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RAINWATER POTENTIAL USE IN DORMITORY BUILDING: DRINKING WATER SAVINGS AND ECONOMIC COSTS

MOŻLIWOŚCI WYKORZYSTANIA WODY DESZCZOWEJ W DOMU STUDENCKIM: OSZCZĘDNOŚĆ WODY PITNEJ I KORZYŚCI FINANSOWE

Abstract: Climate change, improper use of water resources, surface waters pollution as well as increase of water requirements are the results of growing population of people in the world. It causes that the most countries, including Poland, are faced with the deficit of water. Because of this a variety of measures are taken continuously in order to reduce the depletion of the global water resources, eg using rainwater in toilet flushing, car washing, washing machines, irrigation of arable land or watering green areas. The use of this type of solutions may also decrease fees charged for water supply to buildings which often constitute a substantial part of their upkeep expenses. In this paper, the financial effectiveness of the use of the rainwater harvesting system (*RWHS*) for toilet flushing is presented. The analysis was conducted using a simulation model and as a subject of study a dwelling-house (a dormitory) located in Poland was chosen. The study also analyzed the influence of a retention tank size on efficiency of the economic use of rainwater utilization system for the dormitory. In the financial analysis two financial ratios were determined: the Net Present Value (*NPV*) and the Discounted Payback Period (*DPP*), and sensitivity studies were conducted as well. The conducted analysis demonstrated that the use of the *RWHS* system in the analyzed building is cost-effective and that it may reduce water requirement for toilet flushing by 11 to 22%, depending on the capacity of the retention tank.

Keywords: rainwater harvesting system, rainwater management, drinking water savings, financial analysis

Introduction

The water resources of our planet are huge and could theoretically satisfy the needs of the Earth's entire population; however, their non-uniform distribution and irrational water management by humankind mean that in many countries the supply of this

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resource is an immense problem. More than 97.4% of the Earth water resources are sea and ocean waters which, due to their salinity, are not fit for use by humankind. The remaining 2.6% of it is fresh water which in substantial part is entrapped in glaciers and snow cover. Only an insignificant part of these resources, equaling 0.6%, is fresh water which can be used as a source of potable water.

The current annual demand for fresh water all over the globe is about 4500 km^3, while the spatial diversification of the ≤ale of needs does not coincide with the distribution and availability of water resources, and causes water deficits in many countries. Moreover, according to some scenarios of economic growth, the annual demand for fresh water will increase to 6900 km^3 in 2030 and may lead to a shortage of 40% in the total global water supply [1]. The water deficit is most painfully felt by the countries of the North and Central Africa, South America and Mid Asia. However, many European countries, including Poland, also have to deal with a water shortage.

According to the United Nations 783 million people all over the globe [2], including more than 120 million in Europe, have no access to a safe source of potable water [3], and every year due to this lack or diseases caused by consumption of bad quality water almost 3.5 million of people die [4], including nearly 1.5 million children [5].

Numerous prognoses also show that in the coming decades global water resources will shrink while the demand for it will increase dramatically. Climate changes, an increasing demand for food (agriculture's water requirement is 70% of the global demand [6]) and energy or the sanitary needs of continuously growing population are factors influencing the water crisis. A serious threat to shrinking water resources is also the improper use of water. Furthermore, urban development, which is the main driving force causing the global changes and environmental degradation, causes rapid depletion of environmental resources [7, 8]. Therefore, natural resource management, including water resources, should be sustainable [9].

Poland is one of the most water-deficient European countries and is ranked 26th in Europe considering the quantity of water resources which are characterized by high seasonal fluctuations and a non-uniform territorial distribution. In Poland the per capita ratio of water resources is 1600 m^3/year while the European average per capita value is estimated at 4500 m^3/year [10]. Poland has not only less and less water but it is also heavy contaminated bacterially and physicochemically. To improve this situation, it is necessary to introduce a strategy of water management related among other things to new methods of using water resources.

One method for reducing use of water resources is the economic utilization of rainwater. Systems for collecting and using this water are also used in other countries. Depending on climate conditions and the type of building where the rainwater system is installed, a saving on the demand for tap water is obtainable at different levels. Rainwater harvesting systems (*RWHS*) are considered by researchers to be one of the strategies enabling the water management sector to adapt to a changing climate [11–13].

In Poland, as it happens in many highly industrialized countries, rainwater cannot be used for consumption purposes due to heavy air pollution and operative regulations, but it can successfully substitute tap water in toilet flushing, car washing, laundering, irrigation of cultivable land or watering green areas [14–20]. Most commonly, the rainwater is used to flush toilets in residential buildings [21–24]. However, such installations are also utilized in large sporting facilities [25] and university facilities [26], in supermarkets [27] and office buildings [28, 29].

In the literature one can find a great deal of information on the calculation of the benefits, in particular financial profits, resulting from RWHS applications. Rahman et al. conducted a life cycle cost (*LCC*) analysis for three different tank volumes and three variants of rainwater use: (i) toilet and laundry (ii) irrigation and (iii) a combination of toilet, laundry and irrigation [30]. They ascertained that for all these cases the cost benefit ratios for a *RWHS* are less than 1. Only with government subsidy is it possible to gain a cost benefit ratio greater than 1.

Ghimire et al. conducted a *LCC* financial analysis of the utilization of rainwater harvesting systems for toilet flushing in industrial facilities. In addition, they also calculated the Net Present Value Benefits (*NPVB*) for these systems. On the basis of their findings, they discovered that *RWHSs* are not cost-effective for the analyzed buildings [31].

And then, Farreny et al. used a Life Cycle Cost analysis to define the total costs of rainwater retention and utilization systems in multi-family buildings in Spain; they analyzed two scenarios for tap water prices: current prices and the prices including a future increase in water buying costs. The findings demonstrate that *RWHSs* used in densely populated areas in a Mediterranean climate are only cost-effective on certain assumptions, *ie* the assumed tap water prices and increase in tap water prices [32].

In England, a financial analysis was conducted for 384 rainwater retention and utilization systems constructed in this country. A Life Cycle Cost methodology was employed for this purpose and different scenarios were taken into consideration for the future performance costs of these systems. In each case it was ascertained that rainwater harvesting was far less cost-effective than supplying the analyzed buildings with tap water alone [33].

The review of the published studies showed that in most cases the use of *RWHS* system is not financially viable, but it is an individual matter and depends on many factors, including the building location, climatic conditions, the technical parameters of the installation and the size of the surface from which rainwater is collected. For improving the financial effectiveness of the use of the *RWHS* system the subsidies from government may affect. An example of this can be research conducted by Gotur and Devendrappa in Karnataka, India, where the government covered more than 40% of the investment. The study of economic viability of investment in *RWHS* systems revealed that the Net Present Value was positive and Pay Back Period was very low [34].

In Poland, the economic use of rainwater utilization systems is rare. There is no detailed data concerning neither their performance nor designing guidelines which enable such systems to be designed in Polish conditions. The findings of analyses conducted on the potential utilization of these systems for residential housing have been presented, inter alia, in papers [35–37].

The subject of this paper is to determine the financial effectiveness of the rainwater harvesting system for toilet flushing in a residential building as well as the possible water savings examined in Polish conditions. For the study purposes, a dormitory building was chosen where the rainwater harvesting system is planned for toilet flushing. The findings concerning the financial effectiveness of this investment may constitute valuable guidelines for an investor in the decision-making process.

Case study

The study of the possible economic use of rainwater was carried out for a facility located within the campus of the Rzeszow University of Technology in the city of Rzeszow, Poland. The city of Rzeszow is a provincial capital of 180 thousand inhabitants and an area of 116 km^2, which has a history dating back 656 years. The city is the biggest center of industry, commercial and service activities, as well as an academic and cultural center, in South-Eastern Poland (Fig. 1).

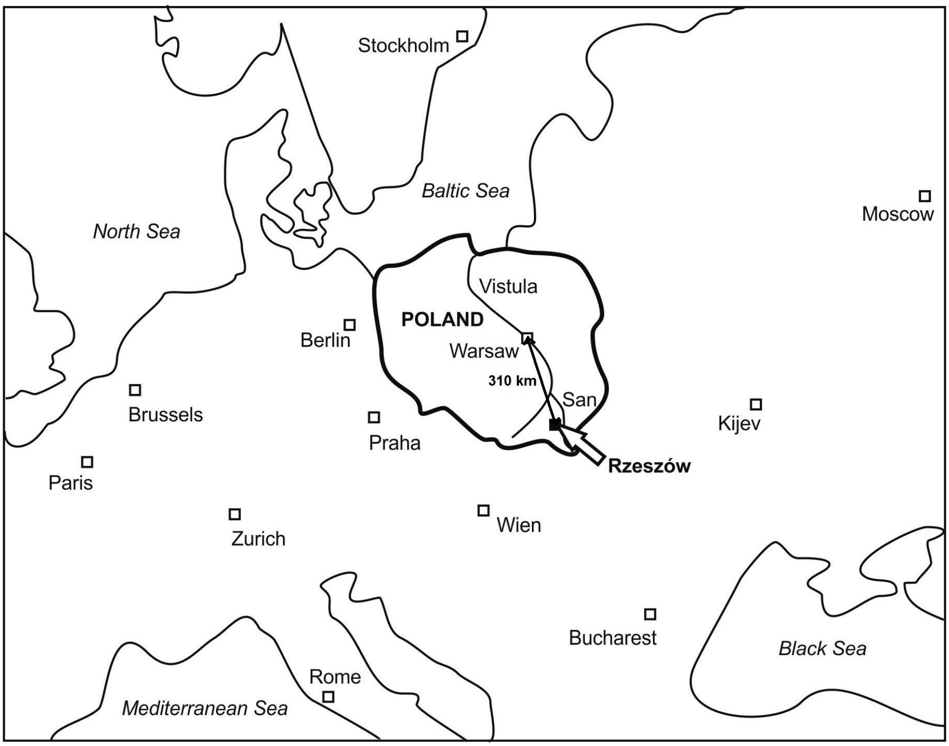

Fig. 1. Location of case study city in Poland

The campus of the Rzeszow University of Technology is located in the city center. On an area of forty thousand square meters there is a complex of seven dormitories which accommodate approximately two and a half thousand students. Because of the planned investment projects aimed at modernizing the water supply systems for the campus, which include the development of the economic use of rainwater, a cost-effectiveness study of *RWHS* in the "Ikar" dormitory was carried out. The university dormitory location within the campus area is shown in Fig. 2. It is an eleven-storey building with a full basement, designed for 600 students.

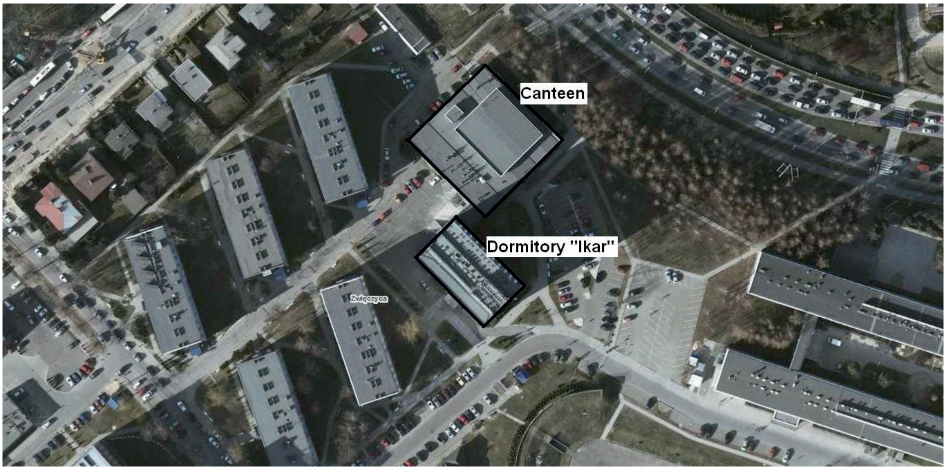

Fig. 2. Location of the analyzed dormitory within the campus area

For the dormitory, the analysis of the possible use of rainwater for toilet flushing was carried out together with a financial analysis of capital expenditure. It was assumed that the rainwater would be collected from the roof surface of the "Ikar" building and a neighboring canteen, and then the water would be drained via a piping system to an underground tank, located in the vicinity of the dormitory.

Method

To analyze the performance of the economic use of the rainwater utilization system at the chosen academic facility, a simulation model has been prepared, the algorithm for which is shown in Fig. 3. The elaborated model is versatile and can be used for a broad range of research. This model can be useful in the research on the *RWHS* performance in different types of buildings as well as for different locations and parameters of the system.

The functioning of the installation in formulated simulation model is described with the following conditions which determine the processes of rainwater flow, its accumulation and release of water to sanitary installation and sewers.

- Filling in and accumulation of rainwater in the tank:
  If $V_{rki} + V_{di+1} > V_z$ to $V_{i+1} = V_z$, $i = 1, 2, ..., n$
  If $V_{rki} + V_{di+1} \leq V_z$ to $V_{i+1} = V_{rki} + V_{di+1}$, $i = 1, 2, ..., n$
- Rainwater intake from the tanks by the installation:
  If $V_{rpi} - V_s < 0$ to $V_{rki} = 0$ and $V_{ui} = V_{rpi}$, $i = 1, 2, ..., n$
  If $V_{rpi} - V_s \geq 0$ to $V_{rki} = V_{rpi} - V_s$ and $V_{ui} = V_s$, $i = 1, 2, ..., n$

- Flow of mains water to the tank:
  If $V_{rpi} > V_s$ to $V_{wi} = 0,\ i = 1, 2, ..., n$
  If $V_{rpi} \leq V_s$ to $V_{wi} = V_s - V_{rpi},\ i = 1, 2, ..., n$
- Discharge of rainwater from the tank to sewers:
  If $V_{rpi} + V_{di} \leq V_z$ to $V_{ki} = 0,\ i = 1, 2, ..., n$
  If $V_{rpi} + V_{di} > V_z$ to $V_{ki} = V_{rki} + V_{di} - V_z,\ i = 1, 2, ..., n$.

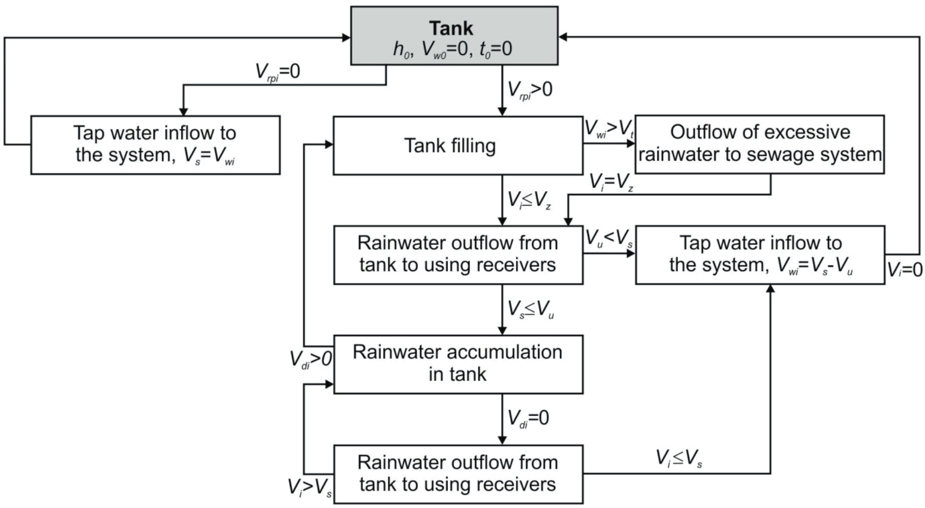

Fig. 3. Computing algorithm of Simulation Model of the economic use of rainwater utilization system (V_i – volume of rainwater retained in the tank at the end of day i, [m^3]; V_{di} – volume of rainwater inflowing on day i, [m^3]; V_{rki} – volume of retained rainwater in the tank after intake by installation on day i, [m^3]; V_{rpi} – volume of rainwater retained in the tank before intake by installation on day i, [m^3]; V_s – volume of water utilized by installation, [m^3]; V_u – volume of rainwater inflowing from retention tank to installation, [m^3]; V_{wi} – volume of mains water transported to installation on day i, [m^3]; V_z – rainwater tank capacity, [m^3])

Precipitation data

In the research carried out with the prepared simulation model of the rainwater utilization system in the university building, real precipitation data were used. The daily precipitation data originated from the meteorological station Rzeszow-Jasionka. For the simulation study, data from the period between 2003 and 2012 were used, for which annual totals are shown in Fig. 4. The average annual precipitation for the analyzed period was 695.35 mm and this does not diverge substantially from the multi-year average annual precipitation. Therefore, it may be assumed that the precipitation data used in the simulation model would provide reliable calculation results.

Figure 5 shows the daily precipitation for the year chosen from the analyzed period with an indicated spring-summer period where the highest rainfall is visible. The remaining days of the year constitute the autumn-winter period with prevailing snowfall.

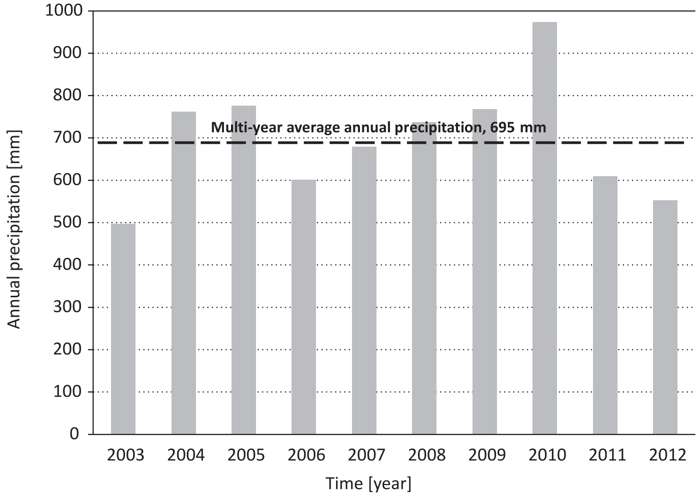

Fig. 4. Annual precipitation between the year 2003 and 2012

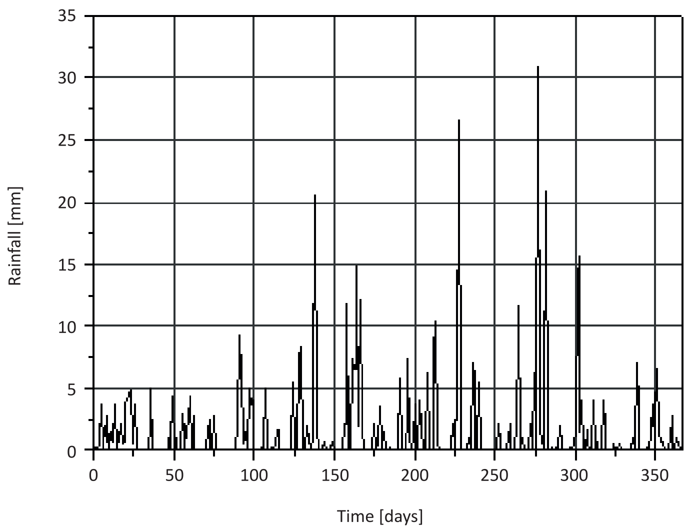

Fig. 5. Daily precipitation in the year 2012

Model input data

The analysis of the performance of the economic use of rainwater utilization system for the "Ikar" dormitory was carried out with a simulation model based on the following input data:

– Canteen roof surface F_S = 1714 m^2;
– Dormitory roof surface F_D = 731.9 m^2;
– Total drained surface F = 2445.9 m^2;

– Number of inhabitants (students) P = 600 persons;
– Average unit water requirement for toilet flushing q_s = 0.035 m^3/P/day;
– Daily water requirement for toilet flushing $V_s = q_s \cdot M$ = 21 m^3/day;
– Runoff index of a drained surface ψ = 0.9;
– Number of days of water retention in a tank during a period of drought t = 7 days.

The unit water requirement for toilet flushing q_s was determined on the basis of the statistical data concerning the structure of water consumption in Poland [38].

Based on the data characterizing the analyzed building and the recommendations of the manufacturers of rainwater tanks, the required capacity of the tank was calculated to be 90 m^3. In the study, this capacity was accepted as a reference value. Nevertheless, in order to conduct a deeper study of the *RWHS* performance in the analyzed object and determine the financial effectiveness of the investment project, two smaller capacities of the tank were also considered, namely, 60 and 30 m^3.

Results and discussion

On the basis of the prepared simulation model and possessed daily precipitation data the analysis of the performance of the economic use of rainwater utilization system for the chosen university facility. Figure 6 shows a graph illustrating filling trends in a period of 10 years in the tank. Figure 7 shows the collection process for rainwater from this tank on specific days of the chosen year.

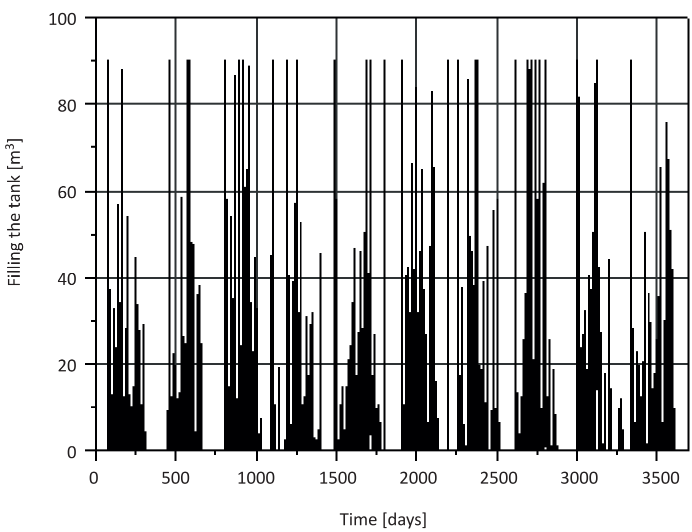

Fig. 6. Filling trends in the storage tank of rainwater for the "Ikar" dormitory with a tank capacity of 90 m^3 and a period between the 2003 and 2012

The collection of 21 m^3/day of water means that the total daily water requirement for toilet flushing in the "Ikar" dormitory is satisfied with the rainwater stored in tank.

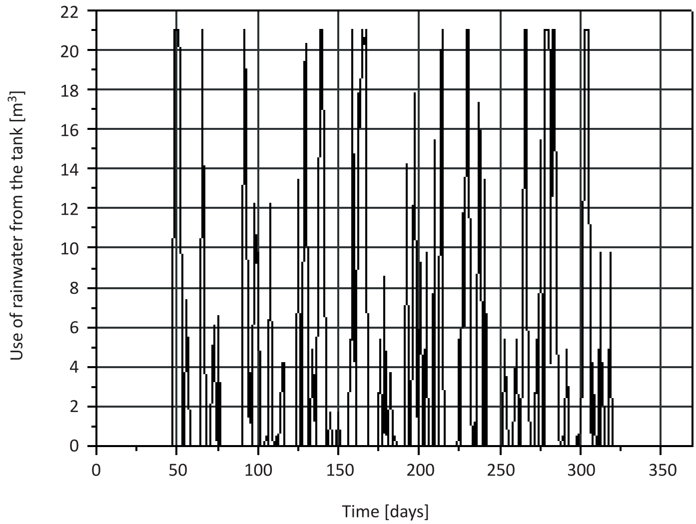

Fig. 7. Use of rainwater from the storage tank for toilet flushing in the "Ikar" dormitory with a tank capacity of 90 m^3 in 2012

A lower collection of water from this tank means that the rainwater quantity is insufficient and it is necessary to provide tap water from a water supply system. This process for a sanitary system in the "Ikar" building for an example year is shown in Fig. 8.

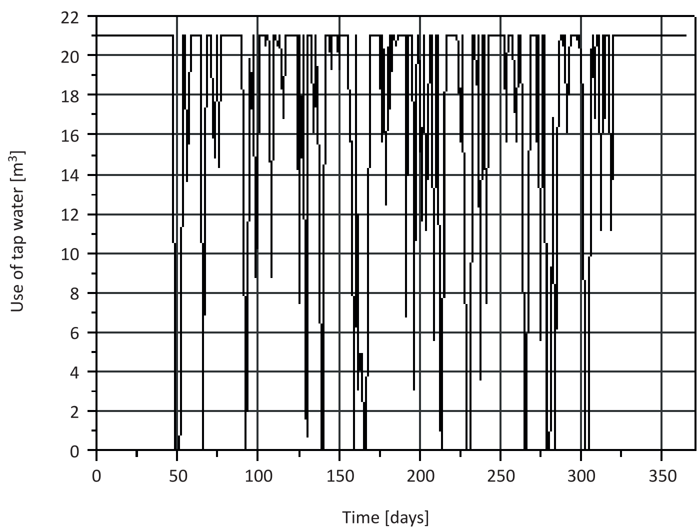

Fig. 8. Use of tap water for toilet flushing for the "Ikar" dormitory with the tank capacity of 90 m^3 in the year 2012

Despite of considerable capacity of the tank, which enables the rainwater downflows from a roof to be effectively retained in it, within the analyzed period some incidents were observed when the excess of rainwater was discharged to a sewage system. Such situations happened mainly in summer periods in which considerably higher precipitation occurred and in the early spring periods when the snow cumulated on the roof melts. The discharging process of the excess of rainwater out of the system is shown in Fig. 9.

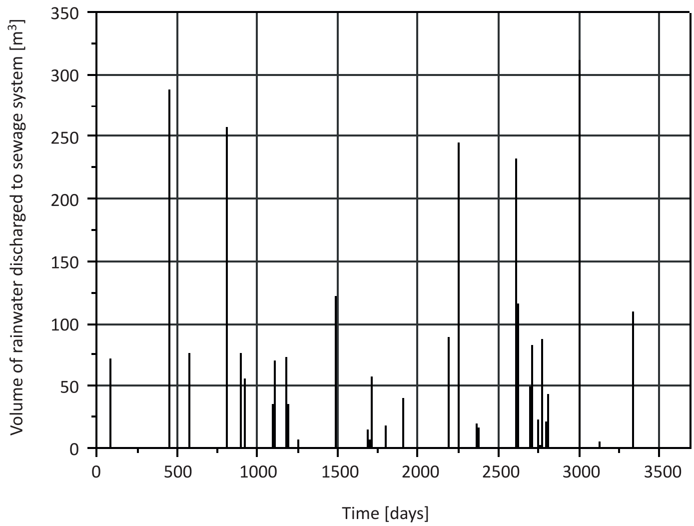

Fig. 9. Volume of an excess of rainwater discharged to a sewage system for the "Ikar" dormitory with the tank capacity of 90 m^3 and a period between the year 2003 and 2012

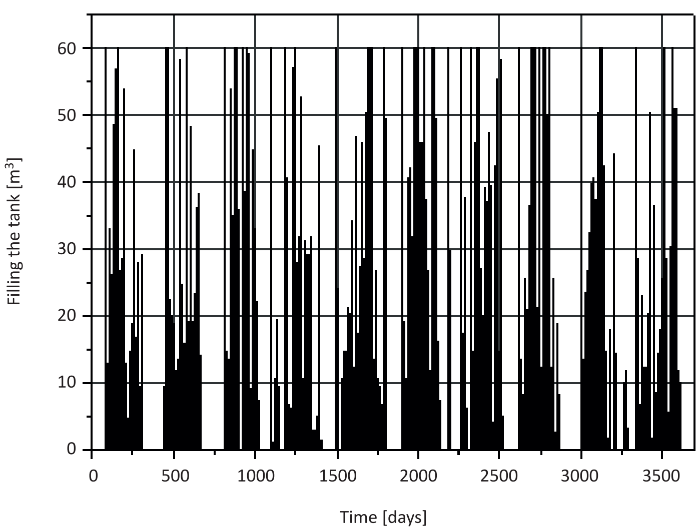

Fig. 10. Filling trends in the storage tank of rainwater for the "Ikar" dormitory with a tank capacity of 60 m^3 and a period between the 2003 and 2012

In the study it was also analyzed the influence of a retention tank size on efficiency of the economic use of rainwater utilization system for the "Ikar" dormitory. For the purposes of the analysis, tank capacities of 30 and 60 m^3 was assumed. Figure 10 shows the filling trends in tank with a capacity of 60 m^3, while Fig. 11 shows trends in the tank with a capacity of 30 m^3. Along with the decrease in the tank capacity, the volume of

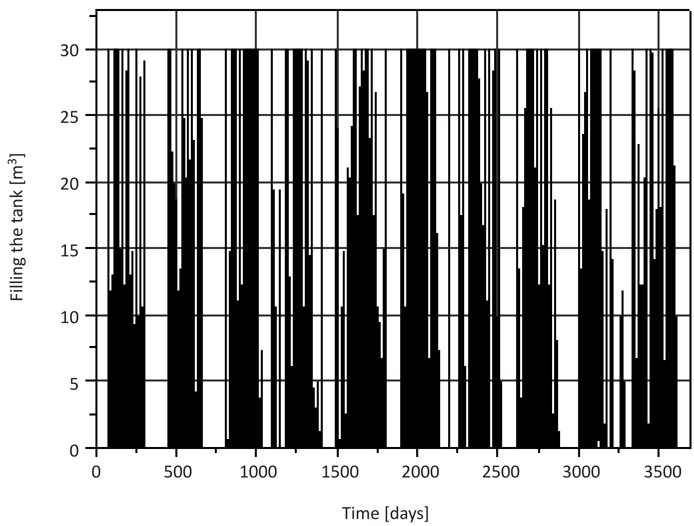

Fig. 11. Filling trends in the storage tank of rainwater for the "Ikar" dormitory with a tank capacity of 30 m^3 and a period between the 2003 and 2012

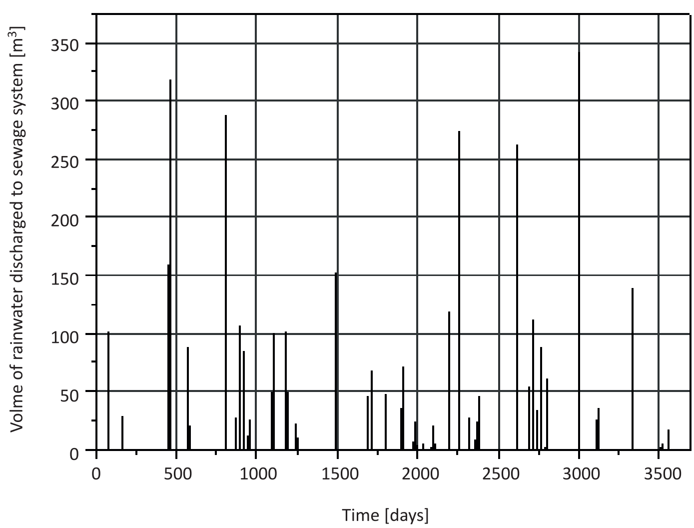

Fig. 12. Volume of an excess of rainwater discharged to a sewage system for the "Ikar" dormitory with the tank capacity of 60 m^3 and a period between the year 2003 and 2012

the rainwater excess discharged to the sewage system increases what is shown in Fig. 12 and 13.

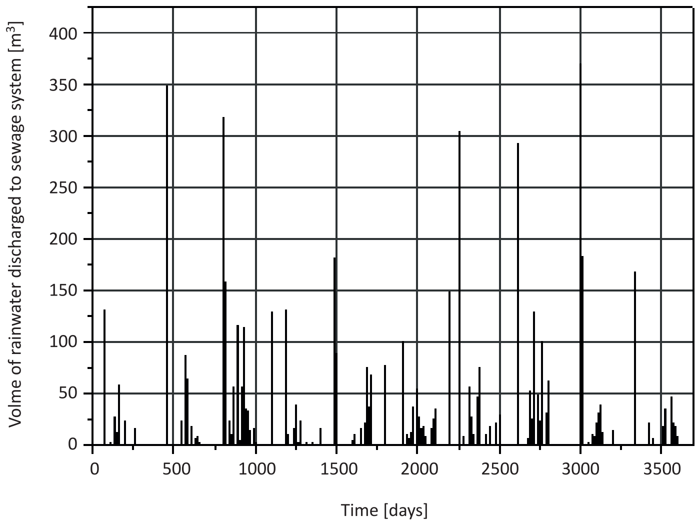

Fig. 13. Volume of an excess of rainwater discharged to sewage system for the "Ikar" dormitory with the tank capacity of 30 m^3 and a period between the year 2003 and 2012

Analyzing a period of 10 years it was found out that the rainwater downflows from a roof coating cannot fully substitute the tap water needed to satisfy the daily demand for toilet flushing. The high proportion of tap water in the water requirement for toilet flushing resulted from the undersized roof surface and the irregular occurrence of precipitation within the year. On the basis of these findings, for each analyzed variant of retention tank capacity, the percentage share of rainwater in the total water requirement for toilet flushing in the "Ikar" dormitory was calculated. It was discovered that the most effective utilization of rainwater occurs with a storage tank of 90 m^3 capacity. Figure 14 shows the results of the research for the 10-year period and the three variants of tank capacity.

Depending on the retention tank capacity, an average saving on lower quality water was 11 to 22%. This low system efficiency in the case of a multi-storey building such as the "Ikar" building is a consequence of the undersized roof surface from which the rainwater is collected and, also of the considerable water requirement from the large number of inhabitants.

In the discussed variants of retention tanks, the possible accumulation of rainwater downflows from the roof is high, and increases along with an increase in tank capacity. The 90 m^3 tank can store an average 85% of rainwater downflows from the roof, while the retention of the smallest tank is 66%. A smaller proportion of accumulation of the rainwater downflows from the roof to tank was either the result of the irregular occurrence of precipitation within the year or substantial amount of heavy rain during which the excess water was discharged from the tank to the sewage system. The

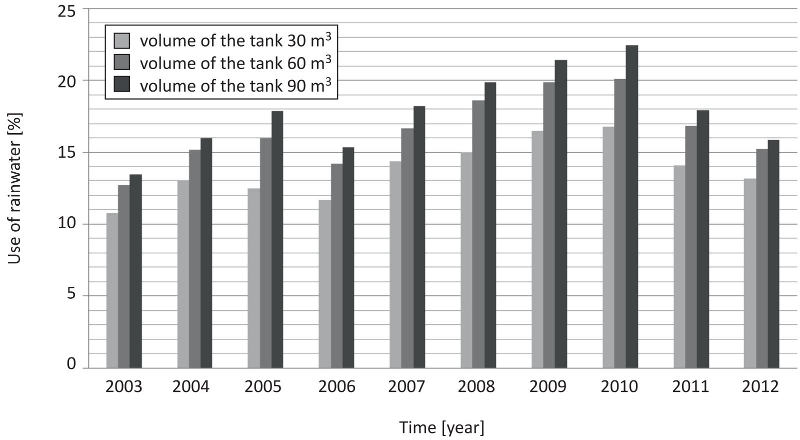

Fig. 14. Percentage share of rainwater in the total water requirement for toilet flushing for the "Ikar" dormitory tank variant capacities between 2003 and 2012

contribution of rainwater accumulated in the tank in relation to the total volume of rainwater brought into the tank from the building's roof is shown in Fig. 15.

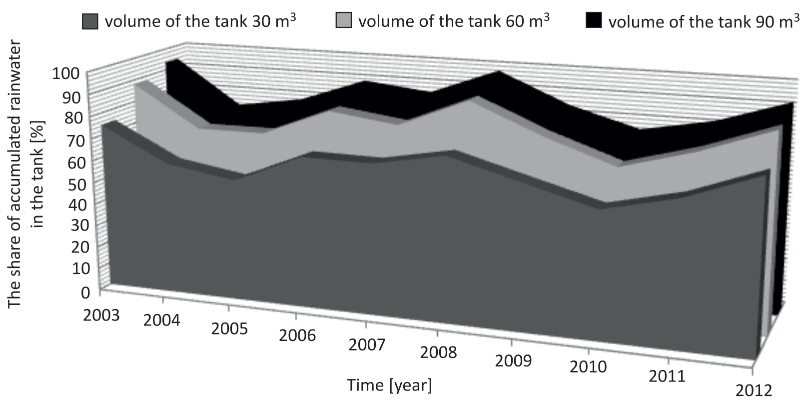

Fig. 15. Contribution of rainwater accumulated in the tank in relation to the total volume of rainwater brought into the tank from the roof

Economic effects of using rainwater harvesting system in the "Ikar" dormitory"

First and foremost, the economic effect of the use of a rainwater utilization system depends on the possible savings on tap water, and capital expenditures and operating costs borne during the system's operation.

The results of the simulation study obtained for different variants of tank capacity enabled us to assess the financial effectiveness of an investment in the possible utilization of rainwater for toilet flushing in the analyzed university facility, and define an optimum variant for the capital project. For this purpose, for the analyzed variant two financial ratios have been determined: the Net Present Value (*NPV*) and the Discounted Payback Period (*DPP*).

The Net Present Value (*NPV*) is the sum of all net profits generated by the investment during the entire operating period of a specific facility, which are discounted before totalization [39]. If the *NPV* value is greater than zero it means that the revenue from the undertaking exceeds the capital expenditures in value and a given investment project is therefore profitable. On the other hand, if the *NPV* value is less than zero it means that a given investment project is unprofitable. The net present value for each study variants k of the rainwater system utilized for toilet flushing was determined from mathematical relation (1).

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

where: CF_{kt} – cash flows in the year t, calculated from Eq. (2), [€];
r – the discount rate, r = 5%;
n – number of years of the operation of the system, n = 30 years.

The discount rate for the Net Present Value was assumed to be 5%, as it was used in calculations by Morales-Pinzon et al [40], Roebuck et al [33] and Liaw and Tsai [41].

The cash flow value CF_{kt} for particular years was defined as the sum of investments INV_{kt} borne in a given year and savings O_{kt} resulting from the economic use of the precipitation water utilization system (2).

$$CF_{kt} = -INV_{kt} + O_{kt} \tag{2}$$

where: INV_{kt} – investment in the year t, [€];
O_{kt} – savings in the year t, calculated from Eq. (3), [€].

Calculations included the savings resulted from the reduced collection of tap water and a reduction in rainwater volumes discharged to the sewage system. The savings in consecutive years of system operation were determined using mathematical relation (3).

$$O_{kt} = (W_{0t} - W_{kt}) \cdot C_{Wt} + (R_{0t} - R_{kt}) \cdot C_{Rt} \tag{3}$$

where: O_{kt} – savings resulted from the economic use of a rainwater utilization system in particular years, [€];
W_{0t} – water utilization for toilet flushing in variant 0 without the use of a rainwater water utilization system, [m^3];
W_{kt} – water utilization for toilet flushing in variant k with the use of a rainwater water utilization system, [m^3];
C_{Wt} – tap water purchase price in consecutive years, [€/m^3];
R_{0t} – rainwater volume discharged from the roof to the sewage system in variant 0 without the use of a rainwater utilization system, [m^3];

R_{kt} – rainwater volume discharged from the roof to the sewage system in variant *k* with the use of a rainwater utilization system, [m^3];
C_{Rt} – price for rainwater discharge to the sewage system in consecutive years, [€/m^3].

For calculations of financial savings O_{kt} the following price values were assumed: C_{Wt} = 1 €/m^3, C_{Rt} = 0.7 €/m^3. In that research, the annual increase in prices was also taken into account for the entire period of RWHS operation. On the basis of the archival data concerning the water rates and wastewater discharging fees in Rzeszow, the trend curve concluded that the annual water rate-raising was approximately 8% while the rate-raising was 4% for the rainwater discharged to the sewage system.

On the basis of these data and the results obtained from the simulation model tests, the cash flows were calculated for a period of 30 years of system operation and each assumed retention tank capacity variant. The results of the calculations are shown in Fig. 16.

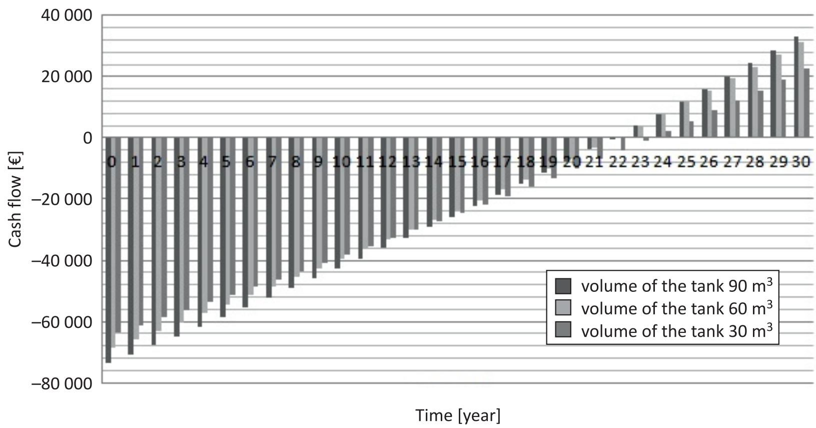

Fig. 16. Cash flow values for the analyzed economic use of rainwater utilization system in the "Ikar" dormitory over a period of 30 years

The annual cash flow values obtained enabled us to determine the *NPV* of investment undertaking for the analyzed variants. Nevertheless, in order to check the influence of tap water buying costs on the *NPV* of the supply of a sanitary system with rainwater two scenarios were analyzed in which an annual increase in water price by 6 and 10% was assumed. The capital expenditures borne in the zero-year included expenditures resulting from the purchase costs of the tank, installation materials, necessary inbuilt plumbing fittings and construction costs of the entire system. Depending on the variant of retention tank capacity, the value of these expenditures for the tank capacity of 30 m^3, 60 m^3 and 90 m^3 was 63 734, 68 784 and 73 833 Euro respectively. Moreover, the annual operating expenses of the rainwater utilization system in the analyzed building include the cost of water pumping from the tank to the sanitary system. Figure 17 shows the functional dependency of the *NPV* on the forecast increase in tap water purchase prices.

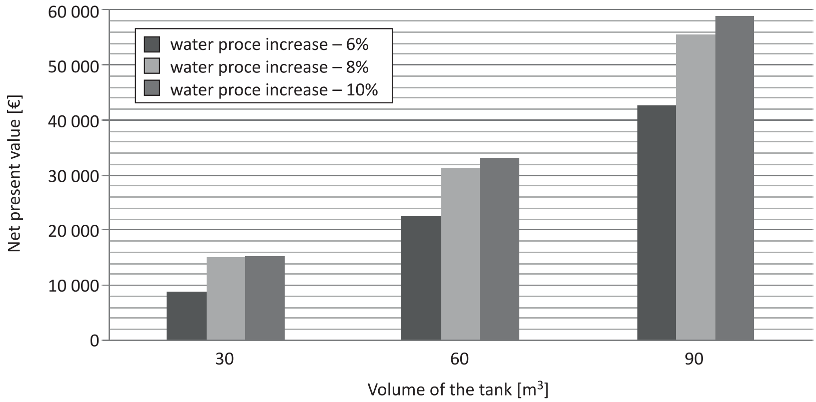

Fig. 17. Net Present Values for the economic use of a rainwater utilization system in the "Ikar" dormitory relative to the tank capacity and assumed increase in tap water purchase prices over a period of 30 years

On the basis of the findings obtained, it can be noted that for the assumed scenarios of increase in tap water purchase prices the *NPV* for each analyzed variant is greater than zero. This means that for the weather data used from a period of 10 years and independently of the retention tank capacity every variant of the investment is profitable. The increased tap water purchase prices resulted in an increase in *NPV*, which became more apparent when the tank capacity was enlarged. The assumed 10% price increase is greater than this one calculated on the basis of historical data, but taking into consideration current forecasts for increases in tap water purchase prices and Poland's shrinking water resources, such a scenario is highly probable.

The next financial ratio to be analyzed was the Discounted Payback Period (*DPP*), calculated using mathematical relation (4). This financial ratio determines the number of years after which the discounted incomes from a realized undertaking compensate for the capital expenditures [42].

$$DPP_k = Y_k + \frac{|NPW_{kY}|}{CF_{(kY+1)}} \tag{4}$$

where: DPP_k – Discounted Payback Period determined for a variant k, [yr.];
Y_k – number of full years before a total payback of expenditures determined for a variant k, [year];
$CFk_{(Y+1)}$ – discounted cash flow in a year $(Y + 1)$, determined for a variant k, [€];
NPV_{kY} – unrecovered expenditures determined at the beginning of the year $(Y + 1)$, determined for a variant k, [€].

The Discounted Payback Period was calculated for three analyzed variants of rainwater retention tank capacity in the economic use of a precipitation water utilization system in the "Ikar" dormitory. The findings are presented in Table 1.

Table 1

Discounted Payback Period for analyzed variants of the rainwater utilization system

Tank capacity [m^3]	Discounted Payback Period [year]
30	23.3
60	21.9
90	22.0

On the basis of the findings obtained, it can be seen that in no analyzed variant of rainwater retention tank capacity did the payback period exceed the one which was assumed for the system's operational life in the building. In the most profitable of the analyzed variants, *ie*, the tank of 60 m^3 capacity, the *DPP* is 21.9 year. Nonetheless, because of very similar values of that ratio for the analyzed variants of the investment projects, it cannot be considered as a critical parameter in the decision-making process. Therefore in the analyzed building, the determined *NPVs* should be taken into consideration first of all.

In order to assess the investment risk connected with the economic implementation of rainwater utilization systems in the analyzed dormitory, the investment sensitivity analysis was conducted. For that purpose, the investment sensitivity indexes *sc* were determined which illustrated to what extent the change in value of independent variables by 1% could influence the obtained *NPV* value. In that method, it is assumed that only a single independent variable is changed at the given moment while the other variables remain at the same basis level. Furthermore, within that analysis the relative safety margins *sm* have also been calculated which define the allowable deviation of the given variable from the basis value at which the investment project is still cost-effective [43]. The calculation was made using the dependences.

$$sc = \frac{\dfrac{NPV_i - NPV_b}{NPV_b}}{\dfrac{Z_i - Z_b}{Z_b}} \tag{5}$$

where: sc – *NPV* sensitivity index against the change in value of variable Z by 1%;
Z_i – i-value of the variable;
NPV_i – *NPV* value at the i-value of variable Zi;
Z_b – basis value of variable Z;
NPV_b – *NPV* value for the variable Z_b.

$$sm = \frac{Z_g - Z_b}{Z_b} \tag{6}$$

where: sm – investment safety margin;
Z_g – limit value of the analyzed variable.

The research also analyzed the influence of increase in investment expenses by 1% on *NPV* as well as the reduction in possible savings by 1% which resulted from the fact that an increase in water rates and wastewater discharge fees for rainwater discharged to the sewage system were changed to a lesser extent than it was assumed.

The values of sensitivity indexes *sc* and relative safety margins were determined for all cases analyzed in this paper, because for all *NPVs* get positive values and this indicates that the analyzed project is cost-effective. The obtained results of calculations are tabulated in Table 2.

Table 2

The summary of calculated values of the sensitivity index *sc* and the relative safety margin *sm*

The analyzed independent variable	Sensitivity index *sc*	Relative safety margin *sm* [%]
The volume of the tank: 30 m^3		
Investment	–4.25	23
Tap water price	3.37	–29
Price for rainwater discharge to the sewage system	2.37	–42
Tap water price + Price for rainwater discharge to the sewage system	5.74	–17
The volume of the tank: 60 m^3		
Investment	–2.19	45
Tap water price	1.93	–52
Price for rainwater discharge to the sewage system	1.25	–79
Tap water price + Price for rainwater discharge to the sewage system	3.18	–31
The volume of the tank: 90 m^3		
Investment	–1.33	75
Tap water price	1.17	–84
Price for rainwater discharge to the sewage system	0.74	–133
Tap water price + Price for rainwater discharge to the sewage system	1.91	–51

The obtained values of sensitivity indexes and safety margins demonstrated that the investment project including the use of the *RWHS* in the analyzed dormitory is most sensitive to the changes in savings caused to a lesser extent by an increase in water-rates and wastewater discharge fees for rainwater discharged to the sewage system. Also it was observed that along with increasing tank capacity, the investment sensitivity index decreased |*sc*|, and for the capacity of 90 m^3 it reached the value of 1.91, at the relative safety margin |*sm*| of –51%. It means that for that tank capacity the capital expenditures could be increased by 75% and savings reduced by 51% and, even so, the investment will still be profitable. Definitely, the project with the tank capacity of 30 m^3 is less sensitive to the capital expenses and the water purchasing prices as well as the wastewater discharging fees. In this case, the relatively high values of the sensitivity indexes |*sc*| testify to the great influence of the analyzed variables on the cost-efficiency of the analyzed investment project. Also, it is evidenced by the determined relative safety margins |*sm*|. For that investment variant, the capital expenses could be increased merely by 23% and the savings reduced by 17%. Otherwise, the undertaking becomes unprofitable.

The conducted sensitivity analysis demonstrated that together with an increase in the capacity of the rainwater tank in the analyzed *RWHS*, the investment sensitivity decreases in either case, namely, an increase in capital expenses born in the year "zero" ("0") and the savings gained during the system operational life-cycle in the building. It was also observed that the directions of changes in the capital expenses and cost-effectiveness of the analyzed undertaking are opposed to each other. It is evidenced by the obtained values of the investment sensitivity indexes ($sc < 0$) as well as the relative safety margins ($sm > 0$). It means that the financial effectiveness of the analyzed investment project increases along with the decrease in capital expenses. However, in the case of changes in the purchasing prices of the tap water and the wastewater discharging fees for the rainwater discharged to the sewer, the direction of such changes corresponds to the direction of changes of the investment profitability level. The increase in those two prices causes an increase in savings resulting from the *RWHS* implementation in the analyzed building, and it consequently led to an increase in the updated *NPV* values.

Conclusion

The accumulation and utilization of rainwater provides many advantages for sustainable urban development and is a key point in strategies used to reduce water shortages in urban conditions.

The elaborated simulation model is versatile and can be used for research on the rainwater harvesting system performance in different buildings as well as for different climatic conditions and the results obtained due to the use of it enable the financial effectiveness to be determined for this type of undertakings.

This paper presents the result of the case study where it is planned to implement the *RWHS*. Therefore, the findings may provide valuable guidelines for the investor in making decisions on the implementation of the *RWHS* in the analyzed dormitory building.

This study on the possible use of a rainwater harvesting system (*RWHS*) in a dormitory enables the following set of conclusions to be formulated.

1. The use of rainwater harvesting system enables tap water consumption for toilet flushing in the analyzed facility to be reduced by 11 to 22% depending on the capacity of the retention tank used.

2. The efficiency of rainwater harvesting system is limited by the roof size from which the rainwater is collected. An increase in this surface area will provide a substantial increase in tap water savings and improve the cost-effectiveness of the investment. Because of this, it would be profitable to deliver rainwater from the roofs of

neighboring buildings to the retention tank. Furthermore, a decrease in the water consumption for toilet flushing will increase the savings.

3. The use of an RWHS in the facility studied is financially profitable. In no analyzed variant of rainwater retention tank capacity did the discounted payback period *DPP* exceed the obtainable "life cycle" of the system in the building.

4. Together with an increase in a tank capacity, the updated investment *NPV* increased as well and it reached its highest value for the tank capacity of 90 m^3.

5. The conducted sensitivity analysis demonstrated that together with increasing tank capacities the *RWHS* implementation undertaking for the analyzed dormitory is less sensitive to both the changes in capital expenses and obtainable financial savings.

6. The use of the *RWHS* with the tank of 90 m^3 capacity enables not only the best financial parameters to be gained, but also the rainwater volumes discharged to the sewage system to be reduced what could favorably influence the drainage system performance as well as the protection of receiving bodies of water, which are most commonly surface flowing waters.

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MOŻLIWOŚCI WYKORZYSTANIA WODY DESZCZOWEJ W DOMU STUDENCKIM: OSZCZĘDNOŚĆ WODY PITNEJ I KORZYŚCI FINANSOWE

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Abstrakt: W pracy przedstawiono wyniki badań określające efektywność finansową systemu wykorzystania wody deszczowej (*RWHS*) do spłukiwania toalet. Jako przedmiot badań wybrano budynek mieszkalny (akademik) zlokalizowany w Polsce. Analizę funkcjonowania systemu *RWHS* przeprowadzono na sformułowanym modelu symulacyjnym. W badaniach przeanalizowano również wpływ wielkości zbiornika retencyjnego na efektywność finansową zastosowania systemu gospodarczego wykorzystania wody deszczowej w rozpatrywanym domu studenckim. W analizie finansowej zostały określone dwa wskaźniki finansowe: wartość bieżąca netto (*NPV*) oraz zdyskontowany okres zwrotu (*DPP*). W celu oceny ryzyka inwestycyjnego związanego z zastosowaniem systemu gospodarczego wykorzystania wody deszczowej w badanym akademiku wykonano analizę wrażliwości inwestycji. W tym celu wyznaczono współczynniki wrażliwości inwestycji *sc*, które obrazują, jak duży wpływ na otrzymaną wartość *NPV* wywiera zmiana wartości poszczególnych zmiennych niezależnych o 1%. Przeprowadzona analiza wykazała, że zastosowanie układu RWHS w analizowanym budynku jest opłacalne i może zmniejszyć zapotrzebowanie na wodę do spłukiwania toalet od 11 do 22%, w zależności od pojemności zbiornika retencyjnego.

Słowa kluczowe: systemy wykorzystania wody deszczowej, zarządzanie wodą deszczową, oszczędność wody pitnej, analiza finansowa