Hydrologic Performance of Experimental Green Roofs Stands as the Effect of Climate Condition

Zuzana Miňová\(^1\), Pavol Purcz\(^1\), Lukáš Takal\(^2\)

\(^1\)Faculty of Civil Engineering, Technical University of Košice, Vysokoškolská 4, Košice 042 00, Slovakia
\(^2\)Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, Praha Suchodol, 165 00, Czech Republic

zuzana.minova@tuke.sk

Abstract. The water storage capacity of a green roof forms several benefits for the building and its environment. The hydrologic performance is traditionally expressed by the runoff coefficient, according to international guidelines and standards. The runoff coefficient is a dimensionless coefficient relating the amount of runoff to the amount of precipitation received. It is a larger value for areas with low infiltration and high runoff (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land). The paper is presenting 3 experimental stands of green roofs. Each stand is unique in terms of its construction. The aim of this paper is to highlight how green roof responds to real climate events. The experiment provides mathematical graphs and behaviour of the geen roof stands from 03/2019 to 01/2021.

1. Introduction
The statistics of weather over long periods of time is called climate. It is measured by assessing the patterns of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time. Climate differs from weather, in that weather only describes the short-term conditions of these variables in a given region. The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents. Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation. The most commonly used classification scheme was the Köppen climate classification [1-4].

Temperature is a physical quantity expressing hot and cold. Temperature is measured with a thermometer, historically calibrated in various temperature scales and units of measurement. The most commonly used scales are the Celsius scale, denoted in °C (informally, degrees centigrade), the Fahrenheit scale (°F), and the Kelvin scale. The kelvin (K) is the unit of temperature in the International System of Units (SI), in which temperature is one of the seven fundamental base quantities. The coldest theoretical temperature is absolute zero, at which the thermal motion of all fundamental particles in matter reaches a minimum. Although classically described as motionless, particles still possess a finite zero-point energy in the quantum mechanical description. Absolute zero is denoted as 0 K on the Kelvin scale, -273.15 °C on the Celsius scale, and -459.67 °F on the Fahrenheit scale [5, 6].
In meteorology, **precipitation** is any product of the condensation of atmospheric water vapor that falls under gravity. Precipitation occurs when a portion of the atmosphere becomes saturated with water vapor, so that the water condenses and "precipitates". Thus, fog and mist are not precipitation but suspensions, because the water vapor does not condense sufficiently to precipitate. Two processes, possibly acting together, can lead to air becoming saturated: cooling the air or adding water vapor to the air. Precipitation forms as smaller droplets coalesce via collision with other rain drops or ice crystals within a cloud. Short, intense periods of rain in scattered locations are called "showers". Precipitation is a major component of the water cycle, and is responsible for depositing the fresh water on the planet [6, 7].

The possible dependence of temperature, resp. moisture from the amount of run-off water was considered for three different samples – experimental stands of green roofs (Figure 6). Achieved results confirm certain average degree of dependence of the given quantities.

2. **Slovakia Climate, average monthly weather in Košice, Slovakia**

Košice lies at an altitude of 206 meter above sea level and covers an area of 242.77 km². It is located in eastern Slovakia, about 20 kilometers from the Hungarian, 80 kilometers from the Ukrainian, and 90 kilometers from the Polish borders. It is about 400 kilometers east of Slovakia's capital Bratislava and a chain of villages connects it to Prešov which is about 36 kilometers to the north. Košice is on the Hornád River in the Košice Basin.

Košice has a humid continental climate, as the city lies in the North Temperate Zone. The city has four distinct seasons. Precipitation varies little throughout the year with abundance precipitation that falls during summer and only few during winter. The coldest month is January, with an average temperature of −2.6 °C and the hottest month is July, with an average temperature of 19.3 °C (Figure 1-5) [8].

- The months May, June, July, August and September have a nice average temperature
- On average, the warmest month is July
- On average, the coolest month is January
- The average annual maximum temperature is: 13.0°C
- The average annual minimum temperature is: 3.0°C

![Figure 1](image.png)

**Figure 1.** Average minimum and maximum temperature over the year [8]

- On average, July is the most sunny
- On average, December has the lowest amount of sunshine
Figure 2. Average monthly hours of sunshine over the year [8]

- On average, July is the wettest month
- On average, January is the driest month
- The average amount of annual precipitation is: 619.0 mm

Figure 3. Average monthly precipitation over the year (rainfall, snow) [8]

- Most rainy days are in December
- On average, December is the most rainy
- On average, September has the least rainy days
- The average annual amount of rainy days is: 147.0 days

Figure 4. Average monthly rainy days over the year [8]

- On average, December is the most humid.
- On average, May is the least humid month.
- The average annual percentage of humidity is: 62.0%
3. Measurements
In Table 1 there are selected values from measurements. The experiment lasted from 03/2019 till 01/2021. In this research, this period is being evaluated. For future research, the experiment is still ongoing and the data are being periodically evaluated.

Table 1. Selected values from measurements (1 measurement / 1 month)

| date      | min. temp. | max. temp. | prec. | min. hum. | max. hum. | irrigation | run-off | run-off |
|-----------|------------|------------|-------|-----------|-----------|------------|---------|---------|
|           | °C         | °C         | mm    | %         | %         | ml         | ml      | %       | %       | %       |
| 28.3.2019 | -3         | 11         | 0     | 28        | 76        | 3000,00    | 1000    | 820     | 0       | 33       | 27       | 0       |
| 26.4.2019 | 8          | 26         | 0     | 32        | 88        | 1500,00    | 980     | 500      | 50      | 65       | 33       | 3       |
| 19.5.2019 | 11         | 24         | 0,6   | 44        | 94        | 1500,00    | 240     | 0        | 0       | 16       | 0        | 0       |
| 28.6.2019 | 15         | 23         | 0     | 41        | 77        | 1000,00    | 170     | 220      | 0       | 17       | 22       | 0       |
| 26.7.2019 | 16         | 31         | 0     | 35        | 94        | 800,00     | 0       | 0        | 0       | 0        | 0        | 0       |
| 28.8.2019 | 17         | 31         | 0     | 40        | 88        | 1500,00    | 0       | 0        | 0       | 0        | 0        | 0       |
| 29.9.2019 | 7          | 20         | 0     | 52        | 100       | 2500,00    | 100     | 0        | 0       | 4        | 0        | 0       |
| 23.10.2019| 8          | 23         | 0     | 57        | 100       | 1500,00    | 900     | 440      | 360     | 60       | 29       | 24      |
| 30.11.2019| -4         | 6          | 0     | 42        | 76        | 1500,00    | 0       | 0        | 0       | 0        | 0        | 0       |
| 20.12.2019| -4         | 5          | 0     | 75        | 93        | 1500,00    | 600     | 500      | 0       | 40       | 33       | 0       |
| 27.1.2020 | -2         | 1          | 0     | 87        | 100       | 1500,00    | 0       | 0        | 0       | 0        | 0        | 0       |
| 22.2.2020 | -5         | 8          | 0     | 46        | 93        | 1000,00    | 850     | 800      | 500     | 85       | 80       | 50      |
| 28.3.2020 | 3          | 17         | 0     | 27        | 70        | 1500,00    | 1000    | 800      | 320     | 67       | 53       | 21      |
| 29.4.2020 | 6          | 22         | 0     | 41        | 87        | 1500,00    | 1050    | 400      | 900     | 70       | 27       | 60      |
| 22.5.2020 | 5          | 19         | 0     | 19        | 66        | 1000,00    | 0       | 0        | 0       | 0        | 0        | 0       |
| 29.6.2020 | 17         | 28         | 0     | 58        | 94        | 1500,00    | 600     | 0        | 0       | 40       | 0        | 0       |
| 30.7.2020 | 18         | 30         | 0     | 40        | 100       | 1500,00    | 0       | 0        | 0       | 0        | 0        | 0       |
| 31.8.2020 | 17         | 27         | 0     | 37        | 83        | 1500,00    | 0       | 0        | 0       | 0        | 0        | 0       |
| 29.9.2020 | 11         | 16         | 0     | 72        | 100       | 1000,00    | 800     | 0        | 300     | 80       | 0        | 30      |
| 21.10.2020| 4          | 12         | 0     | 67        | 100       | 1500,00    | 800     | 500      | 200     | 53       | 33       | 13      |
| 24.11.2020| -2         | 1          | 0     | 93        | 100       | 1100,00    | 500     | 400      | 300     | 45       | 36       | 27      |
| 15.12.2020| 1          | 2          | 0     | 93        | 100       | 1000,00    | 600     | 500      | 400     | 60       | 50       | 40      |
| 17.1.2021 | -9         | -5         | 0     | 74        | 93        | 1000,00    | 0       | 0        | 0       | 0        | 0        | 0       |
4. Results and discussions

Temperature and humidity measurements (minimum and maximum), the amount of precipitation as well as the amount irrigation, resp. of run-off water were performed once every few days in each month from March 2019 to January 2021. Possible dependence of temperature, resp. moisture from the amount of run-off. As the amount of precipitation, resp. of the water supplied were not the same, this dependence was not sought for the absolute amount of water drained, but for its relative value expressed as a percentage of the amount of water supplied.

The initially calculated correlation coefficients were (in absolute value) very small and therefore not applicable for the correct drawing of any conclusions. The reason was that at the beginning of this period, the green growth was still planted in the substrate and it took almost 3/4 years to fully develop and cover the entire area (Figure 7).

For this reason, only data from the beginning of July 2020 until the end of the considered period - until the beginning of 2021, which represents a period of 6 months, resp. data in 37 measurement cases.

The first table of correlations (Table 2) shows the degree of dependence of the amount of relative amount of drained water (in %) not only on the minimum and maximum temperature, resp. humidity, but also from their average values, resp. also from the difference in daily temperatures. The results show the best, average dependence in the case of sample No. 3 and the worst, weak dependence in the case of sample No. 2. Two of the most significant dependencies are also shown graphically, see the Figure 8. In the case of the dependences of the amount of relative amount of drained water (in%) on...
the temperature, it is a type of indirect proportionality, while the dependence on humidity is, on the other hand, a type of direct proportionality.

Table 2. Correlation

|       | correlation | min. | max. | aver | differ. | min. | max. | aver | correlation | min. | max. | temp-hum | temp | temp | temp | average |
|-------|-------------|------|------|------|---------|------|------|------|-------------|------|------|---------|------|------|------|---------|
| 1     | run-off %   | -0.32051079 | -0.4142362 | -0.38236932 | -0.42456498 | 0.420111912 | 0.479735333 | 0.46206803 | min hum     | -0.58107935 | -0.812208 | -0.7962967 |
| 2     | 0.56267108  | -0.41573913 | -0.41191912 | -0.421456498 | 0.424564987 | 0.442688243 | 0.442688243 | 0.46206803 | max hum     | -0.58107935 | -0.55204258 | -0.51132596 |
| 3     | -0.40317116 | -0.33786045 | -0.36530274 | -0.36102418 | 0.479733333 | 0.46206803 | 0.46206803 | 0.46206803 | aver hum    | -0.58107935 | -0.812208 | -0.7962967 |

Figure 8. Two of the most significant dependencies

Further research and measurement shows the degree of dependence between temperature and humidity (minimum, maximum and average) for our measured values. The results show the average to high dependence of the type of indirect ratio between these two quantities. Again, two of the most significant dependencies can be shown graphically.
5. Conclusions
The water storage capacity of a green roof forms several benefits for the building and its environment. The hydrologic performance is traditionally expressed by the runoff coefficient, according to international guidelines and standards. The paper presented 3 experimental stands of green roofs. Each stand is unique in terms of its construction. The aim of this paper was to highlight how green roof responds to real climatic events. The experiment provides mathematical graphs and behaviour of the green roof stands from 03/2019 to 01/2021.

Acknowledgment(s)
This work was supported by: APVV-18-0360 ACHIEve Aktívna hybridná infraštruktúra pre špongiové mesto, VEGA 1/0217/19 Výskum hybridnej modrej a zelenej infraštruktúry ako aktivných prvkov 'špongiového' veľkomesta a SWAMP - Zodpovédny management vody v intravilánu obce ve vztahu k okolní krajině (č. CZ.02.1.01/0.0/0.0/16_026/0008403).

References
[1] R., Gutro, NASA - What's the Difference Between Weather and Climate? [Online] 2015 [Accessed March 03, 2021] Available at: https://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html.
[2] Britannica, Climate. [Online] 2021 [Accessed March 03, 2021] Available at: https://www.britannica.com/science/climate-meteorology/Solar-radiation-and-temperature.
[3] Precipitation. [Online] 2015 [Accessed March 03, 2021] Available at: https://www.britannica.com/search?query=precipitation.
[4] N. V. Patel, Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st century [Online] 2018 [Accessed March 03, 2021] Available at: iopscience.iop.org/article/10.1088/1748-9326/aaa00e.
[5] ScienceDaily, Temperature. [Online] 2021 [Accessed March 14, 2021] Available at: https://www.sciencedaily.com/search/?keyword=temperature#gsc.tab=0&gsc.q=temperature&gsc.page=1.
[6] S. Russo, J. Sillmann, and A. Sterl, Humid heat waves at different warming levels [Online] 2017 [Accessed March 14, 2018] Available at: www.nature.com/articles/s41598-017-07536-7.
[7] E. Stephens J.J. Day F. Pappenberger and H. Cloke, Precipitation and floodiness. Geophysical research letters. AGU Publications. [Online] 2015 [Accessed March 03, 2021] Available at: onlinelibrary.wiley.com/doi/10.1002/2015GL066779/epdf.
[8] World weather Online [2021] [Accessed March 14, 2021] Available at: http://worldweather.wmo.int/en/city.html?cityId=8.