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Analysis of the retention capacity of green roofs

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Abstract

Green roofs are one of the modern solutions used to achieve sustainable stormwater management in urban areas. These structures are still more often designed for newly constructed buildings in Poland, based on the observations of changes in urban areas that result in the increased sealing of soil surface and thus in the limitation of natural stormwater infiltration and retention sites. In spite of a growing interest in green roofs, the data related to their retention capacity in Polish conditions is still insufficient.

This study presents the results of the author's tests, conducted in the years 2009–2010 on experimental sites located on the roof of the Science and Education Centre building of the University of Environmental and Life Sciences in Wrocław. The aim of these tests was to determine the retention capabilities of green roofs and the runoff delay and peak runoff reduction during rainfall events recorded in local conditions.

The results show that green roofs can play a significant role in the reduction of total outflow volume of stormwater falling on their surface. Multi-layered structure of green roofs contribute also to a slowdown in the outflow of stormwater and to reduction in the peak runoff volume in comparison to the maximum recorded intensity of rainfall. Mean retention for 153 analysed rainfall events amounted from 82.5% to 85.7% for green roofs. In the case of rain events up to 1 mm a day, the retention for green roofs reached nearly 100%.

Key words: *green roofs, peak runoff reduction, retention, stormwater, urban area*

INTRODUCTION

Urbanization and the increase in impervious surfaces typically associated with urban development have consistently been shown to result in degraded aquatic ecosystems [CARTER, JACKSON 2007; MILTNER *et al.* 2004]. These effects are a function of increased stormwater runoff volumes across a watershed due to the efficient routing of stormwater off impervious surfaces and into a storm sewer system that ultimately discharges into a receiving water body. Overcharging of the natural water bodies leads to an increased risk of flood and a limitation of groundwater supply. Rapid and efficient pollutant transport has resulted in decreased water quality. Conventional solutions used so far to discharge stormwater by means

of direct discharge of the water through sewage systems to natural water bodies are becoming insufficient in constantly developing and expanding urban areas. Therefore, still more actions are being undertaken to implement the Sustainable Urban Drainage Systems (SUDS), whose main task is to re-create, to the highest possible extent, natural infiltration and retention sites, as well as to control the volume of runoff from urban areas. Such solutions include, among others, green roofs. Foreign studies [BENGTSSON 2005; BENGTSSON *et al.* 2005; FIORETTI *et al.* 2010; GETTER *et al.* 2007; PALLA *et al.* 2008; 2011; STOVIN 2009; STOVIN *et al.* 2007; VAN WOERT *et al.* 2005; VILLARREAL and BENGTSSON 2005] show that the multi-layered structure of green roofs enables temporary retention of stormwater, limits the maximum runoff

intensity and thus slows down the discharge of water to sewage systems and improves the efficiency of wastewater treatment plants during rainy periods. Although numerous tests and experiments have been conducted abroad, it is still difficult to apply their results to the effectiveness of usage of green roofs in Polish conditions, and scarce information published by Polish authors, including MROWIEC [2008] and SZAJDA *et al.* [2008] confirm the necessity to conduct systematic research in this area.

MATERIAL AND METHODS

The tests aimed at the determination of the retention capacity of green roofs have been conducted on the roof of the Science and Education Centre building of the Wrocław University of Environmental and Life Sciences since 2009. Five test plots in a form of roof platforms were constructed on the site. Four of them replicated a commercial extensive green roofs, and one roof platform has been constructed as a conventional (reference) roof, marked in this study with the symbol CR-1 (Fig. 1a). This study presents the results of measurements conducted during from 26 June 2009 to 26 June 2010 (first year of research), recorded on

two out of four green roof platforms and on the reference roof. The first of the green roof platforms, marked here with the symbol GR-1 (Fig. 1b) has been constructed in compliance with the extensive green roof solution system with the use of drainage manufactured by Optigrün. The platform contains the following structural layers (from bottom to top): absorptive-protective geotextile type RMS 500 (4), plastic profiled drainage elements type FKD 12 (height: 1.2 cm) (5), filtration geotextile type 105 (6), extensive substrate type E (7), characterised, according to the manufacturer's specification, by a high water and air capacity. Sheep fescue var. *Sina* (*Festuca ovina* 'Glauca') was planted on the substrate layer (8). The second analysed test plot, marked hereinafter with the symbol GR-2 (Fig. 1c) is a platform with extensive green roof using gravel layer, with the following arrangement of structural layers (from bottom to top): absorptive-protective geotextile RMS 500 (4), gravel layer consisting of a layer of gravel of a granulation from 2 to 5 cm (9), filtration geotextile type 105 (6) and a layer of substrate type M manufactured by Optigrün (10). Perennial *Sempervivum x hybridum* 'Othello' was planted on the site containing green roof GR-2 (11). The layers were placed on woodframed platform

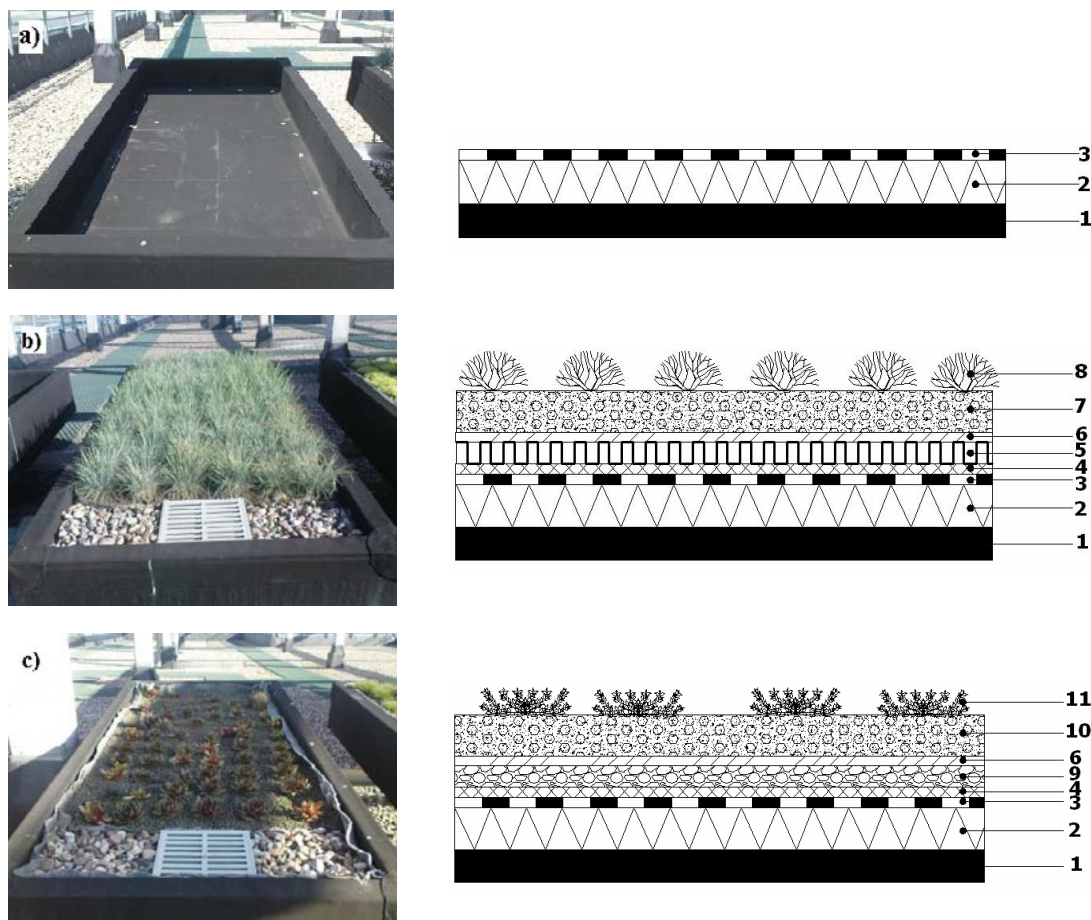


Fig. 1. Test plots with the construction details: a) reference roof (CR-1), b) extensive green roof (GR-1) with plastic profiled drainage elements, c) extensive green roof (GR-2) with gravel drainage layer (numeration is explained in the text)

(1) which was covered with a XPS thermal insulation (2) and waterproofing membrane EPDM (3). Construction details are presented in Figure 1a–c. Each of the test plots containing extensive green roofs was equipped with drainage, consisting of a DALLBIT 62H inlet of a diameter of 75 mm, a drain hole and a gravel layer band of the following dimensions: width 0.25 m x length 0.7 m, measured along the narrow edge. All constructed platforms have external dimensions of 2.40/1.20/0.35 (length/width/ height) and a slope of 7.7%. Their internal capacity equals 0.6 m³.

Rainfall and runoff from test plots was continuously, automatically recorded at 30 seconds resolution. Runoff was captured by Naja 0404 meters that measure the weight of the runoff. The meters are connected to a Memory Hilogger 8430-20 data logger, manufactured by HIOKI. Rain depth and intensity was monitored using a Parsivel laser precipitation sensor manufactured by the German company OTT MESS-TECHNIK GmbH&Co.KG [LICZNAR 2007]. The precipitation station was located on the roof of the Science and Education Centre building of the University of Environmental and Life Sciences in

Wrocław at a distance of approximately 20 m from the test plots.

RESULTS AND DISCUSSION

The results of the analysis of rainfall and runoff presented in this study concern the period from June 2009 to June 2010. During that period, 153 days with the daily rainfall ranging from 0.01 to 77.75 mm were recorded and analysed. Snowfall that occurred from December to March was not taken into account due to the fact that very low air temperatures forced us to disassemble the monitoring equipment for the winter period so that measurements were taken only manually. Over 40% of all recorded rainfall events consisted of daily rainfalls not exceeding 1 mm. Rainfalls exceeding 20 mm occurred occasionally and accounted for less than 4% of all rain events (Fig. 2). The months when as many as 77.4% of all days were rainy were October and December 2009 and May 2010. The months with the smallest recorded number of rainy days were June 2010 and April 2010, when rainfall occurred on, respectively, 43.3% and 46.7% of the days.

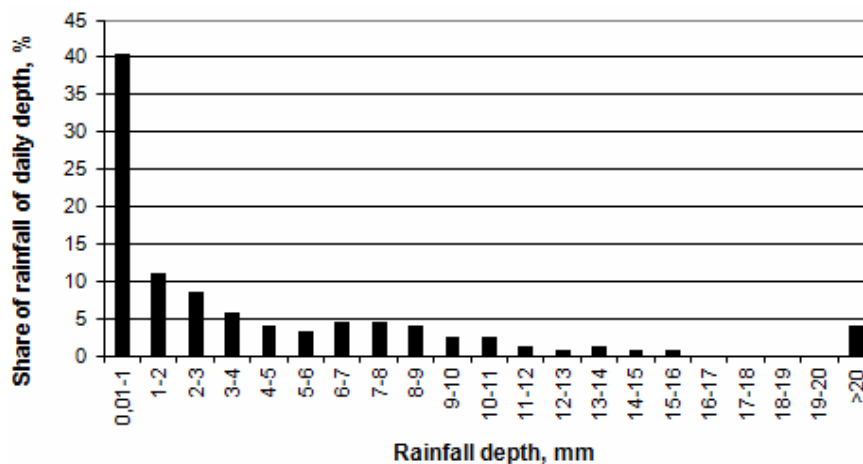


Fig. 2. Share of rainfall of daily depth falling into specific ranges in total precipitation from June 2009 to June 2010

Retention of single (daily) rainfall determined as the percentage of water volume retained in the sites in relation to the volume of stormwater falling on the model surface of the roofs during the analysed period fell within the range from 1.9 % to 100% for the conventional roof and from 10.3% to 100% for green roofs. Mean retention for 153 analysed rain events was, respectively, 52.5% for the reference roof (CR-1), 82.5 % for green roof GR-1 and 85.7% for green roof GR-2.

Considering the mean retention for rainfall in various ranges of daily rain depth it can be noted that the highest retention, amounting to nearly 100% for green roofs and approx. 90% for the conventional roof

occurred in the case of rainfall of daily depth not exceeding 1 mm, i.e. those events that occurred most often during the analysed period. However, from the sewage system operation viewpoint, more important are the rainfall events of bigger depth. The results of measurements prove that the retention capacity decreases gradually along with the increase of daily rain depth, and the difference in stormwater retention capacity of the conventional roof as compared to green roofs increases (Fig. 3). Similarly CARTER and RASMUSSEN [2006] found an inverse relationship between the depth of rainfall and the percentage of rain that was retained. The increased retention on green roofs compared with the conventional roof results mainly

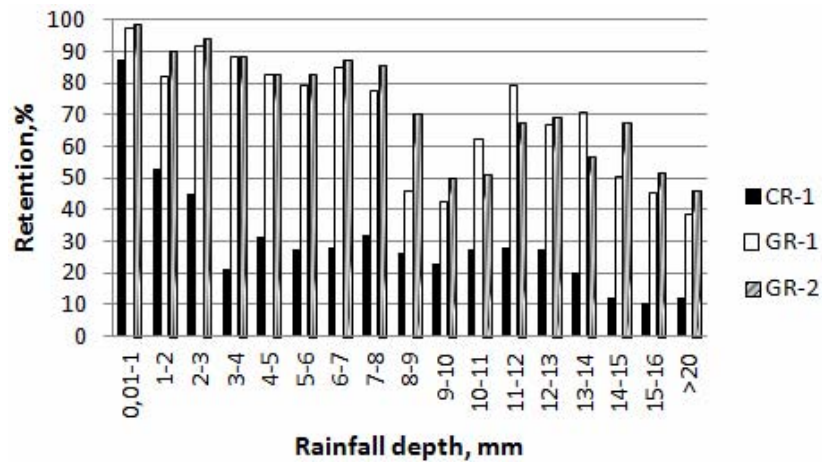


Fig. 3. Retention capacity on each test plot in relation to daily rain depth

from the structure of such roofs, as green roofs retain part of the water in the substrate layer and in the remaining structural layers (mostly in the drainage layer consisting of porous media or plastic profiled drainage elements), even during more intense rainfall events, and some water is evaporated to atmosphere through the rooftop covered by vegetation. Only the excess of stormwater flows out of the multi-layered structure. In the case of conventional roof, after the rooftop surface is initially wetted, a slight volume of stormwater is retained in the irregularities of the construction material, and at sufficiently high air temperature some of the water evaporates from the heated rooftop surface, the remaining volume of water is relatively quickly discharged in a form of runoff.

During the analysed test period the smallest volumes of water were retained on green roofs for rainfall events of a depth of 9–10 mm, and the retention for such rain events was 42.6% for GR-1 and 50.0% for GR-2. Similar retention capacity was noted for rainfall events of a daily depth of 15–16 mm, where the retention was 45.5% for GR-1 and 51.5% for GR-2. Rainfall events of such depth accounted for less than 1% of all rain events that occurred during the period from 26 June 2009 to 26 June 2010. Also for the conventional roof, the retention was lowest for the same range of rain depths amounting less than 10%. For the largest recorded rainfall event of a daily depth of 74.6 mm, the retention was 4% for reference roof and almost 11% for green roofs.

Exact values of runoff reduction (presented as % of precipitation) can hardly be compared with different studies due to different conditions in which studies were performed (e.g. weather) and different number of events (length of study period) which were included to calculate the presented retention values. BENGTTSSON [2005] for the green roofs at Augustenborg (southern Sweden) found that annual runoff can be reduced by up 50%. In Michigan (USA) the green roofs retained 80.2% of precipitation, on average [GETTER *et al.* 2007]. Based on examples from cities

such as Chicago, Philadelphia and Portland SCHOLZ-BARTH [2001] claimed that on average 75% of stormwater was retained by extensive green roofs in the United States.

The ability to retain the stormwater on roofs allows to delay the runoff of stormwater from test plots in relation to the time of beginning (start) of rainfall. Many studies demonstrate that the green roofs influence runoff dynamics by lowering and delaying the runoff as compared to the precipitation or reference roof runoff. CARTER and RASMUSSEN [2006] found that peak discharge for small storms was much lower from the green roof than from a reference roof but this effect was much reduced for larger storms. Quantitative differences reported by different studies are large. Considerable delays of the start of runoff were observed by DENARDO *et al.* [2005]. Studied green roofs delayed the start of runoff by 5.7 h on average. MORAN *et al.* [2005] showed that for 60% of rain events the delays of runoff were 30 min at minimum. On most of the measurement days in this study the first recorded runoff from green roofs occurred after several hours from the beginning of rainfall, while the runoff from the reference roof usually occurred after several minutes for the same rain events (Tab. 1). The time of stormwater retention and runoff delay is influenced by the duration of the antecedent dry period, duration of the rainfall and rain hyetograph, while daily rain depth has a weaker influence on the runoff delay. This is illustrated, among others, in the examples of rainfall on 11.08.2009, 17/18.08.2009, and 7.10.2009. These rain events are characterised by a similar daily depth (6.67, 6.36 and 6.78 mm, respectively), but the duration of the antecedent dry period, duration of the rainfall, and, most importantly their rainfall hyetographs are different (Tab. 1 and Fig. 4). In the first analysed case the rain reached maximum intensity in the third hour of rainfall, and thus runoff from green roofs could be observed around that time. In the case of the rainfall that occurred on the 17th/18th of August 2009, the maximum intensity of rainfall

Table 1. Monitoring data for selected rain events during the analysed period

Event dd/mm/yyyy	Rain depth mm	Antecedent dry period	Rain duration h:min:s	Runoff delay, min		
				CR-1	GR-1	GR-2
01.07.2009	3.70	18 h 34 min	02:54:00	9.0	200.0	223.0
11.08.2009	6.67	4 h 17 min	04:32:00	9.5	214.0	178.0
17/18.08.2009	6.36	3 d 17 h 38 min	01:38:00	3.5	8.0	33.0
01.10.2009	3.09	1 d 22 h 40 min	03:16:00	6.0	10.5	9.5
07.10.2009	6.78	8 h 24 min	02:24:30	34.0	67.1	66.5
10/11.10.2009	8.61	2 d 6 h 32 min	09:10:00	6.5	216.0	160.5
14/15.10.2009	22.82	11 h 9 min	10:19:30	215.0	654.5	625.5
22/23.10.2009	11.24	1 d 7 h 32 min	06:46:30	28.0	151.5	126.5
28/29.10.2009	4.88	1 d 4 h 6 min	13:58:00	157.5	472.5	481.5
8/9.11.2009	13.42	1 d 4 h 40 min	09:35:30	13.0	48.0	74.5
27.03.2010	5.95	5 d 4 h 13 min	07:05:30	7.0	61.5	104.5
28.03.2010	7.56	10 h 33 min	02:08:00	23.5	1050.5	1063.0
31.03.2010	11.50	1 d 14 h 38 min	07:39:00	13.0	47.0	80.5
05.04.2010	4.23	2 d 12 h 32 min	05:41:00	12.0	70.5	333.5
26.04.2010	6.15	3 d 16 h 21 min	01:55:00	8.5	42.0	91.0
5/6.05.2010	21.97	1 d 9 h 38 min	13:04:00	21.5	94.5	135.0
10.05.2010	5.63	3 d 4 h 21 min	06:53:00	38.0	264.0	327.0
21.05.2010	8.18	3 h 21 min	01:39:30	8.0	29.5	69.5
14.06.2010	15.20	6 h 4 min	09:58:00	21.5	51.0	80.5

occurred as early as in the second minute of the event, so that runoff delay periods were relatively short, both for green roofs and for the reference roof. Similar situation was observed in the case of rainfall that took place on the 7th of October, 2009. Maximum rainfall intensity that occurred in the second hour of the rain event was preceded by a slightly smaller „peak”, which initiated runoff, first from the conventional roof and after another 30 minutes also from green roofs (Fig. 4).

The test results also prove that green roof GR-2 (equipped with gravel drainage) is characterised by longer runoff delay time than green roof GR-1 (equipped with plastic profiled drainage elements) for most of the analysed rain events (Tab. 1).

The slowdown in runoff and the attenuation of part of the rainfall within the structure of green roofs causes a noticeable peak runoff reduction, as compared to the maximum recorded intensity of rainfall. During all the analysed rain events the peak runoff reduction on the reference roof was lower than the reduction recorded on green roofs (Fig. 4). However, neither on the reference roof, nor on green roofs any clear correlation was noted between the intensity, depth and duration of the rainfall and the value of peak runoff reduction. This phenomenon requires further analysis in order to formulate more precise conclusions.

CONCLUSIONS

The experiments conducted on test plots with extensive green roofs and on the reference roof in local

Wrocław conditions lead to the following conclusions:

1. Green roofs can play a significant role in the reduction of total outflow volume of stormwater falling on their surface. Mean retention for 153 analysed rainfall events amounted to 82.5% for GR-1 and 85.7% for GR-2. In comparison, on the reference roof (CR-1) 52.5% of the stormwater volume was retained.

2. The volume of stormwater retained in the multi-layered structure of green roofs decreases along with the increase of daily rain depth. During the analysed period, the smallest amounts of water were retained on green roofs in the cases of rainfall of the depth of 9–10 mm and 15–16 mm. Rainfalls of such depths constituted an insignificant part of all rain events recorded during the period from June 2009 to June 2010. In the case of most often rain events (those characterised by daily depth up to 1 mm) the retention for green roofs reached nearly 100%.

3. The analysed systems of extensive green roofs contribute to a slowdown in the outflow of stormwater. On most of the measurement days the first recorded runoff from green roofs occurred after several hours from the beginning of rainfall. The longest delay in runoff was observed for the test plot with green roof GR-2. For the same rainfall events, runoff from the reference roof usually occurred after a few or over ten minutes from the beginning of rainfall.

4. The slowdown in runoff and attenuation of stormwater in the structure of green roofs led to a reduction in the peak runoff volume in comparison to the maximum recorded intensity of rainfall. During each of the analysed rain events the peak runoff re-

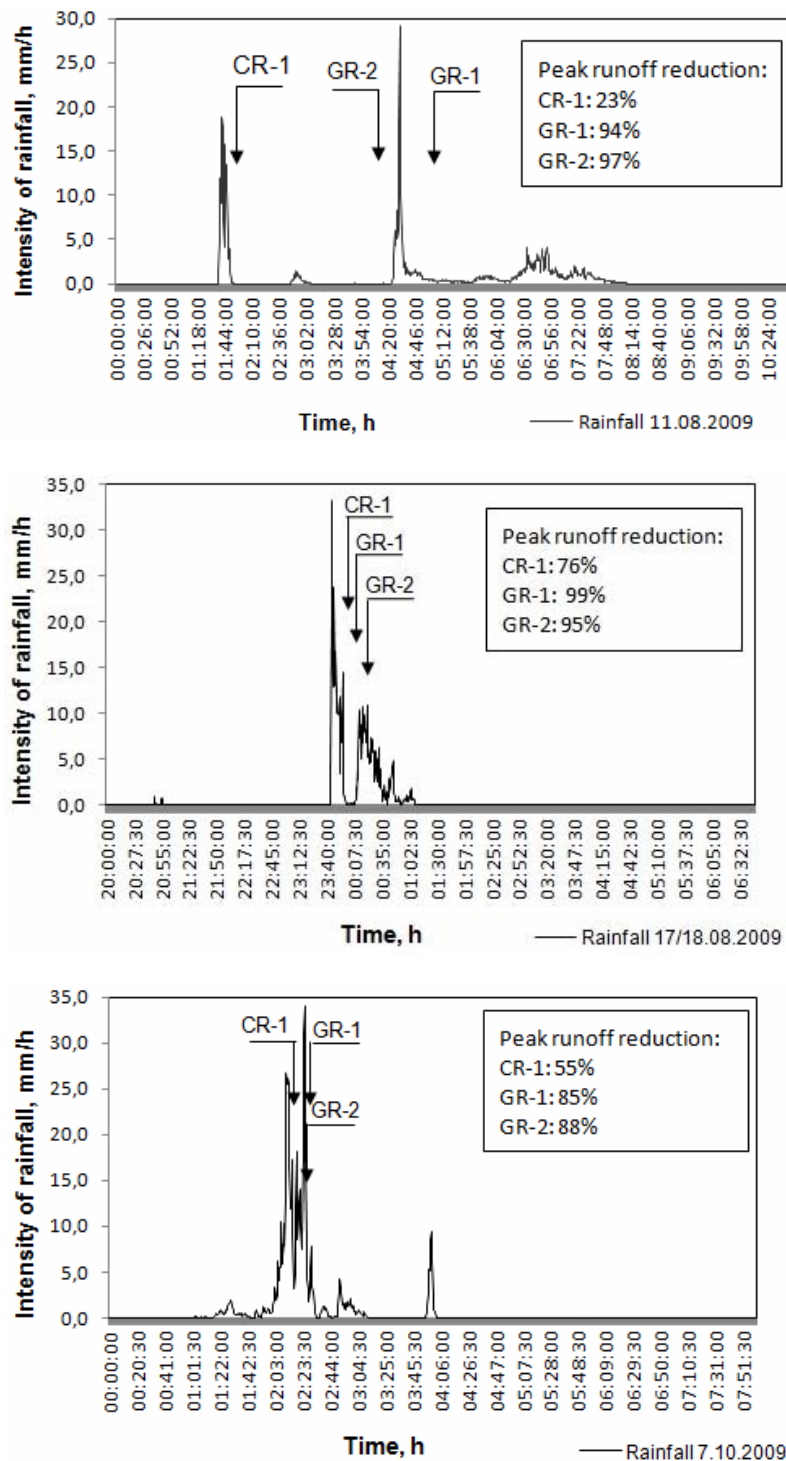


Fig. 4. Sample rainfall hyetographs with marked time of the beginning of runoff for the conventional roof (CR-1) and green roofs (GR-1 and GR-2)

duction for the reference roof was lower than that recorded on green roofs.

5. During the experiment it was noted that the characteristics of the rainfall, i.e. the intensity, daily depth and duration did not have a significant effect on the peak runoff reduction. This phenomenon requires further analysis in order to formulate more precise conclusions.

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Badania zdolności retencyjnych zielonych dachów

STRESZCZENIE

Słowa kluczowe: *redukcja szczytowej fali odpływu, retencja, tereny miejskie, wody opadowe, zielone dachy*

Zielone dachy są jednym z nowoczesnych rozwiązań, wykorzystywanych do osiągnięcia zrównoważonej gospodarki wodami opadowymi na terenach zurbanizowanych. Obserwując zmiany zachodzące w wyniku zabudowy na terenach zurbanizowanych, wiążące się ze wzrostem stopnia uszczelniania powierzchni, a tym samym z ograniczeniem miejsc naturalnej infiltracji i retencji wód opadowych, coraz częściej, również w Polsce, projektuje się te konstrukcje na nowych obiektach budowlanych. Pomimo rosnącego zainteresowania zielonymi dachami wciąż brakuje danych na temat ich zdolności retencyjnych w warunkach Polski.

W artykule przedstawiono wyniki własnych badań, wykonanych w latach 2009–2010 na stanowiskach badawczych zlokalizowanych na dachu budynku Centrum Naukowo-Dydaktycznego Uniwersytetu Przyrodniczego we Wrocławiu. Badania te miały na celu określenie możliwości retencyjnych dachów zielonych oraz opóźnienia spływów i redukcji szczytowej fali odpływu podczas opadów atmosferycznych, zarejestrowanych w warunkach wrocławskich.

Wyniki badań wykazują, że zielone dachy mogą odgrywać znaczącą rolę w redukcji całkowitej objętości opadu dostającego się na ich powierzchnię. Wielowarstwowa struktura zielonego dachu umożliwia także spowolnienie odpływu i zmniejszenie wysokości szczytowej fali odpływu w porównaniu z maksymalną intensywnością zarejestrowaną w opadach. Średnia retencja na zielonych dachach dla 153 analizowanych zdarzeń opadowych kształtowała się w granicach od 82,5% do 85,7%. Dla opadów, których wysokość dobowej warstwy opadu nie przekraczała 1 mm, retencja na zielonych dachach wynosiła blisko 100%.