Decision Analysis Tool for Appropriate Water Source in Buildings

D. Káposztásová and Z. Vranayová

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Abstract To attain sustainability of water resources involves taking economic, environmental, and socially feasible measures without detrimental consequences for the time to come. Providing adequate water supply and sanitation is a challenging task throughout the world. We are facing the need to ensure water quality by using technical systems, and thus a one of the necessary requirements of life for today's civilization is becoming water saving, treatment, and its management. Lots of aspects may contribute to the solution on how to collect, produce, and finally use alternative water sources. Massive use of reused water for non-potable purposes in buildings promotes the conservation of natural water resources. While respecting the basic parameters of alternative water sources, it is required for the end user or building manager to ensure the prescribed quality of water depending on the purpose.

This chapter's aim is to present decision analysis tool on alternative water use at the building level. Water management strategies and presented 11 portfolios should provide general guidance on the issues and information to support decisions on alternative water use and make it more attractive to public. The evaluation of the two

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A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 269–284,
DOI 10.1007/698_2017_223, © Springer International Publishing AG 2018,
Published online: 19 May 2018

main criteria, as economic and environmental, could be used to change the water habits or help investor to make the right decision for the best water management portfolio. Presented costs and benefits of the portfolios are scored and compared to screening criteria calculated by analytical hierarchy process. The decision analysis tool could fill the information gap on sustainable water strategies in Slovakia by better understanding the building water cycle and help to change the thinking of the society to be in balance with the nature.

Keywords AHP, Building water cycle, Decision analysis tool, Reused water, Water sources

1 Introduction

Water is a global challenge of the twenty first century, both in terms of available resource management and the world's population access to drinking water and sanitation. We are facing the need to ensure water quality by using technical systems, and thus a basic requirement of life for today's civilization involves treatment, transport, heating, and purification of water. It is all about the water. Recognizing that water-related problems are one of the most essential and immediate challenges to the environment and public health, it is vital to act now [1]. The total volume of water in the world remains constant. What changes is its quality and availability [2]. Water scarcity and water pollution are some of the crucial issues that must be addressed within local and global perspectives. One of the ways to reduce the impact of water scarcity as well as minimizing water pollution is to expand water and wastewater reuse [1]. Many researchers confirmed that the importance of water savings is rising every day (Fig. 1).

Implementing appropriate urban water policies will be achieved through an increased understanding of urban water cycle (water supply, wastewater, and storm water infrastructures). Within this framework, we pay particular attention to energy-water relationships, water scarcity, and the development of tools and techniques to implement integrated water and energy resource management. Contributions to meeting this challenge should consider levels of service and reliability, risk of service failure, and risk acceptability [3]. Particularly considering climate change, it is crucial to improve the sustainable use of water and energy while minimizing the carbon footprint as well as to plan and promote climate change adaptations in a phased way [4]. Water, energy, and waste are essential parts of the environmental assessment of buildings with an expected impact on the residents' quality of life – in the rigorous application of measures resulting from risk management. We assume that inhabitants living in new green buildings which focus on environmental sustainability will report higher life satisfaction than in the "traditional" buildings (without the "progressive technologies"). There is no documented transformation impact of buildings on green building as a living system on the quality of life of users living in these buildings. Ken Yeang, father of bioclimatic skyscraper, claims that green design is the blending of four infrastructure strands into a seamless system [5].

Fig. 1 Water challenge

2 Suitability and Availability of Water

According to the World Water Assessment Programme (WWAP), about 70% of water use in the world is used for irrigation, about 22% for industry use, and about 8% for domestic use. In many countries the hydrological cycle is managed to provide enough water for industry, agriculture, and domestic use. Common household uses consume much water. There is a need to manage its end use as sustainable as our conditions allow us [6]. In the European Union, it is common to use well and rainwater source for purposes such as irrigation, toilet flushing, etc. Gray water reuse is in our condition still rare [7].

We can reduce water in household by:

- Efficient water use in buildings.
- Alternative water supplies (rainwater, etc.)
- Recycling and reuse of water (gray water, etc.) [8].

It is essential to foster the aptitude of various water types to meet the correct amount of water requirements for different end uses within the building. Public should be educated in water efficient usage and the potential implication of their consumption [8] (Fig. 2).

The Water Framework Directive (WFD) supports sustainability in water management. The primary objective of the WFD is to create a suitable mechanism that can establish the basic principles of sustainability in water policy and subsequently

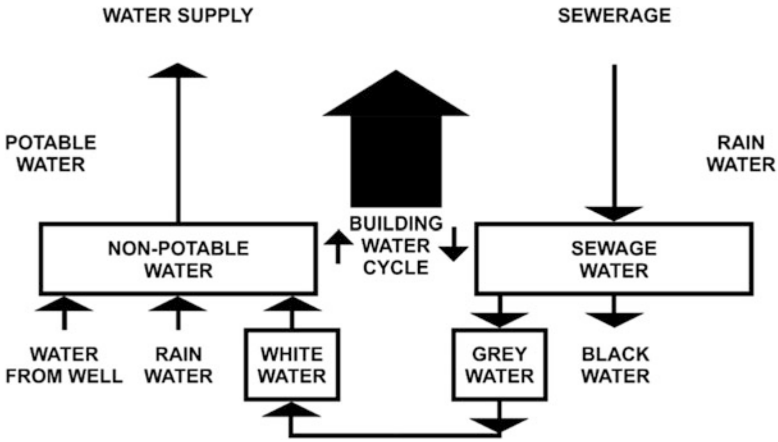

Fig. 2 Water in building water cycle

water management [9]. A significant step toward sustainability in Europe is that water and wastewater treatment are no longer seen in isolation but as integral part of the urban water cycle, which itself forms a part of the natural hydrological cycle [2].

The water management options that are combined and described in this section are as follows (systems are more in-depth described in previous chapter):

- Main water supply
- Well water supply
- Rainwater harvesting system
- Gray water reuse system

Most of the water management options would reduce demand on the potable water system. These reduced demands could result in cost savings for the potable water system in terms of smaller infrastructure needs and lower operating costs. These water management options could be directly implemented by customers [10]. The water efficiency labeling of products has been implemented voluntarily in various countries. For example, in some countries, efficiency is not graded, but efficiency label is awarded when consumption is less than a specific amount. This is the labeling system in use in the USA and Scandinavia, for example. In Australia and Ireland (Dublin), however, the label indicates a classification that varies with the product's efficiency [11]. Using these appliances will lead to the change of habits and less gray water production and result that gray water system could be not viable. The ability of supply to meet demand will always need to be evaluated on a case-by-case basis. A balance evaluates how water is used in a building and can help identify opportunities for water savings.

In ETA 0808 – specifications for assigning ANQIP water efficiency labels to taps and flushing valves [12] – and in ETA 0905, systems of reuse and recycling of gray water in buildings, the water balance in residential buildings with efficiency devices [13] was presented. A common vision in foreign countries is to use efficiently all sources of water that you have at your property. It can be stated that water efficiency is the best way to contribute to policies for sustainable use of water.

3 Decision Analysis Tool for Appropriate Water Source in Buildings (DATAWs)

This chapter describes decision analysis tool for appropriate water source in buildings (DATAWs). The target of the integrated water management is to take into account water management evaluation criteria which were set up by the expert group and might increase the water sustainability and reliability [7, 14]. The main aim for creating the DATAWs was to help customer and designer to make the right decision when designing new house to fulfill all their requirements and support the sustainable water use at the building level. We used the Analytical Hierarchy Process (AHP) procedure to decompose the decision problem into a hierarchy that consists of the most critical elements of the decision problem. The hierarchical structure is represented by descending from general objective to more specific arrangement of the elements in order to reach the top level of the final determination. However the findings indicate that the specific arrangement of structural elements and their mutual influence can determine the solution to a particular decision problem [7, 15].

The DATAWs methodology consisted of three main steps:

Step 1: Evaluation of Water Habits

The first step was to find the pattern of water use by the evaluation of different groups of end users. Four main water types were used as described in Fig. 2. The evaluation was made by sophisticated decision analysis based on Saaty methodology – AHP (Fig. 3). Chosen method as an algorithm was successfully implemented on the platform Excel using the programming tools of the Visual Basic.

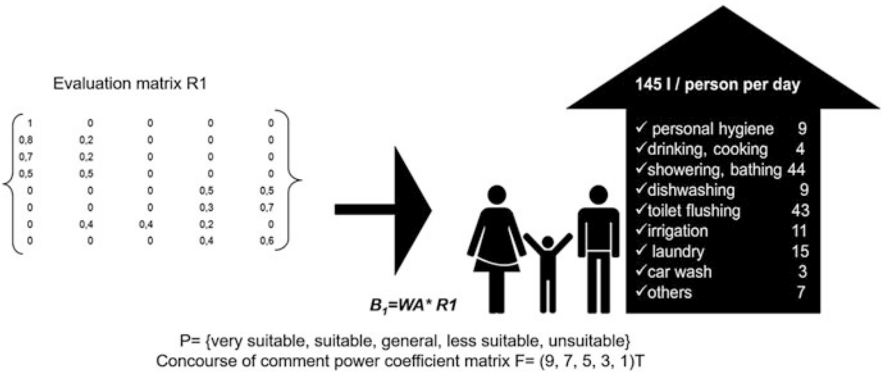

Fig. 3 Evaluation matrix R1 and nine purposes of water use

The fuzzy comprehensive evaluation of water habits was described step by step in [16].

It was basic to start with findings on how the water is used and what we should do to raise the customers' awareness of the water savings. According to the medium results of G1 (classic user) and G2 (different user), there are a lot of options on how to encourage the people to change their water consumption habits. It is well-known that the companies G4 that work with water saving systems have had the best practices. As the Slovak pattern is insufficient, we will need to learn from them and adapt a better pattern of usage [7, 16]. So the importance of DATAWs was confirmed, and we have continued with Step 2 dedicated on all possible water portfolios and their combination.

Step 2: Description of Water Portfolios and Possible Combinations
This step defines and evaluates combinations of water management options, referred to as water management portfolios. The 11 case portfolios were prepared in two alternatives – connected to main water supply and without the connection (four water sources and nine end-use purposes) (Fig. 4).

The portfolio means the combination of possible water sources and their limitation in alternative 1 where eight portfolios were set. "The same approach is used in alternative 2 but potable water is replaced by water from well. In this case we have four portfolios: Well water, W+R, W+R+G, W+G" [17]. The detailed description of portfolios is in [7], and they are giving the customer the options that are ideal for his case. Each portfolio must be actualized according to the inputs dedicated to his situation (rainfall data, roof area, fixtures, etc.).

The equation of the water audit shows that the entering volume of water in the building is the same as the volume at the exit. In terms of addressing water efficiency issues, it is necessary to take into consideration all changes in water use in order to

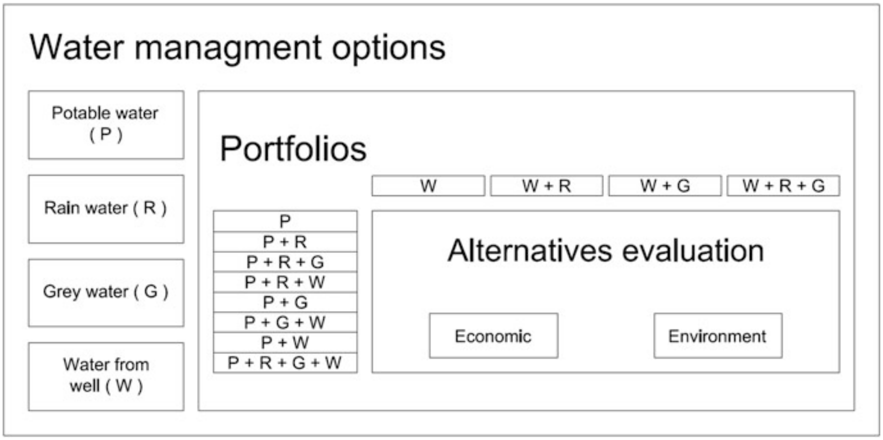

Fig. 4 Water management options [14]

take the final decision whether to put a rainwater, well water, or gray water system to use [8].

According to the presented nine purposes, all possible combinations with four or three sources were calculated (Fig. 3). To define all possible combinations of water management options referred to as water management portfolios for both alternatives, the classical combinatorial task of determining the number of combinations was used (1).

Alternative 1

- 63 combination
- 66l fixed for potable purposes
- Connected to main water supply

Alternative 2

- 26 combination
- 66l fixed for potable purposes
- Not connected to main water supply

$$\binom{n}{k} = \frac{n!}{(n-k)!n!} \tag{1}$$

Step 3: Economical and Environmental Impact
The main aim of authors is to present methodology of economic and environmental impact, presented in Step 3.

3.1 Environmental and Economic Approach

This part presents and describes the most essential part of DATAWs – the screening criteria used to rank the water management portfolios described above. Screening criteria are grouped into two major categories: environmental and economic. Each category of screening criteria has subcategories of criteria that make up the details of the more extensive criteria.

- *Environmental approach*
  In environmental view, other motives are considered, such as wishing to conserve water, helping the environment, and saving the water.
- *Economics approach*
  The economics include the present worth cost of the capital and operations and maintenance costs and the cost of water.

To demonstrate the best solution to a customer according to his preferences, it is inventible to consider hypothetical economic or environmental approaches (Fig. 5). It can be done by AHP. Two calculation methods could be used.

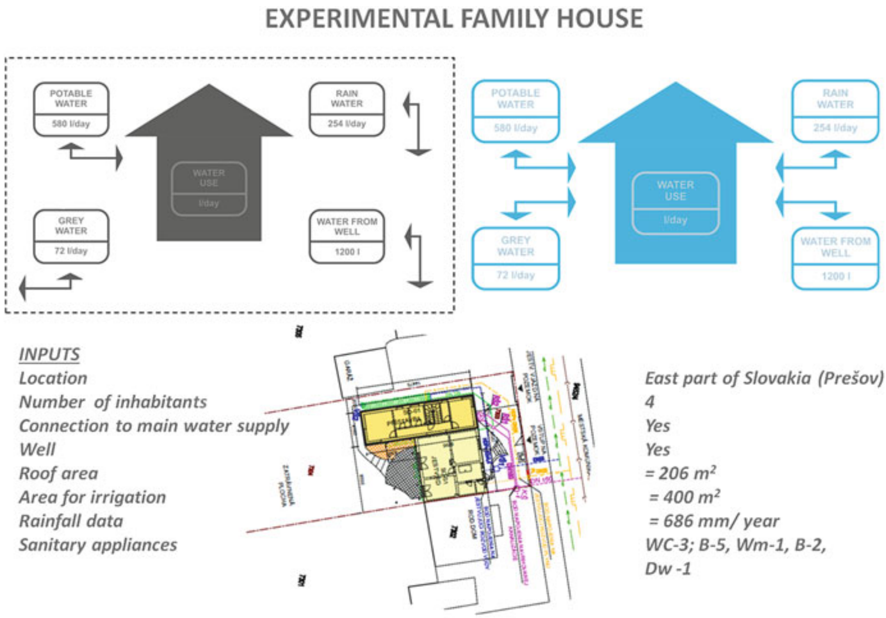

Fig. 5 Inputs for examination of experimental family house

The problem involves evaluating a set of proposed water management portfolios in two alternatives (Alternative 1, 1–8 and Alternative 2, 1–4) for customer on the basis of economic and environmental approach.

The objectives are measured in terms of five criteria: (1) *investments*, (2) *payback period*, (3) *impact on health (risks)*, (4) *water source*, and (5) *water saving*.

The first step after identifying all portfolios suitable according to the customer request is to identify whether the environmental or economic point of view is preferred. Also when using the expert method, the weights are calculated according to the expert's experience and knowledge. The other possible way on how to calculate the weights is by setting only opinions of the customer and calculates the weights by normalizing vector matrix. One can expect that any human judgment is to some degree imperfect (or inconsistent). Therefore, it would be useful to have a measure of inconsistency associated with the pairwise comparison matrixes. In order to measure the degree of consistency, we can calculate the consistency index that could be used in evaluation [18].

3.2 Methodology of Evaluation

The AHP methodology consists of pairwise comparison as the basic mode. The reduction of conceptual complexity is set by only two components at any given time.

Set by 3 steps: "(i) developing a comparison matrix at each level of the hierarchy, beginning at the top and working down, (ii) computation of the weights for each element of the hierarchy, and (iii) estimation of the consistency ratio" [8, 18]. After the comparison, the summarized preferences get the relative importance.

This can be achieved by computing a vector of the weights and priorities and attributes associated with the objectives. This can be accomplished by normalizing the eigenvector associated with the maximum eigenvalue of the pairwise comparison matrix [18]. In this framework, we shall assume that the two first steps of the AHP have been achieved, which are formation of the hierarchical structure and calculation of the relative weights of the elements (objectives and attributes) of the hierarchy by conducting pairwise comparisons (Fig. 6). The overall goal here is to identify the best portfolio to customer. This requires assessing the relative importance (weights) of the elements at each level of the decision hierarchy. This could be done by experts or normalizing by program [19].

The economic objective has been judged to be three times as important as the environmental objective in this case. This results in assigning weights of 0.71 and 0.29 to the two objectives (Table 1). The economic objective is measured by three attributes, investments, payback period, and risks. Table 2 shows the pairwise comparison matrix and calculated weights for the attributes of economic objectives.

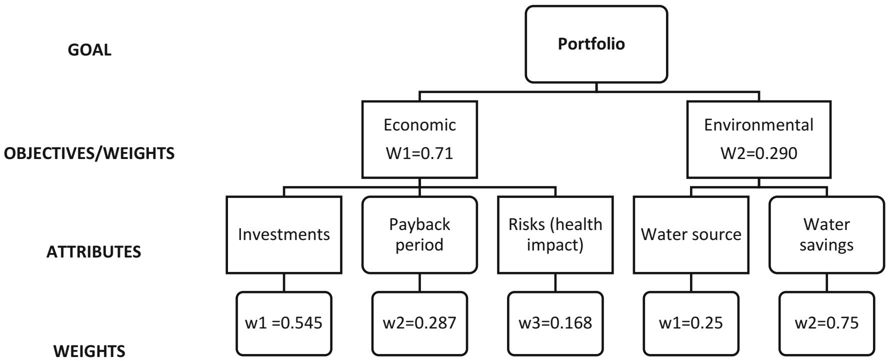

Fig. 6 Formation of the hierarchical structure and calculating the relative weights of the elements

Table 1 Pairwise comparison matrix of the level of objectives and calculated weights

	Economic	Environmental	Weight
Economic	3	1	0.71
Environmental	0.5	1	0.29

Table 2 The pairwise comparison matrix and calculated weights for the attributes of economic objectives

	Investments	Payback period	Risks	Weight
Investments	1	2	3	0.545
Payback period	0.5	1	2	0.287
Risks	0.333	0.5	1	0.168

Table 3 Pairwise comparison matrix of environmental attributes and calculated weights

	Water saving	Water source	Weight
Water saving water source	3	1	0.75
Water source	0.333	1	0.25

Fig. 7 Rating and ranking of portfolios: results in proposed case

The environmental objective is measured in terms of two attributes, water source and water savings. The water saving attribute has been estimated to be three times more important than water source. Consequently, weights of 0.75 and 0.25 have been assigned to water source and savings, respectively (Table 3).

This model demonstrated how, by applying different quantifiers, a decision-maker could obtain a wide range of decision strategies and scenarios for customer.

From the calculation, we can see the difference between method 1 (Wp8) and normalized method 2 (Wp8n). The suitability of the method is set according to the customer requirements (Fig. 7).

$$\mathrm{Wp8} = [0.846623 \quad 0.419978 \quad 0.408059 \quad 0.408059 \quad 0.846623 \quad 0.419978 \quad 0.408059 \quad 0.408059]$$
$$\mathrm{Wp8n} = [0.796233 \quad 0.753635 \quad 0.693129 \quad 0.796233 \quad 0.753635 \quad 0.693129 \quad 0.753635 \quad 0.693129]$$

According to the proposed case (Fig. 7 portfolio 1), 80% is the most suitable from the economic view. This strategy could be applied very quickly to show the customer the potential from both economic and environmental approaches.

4 Discussion and Limitations

Consideration of both capital and annual maintenance and operating costs is necessary to provide the complete picture of the actual cost of a portfolio. The principle of linear regression was used and prediction model created for savings from year 2015 to 2031.

Following tables shows the possible water bills reductions per year by replacing the around 55% of water demand by alternative water source (Tables 4 and 5). Of course when calculating savings, we need to take into account the total installed

Table 4 Example water savings: rainwater system [16]

Without RWH system						With RWH system					
Year	Metered water charges (€ VAT)		Σ € VAT	Water consumption (m^3/year)	PW price (€/year)	RW consumption (m^3/year)	RW price (€/year)	RW price + energy (€/year) 1 m^3	RW price (€/year)	Price P + R (€/year)	Savings (€/year)
2015	1.57	1.08	2.65	211.70	561.43	116.435	125.75	0.49	183.15	435.79	125.63
2016	1.90	1.28	3.18		673.56		148.84	0.51	208.18	511.28	162.28
2017	2.00	1.34	3.34		707.73		156.45	0.52	217.12	535.60	172.13
2018	2.10	1.41	3.50		741.90		164.07	0.53	226.11	559.96	181.94
2019	2.19	1.47	3.67		776.06		171.69	0.54	235.14	584.36	191.70
2020	2.29	1.54	3.83		810.23		179.31	0.56	244.21	608.81	201.42
2021	2.38	1.61	3.99		844.39		186.93	0.57	253.33	633.31	211.09
2022	2.48	1.67	4.15		878.56		194.55	0.58	262.50	657.85	220.71
2023	2.58	1.74	4.31		912.72		202.17	0.60	271.71	682.44	230.28
2024	2.67	1.80	4.47		946.89		209.79	0.61	280.98	707.08	239.81
2025	2.77	1.87	4.63		981.05		217.40	0.63	290.30	731.78	249.28
2026	2.86	1.93	4.80		1,015.22		225.02	0.64	299.67	756.52	258.70
2027	2.96	2.00	4.96		1,049.39		232.64	0.66	309.10	781.33	268.06
2028	3.05	2.06	5.12		1,083.55		240.26	0.67	318.59	806.19	277.36
2029	3.15	2.13	5.28		1,117.72		247.88	0.69	328.13	831.11	286.61
2030	3.25	2.19	5.44		1,151.88		255.50	0.71	337.74	856.08	295.80
2031	3.34	2.26	5.60		1,186.05		263.12	0.72	347.40	881.13	304.92

PW potable water, *W* water, *WW* white water, *RW* rain water, *WW* water form well

Table 5 Water savings – gray water system [16]

Without gray water						Gray water reuse system					
Year	Metered water charges (€ VAT)		Σ € s VAT	W cons. (m ^{3}/year)	PW price (€/year)	White water consumption (m^3/year)	PW price (€/year)	White water (€/year) 1 m^3	WW price (€/year)	WP white + gray (€/year)	Savings (€/year)
2015	1.57	1.08	2.65	211.70	561.43	116.435	492.48	0.41	47.83	540.31	21.12
2016	1.90	1.28	3.18		673.56		590.84	0.42	49.45	640.29	33.27
2017	2.00	1.34	3.34		707.73		620.81	0.43	50.56	671.37	36.36
2018	2.10	1.41	3.50		741.90		650.78	0.44	51.69	702.47	39.42
2019	2.19	1.47	3.67		776.06		680.75	0.45	52.87	733.62	42.44
2020	2.29	1.54	3.83		810.23		710.72	0.46	54.08	764.80	45.43
2021	2.38	1.61	3.99		844.39		740.69	0.48	55.33	796.02	48.37
2022	2.48	1.67	4.15		878.56		770.66	0.49	56.62	827.28	51.28
2023	2.58	1.74	4.31		912.72		800.63	0.50	57.96	858.58	54.14
2024	2.67	1.80	4.47		946.89		830.60	0.51	59.33	889.93	56.96
2025	2.77	1.87	4.63		981.05		860.57	0.52	60.75	921.31	59.74
2026	2.86	1.93	4.80		1,015.22		890.54	0.53	62.21	952.74	62.48
2027	2.96	2.00	4.96		1,049.39		920.50	0.55	63.72	984.22	65.16
2028	3.05	2.06	5.12		1,083.55		950.47	0.56	65.27	1,015.75	67.80
2029	3.15	2.13	5.28		1,117.72		980.44	0.57	66.88	1,047.32	70.40
2030	3.25	2.19	5.44		1,151.88		1,010.41	0.59	68.53	1,078.95	72.94
2031	3.34	2.26	5.60		1,186.05		1,040.38	0.60	70.24	1,110.62	75.43

PW potable water, *W* water, *WW* white water, *RW* rain water, *WW* water form well costs including the water reuse system with all storage, pipework, disinfection, power supply, and commissioning requirements. The fact is that for retro-fitted system the costs will be higher [8].

4.1 Description of the Used Methodology

To assess the investment options, we used the method of net present value (NPV). The net present value is a dynamic method to assess the effectiveness of investment options. The effect of investment is cash income from the project (expected profit after tax, depreciation, respectively, other income; in our case it was water saving). It is calculated as the difference between the discounted cash inflows and (discounted) capital expenditures. In the calculations, among others, technological factors reflected mainly the time factor, which affects the value of an investment and its life. Using this method, we get the real value of savings, which reflects a lifetime. The difference between savings and investment costs gives the current value. At the moment when the NPV is positive, there is a return on investment in the technology [20].

Of course, the NPV of the influence of several facts, not just time. Also noteworthy is the interest rate or inflation. Therefore, for each variant, we assume inflation of 1.5 and 3%. Interval or values that we have set are based on several studies, the statistical office. Inflation developed over the last 10 years, and the prediction shows that it is highly likely that inflation will continue in the coming years in the interval. The evolution of prices (the linear regression was used), or even monitor inflation in industrial production (energy prices, etc.). Slovakia is moving in the same range, therefore, was as optimistic model set at 1.5% and pessimistic at 3%.

The payback period varies, depending on factors including:

- Number of users to a system
- Volume of reclaimed water generated
- Cost of the system, operation, and maintenance
- Current and future metered water charges [8]

Domestic rainwater and gray water systems for typical home are similar in price, can be installed, and are relatively low compared to building price. According to the studies in the world, it is known that rainwater systems are cheaper to operate and maintain per cubic meter of reclaimed water than gray water systems.

The indicative life expectancy of these systems is an essential factor while assessing the economics. The life expectancy of gray water system varies from 15 to 18 years depending on the quality of components. The table below shows some indicative life expectancy.

A big study was taken in Innsbruck about the feasibility of advanced gray water systems for the single-family house. Within the small single household, the onsite MBR is the most popular among the suppliers. In this study, the high payback periods were calculated for the experimental house. The similar results were

Table 6 Payback period results for experimental house [16]

Payback period		Water system			Well			
	Gray water		Rain water		Digging		Drilling	
Inflation (%)	cca (€) first year return	Year	cca (€)	Year	cca (€)	Year	cca (€)	Year
1.50	200	20	200	18	180	6	134	6
3	188	25	190	20	80	6	75	6

conducted by Jaboring. The payback period for the gray water system installed in family house was calculated to 15 years if the water consumption is around 600 L/day. Also, the project report [6] states that economics for gray water system is much less specific – around 20 years. The research results from the Czech Republic also confirm the extended payback period [21]. Table 6 describes payback period for single-family house – experimental house.

Rainwater systems are more effective in big buildings compared to small buildings. For example, in the administrative building, they can replace 30% of water consumption. To sum up, these systems at the single-family house are likely to be less economical than larger systems.

5 Conclusions

The provision of safe water and sanitation has been more effective than any other interventions in reducing infectious disease and increasing public health. The water management field in the environmental assessment system (BEAS) used in Slovakia has a percentage weight of 8.88%, which has a significant role in the environmental assessment compared to other fields [22]. The public expects to have safe water and sanitation; therefore, when recycling water, it is essential to protect public health and the environment [23]. DATAWs is a tool that helps to understand the water building cycle set on the pattern of water user in Slovakia. The classic pattern consists of potable use for all purposes, and sometimes the well water is used for irrigation. The questionnaire results just confirmed the real situation and the needs for water audits. The change of a classic family house to house that saves water using the alternative water sources led to a reduction of water bills. The saved costs for water in the year 2018 could be around 190€, but the main aim was to give as much as possible information to the customer to change his thinking to a sustainable solution even when they are not so cost-effective. We can assume that better understanding of building water cycle and suitable water use by inhabitants can help us to save the water globally, and it is showing us a new way on how to fight water scarcity starting at the building level.

6 Recommendations

There is a need of deeper financial analysis of proposed systems by prediction models. The AHP_OWA methodology for environmental and economic evaluation could give the more precise results. This methodology has potential for water industry with the prediction scenarios for future. Evolving the application for smart phones to raise people awareness about water systems is also a part of future goals.

Acknowledgment This work was supported by project VEGA n. 1/0202/15: Sustainable and Safe Water Management in Buildings of the 3rd Millennium.

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