Environment Protection Engineering

Vol. 39 2013 No. 4

DOI: 10.5277/epe130407

MERT EKŞİ[1]

A FIELD STUDY TO EVALUATE THE RUNOFF QUANTITY AND STORMWATER RETENTION OF A TYPICAL EXTENSIVE GREEN ROOF IN BAHÇEKÖY, ISTANBUL

Impervious surfaces in urban areas are increasing as a result of urbanization and development. Roof surfaces constitute a large portion of impervious cover in cities. Within the scope of the sustainability principle and urban policies in the world, water retention benefits of the green roofs to the urban environment have been assessed with various academic studies. In recent years, green roof systems are being used to reduce stormwater runoff in urban areas. In the research, main aim was to determine the rainfall–runoff relationship of a typical extensive green roof with 50 mm thick substrate and to perform comparisons with an unvegetated roof based on field measurements. Hydrological performance of green roofs such as water retention and runoff delay were investigated in local climate of Bahçeköy, Istanbul. Through comparative field measurements at Istanbul University Faculty of Forestry Landscape Architecture Department, Green Roof Research Station (IUGRRS), stormwater retention performance of green roofs was investigated in terms of sustainability. From the derived data, moisture changes in the substrate, outdoor environment interactions and the runoff characteristics of the green roofs were evaluated. According to rainfall characteristics, a typical extensive green roof system delayed the runoff between 1 to 23 h in several rain events and prevented the runoff between 12.8% and 100%. Overall, green roof systems may provide an alternative and sustainable solution for the impervious roof surfaces in cities.

1. INTRODUCTION

In developed countries, the level of urbanization is still increasing and expected to reach 83% in 2030 [1]. Roof surfaces account for a large portion of their impervious cover. Establishing vegetation on roof-tops, known as green roofs, is one method of recovering lost green space that can aid in mitigating stormwater runoff [2]. Rainfall in urban areas is typically more problematic than in rural areas, because of impervious

[1]Istanbul University Faculty of Forestry Landscape Architecture Department, Bahçeköy/Sariyer 34473, Istanbul, Turkey, e-mail: merteksi@istanbul.edu.tr

surfaces such as roofs, parking lots and roads [3]. Compared to other local stormwater management solutions, green-roofs have the advantage of requiring no additional space, as land can be at a premium in urban areas. Conversely, they have the potential to transform between 40 and 50% of the total impervious areas of cities into usable space [4].

Rapid runoff from roofs and other impervious surfaces can exacerbate flooding, increase erosion, and result in combined sewer overflows that could potentially discharge raw sewage directly into our waterways [2]. According to USEPA [5], a typical city block generates more than times more runoff than a woodland area of the same size.

Green roof vegetation can influence hydrological performance in a number of ways: through interception and evaporation of rainfall by the vegetation canopy and plant surfaces, through uptake and storage of water in plant tissues, and through transpiration of water from the plant back to the atmosphere [6]. Green roofs may significantly reduce the runoff peak of the most rainfall events. The reduction consists in: (i) delaying the initial time of runoff due to the absorption of water in the green roof system; (ii) reducing total runoff by retaining a part of rainfall; (iii) distributing the runoff over a long time period through a relative slow release of the excess water that is temporary stored in pores of substrate [7].

Research studies show that green roofs can reduce the stormwater runoff in urban scale. Gregorie and Clausen [8] discovered that a green roof with a substrate depth of 10 cm can retain 41.6% of the precipitation. In another research, Vanwoert et al. [2] tested various roof surface treatments to quantify differences in stormwater retention of a standard commercial roof with gravel ballast, an extensive green roof system without vegetation, and a typical extensive green roof with vegetation. Overall, mean percent rainfall retention ranged from 48.7% (gravel) to 82.8% (vegetated). Berghage et al. [9] report that a green roof can retain over 50% of the total precipitation. In addition nearly all the precipitation was retained during summer months. During the winter, retention was smaller (<20%) [9].

Hilten et al. [10] determined the effectiveness of green roofs to mitigate stormwater with a computer simulation model. Simulations showed that green roofs are highly effective for small storms (<2.54 mm). For larger storms (>2.54 mm), green roofs can act to extend runoff duration thereby reducing surge normally evident with impervious surfaces [10]. Similar to simulation studies, Carter and Rasmussen [11] found that green roof precipitation retention decreased with precipitation depth; ranging from just under 90% for small storms to slightly less than 50% for larger storms (>7.62 cm). In addition, plants have an effect to water retention. Rowe et al. [12] found that Sedum vegetation cover increased rainfall retention from 63% to 66% compared with substrate alone. The range in retention observed is partly due to time of year studied, sampling methods, climate, and the method used to calculate retention [12].

Main aim of this study was to design and install a research site, Istanbul University Faculty of Forestry Landscape Architecture Department, Green Roof Research Station (IUGRRS), and to evaluate stormwater runoff characteristics of a typical extensive green roof through comparative field measurements in Bahçeköy, İstanbul region. The expectation is that stormwater retention data presented here will provide a basis for the behavior of a typical extensive green roof in climate conditions of Istanbul.

2. EXPERIMENTAL

Bahçeköy region is located on the northern part of Istanbul which has a slightly different precipitation characteristics compared to the Istanbul averages. Climate of the Istanbul city is Mediterranean and through the Northern parts it is somewhat modified by the cooler Black Sea and northerly colder air masses of maritime and continental origins. This type is locally called "the Black Sea Climate" and described as having lower temperatures in both winter and summer, and usually experiences more rains compared to the climate of the Mediterranean coasts of Turkey [13]. According to meteorological data obtained from the State Meteorological Service of Turkey, average annual precipitation of Istanbul is about 650 mm and the northern parts of Istanbul receive 850 mm precipitation per year which is 200 mm more than Istanbul average.

In this local climate, two roof surfaces with overall dimensions of 3.20×3.20 m were allocated on the research station IUGRRS. On these two roofs, a typical extensive green roof and a reference bituminous one were installed. Roof of the research station was built with the slope of 1%. Green roof system (GR) had a total thickness of 90 mm and consisted of two-layer FLL certificated waterproofing membrane, water retention mat (4.5 mm), drainage layer (Zinco FD25, 25 mm), filter cloth, substrate (50–55 mm Zincolite) and vegetation. Reference roof (RR) consisted of two-layer water insulation membrane. Upper layer of water insulation was covered with a mineral-coated water insulation membrane.

During rainfall, while water passing through the green roof system, green roof substrate saturated with sufficient rainfall and excess water passed through the filter cloth to the drainage layer. The drainage layer fills with water and drains the excess water to the water retention mat. Saturated retention mat releases the excess water to the drainage system. Water released to the drainage system generates the runoff from the roof system. Green roof system which was used in this research has the water holding capacity of 20–30 dm^3/m^2 and total water holding capacity of the green roof system can be calculated as 300 dm^3.

Three drought tolerant plant species included *Sedum reflexum*, *Sedum spurium* Album and *Sedum spurium* Atropurpureum were selected in this study. The plant mix was applied as plugs on 18 September 2010. After planting, plant coverage was about 40%. During research, plant coverage on the roof reached up to 85%.

To record meteorological parameters (ambient air temperature, relative humidity, wind direction and speed, etc.), an automated weather station was installed 200 cm above the roof (DeltaOhm HD2003 Three Axis Ultrasonic Anemometer). For the precipitation measurements, rain gauge (DeltaOhm HD 2003 tipping bucket) were mounted on the roof (Fig. 1).

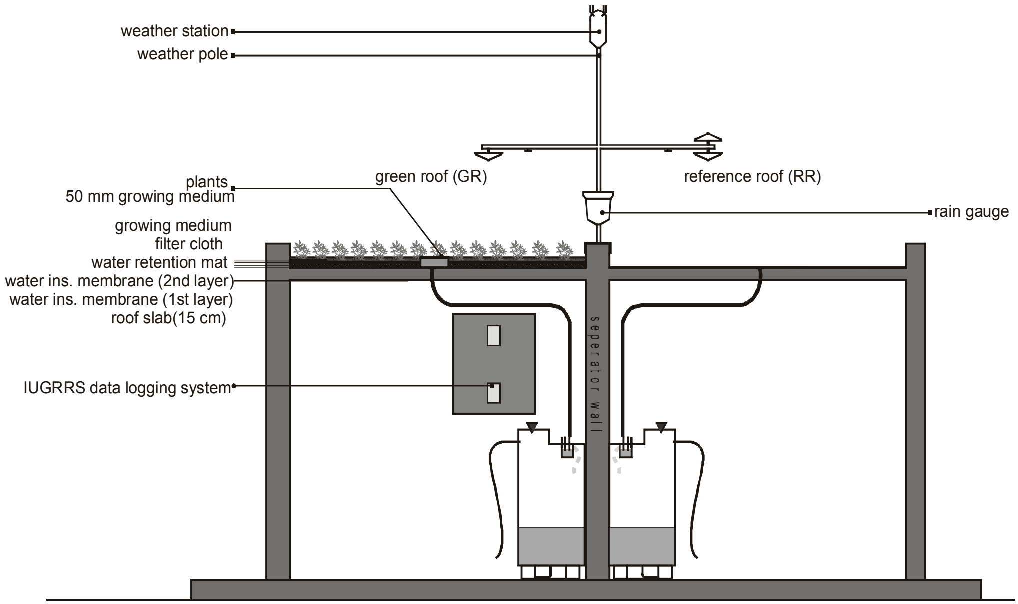

Fig. 1. Section drawing of the IUGRRS

During the rain, the runoff from the roofs was drained through the pipes inside the research station and collected in cylindrical polyethylene containers (container dimensions: r = 21.5 cm, h = 79 cm). The travel time from the roof surface drain to the weirs through the drainage pipe was negligible. In the containers, increase of the water column was measured with the ultrasonic level transmitters. Drainage of water from the roofs (control and treatment) was monitored and recorded at 15 min intervals with a ultrasonic level transmitter (ENSIM, EL-ORION-201). With the start of the rain, drained water from the roof systems filled the container and instant runoff (peak flow rate) could be monitored. After each rain event, containers were emptied (Fig. 2).

Runoff from the roofs was adjusted to calculate the instant runoff during a rain event. Containers used in this research had the base area of 0.012 m^2. Results of measurements from the level transmitter (in mm) were converted to obtain actual instant runoff in mm, to provide comparable units with the precipitation data (e.g. the height of the 100 mm water column in the container was multiplied by 0.012 m^2. Runoff amount can be calculated as 0.012 $m^2 \times 0.1$ m = 0.0012 m^3).

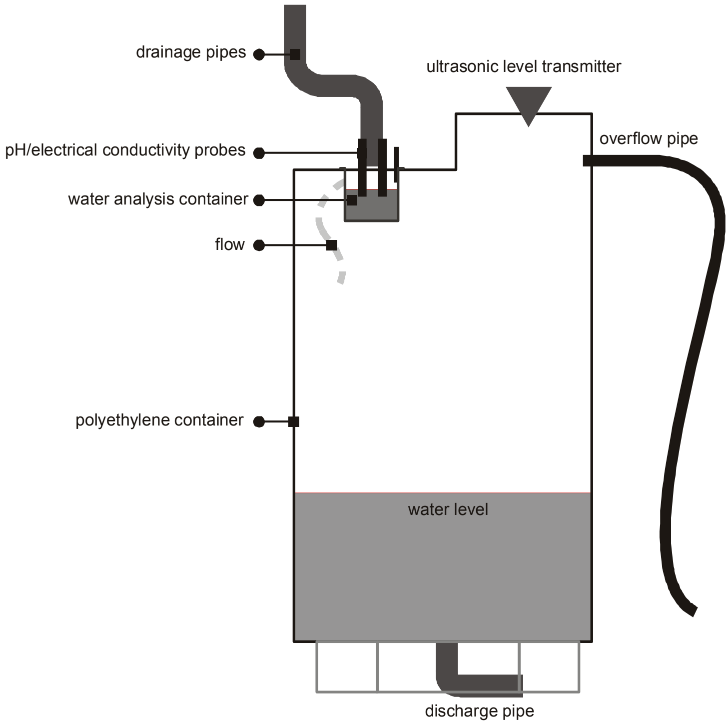

Fig. 2. Container system for monitoring rooftop stormwater runoff

In the study period, runoff measurements were calculated from randomly selected rainy days of the four different seasons. During rain events, instant runoff (peak flow) from the roof systems was determined with the measurements performed in 15 min intervals.

3. RESULTS AND DISCUSSION

Daily distribution of the precipitation and runoff values were analyzed to obtain the stormwater runoff characteristics of roof systems. In addition, moisture level of the growing media and runoff relations were analyzed.

During the study period, the longest drought period was 39 days which was observed between 12 August and 20 September 2011. The second longest drought period was observed between 3 July and 10 August 2011 which consisted of 33 days. Moisture content of the green roof growing media is given in Table 1.

Table 1

Moisture content of green roof growing media, total precipitation and drought periods (monthly average values)

Month	Total precipitation [mm]	Variation of the moisture content of growing media in maximum drought periods [centibars]	Drought period [days]	Air temperature [°C]	Substrate temperature [°C]
December	87.2	13.8–16.81	12	10.7	7.6
January	112.1	15.52–13.17	8	6.5	4.2
February	52.0	15.75–141.33	14	6.3	4.0
March	46.3	16.57–35.50	5	8.8	6.7
April	95.7	13.37–124.47	6	10.4	10.2
May	46.5	21.82–200.0	22	16.1	19.2
June	14.2	200.0–200.0	12	20.8	26.3
July	24.7	103.30–200.0	29	23.6	31.0
August	24.7	13.17–200.0	20	22.2	26.8
September	28.1	200.0–200.0	20	21.5	23.8
October	93.6	9.38–173.0	8	15.3	12.4
November	68.0	14.15–15.36	5	11.9	6.5

As seen in Table 1, drought periods have significant effect on moisture content and temperature variation of the growing media. Despite similar precipitation values, moisture level in the growing media varied due to drought periods. Temperatures of the growing media were affected by the moisture level due to low evaporation.

In randomly selected days, runoff characteristics of the roof systems were analyzed. Amount of precipitation ranged between 3 and 40.6 mm in selected days. In Table 2, precipitation and runoff volumes of the roof systems in randomly selected days during research period are shown.

In spring, 14 April 2011, due to moisture content in the growing media, the runoff observed from the green roof was relatively lower than from the reference roof. Green roof delayed the runoff over 3 h and reduced its volume by 41%. The green roof system retained 59% of the total daily precipitation of 10.3 mm. In 18 April 2011, a heavy rainfall occurred with the total amount of 27.4 mm. With the beginning of the rainfall, runoff from the reference roof had instantly reached its peak level. However, the amount of water drained from the green roof system reached its peak level in 9 h. While green roof delayed the runoff, it also provided a runoff retention ratio of 32.8%.

In summer season, moisture content in the substrate of the green roof significantly decreased due to consecutive days without rainfall. Thus, green roof mostly retained rainfall. After thirty days of drought period, rainfall occurred with the total amount of 3.8 mm in 13 June 2011. In this rain event, the green roof retained whole precipitation and prevented runoff. In addition, despite the rainfall, moisture content of the growing media remained on same level.

Table 2

Precipitation, runoff volumes and runoff reduction of the roof systems in selected days

Date	Total precipitation [mm]	RR runoff [mm]	GR runoff [mm]	Runoff reduction [%]	Runoff delay [h]
06.01.2011	4	69.6	57.8	17.0	–
19.02.2011	3.4	76.3	0.0	100.0	–
10.03.2011	3.3	177.2	113.1	36.1	–
14.04.2011	10.3	223.1	130.7	41.4	3
18.04.2011	27.4	950.7	638.5	32.8	9
04.05.2011	40.6	174	130	25.6	1
13.06.2011	3.8	86.2	0.0	100.0	–
11.08.2011	24.6	70.7	23.4	66.9	14
21–22.09.2011	5.6	37.2	0.3	99.2	23
30.09.2011	22.1	187.3	80.0	57.3	14
09.10.2011	21.7	247.0	100.9	59.2	11
14.10.2011	19.4	107.6	93.8	12.8	1

During the research period, the longest drought period was observed between 2 July and 11 August 2011 which can be expressed as 39 days of consecutive rainless days. In this drought period, moisture content in the growing media significantly decreased. At the end of drought period, at 11 August 2011, a heavy rainfall occurred with the total amount of 24.6 mm. Green roof retained 20 mm of total precipitation and delayed the runoff for 14 h. In addition, rapid increase in the moisture content of the growing media was detected after rain started. Moisture content of the growing media increased from 200 centibars to 10 centibars with 24.6 mm of precipitation after 39 days of the drought period (Fig. 3). In total, 200 mm of the runoff was retained by the green roof system.

Moisture content of the growing media decreased from 30 centibars to 200 centibars in the first 6 days of drought period (Fig. 4) Decrease in the moisture content resulted in the increase on the temperature of the growing media.

In autumn, after the drought summer period, first heavy rainfall was observed in 30 September 2011 which has the total amount of 22.1 mm. Green roof delayed the runoff for 14 h and retained 17.4 mm of rainfall. Green roof system reduced the amount of runoff by 57% compared to the reference roof. In 9 October 2011, green roof delayed and reduced the amount of the runoff during rainfall. Total rainfall recorded was 21.7 mm and the green roof reduced the runoff by 59.2%. Runoff delay provided by the green roof system was recorded as 11 h.

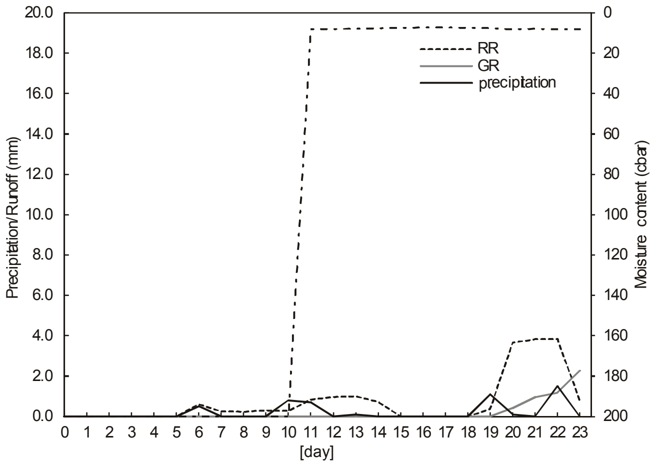

Fig. 3. Variation in moisture content of the growing media after drought period in 11 August 2011

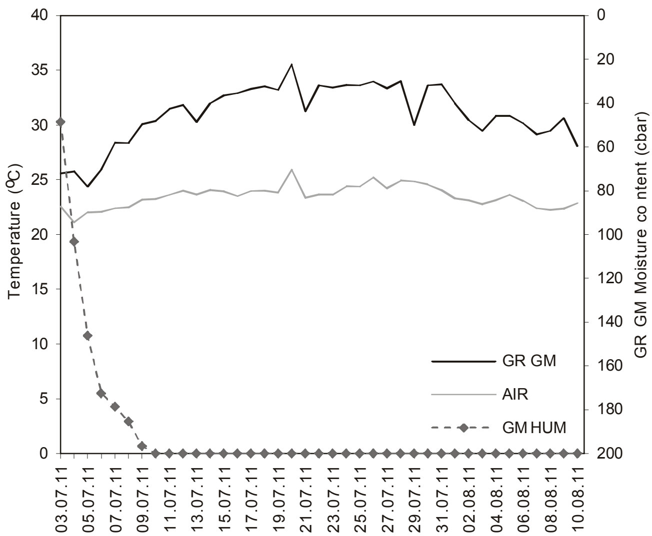

Fig. 4. Variation in moisture content of the growing media in the longest drought period

Runoff values of the roof systems and precipitation pattern are shown in Fig. 5. The runoff from the reference roof has shown similar characteristics with the rainfall, while that observed from the green roof varied due to the retention ability of the green roof. This variation occurred according to the moisture content in the green roof media and evaporation rates. The saturation ratio of the growing media has increased the runoff from the green roof.

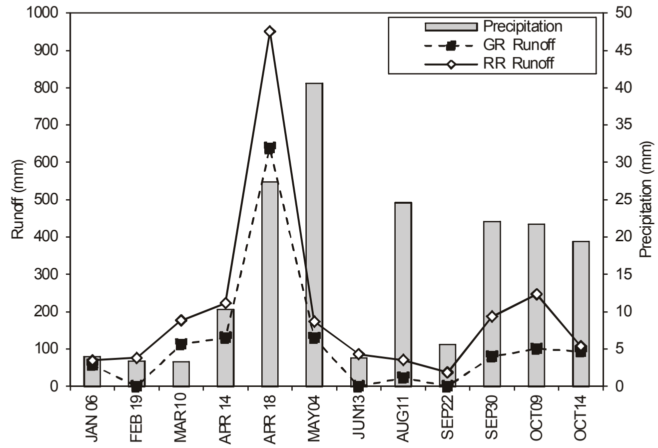

Fig. 5. Precipitation and runoff values of roof systems in selected days

4. CONCLUSION

Runoff characteristics and stormwater retention abilities of two roof systems were analyzed through comparative field measurements in the climate conditions of Bahçeköy, Istanbul. During the research period, a typical extensive green roof system retained greater quantities of stormwater than the reference roof with a bituminous membrane. Precipitation usually drained directly by the reference roof to the sewer system. Vegetation, growing media, drainage layer and water retention mat affected the runoff volume and increased the retention ability of the green roof.

During the research, drought periods significantly affected the temperature and moisture level of the growing media. Upon increasing the air temperature, shallow growing media of the green roof (50 mm) failed to retain moisture. However plants on the roof benefited from the vaporized water from its lower layers and survived from these tough conditions. Media depth (50 mm) influenced the moisture content in the growing media. Especially during drought periods in summer, decrease in the moisture content was evident. After heavy rainfall, moisture content in the growing media was evaporated in 6 days. It was seen that deeper substrates will retent higher amount of water.

Plants on the roof withstand to drought periods up to 30 days and extreme weather conditions like snow and rain events. Plant growth on the roof was not remarkable in November 2010 to April 2011 because of seasonal conditions. Towards the end of April, with the increase in air temperature and seasonal change, plant coverage on the roof reached 82%.

Green roof system delayed the runoff between 1 to 23 h in several rain events. In summer, retention ability of the green roof system was higher because of the moisture content of growing media. In addition, green roof prevented the runoff between 12.8% to 100%. In general, conventional roof generated by 43% more runoff than the reference roof. Results show that green roofs are highly effective for light precipitation events (3.0 mm<) and the retention was smaller during the winter. For larger rain events, it was observed that the green roof provided a delay in peak flow of runoff. Obtained results correspond to the findings of other researchers [2, 8, 9, 10].

Overall, green roofs have ability to reduce the runoff compared to the runoff which is generated by impervious surfaces and conventional roof systems. Despite the limited substrate depth of 50 mm, obtained results show that green roof systems can be used as tool for mitigating stormwater runoff and reduce the load to the sewer system in the Istanbul climate. However, green roofs will never fully solve the urban runoff problem. This structure needs to be planned with other runoff reduction solutions and especially green spaces. In addition, deeper substrates will increase the stormwater retention ability of the green roofs. Green roofs must be taken into consideration by the city planners and decision makers for sustainable urban planning and reuse of water. In Istanbul, this new concept can be implemented as an urban policy to reduce the negative effects of urbanization and impervious surfaces.

ACKNOWLEDGEMENTS

This study is a part of the research project *Evaluation of the Green Roof Systems in Terms of Water and Energy Balance: A Case Study in Istanbul* conducted at the Istanbul University Institute of Science and supported by the Istanbul University Scientific Research Projects Department with the project No. 10207.

REFERENCES

[1] *Millennium Ecosystem Assessment, Ecosystems and Human Well-being Current State and Trends*, United Nations, Island Press, Washington, DC, 2005.

[2] VANWOERT N.D., ROWE D.B., ANDRESEN J.A., RUGH C.L., FERNANDEZ R.T., XIAO L., *Green roof stormwater retention: effects of roof surface, slope, and media depth*, J. Environ. Qual., 2005, 34 (3), 1036.

[3] TEEMUSK A., MANDER U., *Rainwater runoff quantity and quality performance from a green roof. The effects of short-term events*, Ecol. Eng., 2007, 30, 271.

[4] VILLARREAL E.L., BENGTSSON L., *Response of a Sedum green-roof to individual rain events*, Ecol. Eng., 2005, 25, 1.

[5] U.S. Environmental Protection Agency, *Report on protecting water quality from urban runoff*, Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division Cincinnati, OH, 2003, AEPA 841-F-03-003.

[6] DUNNETT N., NAGASE A., BOOTH R., GRIME P., *Influence of vegetation composition on runoff in two simulated green roof experiment*s, Urban Ecosyst., 2008, 11, 385.

[7] MENTENS J., RAES D., HERMY M., *Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century*, Landscape Urban Plan., 2006, 77, 217.

[8] GREGOIRE B.G., CLAUSEN J.C., *Effect of a modular extensive green roof on stormwater runoff and water quality*, Ecol. Eng., 2011, 37, 963.

[9] BERGHAGE R.D., BEATTIE D., JARRETT A.R., THURING C., RAZAEI F., O'CONNOR T.P., *Green roofs for stormwater runoff control*, National Risk Management Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH, 2009, 9-26. EPA/600/R-09/026, <www.epa.gov/ord>.
[10] HILTEN R.N., LAWRENCE T.M., TOLLNER E.W., *Modeling stormwater runoff from green roofs with HYDRUS-1D*, J. Hydrol., 2008, 358, 288.
[11] CARTER T.L., RASMUSSEN T.C., *Hydrologic behavior of vegetated roofs*, JAWRA, 2007, 42 (5),1261.
[12] ROWE D.B., RUGH C.L., VANWOERT N.D., MONTERUSSO M.A., RUSSELL D.K., *Green roof slope, substrate depth, and vegetation influence runoff*, Proceedings of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities Chicago, The Cardinal Group, Toronto, 2003, 354–362.
[13] EZBER Y., SEN O.L., KINDAP T., KARACA M., *Climatic effects of urbanization in Istanbul. A statistical and modeling analy*sis, Int. J. Climatol., 2007, 27, 667–679.