 DOI: 10.22616/RRD.30.2024.035

RAINWATER DISCHARGE FROM GREEN ROOFS AT NATURAL CONDITIONS

***Vilda Grybauskiene[1], Gitana Vyciene[1], Inga Grinfelde[2]**
[1]Kaunas Forestry and Environmental Engineering University of Applied Sciences, Lithuania
[2]Latvia University of Life Sciences and Technologies, Latvia
*Corresponding author's e-mail: vilda.grybauskiene@gmail.com

Abstract
Newly constructed buildings are subject to stricter requirements - the building must not harm the environment, they must be energetically and economically efficient, comfortable, ecological, etc. One such green energy-saving idea is green roofs and walls of buildings. The purpose of this study is to determine the dynamics of rainwater runoff under real natural conditions, in a typical green roof construction, compared to runoff from a roof covered with bituminous tiles. The study was conducted in the year 2022-2023 by installing two 1 m^2 stands, which are affected by real climatic conditions. One stand was covered with traditional bituminous tiles, but the other was covered with a 'green roof' coating. Meteorological data were obtained from the Kaunas City meteorological station. During the first months of observation, it was possible to record the tendency that rainwater runoff is slow in the case of a green roof, but it continues even after the intense rain has ended. Analyzing the data, it was found during the research that the regression coefficients are very small in assessing the relationship between average daily temperatures and runoff in individual months, R2 - 0.0453 to 0.0553. The study showed that under certain meteorological conditions, a green roof can accumulate up to 35-45 percent more water than a roof covered with bituminous tiles. This means that the water is accumulated and then slowly drains into the rain collection systems.
Keywords: rainwater, green roof, precipitation, water collection.

Introduction

The extensive green roofs offer a multifaceted approach to stormwater management in cold and wet climates, providing benefits for both the environment and urban infrastructure (Abass *et al*., 2020). As cities continue to grapple with the challenges of climate change and urbanization, green roofs are likely to remain a valuable tool for sustainable water management strategies (Johannessen, Hanslin, & Muthanna, 2017). A small amount of field research data can be found for different users in northern regions, where frost and snow cover have different influences on construction. While there has been significant research and documentation on green roof technology for stormwater management in various climates, including wet and cold regions, it is true that gaps in knowledge still exist regarding their specific functions and potential use in these environments. Mentens, Raes, & Hermy (2013) conducted a comprehensive review of contemporary literature sources and conducted a reanalysis of collected data to develop an empirical model. The study encompassed data retrieved from 18 relevant publications, comprising a total of 628 records. These records were meticulously scrutinized to extract pertinent information regarding roof properties, precipitation patterns, and runoff characteristics. Through rigorous analysis, the findings unequivocally underscored the predominant influence of roof type on runoff dynamics. Moreover, statistical analyses revealed significant correlations ($p<0.05$) between annual precipitation levels, roof type, number of layers, and substrate layer depth, with the annual runoff volume. Conversely, factors such as green roof age, slope angle, and roof length exhibited no statistically significant correlations ($p>0.05$) with annual runoff. Notably, for non-greened roofs, runoff was found to be exclusively dictated by precipitation levels. These findings elucidate key determinants governing runoff behavior and highlight the multifaceted interplay of factors shaping stormwater management efficacy in built environments.

Alfredo, Montalto, & Goldstein (2010) undertook a rigorous simulation study to analyze the hydrologic performance of green roofs across diverse precipitation scenarios. Their investigation illuminated the escalating urbanization pressures, prompting both regulators and developers to seek innovative green infrastructure solutions and low-impact development technologies. These initiatives aim to judiciously assimilate built infrastructure within the broader landscape while mitigating adverse environmental impacts and enhancing urban resilience.

Such characteristics of the green roof allow for the reduction of rainwater peaks and the removal of momentary loads from the urban rainwater drainage system (Forouzani & Karami, 2011).

Studies confirm that the accumulated moisture is evaporated back into the atmosphere (Blank *et al*., 2013). The important thing is that the pollutants that were in the rainwater remain in the soil. As a result, not only does the microclimate of the environment improve (due to higher air humidity), but at the same time the cleanliness of groundwater is maintained (pollutants no longer penetrate to them through the soil) (European Commission, 2023).

The amount of water collected and evaporated on a green roof depends on three things:

- types of plants growing on the roof (moss accumulates moisture better than ordinary grass);
- the depth of the substrate (extensiveness/ intensity of planting);
- the type of substrate (Mentens, Raes, & Hermy, 2006).

Germany has emerged as a pioneer in the installation of green roofs in Europe, with over 25,000,000 m^2 of green roofs installed in 2000–2001. The growing popularity of green roofs has led to stricter installation requirements, which contribute to mitigating the impact of local floods during the rainy season (Cascone *et al*., 2018). Furthermore, the absorption of moisture by green roof coverings reduces the burden on the sewage network and the separated rainwater system (Mentens, Raes, & Hermy, 2006). Since the green roof covers and absorbs part of the moisture in its structural elements, there is less load on the general sewage network and the separated rain drainage system. The soil layer of green roofs acts as a filter – it cleans nitrogen pollutants from the rain and neutralizes the acid rainwater that has run off. The authors also suggest future research on the influence of various filter materials, such as zeolites, on improving the quality of this water treatment (Wong *et al*., 2003). The thermal insulation efficiency of green roofs was studied by researchers at Nottingham, Trent University (Wong *et al*., 2003). Research has shown that with an average daily temperature of 18.4°C, the temperature of the shelter on an ungreened roof reaches 32°C, but on a greened roof it reaches 17.1°C. And this is almost twice as low the temperature (Wong *et al*., 2003).

Typically, beneath the substrate layer of green roofs, a series of additional strata are commonly installed, including a filter layer, drainage layer, anti-root barrier, and waterproof membrane. The selection and configuration of these layers are contingent upon the prevailing climatic conditions of the installation site. In certain climates, the implementation of an irrigation system may be deemed essential to safeguard the viability and sustenance of vegetation atop the green roof structure. Such measures are crucial for optimizing plant health and promoting ecological resilience within the urban environment (Besir & Cuce, 2018).

The green building walls support a healthier microclimate in the building environment. Plants release oxygen and clean the air we breathe. They reduce the concentration of heavy metals, solid particles, dust, and volatile organic compounds in the air (Shafique, Kim, & Rafiq, 2018). It was established that 1.5 m^2 of uncut grass produces the annual amount of oxygen consumed by humans. A properly installed green roof allows the building to ‘breathe’ (Sajedeh Sadat, Hilmi Mahmud, & Muhammad Aqeel Ashraf, 2015).

The purpose of this study is to determine the dynamics of rainwater runoff under real natural conditions, in a typical green roof structure compared to runoff from a roof covered with bituminous tiles.

Materials and Methods

The research was carried out between 2021 and 2022, using two 1-square-meter stands to observe natural conditions. One stand was covered with bituminous tiles while the other had a green roof composed of an insulating film, a water retention membrane, and a layer of perennial grasses. These stands were set up in the courtyard of the Water Research Laboratory of the Kaunas Forestry and Environmental Engineering University of Applied Sciences. They were equipped with a rain gauge and soil thermometer and had a 15-degree slope. All runoff water was collected by catch channels, led to containers, and measured regularly at five-day intervals. Meteorological data was sourced from the Kaunas hydro-meteorological station, and the observation period lasted from 09/15/2021 to 03/15/2022. The data was analyzed using the MS Excel program. Regarding the subject being investigated, the foundation that supported the water-collecting tray was constructed using waterproof plywood. ‘Figure 1’ shows a cross-section of a green roof from the example presented in GSA.US (2011). To avoid any water leakage during intense rainfall, the simulated rooftop featured a molded barrier encircling its periphery.

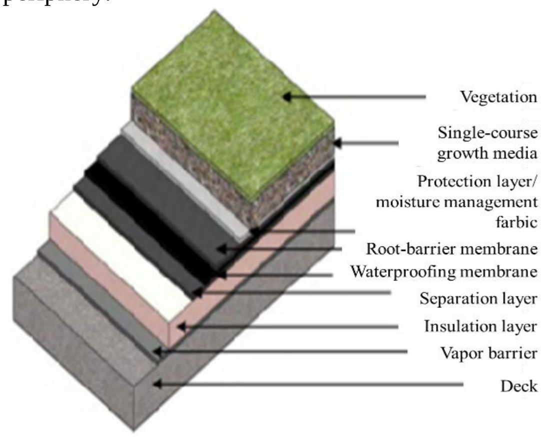

Figure 1. Single course extensive green roof experimental plot cross-section.

The roofing component was coated with bitumen, as depicted in ‘Figure 2’.

Figure 2. The rainwater harvesting system from the roof with bituminous tiles.

During the case study, plastic containers were used to collect surface water from rain and snowmelt after the roof collection system, under the downpipe installation principle. The amount of leakage was measured in liters. Additionally, meteorological data was gathered via a rain gauge and soil thermometer situated on a green roof stand. This data was supplemented by information from the Kaunas City Meteorological

Station (LHMT), accessed online. As there were no variations detected between meteorological readings throughout the observation period, data from the station was utilized.

Results and Discussion

A summary of meteorological data and runoff from the experimental stands is presented in the form of processed graphs in 'Figure 3'.

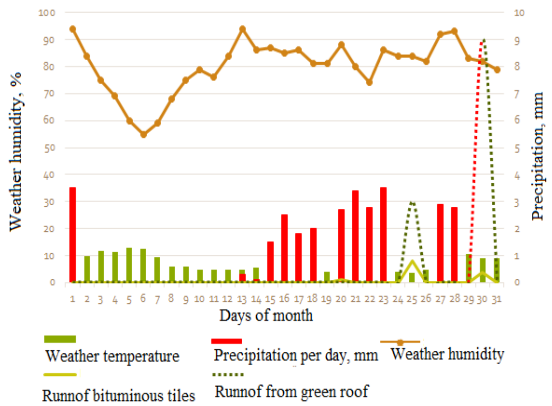

Figure 3. Schedule of summarized meteorological data for October (2021, 10-31).

During October, there was no leakage recorded in the covered stands between October 1st and 20th, due to very low rainfall. However, runoff from the bituminous roof was observed on October 25th and 30th. In total, only 29.8 mm of precipitation fell throughout the month, with 3.5 mm recorded in the first decade, 10.9 mm in the second, and 15.4 mm in the third. At the stand with a green cover, 13 liters of drainage were recorded for the whole month, while 12 liters were recorded from the green roof. During the first few months of observation, it was noticed that rainwater runoff from the green roof is slower than that of bituminous roofs, but it continues even after the intense rain has ended. This confirms the claims of foreign authors that green roofs accumulate and retain rainwater, thus reducing the runoff peak during rain.

In November, the first minus temperatures were recorded, with -2.2 °C on November 9th and -4 °C and -5°C on November 22nd and 23rd respectively. On November 30th, the temperature was fixed at 8.9 °C, resulting in an average daily temperature of 4.2 °C for the month. A total of 58.5 mm of precipitation fell during November, with 12.6 mm in the first ten days, 9.4 mm in the second, and 36.5 mm in the third. The runoff from the bituminous roof was 31.8 liters, but from the green roof, it was 40.3 liters.

In December, only 9 out of 30 days had fixed plus temperatures. The coldest day was December 15th, with a temperature of -15.6°C. The view of frozen experimental plots is presented in 'Figure 4'.

During this period, frost prevailed at night, and precipitation fell in the form of mixed precipitation during the night and day. In the first ten days, 15.9 mm of precipitation fell, followed by 12.4 mm in the second ten days and 9.5 mm in the third. The mixed precipitation runoff from the roof covered with bituminous tiles amounted to 2 liters, while from the green roof, it was fixed to 4 liters.

Figure 4. The view of frozen experimental plots in December.

The dynamics of meteorological phenomena in December are presented in 'Figure 5'.

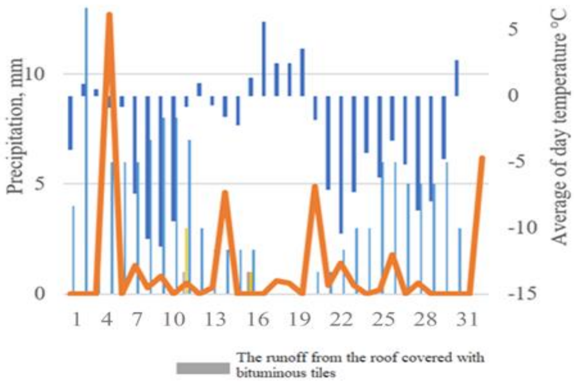

Figure 5. Schedule of summarized meteorological data for December (2021, 01-31).

There were no active observations in January, but the meteorological station provided data. From these data, it can be seen that the average daily temperature for the first ten days was -0.8°C, for the second decade -0.3°C, and for the third -0.4°C. During January, 69 mm of precipitation fell: in the first decade - 28 mm, in the second decade - 10.5 mm, and the third - 29.7 mm. Snow thickness varied between 1-3 cm and reached 5 cm on January 31. Only total runoff from the experimental stands was recorded this month. The runoff from the roof covered with bituminous tiles was 27 liters, whereas the runoff from the green roof was 35.8 liters.

Similar temperature trends were recorded in February, but February was distinguished by a very abundant runoff from the green roof stand. During the month, 60.6 liters of leakage was recorded, and from the roof with bituminous tiles, it amounted to 27 liters, almost half as much. Due to the manual measurement of the mechanical leakage even twice on days 15 and 20, the container used did not contain all the leakage. Therefore, a larger 20-liter vessel was added later that showed 16.9 liters of leakage by February 25. This month has shown that green roofs are excellent at accumulating mixed precipitation, and snowmelt water, and giving it to the drain during the day in plus temperatures and sunshine.

The month of March did not differ in terms of runoff, because during the whole month, only 3 liters of water escaped from the roof covered with bitumen and 9 liters from the green roof. This leak was recorded on March 5. Later until March 15, the drain was not fixed, and the vessels were empty.

Analyzing the data during the winter research, it was found that the regression coefficient is very low when assessing the relationship between average daily temperatures and runoff. R^2 equals 0.0453. The regression coefficient between average daily temperatures and runoff in individual months is presented in ‘Figure 6’.

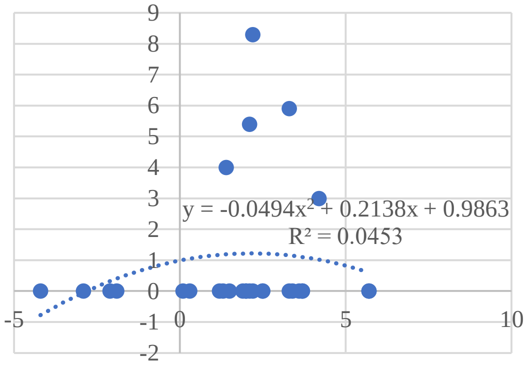

Figure 6. Regression coefficient between average daily temperatures and runoff in individual months.

Such weak dependencies between the two phenomena may be due to inadequate data collection. Runoff was recorded every 5 days, and daily average temperatures were recorded every day. This dependence was tested only between the roof covered with bituminous tiles and the average temperatures in February, and they were negative. This experiment showed that green roof research should be continued for at least several growing seasons to determine the amount of accumulated water and support for urban rain drainage systems and more stands with different layer thicknesses should be installed. Another aspect that emerged only because the low ambient temperatures were observed is the cooling of the structure, which is impossible if the green roof covering was formed as part of the residential building. We believe that this also distorts the results of the study. Our research confirmed the research of many authors that the climate is one of the main factors determining the effective work of this structure.

Green roofs offer various environmental benefits such as improved storm-water management, regulation of building temperatures, reduction of urban heat-island effects, and increased urban wildlife habitat (Oberndorfer *et al.*, 2007).

Green roofs, while beneficial, have notable disadvantages. High initial costs stem from installation expenses, specialized materials, and potential structural reinforcements needed to support additional weight. Maintenance, involving watering, weeding, and fertilizing, often requires professional services, increasing long-term costs. Waterproofing and drainage issues can cause leaks and waterlogging, leading to root damage if improperly handled. The structural load of green roofs varies seasonally, stressing building frameworks and potentially necessitating costly reinforcements. Installation is complex, requiring specialized skills and more time than conventional roofs. Plant selection is limited by local climate conditions, and maintaining plant health can be challenging. Green roofs can attract pests, adding to maintenance concerns. Insurance premiums may be higher due to perceived risks, and compliance with local building codes can complicate installation. Although green roofs can enhance energy efficiency, their performance varies, and the energy savings may not always justify the costs (Clark, Adriaens, & Talbot, 2008).

The integration of green roofs with certain architectural styles can be challenging due to compatibility issues with different building designs. This challenge highlights the importance of meticulous planning, precise installation, and consistent maintenance to ensure the long-term success of green roof projects (Thuring, Berghage, & Beattie, 2010). Green roofs offer various environmental benefits but also present drawbacks such as high initial costs, demanding maintenance requirements, waterproofing and drainage issues, structural load concerns, and complexities in installation and plant selection (Peng & Jim, 2013).

To determine the appropriate size for a green roof prototype, it is essential to consider various factors such as stormwater retention capacity, thermal performance, and environmental benefits. Research by Silva *et al.* (2019) assessed the retention capacity of an experimental green roof prototype, indicating a retention rate of 68% to 82% for specific rainfall amounts.

The above conditions shall be taken into account when planning the construction of green roofs and further research shall be carried out prior to the commencement of the design work.

Conclusions

1. During the study, it was found that a green roof has the potential to reduce the load on rainwater systems and retain precipitation in roof layers. The research also observed that rainwater runoff is slow in the case of a green roof, and it continues even after the intense rain has ended. This confirms the claims of foreign authors that green roofs accumulate, retain rainwater, and reduce the runoff peak during rain.
2. However, the study also found that there was a weak correlation between average daily temperatures and runoff in individual months. This could be due to improper data collection. Some authors only record the water retention coefficient of green roofs, which is done under laboratory

conditions where the exact amount of water is known to have entered and left the green roof.
3. Under certain meteorological conditions, a green roof can accumulate up to 35-45% more water than a roof covered with bituminous tiles. This means the water is accumulated and slowly drained into the rain collection systems.
4. The study also recorded that cloudy water runs from the green roof during the first few months of observation. This confirms scientific research that soil particles are removed from the flooded soil layer with the first rainfall, and water erosion occurs.

References

Abass, F., Ismail, L. H., Wahab, I. A., & Elgadi, A. A. (2020). A review of green roof: definition, history, evolution and functions. In *IOP Conference Series: Materials Science and Engineering.* 713(1), 012048. IOP Publishing. DOI: 10.1088/1757-899X/713/1/012048.

Alfredo, K., Montalto, F., & Goldstein, A. (2010). Observed and modeled performances of prototype green roof test plots subjected to simulated low-and high-intensity precipitations in a laboratory experiment. *Journal of Hydrologic Engineering*. *15*(6), 444-457. DOI: 10.1061/(ASCE)HE.1943-5584.0000135.

Besir, A. B. & Cuce, E. (2018). Green roofs and facades: A comprehensive review. *Renewable and Sustainable Energy Reviews*. *82*, 915-939. DOI: 10.1016/j.rser.2017.09.106.

Blank, L., Vasl, A., Levy, S., Grant, G., Kadas, G., Dafni, A., & Blaustein, L. (2013). Directions in green roof research: A bibliometric study. *Building and Environment*. *66*, 23-28. DOI: 10.1016/j.buildenv.2013.04.017.

Cascone, S., Catania, F., Gagliano, A., & Sciuto, G. (2018). A comprehensive study on green roof performance for retrofitting existing buildings. *Building and Environment*. *136*, 227-239. DOI: 10.1016/j.buildenv.2018.03.052.

Clark, C., Adriaens, P., & Talbot, F. B. (2008). Green roof valuation: a probabilistic economic analysis of environmental benefits. Environmental Science &Amp; Technology, 42(6), 2155-2161. DOI: 10.1021/es0706652.

European Commission. (2023). Directorate-General for Environment, *Green roofs as nature based solutions for a better life in cities*, Publications Office of the European Union, 2023. Retrieved February 21, 2024, from https://data.europa.eu/doi/10.2779/518419.

Forouzani, M. & Karami, E. (2011). Agricultural water poverty index and sustainability. *Agronomy for Sustainable Development*, *31*, 415-431. DOI: 10.1051/agro/2010026.

GSA.US. (2011). The Benefits and Challenges of Green Roofs on Public and Commercial Buildings A Report of the United States General Services Administration Retrieved February 21, 2024, from https://www.gsa.gov/system/files/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.pdf.

Johannessen, B. G., Hanslin, H. M., & Muthanna, T. M. (2017). Green roof performance potential in cold and wet regions. *Ecological Engineering*, *106(A)*. 436-447. DOI: 10.1016/j.ecoleng.2017.06.011.

LHMT. (2024). *Lietuvos Hidrometeorologijos Tarnyba* (Lithuanian Hydrometeorological Service). Retrieved February 21, 2024, from http://www.meteo.lt/lt/oro-temperatura.

Mentens, J., Raes, D., & Hermy, M. (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landscape and urban planning*. *77*(3), 217-226. DOI: 10.1016/j.landurbplan.2005.02.010.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R., Doshi, H., Dunnett, N., … & Rowe, B. (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. BioScience, 57(10), 823-833. DOI: 10.1641/b571005.

Peng, L. L. & Jim, C. Y. (2013). Green-roof effects on neighborhood microclimate and human thermal sensation. Energies, 6(2), 598-618. DOI: 10.3390/en6020598.

Sajedeh Sadat, G. H., Hilmi Mahmud, H. M., & Muhammad Aqeel Ashraf, M. A. A. (2015). Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: a review. 52, 669-679. DOI: 10.1016/j.rser.2015.07.163.

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities, and challenges–A review. *Renewable and Sustainable Energy Reviews*. *90*, 757-773. DOI: 10.1016/j.rser.2018.04.006.

Silva, M. d., Najjar, M. K., Hammad, A. W. A., Haddad, A., & Vazquez, E. G. (2019). Assessing the retention capacity of an experimental green roof prototype. Water, 12(1), 90. DOI: 10.3390/w12010090.

Thuring, C., Berghage, R., & Beattie, D. (2010). Green roof plant responses to different substrate types and depths under various drought conditions. HortTechnology, 20(2), 395-401. DOI: 10.21273/horttech.20.2.395.

Wong, N. H., Chen, Y., Ong, C. L., & Sia, A. (2003). Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment*. *38*(2), 261-270. DOI: 10.1016/S0360-1323(02)00066-5.