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An Analysis of the Effectiveness of Two Rainwater Harvesting Systems Located in Central Eastern Europe

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Abstract: Decentralized water systems are perceived as solutions that not only save water, but also as a way to partially or completely become independent from centralized suppliers. Taking this into account, an analysis of the effectiveness of rainwater harvesting systems (RWHS) for toilet flushing in existing academic facilities located in Poland and in Slovakia was carried out. The tests took into account the different volumes of storage tanks collecting rainwater. On the basis of two financial ratios, namely Net Present Value and Discounted Payback Period, the profitability of these systems was also assessed. The research was extended by the sensitivity analysis, which allowed determination of the impact of changes in individual cost components on the financial effectiveness of the investments considered. The results obtained clearly showed that the implementation of RWHS in the dormitory in Rzeszów was unprofitable for all tank capacities tested, and the payback period significantly exceeded the period of 30 years accepted for the analysis. Completely different results were obtained for RWHS in a dormitory located in the city of Košice, for which the financial ratios NPV (Net Present Value) and DPP (Discounted Payback Period) were very favorable. It was also confirmed by the results of the sensitivity analysis. The use of rainwater for toilet flushing caused that it was possible to achieve water savings of an average of 29% and 18%, respectively, for facilities located in Slovakia and Poland. The results of the research have a practical aspect and can provide an indication for potential investors and managers of academic facilities, similar to those analyzed in the article. Taking into account that in many countries water and sewage rates are significantly higher than in Poland and Slovakia, the cost-effectiveness of using the analyzed installation options in these countries could be even higher.

Keywords: rainwater harvesting; alternative water sources; toilet flushing; financial analysis

1. Introduction

Sustainable exploitation of natural resources and their protection is of key importance for smart development [1,2]. To achieve this, it is necessary to implement alternative sources of water and energy in all areas of the economy, especially in housing, which is characterized by a high demand for water and energy [3,4]. It is estimated that domestic use of freshwater is about 10% of the total global water demand [5].

An increase in the world's population, industrialization, and an accompanying increase in the level of environmental pollution cause some deterioration of the quality of water resources and limits their availability [6–8]. The excessive and unconscious water consumption is also important for their condition. While analyzing the typical consumption of water in residential buildings, it can be observed that over 50% is used for purposes where the quality of drinking water is not required. Water resources are also affected by climate change and the intensification of the urbanization process, which also causes significant hydrological changes in catchment areas. These changes have a negative impact primarily on the quantity and quality of rainwater, causing an increase in the speed and volume of runoff, a reduction in infiltration, an increased risk of flooding, and the hydraulic overload of sewage systems [9–11].

When looking for alternative sources of water, special attention was paid to rainwater, which usually is characterized by a low degree of pollution, which does not require advanced cleaning processes [12–14]. This applies mainly to rainwater coming from areas located far from city centers and industrial plants, from which anthropogenic pollution emitted to the atmosphere can significantly affect the quality of atmospheric precipitation.

A typical rainwater harvesting system (RWHS) consists of a rainwater harvesting system from the roof of a building, a storage tank for incoming water, a filter, and a pump for pre-treated water [15–17]. However, as numerous studies show, the capacity of the tank has a decisive impact on the RWHS efficiency [18–20].

Besides meeting demand, rainwater harvesting systems can improve rainwater management in urban areas, and a reduction of drained volume and peak flow in sewage systems [21–23]. It is very important because the drainage systems are the most capital-intensive type of sewage system [24], and it is necessary to reduce the costs of their construction and functioning by implementing LID (Low Impact Development) practices. Low impact development techniques include mainly decentralized devices and objects, whose operation is to imitate natural hydrological processes, such as infiltration, evaporation, and retention of rainwater, which take place in the catchment. One of the LID practices is the collection and use of rainwater (RWHS).

Many publications point to the economic and ecological advantages of rainwater harvesting systems [25–29]. The rainwater collected is mainly used as a substitute for tap water for non-potable purposes, such as toilet flushing, washing, car washing, cleaning, and watering green areas [30–33].

In Poland, although drinking water supplies are among the poorest in Europe, rainwater as an alternative source of water is still rarely used. A similar situation is in Slovakia, where RWHS are also rarely used. The surveys carried out have shown that the probable reason for this is the conviction of the public that these systems are not profitable, as 80% of respondents indicated that co-financing for investments would be a great incentive for them to implement RWHS [34]. Despite the growing popularity of RWHS, it is necessary to run information campaigns, introduce subsidies that encourage society to use them, and establish appropriate legal provisions, as is the case in other countries [35,36].

Taking the above into account, research was conducted in order to determine the efficiency and cost-effectiveness of rainwater harvesting systems in facilities located in Poland and Slovakia. So far, research has been carried out mainly for single-family buildings [37,38] or multi-family buildings [39]. Therefore, two academic facilities with a large daily demand for water for toilet flushing have been selected. An intention of the research was also to increase the awareness of Polish and Slovak society in the scope of water saving opportunities through the use of RWHS, whose implementation is not always financially viable, but can bring significant environmental benefits.

2. Materials and Methods

2.1. Study Area

Student dormitories located in Poland and Slovakia were selected for the study. One of the facilities (Ikar dormitory) is located in the south-eastern part of Poland in the city of Rzeszów, and the other one (Nemcova dormitory) in eastern Slovakia in the city of Košice (Figure 1). Rzeszów is the largest city in this region of Poland, inhabited by 180,000 people. In turn, Košice, the second largest city of Slovakia in terms of the number of inhabitants, amounts to almost 240,000 people.

Ikar is a 11-storey building located in the academic town of the Rzeszów University of Technology. Nemcova dormitory is an academic facility of the Technical University of Košice. The dormitory consists of four-story blocks connected with one another, of which there are four in total. The objects were chosen for the research because, due to the number of students living in them, they are characterized by a high demand for water. Their modernization in terms of the use of rainwater harvesting systems could contribute to a noticeable reduction of water consumption and financial fruition.

Figure 1. Location of case study cities in Europe.

2.2. Description of the Simulation Model

The simulation model developed by Słyś [40] used for the research is based on the daily mass water balance, which can be described in general by the equation (1):

$$V_i = I_i + V_{i-1} - R_i - F_i, \tag{1}$$

where V_i is the volume of rainwater retained in the tank at the end of the day i-th, m^3; I_i is volume of rainwater coming from the roof to the tank on the i-th day, m^3; V_{i-1} is volume of rainwater remaining in the tank from the previous day, m^3; R_i is volume of rainwater supplied on the i-th day from the tank, m^3; F_i is volume of excess rainwater discharged from the tank to the sewage system on the i-th day, m^3.

The inflow of rainwater to the I_i tank depends on the surface of the roof and precipitation occurring in a given day. The inflow size is determined from Equation (2):

$$I_i = \psi \cdot A \cdot H_i, \tag{2}$$

where ψ is runoff coefficient, -; A is surface area, m^2; H_i is daily precipitation, m.

A detailed description of the applied simulation model was presented in the publication [40]. It does not take into account the impact of rainwater quality on the functioning of rainwater harvesting systems, but this assumption is identical with other models [41,42]. In addition, rainwater is usually considered to be of fairly good quality, especially for non-potable uses. However, their quality depends on many factors, including air quality, type of catchment management, type of roof coverage, and its decline [43–46]. In the case of using rainwater for non-potable uses (toilet flushing, garden watering), it is usually sufficient to use a filter to pre-treat them. The exception is the case when RWHS are used for washing. Then, more advanced rainwater purification processes are required.

This model is very similar to other models, such as the one developed by Fewkes [47]. The model algorithm is based on the YAS (Yield After Spillage) operating rule. The general principle of YAS operation is as follows. The volume of rainwater supplied to the tank in the current time interval is added to the volume of rainwater remaining in the tank from the previous time interval and the excess water is removed by the overflow. The initial storage volume (V_{i-1}) for the second time step would be the volume of water at the end of the first step (V_i). Duration of time interval can be hourly, daily, or monthly [47]. The daily time interval was used in these studies.

The study assumes that the rainwater demand is limited to toilet flushing and is considered to be permanent. This assumption is justified because the time series of the demand generated by the use of toilets do not show excessive daily differences [47].

Several parameters, such as the roof surface, non-potable water demand, precipitation volume, and tank capacity affect the RWHS efficiency. All these factors were included in the study. In the case of the Ikar dormitory, it was assumed that rainwater would be collected from the roof surface and from the roof of the adjacent academic canteen. These waters will be discharged through a pipe system to an underground tank located in the neighborhood of the dormitory. Then, the rainwater stored in the tank will be transported through the pumping system to the sanitary installation in the building. A similar system concept was adopted for the Nemcova dormitory in Košice.

The analysis of RWHS functioning in university facilities was carried out using the data shown in Table 1. The capacity of the tank is determined mainly by the rainfall, roof surface, and the demand for non-potable water. The tank capacity adopted for the academic facilities was supported by the results of simulation tests on the model. This amount was not intended to store all the rainwater delivered to the tank during the rainy season in order to be used later in the dry season, and this assumption is identical with other publications [48]. Depending on the year, the capacity of the reference tanks allowed for retention of 63% to 82% (average 74%) and from 73% to 97% (average 85%) rainwater runoff from the roof to the tank for Nemcova dormitory and Ikar dormitory, respectively. The financial aspect related to the implementation of RWHS in dormitories was also taken into account when determining tank capacities. The acceptance in both cases of larger volumes of reference tanks would result in their efficiency being increased by only 2–3% and would entail additional costs. Despite these assumptions, in order to conduct a broader analysis, the tests were also carried out for other tank capacity variants.

The demand for water was constant, as these are existing facilities and the number of students living in them is constant, as it results from the availability of beds. Based on the design recommendations of producers of rainwater tanks, the tank capacity was determined to be 100 m^3 and 90 m^3, respectively, for Nemcova dormitory and Ikar dormitory. This volume was adopted in the analysis as a reference value. On the other hand, for the purpose of a detailed analysis of the functioning of the marketing system for the use of rainwater in academic facilities, other variants of the volume of tanks were also adopted for the research. The difference in the value of the runoff/drainage coefficient for the roof is related to its construction. The roof of the Nemcova dormitory building is a sloping roof, while in Ikar dormitory the roof is flat.

Table 1. Input data of the simulation model characterizing the examined objects.

Data	Nemcova Dormitory	Ikar Dormitory
Roof area A, m^2	4900	2450
Number of students N	600	600
Average unit water requirement for toilets flushing q_{wc}, m^3/day/person	0.035	0.035
Daily water demand for toilets flushing D_i, m^3	21	21
Runoff coefficient of the drainage surface ψ, -	0.9	0.8
Number of days of water accumulation in the tank, days	7	7
The volume of the retention tank C, m^3	80,100 and 120	7090 and 110

Simulation studies were carried out using real daily precipitation data, which were registered at the Rzeszów-Jasionka meteorological station and the station in the Košice city. In the study, the data from the years 2003–2012 were applied. The average annual precipitation amounts for this period are shown in Table 2. In the period analyzed, the average annual precipitation totals amounted to 695.4 mm for Rzeszów and 640.1 mm for Košice and did not differ significantly from sums from other years. In addition, according to other researchers, the length of a series of precipitation of 10 years leads to similar results as for longer time series of precipitation, which is why it was decided to accept such a period for research [49,50].

Table 2. Average annual H precipitation for the cities of Rzeszów and Košice in the years 2003–2012.

City	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Rzeszów, H (mm)	497	761	777	601	679	737	768	973	609	552
Košice, H (mm)	492	646	669	683	631	630	625	958	527	549

While analyzing the precipitation data in detail, it was noted that 2003 was the year of the lowest precipitation both in Košice and Rzeszów. However, 2010 was the year that was characterized by the highest precipitation in both locations. The closest to the average precipitation of the 10-year period was 2004 for Košice and 2007 for Rzeszów (Figure 2).

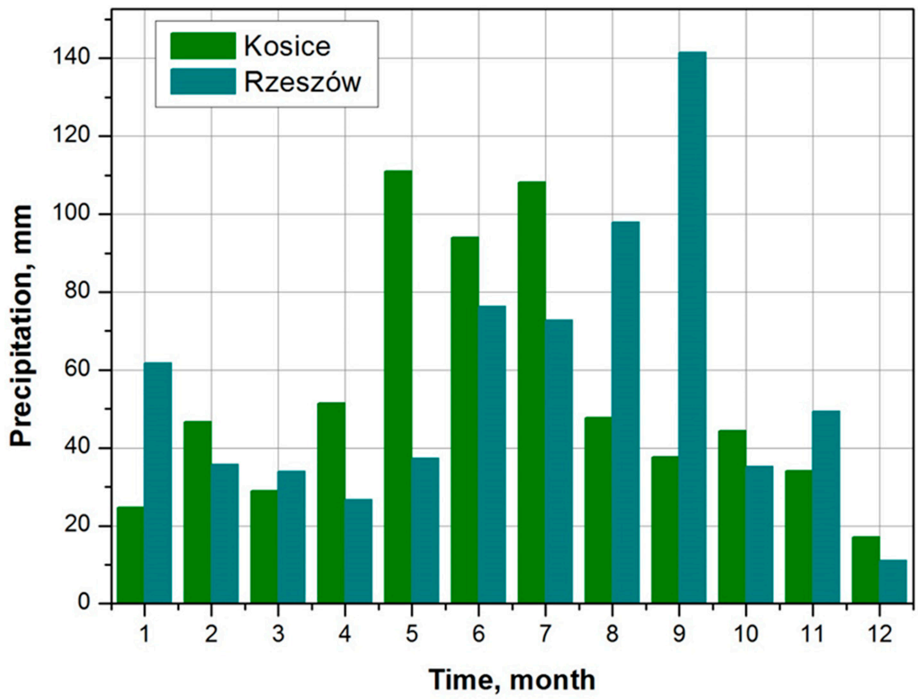

Figure 2. Monthly precipitation in Košice in the year 2004 and Rzeszów in the year 2007.

Based on the results obtained from the RWHS simulation tests, it is possible to determine the total water saving effectiveness rate in a given building. According to Fewkes (2000), water-saving efficiency E is a measure of how much mains water has been conserved in comparison to the total demand for toilet flushing. The E value was calculated based on Equation (3) [47].

$$E = \frac{\sum_{i=1}^{T} R_i}{\sum_{i=1}^{T} D_i} \cdot 100, \tag{3}$$

where E is water-saving efficiency, %, R_i is daily volume of rainwater supplied, m^3, D_i is daily demand for water to flush toilets, m^3, and T is total time under consideration.

2.3. Financial Analysis

The results of the research obtained on the simulation model of rainwater harvesting systems (RWHS) served as input data for an assessment of the financial efficiency of the investment regarding the possibility of using such systems in the academic facilities. Due to the fact that the investment would include the modernization of these buildings by adjusting the existing technical infrastructure and implementing the RWHS, the financial analysis was carried out on the basis of two ratios: Net Present Value (NPV) and Discounted Payback Period (DPP). Each of them provides useful information in the decision-making process, where NPV is the most-used criterion in the assessment of investment projects [51].

The NPV method belongs to the discount methods for an assessment of investment projects, whose essence is to determine the current value of the project based on forecasted net cash flows, which are a measure of the investor's future benefits. This method allows one to make an investment decision after analyzing the discounted cash flows, which have been reduced by capital expenditure. The project will be accepted when NPV is greater than zero. The NPV value can be determined from formula (4).

$$NPV_k = \frac{\sum_{t=0}^{n} CF_{kt}}{(1+r)^t}, \tag{4}$$

where CF_{kt} is cash flows in the year t, calculated from Equation (5), €; r is the discount rate; n is system life span, and t is year of system operation.

The cash flow value CF_{kt} for particular years was defined as the sum of investments INV_{kt} in a given year, and savings S_{kt} and maintenance and operation costs MO_{kt} resulting from the functioning of the analyzed rainwater harvesting systems analyzed. The value of cash flows was determined from Equation (5).

$$CF_{kt} = -INV_{kt} - MO_{kt} + S_{kt}, \tag{5}$$

where INV_{kt} is investment in the year t, €; S_{kt} is savings in the year t, €; MO_{kt} is maintenance and operation costs in the year t, €.

The discount rate is a very important parameter affecting the final results, and thus the profitability of the investment. The discount rate for the Net Present Value was assumed to be 5%, as it was used in calculations in other studies [52–54].

In order to obtain more detailed information on the cost-effectiveness of using the RWHS system in the examined academic facilities, the second financial ratio was determined. The discounted payback period (DPP) is included in the dynamic methods of assessing the profitability of investment projects. It sets the time after which the investment inflows will cover the investments incurred for the project, and thus after which time they will be recovered [55]. The DPP value was determined from the dependence in Equation (6).

$$DPP_k = Y_k + |NPV_{kY}| / CF_{k(Y+1)}, \tag{6}$$

where DPP_k is discounted payback period, designated for option k, years; Y_k is the number of full years before total return determined for option k, years; $CF_{k(Y+1)}$ is discounted cash flow in the year

($Y + 1$), designated for variant k, Euro; NPV_{kY} is unrecovered expenditure determined at the beginning of the year ($Y + 1$), designated for variant k, Euro.

Using the discounted payback period as the decision criterion, an investor has an option of comparing the payback period with the threshold value, i.e., with a discounted period, choosing to implement those projects for which the DPP is shorter than the threshold value. Investment projects are preferred with the shortest discounted payback period.

The initial investment expenditure of INV_k, including the cost of purchase and assembly of the installation together with the devices allowing to reduce water consumption in the analyzed buildings, was determined on the basis of producer prices for individual systems in Poland and Slovakia. In all variants differing in tank capacity, based on the obtained data from the RWHS simulation model, the annual operating costs of MO_k were calculated. They were from the purchase of water from the water supply network and electricity consumed by the pump in the tank, as well as costs caused by sewage discharge to the sewage system. The operating costs also include the cost of replacing some system components whose consumption occurs after the time specified by their producers. Similarly to [52], the research also includes a constant annual increase in water, sewage, and energy prices. The detailed data adopted for the financial analysis are presented in Table 3.

Table 3. Data used in the financial analysis.

Parameter	Parameter Value	
	Nemcova Dormitory - Košice	**Ikar Dormitory - Rzeszów**
Investments		
The cost of purchasing and installing the rainwater harvesting system RWHS INV_{RWHS}	70,000 €, 76,000 €, 84,000 €	65,000 €, 71,000 €, 78,000€
Operating costs		
The annual increase in electricity prices i_e	3%	2%
The annual increase in the prices of purchase of water from the water-pipe network i_w	1.5%	4%
The annual increase in the prices of sewage discharge to the sewage network i_s	2%	4%
The cost of purchasing electricity in the year 0 c_e	0.165 €/kWh	0.135 €/kWh
The cost of purchasing water from the water-pipe network in the year 0 c_w	1.603 €/m^3	1.076 €/m^3
The cost of sanitary sewage discharge to the sewage network in the year 0 c_s	1.184 €/m^3	0.981 €/m^3
Other parameters		
Analysis period T	30 years	
The discount rate r	5%	

2.4. Sensitivity Analysis

In order to assess the investment risk associated with the application of the rainwater management system in the academic facilities, an investment sensitivity analysis was carried out. The tests were carried out for installation variants with various tank capacities, i.e., 70 m^3, 90 m^3, and 110 m^3 for Ikar dormitory, and 80 m^3, 100 m^3, and 120 m^3 for Nemcova dormitory. This analysis consisted of determining the value of the considered NPV and DPP financial ratios, assuming that only one independent variable, which would be individual components of operating costs or capital expenditure, would change at any given time. The influence of changes in investments on RWHS performance in the range of ±5%, ±10%, and ±20% for both dormitories and changes in the assumed increase in water and wastewater prices by ±2% and +4% for Ikar dormitory were examined. In the case of Nemcova dormitory, due to the low price increase adopted as the base, a decrease or an increase in water and wastewater prices by +2%, +4%, and −1% were analyzed.

3. Results and Discussion

3.1. Efficiency of the RWHS System in the Researched Dormitories

The study considers using rainwater only to flush toilets. The use of these waters for irrigation of outside areas is not taken into account, as there are very few green areas around these buildings. In addition, there is no provision for the use of rainwater for washing due to the need for advanced pre-treatment systems, and this would additionally result in an increase in investments and operating costs.

The tests carried out on the simulation model allowed determination of the effectiveness of rainwater harvesting systems in the objects considered. The impact of precipitation volumes (dry year and wet year) on the amount of rainwater collected from the tank and the amount of excess water discharged from the tank to the sewage system were analyzed. The tests were first carried out for the calculated reference tank capacities, i.e., 90 m^3 for Ikar dormitory and 100 m^3 for Nemcova dormitory.

In the wet year, it takes 29% and 40% more rainwater from the tank than in the dry year for Nemcova dormitory and Ikar dormitory, respectively. When analyzing the amount of rainwater discharged from the tank to the sewer system in Nemcova dormitory, it was found that 85% more was discharged in the wet year compared to the year with low precipitation. A similar value of 87% was obtained for Ikar dormitory.

Depending on the amount of annual precipitation, different E rainwater harvesting system efficiency values were obtained (Figure 3). It is obvious that the largest water savings in both dormitories were obtained for the wet year (2010), with 36% and 23% for Nemcova and Ikar dormitory, respectively, and the lowest efficiency was obtained in 2003. In the case of Nemcova dormitory, savings in the dry year were still significant, reaching the level of over 25%, which exceeded the value of E ratio in the wet year for RWHS located in Ikar dormitory. The Ikar dormitory has a significantly lower water surface area, from which rainwater is collected, because the daily demand for water for toilet flushing is identical in both facilities. The average value of the E ratio from the period of 10 years is 29% and 18% for rainwater harvesting systems located in Nemcova and Ikar dormitory, respectively.

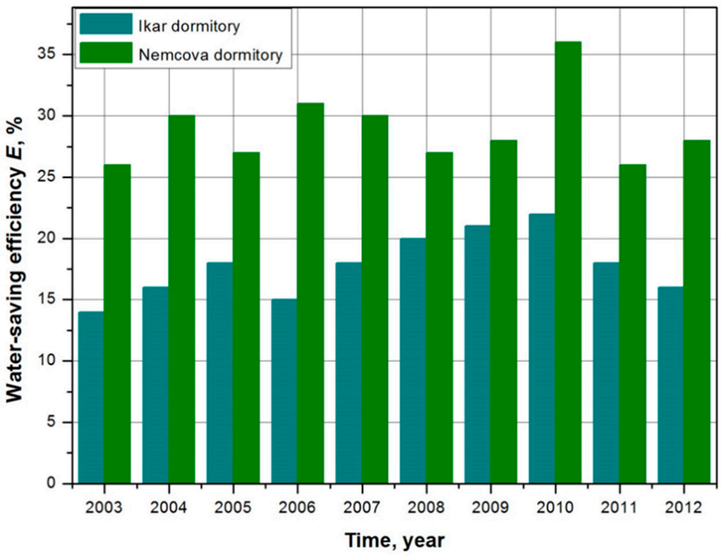

Figure 3. Water-saving efficiency in analyzed academic facilities for reference tank capacities (90 m^3 for Ikar dormitory and 100 m^3 for Nemcova dormitory).

The studies also analyzed the impact of tank capacity on the efficiency of the rainwater harvesting system (Figures 4 and 5). An increase or a decrease in the RWHS efficiency, both for the building located in Košice and Rzeszów were insignificant, at the level of 1–2%. With such small differences in water savings that can be obtained by replacing it with rainwater, it is the financial analysis that should show what variant of the system will be the most advantageous for the considered academic facilities. The results of such an analysis are described in Section 3.2.

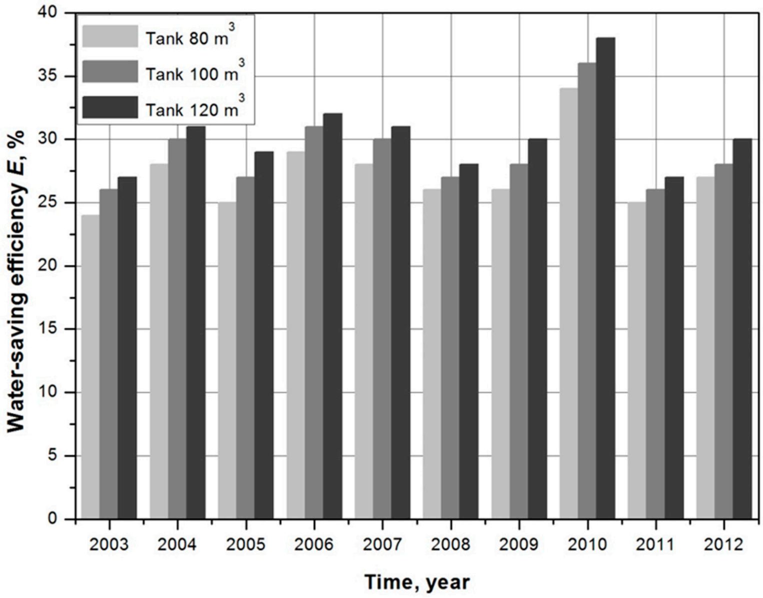

Figure 4. Water-saving efficiency for various tank capacities for Nemcova dormitory.

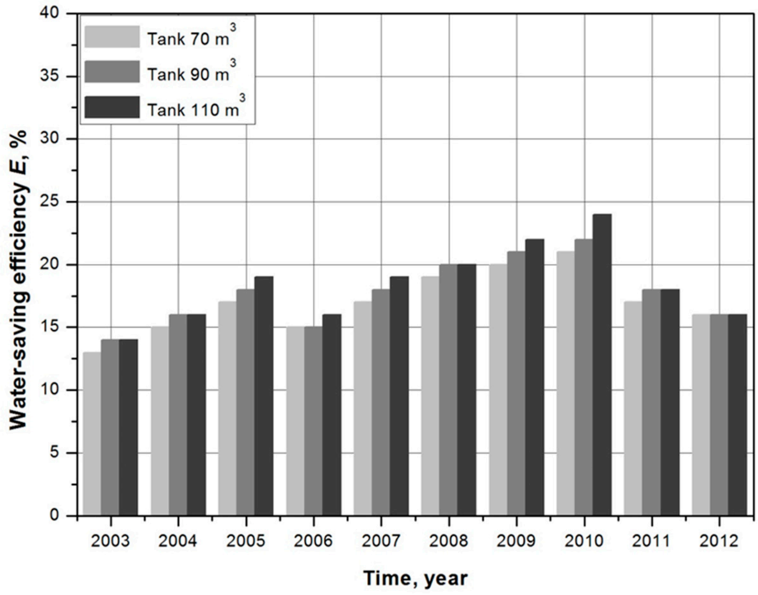

Figure 5. Water-saving efficiency for various tank capacities for Ikar dormitory.

3.2. Financial Effectiveness of the RWHS System in the Researched Dormitories

The economic effect of using the rainwater management system is primarily affected by the possibility of saving tap water, as well as investments and operating costs incurred in the period of operation of this system.

The results of simulation tests obtained for different variants of the volume of retention tanks allowed for assessment of the financial efficiency of the investment regarding a possibility of using rainwater for toilet flushing in the academic facilities. For this purpose, two financial ratios were determined for the variants analyzed, Net Present Value (NPV) and Discounted Payback Period (DPP), and the results are summarized in Table 4. It is clear that the use of RWHS in Ikar dormitory is not profitable in terms of financial statements. For all the variants of the tank capacity, the NPV value was lower than 0, which means that capital expenditures are higher than the inflows from the implementation of the investment and this project should be rejected because it is unprofitable. In addition, the discounted payback period for Ikar dormitory significantly exceeds the period taken for analysis, which was 30 years. Such adverse financial results are affected by slight water savings, which in this case are determined by a roof area, which the size is almost half the size of the Nemcova dormitory roof.

Table 4. Summary of financial analysis results.

Dormitory	Tank Capacity, m^3	Net Present Value (NPV), €	Discounted Payback Period (DPP), Years
Nemcova	80	19,962	20.94
	100	21,234	20.27
	120	18,983	21.53
Ikar	70	−9302	-
	90	−11,797	-
	110	−16,360	-

In the case of Nemcova dormitory, the use of rainwater for toilet flushing would bring significant financial benefits to all analyzed capacities of the retention tank. However, the variant with a 100 m^3 tank was the most cost-effective one, which confirmed the acceptability of such tank capacity as the reference. The shortest payback period of 20.27 years, almost 10 years shorter than the one assumed for the analysis, was also obtained for this tank capacity. The NPV value for optimal tank capacity was almost 11% higher than the NPV for the variant with a 120 m^3 tank and almost 6% higher for the RWHS equipped with a 80 m^3 tank.

The profitability analysis of the RWHS application in academic facilities was also extended by calculations made for various amounts of the discount rate r, since, as numerous studies show, its value may be of key importance in the process of making investment decisions. The calculations made, whose results are summarized in Table 5, confirm that with an increase in the value of r, the financial efficiency of the undertaking decreases. In the case of Nemcova dormitory, an increase in the discount rate to 7%, depending on the capacity of the tank, decreases the NPV value from 93% to 96%, but still the investment is still profitable, as NPV > 0. The discount rate of 7% also affects significant extension of the DPP by approximately 8 years. A further increase in the discount rate to 9% drastically reduces the NPV value below 0 for all tank capacity variants, making the use of RWHS in Nemcova dormitory cease to be a viable undertaking. Due to the fact that the discount rate at the initial level of 5% already determined that the economic use of rainwater in Ikar dormitory did not bring financial benefits, it was also checked how a decrease in the value of r to 3% would be significant. The results shown in Table 5 indicate that regardless of tank capacity, the use of RWHS in this academic facility would be a viable undertaking, however, the biggest benefit would be for a variant with a 70 m^3 tank, for which the NPV is € 10,560 and the discounted payback period DPP = 26.41 years.

The above results indicate that the acceptance of a longer system functioning period of 50 years, as done by other authors [42,52,53], would lead to more favorable results from the investor's point of view. This is also supported by the durability of materials currently used for installation in buildings, being mainly plastics for which manufacturers declare a minimum life span of 50 years. Therefore, for the initial input data received, tests were conducted where the values of financial ratios characterizing the analyzed enterprise were changed. The life span of the rainwater harvesting system was extended to 50 years. The results of calculations in this respect are shown in Table 6. They show that if the analysis time is 50 years, the investment is always profitable, regardless of the capacity of the tank, including for Ikar dormitory. For the RWHS located in Ikar dormitory, the most cost-effective option, as with the discount rate r of up to 3%, was the installation with a 70 m^3 tank, for which the NPV is € 22,754, more than 290% more than when the life span RWHS is 30 years old. This variant of the tank, despite being characterized by the most favorable financial indicators, brings the least water savings, as described in point 3.1. Its profitability is, therefore, influenced by the lowest value of the initial INV investments from among the container volumes considered. However, it should be emphasized that the difference between the NPV value for the variant with a 70 m^3 and 90 m^3 tank is less than 3%, which would suggest the selection of a larger tank capacity, as it will contribute to a greater reduction of water intake from the water supply network, and thus to greater protection water resources.

Table 5. Calculation results for different rates of the discount rate r.

Dormitory	**Tank Capacity, m^3**	**Net Present Value (NPV), €**	**Discounted Payback Period (DPP), Years**
		Discount Rate r = 3%	
Nemcova	80	46,965	17.18
	100	50,458	16.26
	120	49,962	16.36
Ikar	70	10,560	26.41
	90	9284	27.08
	110	5568	28.29
		Discount Rate r = 7%	
Dormitory	Tank Capacity, m^3	Net Present Value (NPV), €	Discounted Payback Period (DPP), Years
Nemcova	80	1331	28.66
	100	1076	28.99
	120	673	29.76
Ikar	70	−22,588	-
	90	−25,900	-
	110	−31,032	-
		Discount Rate r = 9%	
Dormitory	Tank Capacity, m^3	Net Present Value (NPV), €	Discounted Payback Period (DPP), Years
Nemcova	80	−11,885	-
	100	−13,220	-
	120	−17,532	-
Ikar	70	−31,715	-
	90	−35,591	-
	110	−41,116	-

Extending the analysis period to 50 years has a very positive effect on the financial parameters of the RWHS application of the dormitory located in the Košice city. As shown in the results in Table 6, the system with the 100 m^3 tank is the most beneficial in financial terms, for which the NPV value increased by 125% in relation to the NPV value for 30 years. Similar to Ikar dormitory, a slight difference between the financial ratios for this variant of the tank and the tank with the largest capacity of 120 m^3 is also noticeable.

Table 6. Summary of financial analysis results for 50 years of rainwater harvesting system RWHS operation.

Dormitory	**Tank Capacity, m^3**	**Net Present Value (NPV), €**	**Discounted Payback Period (DPP), Years**
Nemcova	80	44,303	22.94
	100	47,726	20.27
	120	47,176	21.53
Ikar	70	22,754	35.46
	90	22,097	36.57
	110	18,810	38.84

3.3. Sensitivity Analysis Results

The investment sensitivity assessment was carried out using the method described in point 2.4. First of all, the impact of changes in the initial investments INV on the financial viability of the entire project was determined. The results of the research in this respect are shown in Tables 7 and 8. Due to the fact that the use of RWHS in Ikar dormitory is a financially unviable project for the initial data, an increase of INV in the range from 5% to 20% caused an even greater reduction of NPV of 140%, 120%, and 95% for tanks with the capacity of 70 m^3, 90 m^3, and 110 m^3, respectively (Table 7). In the case of Nemcova dormitory, the investments remain viable for all tank capacity options, even if the capital expenditures increase by 20%. With such an increase in INV, depending on the capacity of the tank, the NPV will drop from 70% to 88% and the DPP payback period will be extended by 6–7 years.

On the other hand, when analyzing the changes in the NPV and DPP financial ratios in the situation when the independent variable INV decreases from 5% to 20%, it was found that only the decline of INV by 20% would cause a significant increase in NPV for Ikar dormitory (Table 8). For such an INV increase only for a 70 m^3 and 90 m^3 tank capacity, the use of RWHS will be profitable. For a capacity of 110 m^3, the value of NPV is still lower than 0, which means that this option should be definitely rejected at the stage of making investment decisions.

In the case of Nemcova dormitory, a reduction in investments will have a significant increase in the RWHS financial efficiency for all tank capacity variants (Table 8). The value of NPV, depending on the variant of the tank, will increase in the range from 70% to 86%, and the discounted period of DPP refund will be shortened from 5.2 to 6.4 years. The reduction of INV by up to 20% will not change the most favorable variant, which is, as well as for the base value, the rainwater harvesting system with a 100 m^3 container.

Considering the fact that the value of the initial investments can already be determined with high accuracy at the investment design stage, their increase or decrease by as much as 20% is unlikely. An implementation of RWHS in the facilities analyzed would involve modernization of the installation in the building, which could result in unforeseen costs or missing parts planned in the cost estimate, which is why the INV ± 5% and ± 10% changes were right.

Table 7. Sensitivity matrix for changes in the amount of initial investments INV.

Dormitory	Tank Capacity, m^3	Base Value		Increase INV 5%		Increase INV 10%		Increase INV 20%	
		NPV, €	DPP, Years	NPV, €	DPP, Years	NPV, €	DPP, Years	NPV, €	DPP, Years
Ikar	70	−9302	-	−12,553	-	−15,803	-	−22,303	-
	90	−11,797	-	−15,347	-	−18,897	-	−25,997	-
	110	−16,360	-	−20,260	-	−24,160	-	−31,960	-
Nemcova	80	19,962	20.94	16,463	21.54	12,963	23.20	5963	26.55
	100	21,234	20.27	17,435	21.68	13,635	23.35	6034	26.72
	120	18,983	21.53	14,784	23.25	10,584	25.04	2184	28.73

Table 8. Sensitivity matrix for changes in the amount of initial capital expenditure INV.

Dormitory	Tank Capacity, m^3	Base Value		Decrease INV 5%		Decrease INV 10%		Decrease INV 20%	
		NPV, €	DPP, Years	NPV, €	DPP, Years	NPV, €	DPP, Years	NPV, €	DPP, Years
Ikar	70	−9302	-	−6053	-	−2803	-	3697	27.73
	90	−11,797	-	−8247	-	−4697	-	2403	28.58
	110	−16,360	-	−12,460	-	−8560	-	−760	-
Nemcova	80	19,962	20.94	23,463	20.07	26,963	18.51	33,962	15.71
	100	21,234	20.27	25,035	18.73	28,835	17.32	36,435	14.80
	120	18,983	21.53	23,184	19.91	27,384	17.86	35,784	15.13

The sensitivity analysis of the investment was also made by calculating the NPV and DPP for the case where the annual increase in the purchase price of water from the water supply network i_w and in the discharge of sewage to the sewage system were changing. The results of the calculation indicate (Table 9) that as with the changes in the value of INV, the use of a rainwater harvesting system in Nemcova dormitory is financially viable, even at a lower rate of growth of i_w than is assumed. On the other hand, an increase in the value of i_w and i_s above the assumed base level results in a significant improvement in investment efficiency, as is also the case for Ikar dormitory, where the use of RWHS becomes financially beneficial. An annual drop in water and wastewater prices at the level of 6% increases the NPV for RWHS in the dormitory from 213% to 260%, and the payback period of DPP expenditure ranges from over 25 years to over 27 years. A 70 m^3 tank turned out to be the most economical variant. At 8 percent growth i_w and i_s, there is a change in profitability hierarchy in favor of the rainwater harvesting system with a 90 m^3 container.

The results of the tests presented in Table 9 showed that the annual increase in water prices to the level of 3.5% and sewage to 4% resulted in an increase of NPV for RWHS in Nemcova dormitory, depending on the capacity of the tank, from 171% to 201%. The discounted payback period of DPP expenditure, on the other hand, was decreased by from almost 4.5 years to 6 years. Further increase of i_w and i_s by another 2% in this case, for the first time among all tests carried out, changed the most profitable variant from a 100 m^3 container to 120 m^3, for which the NPV value increases by 490% in relation to the base value.

The sensitivity analysis showed that the investment under investigation for both locations was more sensitive to changes in the prices of water purchase and sewage disposal than changes in the initial capital expenditures. In general, it can also be concluded that the implementation of RWHS in Nemcova dormitory is a less sensitive project for changes in the independent variables tested, compared to the use of RWHS in Ikar dormitory. In the vast majority of calculation cases for RWHS located in a dormitory in Slovakia, the most advantageous financial option was the system variant with a 100 m^3 tank. It can be assumed, therefore, that the modernization of the installation at Nemcova dormitory consisting of the use of RWHS with a 100 m^3 container is fraught with low investment risk.

Table 9. Sensitivity matrix for changes in the assumed annual increase in purchase prices for water and in sewage discharge.

Dormitory	Tank Capacity, m^3	The Annual Increase in Water and Sewage Prices 2%		Base Value—The Annual Increase in Water and Sewage Prices 4%		The Annual Increase in Water and Sewage Prices 6%		The Annual Increase in Water and Sewage Prices 8%	
		NPV, €	DPP, Years	NPV, €	DPP, Years	NPV, €	DPP, Years	NPV, €	DPP, Years
Ikar	70	−25,951	-	−9302	-	14,616	25.38	49,381	20.51
	90	−29,283	-	−11,797	-	13,326	26.06	49,841	19.63
	110	−34,429	-	−16,360	-	9600	27.26	47,331	21.80
		The Annual Increase in Water Price 0.5% and Sewage Price 1%		Base Value— The Annual Increase in Water Price 1.5% and Sewage Price 2%		The Annual Increase in Water Price 3.5% and Sewage Price 4%		The Annual Increase in Water Price 5.5% and Sewage Price 6%	
Nemcova	80	6872	24.63	19,962	20.94	54,098	16.54	103,053	13.83
	100	7281	24.51	21,234	20.27	57,625	15.71	109,812	13.31
	120	4346	26.71	18,983	21.53	57,156	15.58	111,898	13.20

4. Conclusions

The search for and the use of alternative water sources these days is essential. The reduction of tap water usage in many regions around the world is not seen as an important topic. This is often related to the low ecological awareness of societies for which the financial criterion is the decisive one.

The research has shown that rainwater harvesting systems can play a significant role as an additional water source for a building. However, as presented in the article, many financial parameters influence their financial efficiency. Therefore, it is very important to carry out a full technical and economic analysis whose results will allow one to make a profitable decision.

The use of the system has many benefits for the environment and sustainable development of cities. In addition to these environmental benefits, as confirmed by the analysis carried out, rainwater harvesting can also be financially viable in many cases.

Considering that in many countries, including Poland and Slovakia, there are no legal regulations or detailed guidelines and social campaigns encouraging the use of rainwater harvesting systems, the research results can also be used while developing local water management strategies in urban areas.

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