The analysis of the possible use of harvested rainwater and its potential for water supply in real conditions

GABRIEL MARKOVIČ, DANIELA KAPOSZTÁSOVÁ, ZUZANA VRANAYOVÁ
Faculty of Civil Engineering, Instituteof Architectural Engineering
Technical University of Kosice
Vysokoškolská 4, 042 00, Kosice
SLOVAKIA
gabriel.markovic@tuke.sk, daniela.ocipova@tuke.sk, zuzana.vranayova@tuke.sk

Abstract: - Activities such as flushing toilets, washing floors or cars, irrigation orlaundry can be easily replaced by rainwater instead of precious drinking water. Continuous growth of population and consequent growing need for drinking water is a global problem. Taking into account that there are still 768 million people in the world without access to water and there are still more than 2.5 billion people without access to improved sanitation[10], any way to save drinking waterhas a great importance.

Key-Words: -rainwater, runoff, coefficient, drinking water, rainfall, measuring

1 Introduction

The use of rainwater is an alternative method of water supply compared to the traditional way through the public water supply.

Every building has potential to be used for capturing rainwater. Rainwater can be used for various activities in the buildings:

- flushing the toilet
- irrigation
- washing
- laundry
- use of rainwater for heating system
- rainwater is used also as drinking water after necessary treatment in some countries

Figure 1 shows the average daily consumption of water of a household - 150 l/person per day. It shows that about 60% of drinking water may be replaced by rainwater. This fact gives credit to reuse of rainwater mostly from the environmental point of view. Among other, reuse of rainwater minimizes the flow of rainwater to waste-water disposal system. Even though rooftop surface represents only a fragment of all urban surface area, drainage of rainwater from rooftops into storage reservoirs minimizes the flow of rainwater to waste-water disposal system and has positive impact on sewerage system[1], [2].

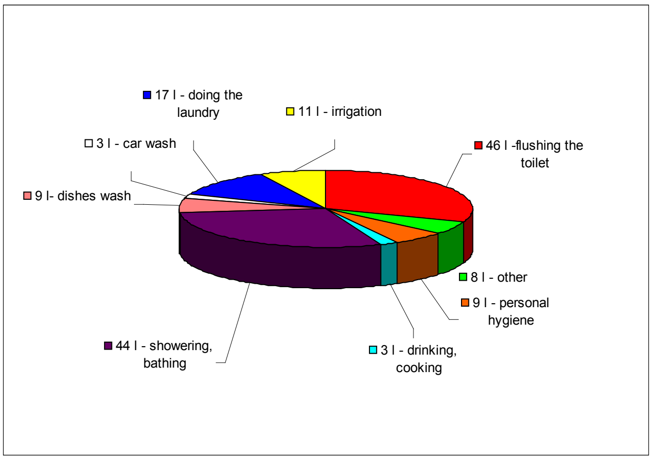

Fig. 1 average water consumption of a household (average consumption 150 l/(person per day))

. There are many methods how to accumulate rainwater.Storage reservoir represents main component of whole system of rainwater reuse.Generally, storage reservoir for rainwater can be located underground, aboveground or can be made as a part of building construction.

Equipment for reuse of rainwater is composed of these main parts:

- rainwater storage reservoir
- water pump
- filters
- pipelines

Fig. 2 System of rainwater harvesting [13]

2 Experimental research in the campus of TU Košice

The project APVV SUSPP-0007-09 relating to quality and quantity of rainwater, taking place at the Faculty of Civil Engineering in Košice-city. The sources tested are located in the premises of TUKE (Technical University of Kosice). The resources that provide us information about the quality and quantity of rainwater are located in the campus of Technical University of Kosice. First is rain gauge (Figure 3) located on the roof of University library and second is real school building PK6. All rainwater runoff from roof of this building is flow into the two infiltration shafts (Figure 4). Roof area of the PK6 building is 548,55 m^2(Figure 5).

Fig. 3 rain gauge on the roof of University library

Fig. 4 location of infiltration shafts near building PK6

Both infiltration shafts are located at the east side of the building PK6. The shafts are realized from concrete rings with the outer diameter of 1000 mm. The measuring devices that provide us information about volume of incoming rainwater from the roof of the building PK6 and also information about the quality of rain water are located in these infiltration shafts [9].

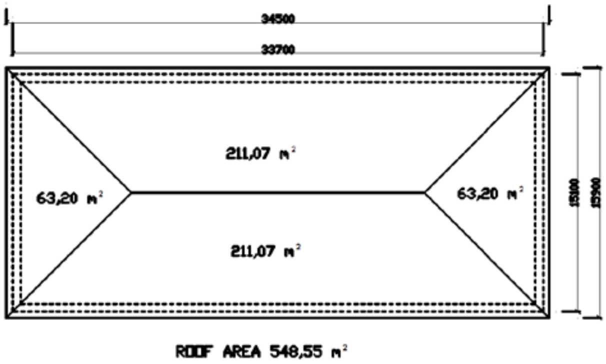

Fig. 5: Ground plan of PK6 roof

2.1 Measuring devices

Headquarters, respectively a control/data unit for generating of measurement data, is a universal data unit M4016, which is situated in the infiltration shaft A (Figure 6). Infiltration shaft B, respectively devices located in this shaft, are also connected to the control unit.

Fig. 6 data unit M4016 in shaft A

Registration and control unit equipped unit M4016 includes universal data logger, telemetric station with build-in GSM module, programmable control automat and multiple flow meter if M4016 is connected to an ultrasonic or pressure level sensor (Figure 6) [8].

Under inflow, respectively rain outlet pipe in the shaft, there are measurement flumes for metering of inflow rainwater from the roof of a building PK6 in both of infiltration shafts. Rainwater from the roof of the building PK6 is fed by rainwater pipes directly into measurement flumes, which are placed under the ultrasonic level sensor which transmitting data of the water level in the measurement flumes to the data unit M4016 (Figure 7).

The unit M4016, in which the signal transmitted from the ultrasonic level sensor is preset up to 14 equations or the most used sharp crested weirs. Flow rate calculation from relationship water level/flow rate. For the purposes of our measurements is to calculate the instantaneous and cumulative flow, calculated from water level used by predefined profile - Thomson weir.

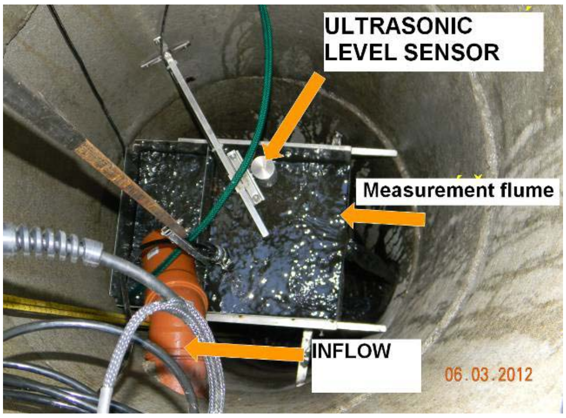

Fig. 7 measurement flume with ultrasonic level sensor in shafts[9].

Thomson weir consists of two overflow edges with an angle of 90°. Axis of this angle must be vertical (Figure 8) [4].

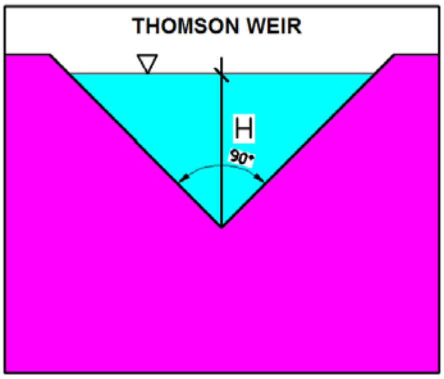

Fig. 8: Thomson weir

3Analysis of system design uses rainwater for water supply

Totals of rainfall represent the theoretical amount of rainfall in mm, falling on surface of interest. Totals of rainfall depend on specific locations.

The average of yearly totals of rainfall is about 770 mm/year in Slovakia.

In general, the rainwater harvesting system depends on:

- Required volume of water
- The amount of precipitation
- The size of roof or another catchment surfaces

2.1 Water demand in PK6 building

As already mentioned above, the research is done in the area of Kosice - at the campus of Technical University of Košice. Mentioned PK6 building is one of the buildings at the campus of Technical University of Košice with two infiltration shafts for rainwater runoff. All rainwater runoff from roof of this building is flow into the two infiltration shafts where are located the measuring devices for measuring the inflow volume of rainwater. Therefore, our analysis can be processed for this building.

The PK6 building has 20 employees and learning capacity is for 401 students. We will consider using rainwater only for flushing toilets for students 6 l/day and staff 12 l/day [3]. Considered daily water demand for students will be 30% of maximum capacity. Table 1shows the calculated daily water demand for flush the toilet in building PK6 and Table 2 summarized monthly water demand.

Tab. 1daily water demand in PK6 building

Water demand for flush the toilet in PK6 building Q_{wc}			
employees	20 pers.	12 l/pers.day	240 l/day
students	120 pers.	6 l/pers.day	720 l/day
			960 l/day
			0,96 m^3/day

Tab. 2monthly water demand in PK6 building

Waterdemandforflushthetoilet in PK6 building			
Month	Workingdays	Q_{wc} (m^3/day)	Q_{wc} (m^3/month)
January	20	0,96	19,2
February	20	0,96	19,2
March	23	0,96	22,08
April	19	0,96	18,24
May	22	0,96	21,12
June	22	0,96	21,12
July	20	0,96	19,2
August	22	0,96	21,12
September	20	0,96	19,2
October	21	0,96	20,16
November	20	0,96	19,2
December	21	0,96	20,16
			240 m^3/year

Initial measurements start and continue in infiltration shaft A since March 2011, when began to measure the inflow of rainwater runoff from the part (212 m^2) of roof of the building PK6. Table 3 represents the measured volumes of rainwater from the roof area of 212 m^2 of PK6 building.

In March 2012, the research was extended of measurements of rainwater quantity in infiltration shaft B. It provides us data of rainwater quantity from all roof area (548,55m^2) of PK6 building. Table 4 represents the measured volumes of rainwater from all roof area 548,55m^2 of PK6 building. (Notice: august 2012 without data due to equipment failure)

Tab. 3 Rainwater inflow to Shaft A – from 212 m^2 of roof

Date	**Volumeofrainwaterinflow to Shaft A – from 212 m^2ofroof (m^3)**
March 2011	7,38
April 2011	1,47
May 2011	23,29
June 2011	23,45
July 2011	36,18
August 2011	6,47
September 2011	3,97
October 2011	3,23
November 2011	0
December 2011	9,75
January 2012	3,22
February 2012	0,32
March 2012	14,48

Tab. 4 volume of rainwater inflow to both shafts – from all roof area 548,55m2

Date	**Volumeofrainwaterinflow to bothshafts A+B fromall 548,55m^2ofroof (m^3)**
April 2012	26,72
May 2012	10,91
June 2012	40,75
July 2012	41,56
August 2012	-
September 2012	17,93
October 2012	36,47
November 2012	16,94
December 2012	12,05
January 2013	17,92
February 2013	15,5
March 2013	16,77
April 2013	9,77
May 2013	30,55
June 2013	30,17
July 2013	36,63
August 2013	3,78
September 2013	8,94
October 2013	13,72
November 2013	38,39
December 2013	1,27

Tab. 5 volume of rainwater inflow to shaft A – from roof area 212 m^2

Date	**Q_{wc} (m^3/month)**	**Real volume inflow (m^3)**	**excess/lack of water (m^3)**
March 2011	22,08	7,38	-14,7
April 2011	18,24	1,47	-16,77
May 2011	21,12	23,29	+2,17
June 2011	21,12	23,45	+2,33
July 2011	19,2	36,18	+16,98
August 2011	21,12	6,47	-14,65
September 2011	19,2	3,97	-15,23
October 2011	20,16	3,23	-16,93
November 2011	19,2	0	-19,2
December 2011	20,16	9,75	-10,41
January 2012	19,2	3,22	-15,98
February 2012	19,2	0,32	-18,88
March 2012	22,08	14,48	-7,6

Table 5 represents the measured volumes of rainwater from the roof area (212m^2) of PK6 building compared with the water demand for flush toilets. From Table 5 shows that, although this is not volume of rainwater from all roof area, water demand is ensured in some months.

Table 6 contains the measured volumes of rainwater from the all roof area of PK6 building compared with the water demand for flush toilets.

Tab. 6 volume of rainwater inflow to both shafts – from all roof area 548,55m^2

Month	Q_{wc} (m^3/month)	Real volume inflow (m^3)	excess/lack of water (m^3)
April 2012	18,24	26,72	+8,48
May 2012	21,12	10,91	-10,21
June 2012	21,12	40,75	+19,63
July 2012	19,2	41,56	+22,36
August 2012	21,12	-	-
September 2012	19,2	17,93	-1,27
October 2012	20,16	36,47	+16,31
November 2012	19,2	16,94	-2,26
December 2012	20,16	12,05	-8,11
January 2013	19,2	17,92	-1,28
February 2013	19,2	15,5	-3,7
March 2013	22,08	16,77	-5,31
April 2013	18,24	9,77	-8,47
May 2013	21,12	30,55	+9,43
June 2013	21,12	30,17	+9,05
July 2013	19,2	36,63	+17,43
August 2013	21,12	3,78	-17,34
September 2013	19,2	8,94	-10,26
October 2013	20,16	13,72	-6,44
November 2013	19,2	38,39	+19,19
December 2013	20,16	1,27	-18,89

Figure 8 represents a graph for number of possible toilet flush with rainwater inflow from roof of PK 6 building per month from March 2011 to December 2013 what is the amount of drinking water saved in the building PK6. Water consumption per one flush is 6 liters.

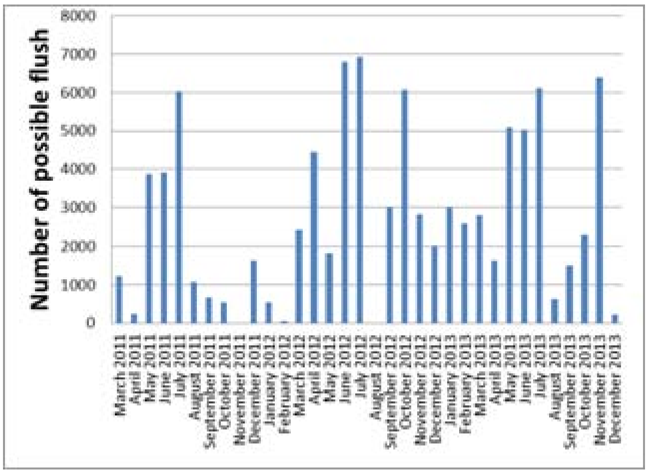

Fig. 8number of possible toilet flushes per month from March 2011 to December 2013in PK6 building

2.1 Rainfall intensity and catchment surface

As already mentioned above, the research is done in the area of Kosice. Figure 9 represents a graph of annual precipitation for the Kosice-city [5] in the years 1900 to 2010, with an average value of annual precipitation for this period about 638 mm/year.

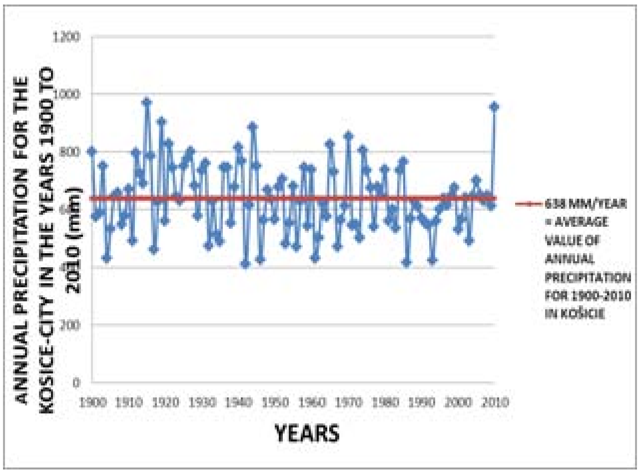

Fig. 9 annual precipitation for the Kosice in the years 1900 to 2010 [5]

Intensity of rainfall in combination with rooftop area or another paved surface will determine maximum volume of rainwater possible to capture and accumulate. Determination of the theoretical volume of rainwater from the catchment area can be determined by the equation:

$$V_{rain} = z_{year}.A.C \qquad (1)$$

Where:

V_{rain} – theoretical volume of rainwater

z_{year} – average yearlong precipitation depth for chosen locality (mm/year),

A – roof or another catchment area (m^2)

C – runoff coefficient (non–dimensional coefficient)

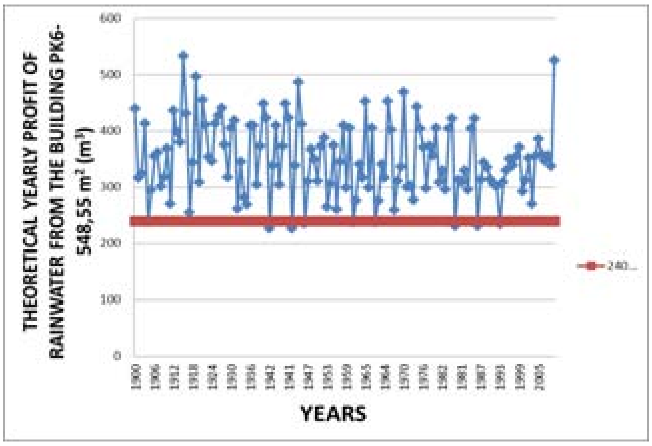

Fig.10theoretical yearly profit of rainwater from the roof area 548,55 m2 of PK6 building against water demand 240 m^3/year in the years 1900 to 2010

If we consider the surface of the roof of the building PK6 548,55m^2, figure 10 shows the theoretical yearly volume of rainwater. Runoff coefficient was considered as C=1, according to Slovak standard STN 73 6760 (table 7) [6].

According to yearly precipitation from the years 1900-2010 for the city of Kosice is apparent that the water demand240 m^3/year for toilet flush in PK6 building would be fulfilled in most of years (Figure 10).

Tab. 7runoff coefficient according to Slovak standard STN 73 6760

Type ofdrainedsurface	Runoffcoefficient C (-)
Rooftops, balconies, roofdecks[a)]	1,0
Rooftopswithpermeablesurfacethickert han100 mm	0,5
[a)] Rainwater drainage coefficient C = 0,8 can be used for rooftops with area over 10 000 m^2	

However, a more accurate view provides analysis of monthly precipitation totals. As already mentioned above, one resource that provides us information about quantity of rainwater is rain gauge located in the campus of Technical University of Kosice on the roof of University library. Figure 11 represents a graph of measured values of rainfall during our research from August 2011 to December 2013.

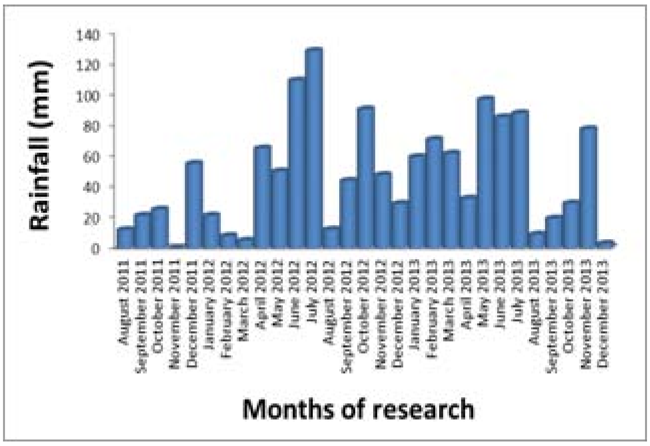

Fig. 11graph of measured values of rainfall during our research

Table 8 summarizes the measured monthly rainfall totals with corresponding theoretical volumes of collected rainwater. Data are presented for the period April 2012 to December 2013 because at that time began measuring of the flow from all roof area of the building PK6 and precipitation measurements simultaneously.

Tab. 8theoretical volume of rainwater from PK6 building (548,55m^2) according to the measured values of precipitation from April 2012 to december 2013

Month	Rainfall (mm)	Theoretical volume from 548,55 m^2(m^3)
April 2012	65	35,65
May 2012	50	27,42
June 2012	109	60,01
July 2012	129	70,65
August 2012	12	6,69
September 2012	44	24,02
October 2012	91	49,69
November 2012	48	26,11
December 2012	29	15,79
January 2013	59	32,58
February 2013	71	38,83
March 2013	62	33,79
April 2013	32	17,66
May 2013	97	53,20
June 2013	85	46,84
July 2013	88	48,27
August 2013	9	4,93
September 2013	19	10,53
October 2013	29	15,90
November 2013	78	42,56
December 2013	3	1,64

Tab. 9measured monthly rainfall totals with corresponding theoretical volumes of collected rainwater and real amount of rainwater from roof of PK6 building (548,55m^2) C=1,0

Month	Rainfall (mm)	Teoretical volume from 548,55 m^2(m^3)	Real volume from 548,55 m^2(m^3)	%
April 2012	65	35,65	26,72	**74,9**
May 2012	50	27,42	10,91	**68,8**
June 2012	109	60,01	40,75	**67,9**
July 2012	129	70,65	41,56	**70,1**
August 2012	12	6,69	-	**-**
September 2012	44	24,02	17,93	**74,6**
October 2012	91	49,69	36,47	**73,4**
November 2012	48	26,11	16,94	**64,9**
December 2012	29	15,79	12,05	**76,3**
January 2013	59	32,58	17,92	**61,1**
February 2013	71	38,83	15,5	**60,5**
March 2013	62	33,79	16,77	**67,4**
April 2013	32	17,66	9,77	**66,6**
May 2013	97	53,20	30,55	**57,4**
June 2013	85	46,84	30,17	**64,4**
July 2013	88	48,27	36,63	**75,9**
August 2013	9	4,93	3,78	**76,6**
September 2013	19	10,53	8,94	**84,9**
October 2013	29	15,90	13,72	**86,2**
November 2013	78	42,56	38,39	**90,2**
December 2013	3	1,64	1,27	**77,2**

Table 9 summarizes the real measured monthly rainfall totals with corresponding theoretical volumes of collected rainwater and real amount of rainwater from roof of PK6 building. The last column represents the percentage of the real volume of inflow rainwater compared with values from theoretical calculation.

As mentioned above, runoff coefficient was considered as C=1 according Slovak standard STN 73 6760. But taking into account loss of rainwater caused by filters, evaporation and absorbency of material we can use runoff coefficient 0,9 or 0,8 in calculation of theoretical rainwater volume. Table 11 shows, thatusing a lower runoff coefficient (0,8) the percentage of total coverage of rainwater is higher. It may increase the accuracy of system design in real conditions. Table 10 represent runoff coefficient according DWA-A 117.

Tab. 10runoff coefficient according standard DWA-A 117E

SURFACE TYPE	TYPE OF ATTACHMENT	Ψ_m
Pitchedroof	Metal, glass, slate, fibre cement	0.9 - 1.0
	Tiles, roofingfelt	0.8 - 1.0

Tab. 11measured monthly rainfall totals with corresponding theoretical volumes of collected rainwater and real amount of rainwater from roof of PK6 building (548,55m^2) C=0,8

Month	Rainfall (mm)	Teoretical volume from 548,55 m^2(m^3)	Real volume from 548,55 m^2(m^3)	%
April 2012	65	28,5	26,72	**93,7**
May 2012	50	21,9	10,91	**86,2**
June 2012	109	48,0	40,75	**84,9**
July 2012	129	56,5	41,56	**87,7**
August 2012	12	5,4	-	**-**
September 2012	44	19,2	17,93	**93,3**
October 2012	91	39,8	36,47	**91,7**
November 2012	48	20,9	16,94	**81,1**
December 2012	29	12,6	12,05	**95,3**
January 2013	59	26,1	17,92	**76,4**
February 2013	71	31,1	15,5	**75,6**
March 2013	62	27,0	16,77	**84,2**
April 2013	32	14,1	9,77	**83,3**
May 2013	97	42,6	30,55	**71,8**
June 2013	85	37,5	30,17	**80,5**
July 2013	88	38,6	36,63	**94,9**
August 2013	9	3,9	3,78	**95,7**
September 2013	19	8,4	8,94	**106,1**
October 2013	29	12,7	13,72	**107,8**
November 2013	78	34,1	38,39	**112,7**
December 2013	3	1,3	1,27	**96,5**

4 Conclusion

One of the methods of effective use of potable water sources used more frequently nowadays, not only in industrial but also in developing countries, is rainwater harvesting from surface runoff (RHSR). Application of RHSR system reduces ecological mark of a building and establishes conditions for permanent future sustainable development [7].

The aim of this article is to analyze the possible use of rainwater in the real building and description of the tools what we use at the campus of TUKE for obtaining the necessary data. As is apparent from the data in tables and graphs, planned use of rainwater in the building is not sufficient in all months. Of course, the possible volume of rainwater is dependent on the intensity of rainfall and roof area. Measured data volumes of rainwater from the roof structure in real conditions also shows that real values are lower than those obtained by the theoretical calculation. Therefore, it is preferable to design the system for rainwater harvesting with a lower coefficient of runoff as C = 1. It may increase the accuracy of system design in real conditions.

The main goal for rainwater harvesting system design should not be full coverage of water demand for a specific purpose in building. The main goal should be to design of these systems as an alternative source of water. This would avoid of wasting precious drinking water which is used for example - for flushing toilets.

References:

[1] P.J. Coombes, G. Kuczera, J. Argue, J.D. Kalma, "An evaluation of the benefits of source control measures at the regional scale," Urban Water, vol. 4 (4), 2002a, pp. 307-320.

[2] V.G. Mitchell, R.G. Mein, T.A. Mcmahon,"Evaluating the resource potential of stormwater and wastewater an Australian perspective," Australian Journal of Water Resources, vol. 2(1), 1997, pp. 19–22.

[3] P. Hlavínek,"Hospodaření s dešťovýmivodami v urbanizovanémúzemí," ARDEC s.r.o., ISBN 80-86020-55-X, 2007.

[4] V. Mosný, Hydrológia - Morfológiapovodia a prietoky. Bratislava, vydavateľstvo STU, ISBN 80-227-1782-7.

[5] H. Hlavatá, "The analysis of changes of atmospheric precipitation in Košice in the years 1900 – 2005," Slovenskýhydrometeorologickýústav Bratislava, RegionálnestrediskoKošice.

[6] STN EN 73 6760: Kanalizácia v budovách

[7] A Master Framework for UWCS Sustainability (April, 2013), Available: http://www.trust-i.net

[8] Technicképodklady Fiedler-magr – Manuál M4016.

[9] G. Markovič: Trvaloudržateľnénakladanie so zrážkovýmivodami z povrchovéhoodtokupriodkanalizovaníbudov, Thesis,Košice 2012.

[10] Zeleňáková, M., Purcz, P., Gargar, I. A. K., Helena, H.: Comparison ofprecipitation trends in Libya and Slovakia. In: River Basin Management 7.Southampton: WIT Press, p. 365-374, 2013.

[11] Gaňová, L., Zeleňáková, M., Purcz, P., Kuzevičová, Ž.,Hlavatá, H.: Arainfall distribution and their influence on flood generation in theeastern Slovakia. In: ActaUniversitatisAgriculturae et SilviculturaeMendelianaeBrunensis, vol. 61, no. 6, p. 1645-1652, 2013.

[12] Słyś, D., Stec,A., Zeleňáková, M.: A LCC analysis of rainwater managementvariants. In: Ecological Chemistry and Engineering, vol. 19, no. 3, p.359-372, 2012.

[13] http://www.buildingtalk.com/Journals//2012/08/06/WPL%20Rainwater%20Harvesting%20Brochure(1).pdf.

[14] M. Zeleňáková, P. Purcz, I. Gargar, H. Hlavatá,"Research of Monthly Precipitation Trends in Libya and Slovakia," Proceedings of the 2014 International Conference on Environmental Science and Geoscience (ESG '14) p.46, March 15-17, 2014, Venice, Italy

[15] A.Bucur, J.L.López-Bonilla, ,"An Approach to the Quality of Drinking Water as a Matter of Multicriterial Decision, Recent advances in energy,environment, ecosystems anddevelopment(EEED '13), p.43, July 16-19, 2013, Rhodes island, Greece

[16] H. Raclavska, J. Drozdova, S. Hartmann, "Municipal Waste Water Toxicity Evaluation with Vibrio Fisheri, "Recent advances in environment,energy, ecosystems anddevelopment(EEEAD 2013), p.226, September 28-30, 2013, Venice, Italy