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Financial efficiency of rainwater utilization system in single-family house

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Abstract. Designing of sustainable water systems should be aimed at reducing the consumption of tap water and the use of alternative water sources, such as rainwater and graywater. Therefore, the aim of the researches conducted was to determine the cost-effectiveness of the economic exploitation of rainwater utilization system in single-family house. As a tool for the analysis, the methodology Life Cycle Cost was used. It provides a comparison of different investment options and the opportunity to choose the one that is characterized by the lowest costs over the entire period of exploitation of the object. The research was conducted for four installation variants: the traditional solution and a solution in which rainwater was used for flushing toilets, washing and watering the garden. Variable parameters for calculations applied in the model were, among other things, different number of occupants and different length of exploitation of the installations. Additionally, the study included co-financing for the initial investment, which could be an incentive for residents to undertake this type of installation. The analysis conducted has shown that the systems with the use of rainwater enable significant reductions in the consumption of drinking water, while the variant with the traditional system was a most cost-effective solution only in few cases.

1 Introduction

A growth of the world's population, urbanization and climate changes, adversely affect water resources. According to numerous forecasts, the world's population will increase from the present level of 7.3 billion to 9.8 billion by 2050 [1] thus contributing to an increased global demand for water by 55% [2]. Urban dwelling populations will, during the same period, also increase to about 66% [1]. These demographic changes and the resulting increase in consumption, combined with climate changes, will have adverse impacts on the functioning of municipal water and sewerage infrastructure and water resources management [3]. This creates the necessity to look for new technologies and alternative solutions that will result in total or partial withdrawal from the traditional, centralized water and wastewater management.

Climate changes observed in recent years also affect the amount and intensity of rainfall and they often cause the occurrence of floods and hydraulic overload of sewer systems [4]. To counteract these phenomena various devices and objects for retention and infiltration of

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rainwater are used in catchments, as well as solutions which allow using rainwater installations in buildings [5, 6].

Designing of sustainable water systems should be aimed at reducing the consumption of tap water, among others, through the use of dredging batteries and devices to reduce the amount of water consumed, economic use of rainwater and recycling of gray water [7–9].

Economical use of rainwater can affect not only the protection of fresh water resources, but also reduce the financial outlays for the construction and maintenance of existing and new water supply networks [10, 11]. Thanks to the fact that the collected rainwater from roofs of buildings has a low degree of contamination, it is most commonly used for purposes where quality of potable water is not required, and that its treatment will not require the use of sophisticated chemical and biological processes. Rainwater Harvesting Systems (RWHS) are primarily used for toilet flushing, watering green areas, washing, car washing and irrigation of farmland [12–15]. The applicability of RWHSs and water savings achieved depend on many factors which include: the amount of rainfall and the frequency of their occurrence and the demand for non-potable water. These parameters also affect the profitability of the financial implementation of these systems in buildings [16–18].

Taking this into consideration the aim of the research conducted was to determine the cost-effectiveness of the economical exploitation of rainwater utilization system in a single-family house located in Poland. As a tool for the analysis, the Life Cycle Cost methodology was used. It provides a comparison of different investment options and the opportunity to choose the one that is characterized by the lowest costs over the entire period of exploitation of the object. The research was conducted for four installation variants.

2 Methodology

In order to determine the cost-effectiveness of the application of the RWHS system and the possibility of saving potable water a financial analysis for four different variants of sanitary installations in the building was carried out:

- Variant 0 - traditional systems (Fig. 1),
- Variant 1 - installation with the use of rainwater for toilet flushing (Fig. 2),
- Variant 2 - Installation with the use of rainwater to toilet flushing and washing (Fig. 3),
- Variant 3 - Installation with the use of rainwater for toilet flushing, washing and watering the garden (Fig. 4).

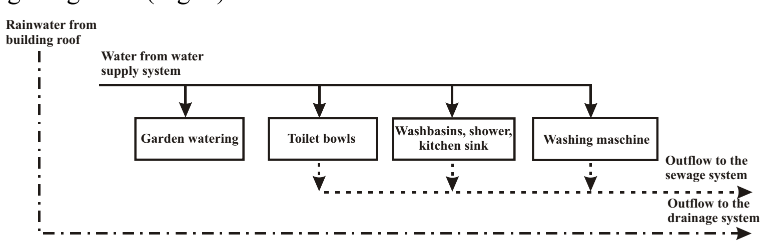

Fig. 1. The solution of installation in Variant 0.

In the study the Life Cycle Cost methodology was used which allowed to take into account all the costs connected with investment (*INV*) and use (*OCt*) of a system and the residual value (*RV*), which is the remaining value at the end of the study period [19]. *LCC* costs for the variants of installation analyzed are based on the formula (1). However, according to the guidelines in the work [20] in justified cases when the life of the system exceeds the length of the period of analysis, the residual value can be omitted. Similar assumptions were made by other researchers who analyzed the financial efficiency of RWHSs [21]. Taking this into account and the assumed lengths of the *LCC* analysis, the *RV* value was not considered. It was also assumed that T parameter in the financial model was a variable parameter, thanks to which it was possible to determine the impact of the length of the analysis period on the profitability of the investment.

$$LCC = INV + \sum_{t=1}^{T} (1+r)^{-t} \cdot OC_t + RV \tag{1}$$

where:
INV – investments, €;
OCt – operating costs in the year t, €;
RV – residual value, €;
T – duration of the *LCC* analysis, years;
r – constant discount rate;
t – another year of the system use.

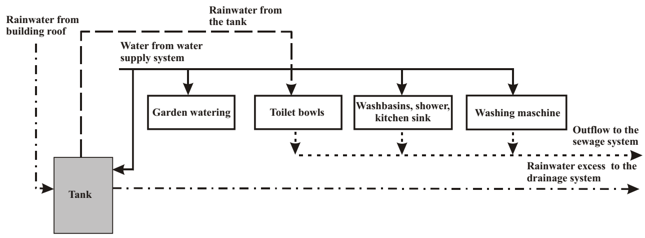

Fig. 2. The solution of installation in Variant 1.

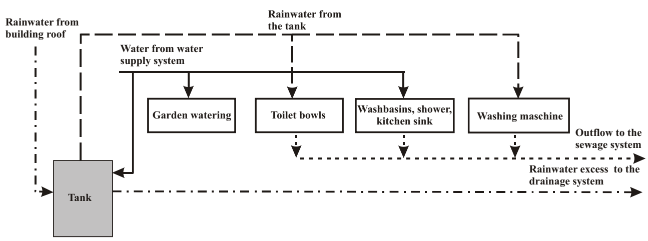

Fig. 3. The solution of installation in Variant 2.

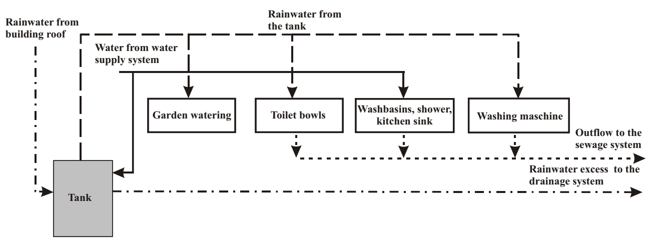

Fig. 4. The solution of installation in Variant 3.

The functioning of the system of rainwater harvesting was analyzed using a simulation model developed by Słyś [22]. This made it possible to determine the amount of rainwater that could be used or discharged into the sewerage system in each of the variants of the

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installation. Calculation algorithm of a simulation model applied was based on a daily water balance. A variable parameter of the simulation model was the number of users of the system (3, 4 and 5 people), which determined the size of the daily demand for water in the building, and this in turn affected the required capacity of the reservoir in the RWHS system.

3 Case study

Research to determine the financial efficiency of the use of RWHs was performed for a single-family building located in Rzeszów (the south-east part of Poland). A daily structure of water consumption in the building per capita is as follows: toilet flushing – 35 dm^3/d, washing – 18 dm^3/d, drinking and cooking – 4 dm^3/d, washing up – 47 dm^3/d, washing dishes – 12 dm^3/d, cleaning and other needs – 8 dm^3/d [23]. It was also assumed that in the period from May to September, 3 times a week a backyard garden will be watered (area 500 m^2), in the amount of 2,5 dm^3/m^2 [24].

Rainwater from the roof of the building with an area of 150 m^2 and a coefficient of runoff ratio of 0,9 will be discharged into an underground tank located near the building. In contrast, from the reservoir via the pump it will be transported to the inner system. On the basis of the demand for water for non-potable uses and guidelines for producers, rainwater tanks of 1,5 m^3 for Variant 1 and of 2 m^3 for Variants 2 and 3 were chosen. The exception for Variant 2 is the case when the system is used by 3 residents, where the volume of the reservoir is also 1,5 m^3. In the calculations a 7-day period of storage of water in the tank is assumed. Because of the possibility of bacterial growth after this time the tank is emptied. In periods of shortage of rainwater the reservoir will be fed with water from the water supply network. However, during intense and prolonged rainfall an excess of water is drained from the tank to the sewage system.

In the simulation model actual rainfall data for Rzeszów from a 10-year period (2003–2012) was recorded. The average annual precipitation H in the analyzed period amounted to 695 mm.

4 Input data of the financial model

The data characterizing the building considered, and the inputs of the financial model are summarized in Table 1. Investments and unit costs resulting from the operation of the system were established on the basis of producer prices and the applicable tariffs for water supply and sewage disposal.

In each of the investment variants, in the *LCC* analysis the initial investments INV_0 arising from the implementation of internal plumbing and sewage were considered. In addition, in variants 1, 2 and 3 capital expenditure associated with the use of rainwater harvesting system were also considered. These costs for the installation of the tank with a capacity of 1,5 m^3 amounted to 1448 euro while for the tank of 2 m^3 the cost was 1728 euro. In view of the fact that the rainwater will be used for washing, the RWHS system in Variants 2 and 3 is additionally equipped with a filter-pipe.

In turn, the operating costs of each variant include the costs of purchasing water from the water supply and sanitary sewage to the sewage network and fees for draining rainwater to the sewage system (the whole water for Variant 0, excess of water for Variant 1, 2 and 3). In Variant 1, 2 and 3 energy costs resulting from the transport of pumping water from the tank into the building and the cost of replacing a pump every 10 years of operation in the RWHS system were also taken into account.

Table 1. Data used in the calculation of LCC costs.

Parameter	Parameter value
Analysis period T	15, 20, 25 years
The annual increase in electricity prices	4%
The annual increase in the prices of purchase of water from the water-pipe network	6%
The annual increase in the prices of rainwater discharge to the sewage network	4%
The annual increase in the prices of sanitary sewage discharge to the sewage system	6%
The annual cost of filter cartridges	€10
The cost of purchasing electricity in the year 0	0.139 €/kWh
The cost of purchasing water from the water-pipe network in the year 0	0.880 €/m^3
The cost of sanitary sewage discharge to sewage network in the year 0	0.894 €/m^3
The cost of discharge of rainwater to the sewage network in the year 0	0.719 €/m^3
The cost of purchasing and installing the RWHS - tank 1,5 m^3 $INV_{RWHS\ 1,5}$	€1448
The cost of purchasing and installing the RWHS - tank 2 m^3 INV_{RWHS2}	€1728
The cost of purchasing and installing the additionally filter INV_F	€72
The cost of purchasing and installing the sanitary systems INV_0	€1920
The discount rate r	5%

Increased initial investments resulting from the use of rainwater harvesting system can be a barrier for potential investors, for whom the financial criterion is the decisive one. In this connection, the studies were also conducted which included some subsidies to make variants of installation of the system of economic use of rainwater. The subsidies amounted to 15, 30 and 45%. Such aid for initial investment could come from the state budget or non-governmental organizations, as in case of many countries around the world.

5 Result and discussion

The studies conducted on a simulation model of rainwater harvesting system functioning in the analyzed building showed that rainwater was not able to completely replace tap water required to meet the demand for water for non-potable uses. Depending on the installation variant and number of residents an decrease in total tap water per year ranged from 14,6% to 30,3%. The high proportion of water from the sewage system in the water demand for non-potable uses is due to insufficient irregularity of the surface of the roof and the occurrence of precipitation during the year.

The results of simulation tests allowed to assess the effectiveness of financial investment on the utilization of rainwater in the building. The financial analysis showed that the use of Life Cycle Cost methodology in the evaluation of the profitability of the investment was the right choice, because the decision only on the basis of the initial investment might lead to the selection of a solution that in the long term might make very high operating costs. Based on the results obtained, which are listed in Table 2, it was found that only in 4 calculation cases the variant with conventional installations (Variant 0) was a solution with the lowest ratio of *LCC*. This was mainly in shorter periods of analysis when T was 15 years. At the same time it should be noted that for these cases the differences in the values of this index between Variant 0 and Variant 3 were insignificant. It also turned out that during the longest period T of 25 years, irrespective of the number of installation users, the best solution financially was always Variant 3, in which the rainwater was used for toilet flushing, washing and watering the garden. A similar situation with one exception was observed for the 20-year analysis period. The exception is the case when the installation is utilized by 3 people. This is caused by less need for rainwater and, consequently, lower savings which result from water purchase from the network for 20 years. The least cost-effective option was the concept of the system where rainwater was used only for toilet flushing (Variant 1). Regardless of the number of inhabitants and the length of operation of the installation the highest values of *LCC* were obtained.

Table 2. Summary of the results of Life Cycle Cost analysis for different investment variants.

Variant	The number of occupants								
	3 persons			4 persons			5 persons		
	T = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years
Variant 0	7 426	9 384	11 410	8 694	11 115	13 628	9 961	12 847	15 846
Variant 1	8 977	10 339	12 218	10 138	11 811	14 105	11 335	13 360	16 090
Variant 2	8 850	9 978	11 741	10 100	11 447	13 573	11 286	12 973	15 530
Variant 3	8 670	9 393	10 949	9 879	10 969	12 968	11 120	12 613	15 074

Tests results presented in Table 2 show that the differences between the values of the *LCC* for all analyzed variants and calculation cases are not great. This is an influence of additional investment costs in alternative installations supplied with rainwater, which are not fully compensated by lower operating costs obtained through the use of rainwater for non-potable uses. In addition the lower profitability of variants of RWHS is affected by the operating costs associated with the replacement of the pump every 10 years and the annual cost of replacement filter cartridges. In this regard the research was also carried out and it aimed at determining the effect of financing to make rainwater harvesting system in the single-family building. It was assumed that funding for the initial investment will amount to 15%, 30% or 45%. The results of these tests are summarized in Tables 3, 4 and 5.

Based on the results obtained one can notice that a subsidy of up to 45% will not change the cost-effectiveness of the use of Variant 0 for the analysis period *T* of 15 years. That means that in a shorter analysis period the reduction of the amount of potable water consumption, and the resulting from it cost savings due to RWHS application, does not fully compensate for the increased initial investment and the cost of replacing parts of the system. This will only reduce the differences in values of *LCC* ratio between Variant 0 and other variants of investment. On the other hand, when the installation is utilized by 3 residents and *T* = 20 years, the subsidy for initial investments in the amount of already 15% will change the most beneficial variant so far (Variant 0) in favor of Variant 3.

Table 3. Results of the *LCC* analysis for different installation variants in the building, taking into account 15% of the funding for capital expenditure.

Variant	The number of occupants								
	3 persons			4 persons			5 persons		
	T = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years
Variant 0	7 426	9 384	11 410	8 694	11 115	13 628	9 961	12 847	15 846
Variant 1	8 744	10 105	11 984	9 904	11 577	13 871	11 101	13 126	15 856
Variant 2	8 605	9 734	11 497	9 830	11 177	13 303	11 016	12 704	15 260
Variant 3	8 400	9 123	10 679	9 609	10 699	12 698	10 850	12 343	14 804

Table 4. Results of the *LCC* analysis for different installation variants in the building, taking into account 30% of the funding for capital expenditure.

Variant	The number of occupants								
	3 persons			4 persons			5 persons		
	T = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years
Variant 0	7 426	9 384	11 410	8 694	11 115	13 628	9 961	12 847	15 846
Variant 1	8 510	9 871	11 750	9 671	11 343	13 637	10 867	12 892	15 622
Variant 2	8 361	9 489	11 252	9 560	10 907	13 034	10 746	12 434	14 990
Variant 3	8 131	8 853	10 410	9 339	10 429	12 429	10 580	12 074	14 534

Table 5. Results of the *LCC* analysis for different installation variants in the building, taking into account 45% of the funding for capital expenditure.

Variant	The number of occupants								
	3 persons			4 persons			5 persons		
	T = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years	*T* = 15 years	*T* = 20 years	*T* = 25 years
Variant 0	7 426	9 384	11 410	8 694	11 115	13 628	9 961	12 847	15 846
Variant 1	8 276	9 638	11 516	9 437	11 109	13 403	10 634	12 658	15 388
Variant 2	8 116	9 244	11 008	9 290	10 637	12 764	10 476	12 164	14 720
Variant 3	7 861	8 584	10 140	9 070	10 159	12 159	10 310	11 804	14 264

6 Conclusions

Economical use of rainwater for indoor and outdoor non-potable purposes makes it possible to reduce the consumption of tap water, and thus protect fresh water resources. It also reduces the amount of rainwater discharged into the sewerage system so improves their functioning. The search for alternative water sources is becoming increasingly important, since a climate change and the growing world population favor the occurrence of water deficits. In addition, fees associated with the operation of water supply and sewage systems in residential buildings represent a significant part of costs paid during the year for the use of the entire facility. Taking these problems into account, the analysis of Life Cycle Cost of the use of rainwater harvesting system in a residential building located in Poland was conducted.

The studies showed that rainwater can be a valuable source of water in the residential building. The use of rainwater for toilet flushing, washing and watering the garden can reduce the consumption of water from the water supply, depending on the variant of the installation, from almost 15% to over 30%. The lowest investment costs are in Variant 0, but after taking into account the operating costs, it turned out that only at the shortest period of analysis of 15 years, and low demand for rainwater, this option was still the most cost-effective. In all other cases, the lowest LCC value obtained for the variant where the rainwater was used to flush toilets, wash and water the garden (Variant 3). The use of rainwater harvesting system for toilet flushing only (Variant 1), or toilet flushing and washing (Variant 2) has a higher index values of *LCC*, but still for longer periods of analysis these options are more cost effective than the traditional solution for the installation.

The results of the financial analysis have a practical aspect and can be a valuable source of information for potential investors to use rainwater harvesting systems already at the stage of investment planning and decision-making. In addition, as confirmed also in studies, funding for initial investment will increase financial efficiency of the use of rainwater harvesting systems. This may be especially important in the case of single-family houses, for which, due to low demand for water resulting from the small number of residents, an implementation of rainwater harvesting system incurs very high investment.

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