensive type with different substrate composition (two mineral-organic mixtures, one mineral mixture). The research was carried out at the Water Centre of the Warsaw University of Life Sciences in Warsaw (Ursynów district) in the period from June to November in 2016. The obtained results were compared with observation of the reference model – bituminous roof. Model studies have shown that green roofs retained water in the range from 9.5 mm to 67.1 mm. The average runoff coefficients for green roof types in the period from June to November in 2016 were from 0.31 to 0.33. The obtained results showed slight differences in outflows with different substrates. During high rainfall, the differences in the runoff between the green roofs and the reference roof were negligible.

Keywords: green roof, water retention, runoff delay

INTRODUCTION

Green roofs are one of the measures of rainwater management in urbanized areas. By the roofs surface planning, green roofs store water during rainfalls, delay the runoff after peak precipitation, and evaporate part of the precipitation into the atmosphere (Liesecke 1999, Kohler and Schmidt 1999, Mentens *et al.* 2005, Pęczkowski *et al.* 2016). It is estimated that green roofs absorb, filter, maintain and store on average about 75% of the annual precipitation that reaches them. This applies to most areas in the United States (FEMP 2006). The amount of water depends on the construction layers, such as the thickness of the substrate, plant composition and plant species, and meteorological conditions: intensity and duration of rainfall (Getter and Rowe 2006, Baryla *et al*., 2014, Burszta-Adamiak 2014). From the hydrological point of the urban catchment green roofs, in addition to rainfall retention, also delay the runoff. Researches carried out by a number of authors (e.g. Ni 2006, Carpenter and Kaluvakolanu 2011, Fassman-Beck *et al*. 2013) show that green roof runoff may be delayed several hours from the start of precipitation. Air temperature, intervals between precipitation, duration of the precipitation and its intensity (Burszta-Adamiak 2014) probably influence time of retention of the rainwater and delayed delivery. Because green roofs retain rainwater, they can mitigate the effects of impermeable surface runoff. The aim of the study was to assess the retention ability of three extensive green roofs with different substrate composition (two mineral-organic mixtures, one mineral mixture).

RESEARCH MATERIAL AND METHODOLOGY

The research was conducted in the period June-November 2016 at the Water Centre of Warsaw University of Life Sciences in Warsaw. Models of extensive green roofs were constructed in three cuvettes, one was developed as a reference unit. Each cuvette was drained using an 8 cm diameter drain pipe. All cuvettes have an internal dimension of 2m/1m/0.2m (length/width/depth) and are inclined at an angle of 2%, their internal volume is 0.4 m^3 (Figure 1). Three types of substrates were used in the green roofs constructions that were implemented in accordance with the DAFA guidelines (2015). The characteristics of the green roofs (ZD 1-3) and reference (RD) model are shown in Table 1.

Rainfall measurements were carried out using a Hellmann rain gauge, placed next to the measuring stations. Outflows in the months June-October were measured by volumetric method after each rainfall. Since the beginning of November, Odyssey appliances were installed and the outflows were recorded at 10 minute intervals. Measurement vessels were calibrated at the Water Centre of Warsaw University of Life Sciences. On the basis of the obtained results of the runoff from the green roofs and the reference roof models, the flow coefficients and the amount of retained water were calculated.

(source: own photo)

Figure 1. Set up of the experiment

Table 1. Characteristics of test models

Designation Abbreviated name	ZD 1	ZD 2	ZD 3	RD
Extensive vegetation	Pre-cultivated vegetation mat XF317 moss-sedum-herbs; thickness of 2.5 cm			
Vegetation layer – an extensive substrate with a thickness of 15 cm.	SPG E-E – mixture of washed sand, gravel, limestone, crushed red brick, ~~broken fine lime~~, peat and compost;	SPG E-M – type 1 mixture of washed sand, gravel, limestone, crushed red brick;	SPG E-M – type 2 mixture of washed sand, gravel, limestone grit, crushed brick, peat;	None
Filter layer	Polyfelt TS 20 polypropylene geotextile with a GRK 2 strength class, weight 125 g/m^2;			
Drainage layer	Terrafond Garden drainage mat 20L, height 2 cm;			
Protective layer	Polyfelt TS 20 polypropylene geotextile with a GRK 2 strength class, weight 110 g/m^2;			
Water insulation	Heat-sealable bitumen sheeting root resistant in accordance with PN-EN ISO 13948;			
Underlay	OSB boards with thickness 16 mm with slots not exceeding 5 mm.			

Source: Kożuchowski. (2016)

As a result of the analysis the precipitation events that occurred during the study in 2016, it can be stated that especially in September and October the precipitation significantly differed from the multi-annual average of 1960-2009

(Majewski *et al*. 2008). October was the month with the highest total precipitation, the monthly sum was 152.2 mm and the highest daily precipitation reached 32.8 mm on 24 October 2016. The lowest total precipitation occurred in September, the monthly sum was 9.6 mm. According to Kaczorowska criterion (1962) months like June, August and November were classified as the average months, July as wet, October very wet and September was extremely dry.

Table 2. Monthly totals of precipitation in 2016 and in the multi-annual period 1960-2009 at the Ursynów station –Warsaw University of Life Sciences [mm]

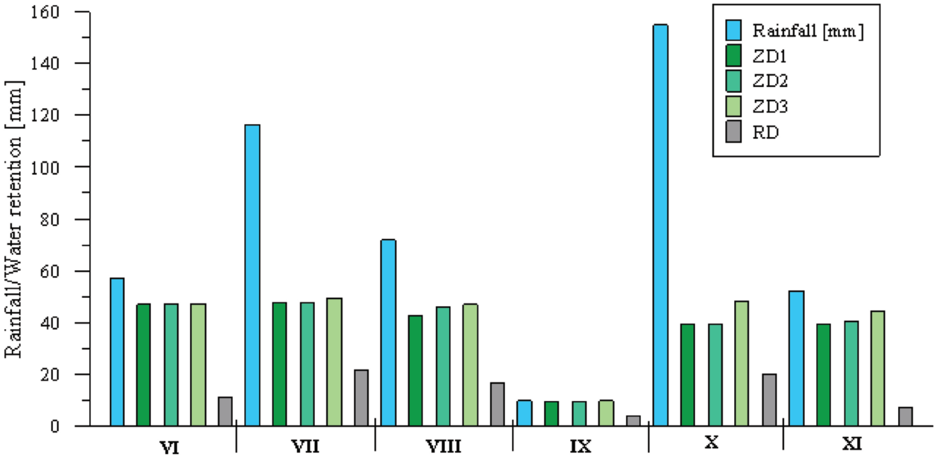
Years	VI	VII	VIII	IX	X	XI
1960-2009 (Majewski *et.al*. 2008)	66.4	75.3	63.7	46.4	37.9	41.2
2016	56.9	116.5	71.7	9.6	152.2	52.2

Source: own elaboration according to data of rainfall gauge Ursynów station –Warsaw University of Life Sciences.

RESULTS AND DISCUSSION

Based on the results of measurements at the test sites, it was found that the average water retention on green roof models ranged from 25% to 100% and on conventional roof from 13% to 38%. The largest retention at the level of almost 100% was obtained in September (the extremely dry month), when the monthly precipitation was less than 10 mm (Figure 2). Simmons *et al*. (2008) obtained similar results for Texas conditions, where rainfall up to 10 mm was retained in 100%. In the climatic conditions of Wroclaw, Pęczkowski *et al*. (2016) showed that the retention of the clay-based profile was 67-96.8%, while perlite-based of 71-98%. They obtained 98% retention for rainfall of 24.1 mm and 61.6 mm. Research by Lee *et al*. (2013) showed that the outflow was insignificant at precipitation of less than 30 mm and when rainfall intensity did not exceed $20 mm \cdot h^{-1}$. Carter and Rasmussen (2006) obtained retention for precipitation of less than 25.4 mm at 88%. Studies results for average years by Roehr and Kong (2010) shown that green roof profiles of 150 mm thickness reduce the annual outflow from 29 to 100% depending on rainfall intensity.

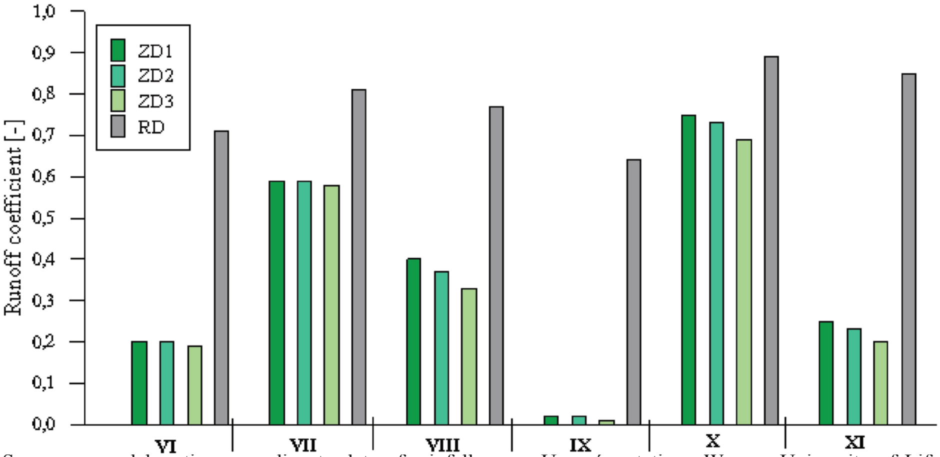
The flow factor is associated with the efficiency of retention of rain water (Burszta-Adamiak 2014). This parameter is important when designing the capacity of retention devices for the management of green roof runoff (Hilten *et al*. 2008). The DAFA guidelines (2015) include the dependency of water flow coefficients on the thickness of the green roof layers and the slope of the roof. According to DAFA (2015) the runoff coefficient is assumed to be 0.3 from a roof with a slope of up to 5% and a thickness of the layers of up to 25 cm. The study showed that the average trajectory coefficient on extensive roof models was 0.31 to 0.33 (Figure 3). Research carried out by Uhl and Schiedt (2008) on green roofs in Hannover showed that the runoff coefficient for extensive green roofs was 0.16-0.31 in the summer period and 0.27-0.51 in the autumn. For the conditions in Warszawa-Ursynów the study's results showed that the runoff coefficient for the reference roof was between 0.70-0.95. The study conducted by Burszta-Adamiak (2014) in Wroclaw indicated that in case of the reference model, the average runoff coefficients were between 0.66 and 0.71 in summer and 0.57 to 0.76 in autumn.



Source: own elaboration according to data of rainfall gauge Ursynów station –Warsaw University of Life Sciences.

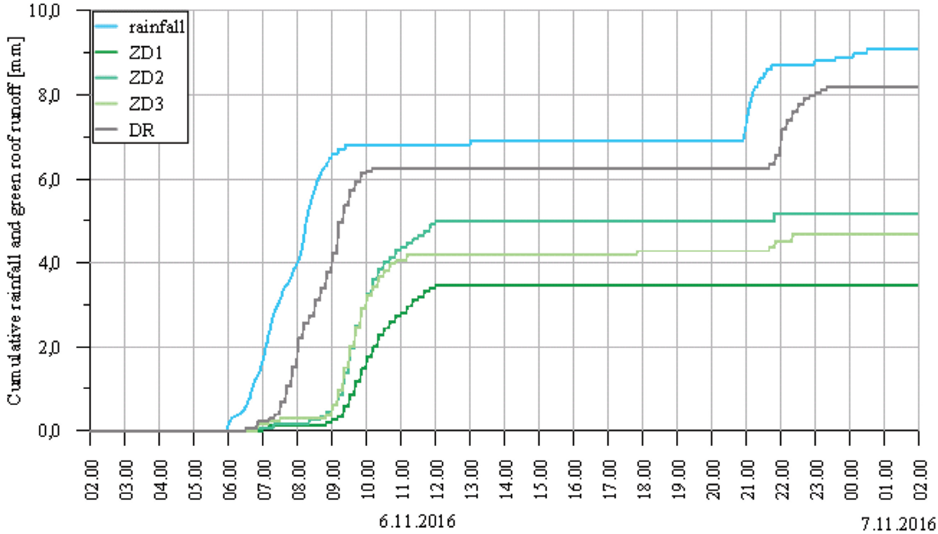
Figure 2. Average retention on green roof models against monthly precipitation in 2016

The cumulative volume of rainfall and runoff from the green roofs and the reference roof model is shown in Figure 4. The total outflow from the traditional roof was similar to the amount of precipitation. The outflow began 30 minutes after the start of rainfall. Green roofs delayed the run-off and showed significant water retention in comparison to the traditional roof. Runoff from the green roof started about an hour after the precipitation began and was characterized by a small amount. Significant outflow occurred after 2.5 hour from the beginning of precipitation. One possible explanation for a 2.5-hour delay may be that the soil was dry before the rain. Low soil moisture causes models to absorb more precipitation and significantly delay outflow until the profile is saturated.



Source: own elaboration according to data of rainfall gauge Ursynów station –Warsaw University of Life Sciences.

Figure 3. Average monthly runoff coefficients for green roofs and reference roof models in June-November 2016



Source: own elaboration according to data of rainfall gauge Ursynów station –Warsaw University of Life Sciences.

Figure 4. Accumulated atmospheric precipitation outflow from green roofs and the reference roof from 6 to7 of November 2016

After the rain stopped, the dynamics of water runoff from the green roof models was reduced. The water was drained out from the system for few more hours after precipitation. Particularly, this can be seen for the rain occurence on November 6, 2016 (Figure 4). The runoff from the traditional roof ended about 20 minutes after the end of the precipitation, while the green roof runoff lasted about 3.5 hours after the end of precipitation. Although, there was a delay in drainage in reference to precipitation, there was also a delay in relation to the reference roof. The drain from the reference roof stopped nearly three hours earlier than the drain from the green roof models. Similar results were obtained by Burszta-Adamiak (2014) where the outflow from green roofs was delayed by several hours from the beginning of rainfall. On the traditional roof, the precipitation runoff occurred immediately after the precipitation started or only a few minutes after.

SUMMARY AND CONCLUSIONS

Green roofs in urban space act as biologically active sites, participate in rainwater retention, but do not require additional land surface. Literature studies indicate that green roofs can reduce runoff by 60% to 100% depending on the type of system used. The investigation carried out in the period of June-November 2016 on extensive models of green roofs in Warsaw-Ursynów allowed to formulate the following conclusions:

1. Models of extensive green roofs showed similar properties, the highest retention efficiency was shown by ZD3 profile, based on the – SPG E-M substrate (type 2 mixture of washed sand, gravel, limestone, crushed brick and peat).
2. The results showed that green roof models retained water in the range from 9.5 mm to 67.1 mm. The average runoff coefficients for the different types of green roofs in the monitoring period ranged from 0.31 to 0.33, while for the reference roof the values ranged from 0.70-0.95.
3. The green roofs delayed the run-off and showed significant water retention in comparison to the traditional roof. Runoff from green roofs started about an hour after the precipitation started, while at the reference roof it started after about 30 minutes.
4. The results of the studies on the three green roofs with different substrate layers confirmed the results found in literature, that green roofs may have a significant effect on retention and elongation of drainage waves in urbanized areas.

ACKNOWLEDGEMENTS

The equipment supplied by the Irrigation and Drainage Lab of the SGGW Water Centre was used to conduct presented investigations.

REFERENCES

Baryła A., Karczmarczyk A., Bus A. (2014). *Analiza stosunków wodnych substratów wykorzystywanych w systemach zielonego dachu.* Inżynieria Ekologiczna (39):9-14.

Burszta-Adamiak E. (2014). *Zielone dachy jako element zrównoważonych systemów odwadniających na terenach zurbanizowanych.* Wyd. UP we Wrocławiu, M CLXXV: 124.

Carpenter D., D. Kaluvakolanu P. (2011). *Effect of roof surface type on storm-water runoff from full-scale roofs in a temperate climate.* Journal of Irrigation and Drainage Engineering. 137 (3): 161-169.

Carter T. L., Rasmussen T.C. (2006). *Hydrologic behavior of vegetated roofs.* Journal of the American Water Resources Association, 42 (5):1261-1274.

DAFA (2015). *Dachy Zielone. Wytyczne do projektowania, wykonywania i pielęgnacji dachów zielonych –wytyczne dla dachów zielonych.* Stowarzyszenie Wykonawców Dachów Płaskich i fasad (DAFA) Opole, Poland DZ.1.01.

Fassman-Beck E., Voyde E., Simcock R., Sing Hong Y. (2013). *4 Livingroofs in 3 locations: Does configuration effect runoff mitigation*? Journal of Hydrology, 490: 11-20.

FEMP (Federal Energy Management Program) (2006). *Green roofs.* Federal Technology Alert.

Getter, K.L., Rowe, D.B. *The role of extensive green roofs in sustainable development.* HortScience, 41 (5): 1276-1285.

Hilten R.N., Lawrence T.M., Tollner E.W. (2008). *Modeling stormwater runoff from green roofs with HYDRUS-1D.* Journal of Hydrology, 358:288-293.

Kaczorowska Z. (1962). *Opady w Polsce w przekroju wieloletnim.* Prace Geogr. IG PAN 33.

Kohler M., Schmidt M. (1999). *Langzeituntersuchungen an begrunten Dachern in Berlin.* Dach+Grun 8 (1): 12-17.

Kożuchowski P. (2016). *Aneks do porozumienia o współpracy 1/KKS/2015 z dnia 02.03.2015*. SGGW w Warszawie.

Liesecke H. J. (1999). *Extensive begrunung bei 50 dachneigun*g. Stadt und Grun 48(5): 337-346.

Lee J.Y., Moon H. J., Kim T.I., Kim H. W., Han M. Y. (2013). *Quantitative analysis on the urban flood mitigation effect by the extensive green roof system.* Environmental Pollution, 181: 257-261.

Majewski G., Przewoźniczuk W., Kleniewska M. (2010). *Warunki opadowe na stacji meteorologicznej Ursynów SGGW w latach 1960–2009*. Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska 2 (48): 3–22.

Mentens J, Raes D, Hermy M. (2005). *Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century*? Landscape and Urban Planning, 77: 21–226.

Ni J. (2006). *Green roof study: stormwater quantity, quality and thermal performance.* Master of Science. Master Thesis, University of Pittsburgh, 252.

Pęczkowski G., Orzepowski W., Pokładek R., Kowalczyk T., Żmuda R. (2016). *Właściwości retencyjne zielonych dachów typu ekstensywnego na przykładzie badań modelowych.* Acta Sci. Pol., Formatio Circumiectus, 15(3): 113-120.

Roehr D., Kong Y. (2010). *Runoff Reduction Effects of Green Roofs in Vancouver, BC, Kelowna, BC, and Shanghai P.R. China.* Canadian Water Res. J., 35(1): 53-68.

Simmons M. T., Gardiner B., Windhager S., Tinsley J. (2008).Green roofs are not created equal: the hydrologic and thermal performance of six different extensive green roofs and reflective and non-reflective roofs in a sub-tropical climate. *Urban Ecosyst.*11: 339-348.

Uhl M., Schiedt L. (2008). *Green Roof storm Water retention –Monitoring Results.* 11th Intern Conf. on Urban drainage, Edinburgh.

Anna Baryła, PhD (corresponding autor)
Warsaw University of Life Sciences –SGGW
Faculty of Civil and Environmental Engineering
Department of Environmental Improvement,
Nowoursynowska 166, 02-787 Warszawa
anna_baryla@sggw.pl

Agnieszka Karczmarczyk, PhD
Warsaw University of Life Sciences –SGGW
Faculty of Civil and Environmental Engineering
Department of Environmental Improvement,
Nowoursynowska 166, 02-787 Warszawa
agnieszka_karczmarczyk@sggw.pl

Michał Wróbel, PhD
Forest Research Institute
Department of Forest Ecology
Sękocin Stary, 3 Braci Leśnej Street
05-090 Raszyn
m.wrobel@ibles.waw.pl

Paweł Kożuchowski
Green Roofs Laboratory
Ceglana 2B, 05-250 Słupno, Poland,
pawel@dachyzielone.pl

Received: 11.07.2017
Accepted:29.11.2017