Solutions for the Reuse of Rainwater in Indoor Plumbing

Assoc. Prof. PhD. Eng. **Adriana TOKAR[1*],** Lecturer PhD. Eng. **Diana FORIȘ[2],** Res. Asst. PhD. student Eng. **Dănuț TOKAR[1],** Res. Asst. PhD. student Eng. **Simona POPA-ALBU[1]**

[1] University Politehnica Timisoara

[2] Transilvania University of Brasov

* adriana.tokar@upt.ro

Abstract: *In agreement with lasting development and ensuring a sustainable future for administrative territorial units (ATUs) in Romania, the article proposes measures to support the environment with positive effects on natural freshwater resources and consumption. The study presents the context, necessity, and justification for plumbing modification from buildings, focused on the reduction of drinking water consumption through the recovery, storage, and reuse of rainwaters. The analysis of climatic parameters, quality indicators of rainwater harvested, and the proposed technical solutions was performed to justify the usefulness and the necessity of implementing the solutions for recovering and reusing this resource.*

Keywords: *Plumbing, rainwater recovery, sustainable development, freshwater protection.*

1. Introduction

The conception, the construction and the execution of the buildings have as determining factors: people, human activity, and nature. For this reason, it can be said that the human settlements can be regarded as factors of transformation for natural resources. Maintaining comfort in a building, considering the need for low energy consumption and to protect natural resources, can be achieved by ensuring efficient building functionality. On international level, we recognize the European Union's actions regarding environmental protection measures and the promotion of sustainable development. The sustainable development involves mechanisms and policies which should ensure economic development while minimizing negative impacts on consumption ecosystems [1, 2].

From the point of view of energy efficiency, the European Energy Performance of Buildings Directive requires all new buildings to have almost zero energy consumption by the end of 2020 [3], which means that these buildings need have very high energy performance. In this respect, investments are needed both for the rehabilitation and modernization of the buildings and their related facilities, as well as for the energy consumption for the inhabitants' comfort (thermal, sanitary, and lighting ones). For these reasons, the small amount of energy these buildings require will be largely derived from renewable sources and the reduction of energy and water consumption will be a priority for any consumer. Therefore, reducing energy consumption on the one hand and protecting natural freshwater resources on the other hand will become global priorities. Over time, the water, the soil, and the air have been treated at market level as free goods. Even though these issues have now been subject to some regulations, between supplying natural resources and the consumed levels, at this moment there is no clear relationship that can be regulated through the price mechanism [4, 5].

Regarding the degradation of ecosystems and freshwater resources, it has been found that they are amplified by the effects of climate change and by a wide range of disasters and crises (economic, technological, biological, etc.) [6]. One of the most urgent problems of the current society is the drinking water, which, lately, due to global warming, it is highly in demand, especially in the warm periods of the year. In Romania, there is almost no financial pressure on users for the efficient use of water resources to ensure the long-term quality and availability of this vital resource.

This can be exemplified by the approach of the water consumption in many small rural tourism destinations in Romania, where buildings are generally supplied with water by individual systems. On the other hand, public water supply systems are used by consumers to irrigate farmland. From the point of view of protecting freshwater resources in buildings from areas of tourist destination,

the design of these systems requires an integrated approach, involving a variety of stakeholders capable of overcoming sector boundary and the rural-urban limit.
Due to the impact of the climate changes, redesigning these systems in human settlements to meet the sustainability criteria, should be safely integrated into the management of water resources and the preservation of the ecosystems.
Thus, in order to reduce the consumption of potable water, it is necessary to encourage the collection, the storage and the reuse of meteoric waters [7] as well as with a new approach to the design of sanitary water supply systems for sanitary objects in the buildings. Previous studies show that replacing a portion of drinking water with meteoric water for domestic activities generates considerable savings in the drinking water resources [2, 8, 9].
Thus, for the integration of this concept, the sanitary installations will be designed taking into account the sanitary objects that require the supply of drinking water and those for which the water it does not need to be drinkable.

2. The aim of the research

Considering the fact that, in the case of environmental protection programs, in Romania, there are mainly programs aimed at improving the energy efficiency of the buildings (increasing the degree of thermal insulation, wind/solar/geothermal energy storage systems or ventilation systems with heat recovery programs), and programs which stimulate the reduction of greenhouse gas emissions, we believe that the creation and implementation of programs aimed at the protection of the natural resource - water is a topic for future approach of environmental protection.
Given that water is an important natural resource and the amount of rainfall decreases, responsible use of rainwater in an ecological and natural way is a solution for sustainable management of natural resources.
The paper deals with aspects regarding the implementation of existing financing programs in Romania to emphasize that there is no major interest in the implementation of programs aimed at saving and protecting the freshwater resource.
The study highlights the advantages of the meteoric waters' recovery and use, and the importance of providing a natural water circuit (infiltration into the soil of precipitation water).
The analysis explores the hypothesis that the meteoric waters in Romania's mountainous areas can fulfil the conditions of use for different household activities or industry, which is why solutions appeared for collecting, storing and the reuse of the rainwater, solutions that lead to the protection of the environment. In order to justify the proposal for the solutions of the reuse of rainwater, different analyses of the quality indicators were performed, regarding the water samples taken from collection systems from Brasov and Predeal.

3. Methodology of investigations

The study was conducted in two steps.
In the first stage, we consulted of the specialized literature on specialists' foresight in regard of the existing water potential in the world [1], [4], [8], [10-16].
In the second stage, possible solutions were considered for the cutback on the consumption of drinking water to protect the freshwater resource.
In this respect, was assessed the sustainability of investments in facilities for the recovery, storage, and the reuse of the meteorological waters by analysing the meteorological parameters in Romania and the captured meteorological water quality indicators.
Given that the mountain areas are much less exposed to the risk of air pollution, so that the meteoric waters that wash the atmosphere and engage pollutants to the ground, can have an adequate quality for their use in certain purposes, the study makes reference to the two mountain destinations of Romania: Brasov and Predeal.

For the analysis of the precipitation water quality indicators, were collected different meteorological water samples from rainwater collection facilities, which serve the buildings located in Brasov and Predeal.

4. Results of research

The analysis of the meteorological parameters carried out for the assessment of the precipitation potential in Romania, indicated that, generally, here, rainfall is moderate. The amount of precipitation that falls on the ground varies annually between the Danube Delta and the mountain areas. According to the statistics, most of the rainfall in the area of Romania falls between December and June, with the largest rainfall occurring in May and June, when atmospheric circulation and climatic conditions allow rapid vertical development of cloud formations [17].
The annual rainfall amounts were analysed using the Meteomanz database, available for free at http://www.meteomanz.com. The database provides data obtained from SYNOP messages issued by global meteorological stations (stations with code number assigned by the World Meteorological Organization).
For the two analysed tourism destinations, Brasov and Predeal, the annual medium rainfall rates for the last 6 years (2014-2019) are presented in Table 1.

Table 1: Annual average rainfall

Brasov Ghimbav Station - Average altitude 535m		**Predeal Predeal Station - Average altitude 1901m**	
Period	Rainfall [l/m²]	Period	Rainfall [l/m²]
Year 2014	362.9	Year 2014	585.5
Year 2015	631.3	Year 2015	871.9
Year 2016	701.7	Year 2016	1114.3
Year 2017	682.0	Year 2017	944.0
Year 2018	710.3	Year 2018	971.5
Year 2019	545.5	Year 2019	860.0

Source: Meteomanz database: http://www.meteomanz.com

In the Table 1 analysis we can observe the annual variation of the amount of precipitation that falls to the ground. Reported in 2014, the rainfall has increased in analysed areas. On the other hand, it can be noticed that at the altitude difference between the two areas, the rainfall increases about 1.4 times in the higher altitude zone.
Studies conducted by the National Meteorological Administration based on climate mathematical models (Ministry of Environment and Sustainable Development 2008), present the assessment of likely climate developments in the decades and even centuries to come. Thus, the map of annual rainfall estimates for the years 2001-2030 (reference interval - 1961-1990) was studied under the conditions of the A1B scenario. A1B scenario assumes a future in which growth will be rapid, which implies a weigh rate of the increase in greenhouse gas concentrations for the 21st century, in order to better estimate uncertainties.
Regarding the variability of global rainfall quantities, an important feature of the temporal variability of precipitation amounts is the pronounced interdecenial component, making it difficult to separate the long-term climatic signal [18].
As in the whole of Europe, we expect increases in the medium annual temperature in Romania compared to the 1980-1990 period (between 1.8°C and 4.0°C). Studies conducted for the period 2090-2099, regarding the pluviometric regime in Romania, indicate for the climate models that, more than 90% of them will be affected by drought in the summer (especially the southern and south-eastern region of Romania - with deviations higher than 20% relative to the reference years 1980-1990), and for winter periods, the deviations are lower, but the uncertainty is higher [19].
Although the values shown in Table 1 indicate an increase in the amount of rainfall over the last 4 years, the forecasts for the 2090-2099 indicate areas affected by drought. Therefore, to protect the future, it is necessary to think and act responsibly in the present through sustainable solutions to current problems regarding the freshwater resource.

As a conclusion of this analysis, it is estimated that the rainfall affects almost all areas of activity (mainly ecosystems, population and agriculture) and indirectly affects the freshwater resource, especially in the deficient areas, which will accentuate the consequences of the lack of water at a global scale.
For the two mountain areas considered for the study, an analysis was performed on the physical-chemical and bacteriological parameters of water samples taken from rainwater collection and evacuation facilities in order to justify the implementation of pluvial water storage and re-use facilities.
Considering that the study proposes the re-use of rainwater only for non-potable sanitary objects, only 8 physical-chemical and microbiological parameters were evaluated (total hardness, nitrates, nitrite, PH, ammonium, chlorides, total germ (NTG) at 22 °C and 37 °C, coliform bacteria, E Coli bacteria and Enterococci) on a single sample of water. The samples were analysed 12 hours after collection at the laboratories of the Public Health Department (DSP) Brasov [20-21] RENAR accredited laboratories. At the level of this study, water quality was analysed globally, the results of the analyses being interpreted by reference to national water quality limits. It is necessary to emphasize that for the internal sanitary installations for water supply of WC tanks and washing machines, it is not necessary for the water to meet drinking conditions, however the parameters analysed in this study are part of the parameters required for water quality assessment drinking.
Table 2 presents the results of laboratory analyses specifying maximum admissible concentrations (CMAs) in accordance with applicable law on drinking water quality, with subsequent modifications [22] and additions or the limit of quantification (LOQ), as well as the method used.

Table 2: Quality Indicators of Meteoric Water

Quality indicator	Measured value [UM]	Admissible values [UM]	Method
Sample rainwater Predeal			
Total hardness	2,64 German degree	Min.5	SR ISO 6059/2008
Nitrates	2,8 mg/l	50 mg/l	Fast test Spectroquant NOVA
Nitrites	0,09 mg/l	0,5 mg/l	SR EN 26777:2002/C91:2006
PH	6,2	6,5-9	SR ISO 10523:2012
Ammonium	0,21 mg/l	0,5 mg/l	Fast test Spectroquant NOVA
Chlorine free chlorine	6,3 mg/l	250 mg/l	SR ISO 9297:2001
NTG la 22° C	37 ufc/100 ml	100/ml	SR EN ISO 6222:2004
NTG la 37° C	42 ufc/100 ml	20/ml	SR EN ISO 6222:2004
Sample rainwater Brasov			
Total hardness	2,75 German degree	Min.5	SR ISO 6059/2008
Nitrates	3,2 mg/l	50 mg/l	Fast test Spectroquant NOVA
Nitrites	0,28 mg/l	0,5 mg/l	SR EN 26777:2002/C91:2006
PH	6,4	6,5-9	SR ISO 10523:2012
Ammonium	0,33 mg/l	0,5 mg/l	Fast test Spectroquant NOVA
Chlorine free chlorine	7,2 mg/l	250 mg/l	SR ISO 9297:2001
NTG la 22° C	23 ufc/100 ml	100/ml	SR EN ISO 6222:2004-
NTG la 37° C	31 ufc/100 ml	20/ml	SR EN ISO 6222:2004

Also, rainwater quality analyses did not indicate the presence of coliform bacteria, E Coli bacteria and Enterococci.
For both mountain tourism destinations the total hardness is well below the admissible drinking water level, but for the supply of non-potable sanitary items (toilet tanks, washing machines, and so on.), this indicator is favourable for the proper operation of the proposed installations.
The recorded values for nitrates, nitrites, ammonium, and chlorides fall well below the detection limits, having similar values.
PH analysis indicates a slightly acidic character, which does not adversely affect the decision to collect, to store and to use the meteoric waters. Analysing the test results for the number of colonies at 22 °C and 37 °C, it appears that this parameter does not show any abnormal change for the two samples.

In conclusion, from the analysis of the measured quality indicators, it can be said that they meet the norms stipulated by the law and there are no notable differences between the values of the parameters for the two studied mountain tourism destinations.

5. Arguments

The recovery, storage and reuse of meteoric waters can be seen in several respects, but it requires a special approach as proposed solutions must be considered by considering the local situations. A general approach may be economically inefficient and unsatisfactory in terms of the expectations of the beneficiaries.
For this reason, the study critically evaluates the importance and implications of the recovery of meteoric waters in two directions:

- For rural localities with tourism destinations, solutions are proposed for the collection, storage, and reuse of meteoric waters for indoor sanitary installations (supply of non-drinking water) and irrigation installations for the agricultural land.
- For urban localities with tourism destinations, solutions are proposed for the collection, storage and re-use of meteoric waters for indoor sanitary installations (supply of non-drinking water), irrigation facilities for green spaces, street washing and public street markets, to assure fire reserve in hard-to-reach areas.

Based on the analysis of the quality indicators of water samples taken from the mountain areas, another possible approach could be considered, providing solutions according to the type of areas (mountain areas, flat areas, industrialized areas). Depending on the results of the analysis of the quality indicators, we can come with the most efficient solutions. Therefore, the solution proposal needs to be tackled taking into consideration all relevant factors.
From the analysis of the meteorological parameters, it can be seen that the stored rainwater can provide first of all the water supply needed for the bath tanks in the bathrooms, for watering the plants in the house and the garden, and the analysis of the quality indicators provide relevant information for the use of water for washing the laundry or pots or even showers. In most areas in Romania, the water is hard and has a high salt content, however, rainwater being clean and low in salt, it does not affect the proper operation of the plumbing [8-9], [23-24].
The pluvial water storage and reuse systems must be designed so that the rainwater supply corresponds to the demand [15]. The precipitations are intermittent, so it will be necessary to store enough rainwater to avoid water depletion during periods of drought.
The Plumbing reuse outfits can be provided with the direct supply of sanitary items from an underground storage tank (Figure 1.a) or from an additional high-level water tank (Figure 1.b).

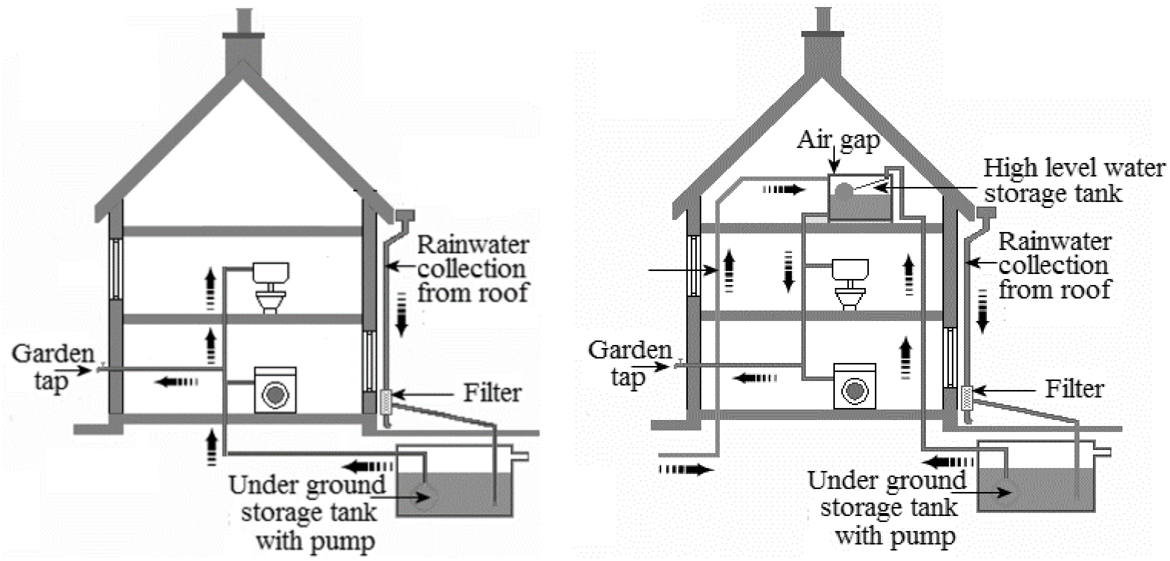

Fig. 1. Rainwater Harvesting Systems: a-direct supply, b-supply with high level water tank
(Source: http://www.lowenergyhouse.com)

The extra high-level water tank will work automatically when the underground storage tank is low. The control system is programmed to fill the network storage tank when there is not enough rainwater.
For these outfits, which supply sanitary items in the buildings, it is advisable to capture the rainwater from the roofs of buildings through gutters and pipe systems. In order to maintain the quality of the collected water from the rooftop, it is necessary to inspect and clean the collection system periodically.
The water frost problem in the collection system pipelines during the cold season can be avoided by installing the de-icing systems. These systems are mounted on the roofs and on gutters and are provided with automation systems to start the heater system when sensing ice formations that can close the rainwater collection systems [25-26].
Collecting rainwater from the ground is more problematic because it can be contaminated, and it will require additional cleaning. However, contamination cannot be a problem if the rainwater is only used for watering house plants or gardens, and also when used to supply sanitary items in the buildings, it needs treatment according to the contaminants.
When water is collected from the rooftops, the simple non-disinfecting filtration is enough to allow the use of rainwater when washing toilets and feeding the washing machines. The filters can be positioned on the rainwater collection pipes or in the underground tank inlet, depending on the most economical option. The efficiency of a filter mounted on the rainwater collection pipes is high when water is clean, but it will decrease significantly if it is not cleaned regularly.
The storage tanks will be mainly placed underground because light and high temperature favour bacterial growth. However, annually, tanks should be inspected to check for sludge accumulation and need to be washed with calcium hypochlorite.
Pumps are required to raise water pressure in sanitary plumbing re-use outfits.
From the point of view of the safety of the sanitary supply which require drinking water, the rainwater re-use facilities will be properly marked, and no connections will be made between the two installations.
The systems presented are principally described and can be complemented with safety and automation systems depending on the local situation, on the area where they are installed and the type of sanitary items.
Consequently, the recovery and re-use of rainwater can play a major role in ensuring water supply availability and that of water saving in draught areas and not only.

6. Conclusion

A sustainable development includes the preservation of ecosystems, and their protection conditions a sustainable development. Through its core coordinates, the strategy for environmental protection is therefore found in the Strategy for Sustainable Development.
Increasing the number and the complexity of safety problems regarding freshwater resources, due to an increasing water consumption, requires new actions to be taken to protect this vital resource.
The study shows the sustainability of solutions to reduce drinking water consumption by collecting, storage and using rainwater in the buildings. In this respect, the analysis of the meteorological parameters and that of the rainwater quality indicators, at least for the mountain areas, indicates as a viable solution the use of rainwater in non-drinking sanitary fittings. The proposed technical solutions can be implemented in both new and existing buildings, as they do not require major changes to the existing domestic water supply installations.
The study concludes that, for the rural and urban areas, the main benefits that rainwater can bring can be quantified by reducing dependence and demand for water supply from the public networks, lowering costs, protecting the natural freshwater resource, protecting the environment, reducing the amount water collected by sewage systems requiring treatment, diminishing soil erosion due to the floods. The actions for the protection of this vital resource are defined in close connection with the economic development policy, the medium and long term economic and social forecasts. Society and the economy must work, and the protection of freshwater and, implicitly, the environment must be done at all costs.

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