Proc. 3rd International Conference on Water and Environmental Engineering (iCWEE2022)
27-30 Nov 2022, Sydney, Australia
ISBN: 978-0-6456692-0-6

Cost survey for Brazilian residential rainwater harvesting systems

Rodrigo Novais Istchuk[1], Enedir Ghisi[2], and Ataur Rahman[3]

[1]MSc., Department of Civil Engineering, Laboratory of Energy Efficiency in Buildings, Federal University of Santa Catarina, Florianópolis, Brazil
[2]Professor, Department of Civil Engineering, Laboratory of Energy Efficiency in Buildings, Federal University of Santa Catarina, Florianópolis, Brazil
[3]Professor, Western Sydney University, Sydney, Australia

Corresponding author's E-mail: rod.istchuk@gmail.com

Abstract

Residential rainwater harvesting (RWH) systems usually have long paybacks and high initial outlays. Studies determining these costs often adopt different conventions, leading to varying results. This study presents a comprehensive cost survey for installing and operating typical residential RWH systems in eight cities in Brazil. The study simulated 432 RWH system design scenarios and two rainwater distribution schemes: indirect (with upper and lower rainwater tanks) and direct (with pressuriser). Initial outlays presented a 24% coefficient of variation among all systems. On average, direct rainwater distribution systems presented initial costs 1.4% lower than indirect systems. In such cases, higher costs corresponding to the pressuriser are equivalent to the savings obtained for not using an upper rainwater tank. Average initial costs for indirect systems ranged from R$ 10,999 to R$ 18,061, depending on the catchment area and rainwater tank size. Operational costs varied by 40% among all scenarios. Such variation is mainly due to the different potable water tariff schemes practised in each city. On average, systems with indirect rainwater distribution presented operational costs 1.8% lower than systems with direct rainwater distribution. As the main conclusion, the cost analysis indicates significant variation in installation and operational costs for RWH systems, pointing to the tariff scheme as a relevant factor for the economic viability of such systems.

Keywords: Economic feasibility, Payback, Initial outlay, Operational cost, Computer simulation.

1. INTRODUCTION

Currently, several Brazilian cities undergo serious water availability problems. For instance, the metropolitan region of São Paulo presents one of the most critical situations nationally regarding the supply of treated water to the population (Lima et al., 2018). In this case, the authors highlight the role of RWH systems in addressing this problem to develop the city's water resource management.

The economic feasibility of RWH systems is fundamental for disseminating this technology. Costs of RWH are characterised by high initial outlays, followed by low operational costs throughout their service life (DTU, 2001). The high market value of this solution is still a limiting factor for its implementation in many cases, and it is recommended that public authorities provide incentives to encourage the population to adopt it (Cáceres et al., 2019).

Teston et al. (2018) observed a wide variety of results regarding the economic feasibility of residential RWH systems in Brazil, which presented, more frequently, payback periods ranging from 20 to 25 years. In this sense, it is important to highlight the significant diversity observed in conventions considered in such studies (Amos et al., 2016), which makes it difficult to compare their results directly.

In Brazil, the technical standard NBR 15527 specifies RWH requirements for roofs aimed at harvesting rainwater for non-potable uses. Such uses may include toilet flushing, garden irrigation, floor and car washing, and decorative applications (ABNT, 2019). RWH systems design must include local characterisation, precipitation regime, and the calculation of a suitable storage tank size to supply the rainwater demand. ABNT (2019) also recommends tank sizing based on the catchment area, rainfall regime, and rainwater demand.

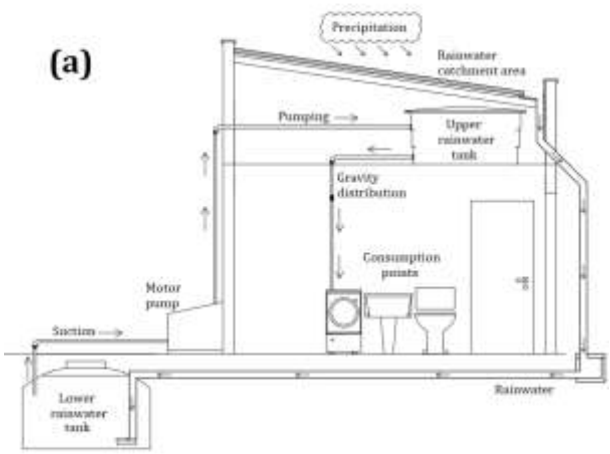
Reliable information regarding the installation and operational costs of RWH systems is essential for developing accurate public policies for its promotion. Conversely, most research about the topic employs varying cost survey approaches and construction conventions, often lacking the detail needed to define public policies assertively. Considering the low concentration of technical information regarding the economic feasibility of residential RWH systems in the literature and on a larger scale in Brazil, this study aims to provide a reliable source for determining their installation and operational costs nationally. The paper compares two rainwater distribution schemes and presents a comprehensible outlay procedure to serve as a reference for future studies or other locations.

2. METHOD

Eight representative cities were selected. Two design configurations were considered for the cost surveys: direct (rainwater distribution via pressuriser) and indirect (via gravity, with two tanks) rainwater distribution. Construction conventions were selected following the recommendations of the Brazilian standard NBR 15227 (ABNT, 2019). Generic single-family RWH systems were then designed considering materials and labour for obtaining installation costs in new buildings. The initial cost survey comprised information from local tank suppliers combined with a federal materials and labour price database (SINAPI, 2021). Computer simulations were used to determine the RWH systems' ideal tank sizes, water savings, and energy consumption based on a range of generic design parameters. Operational costs were obtained by combining results from RWH systems' water balance, conventions adopted from the literature, and local water and energy tariffs.

2.1. Rainwater distribution schemes

The first RWH scheme, with indirect rainwater distribution, contemplates two rainwater tanks. Collected rainwater flows by gravity to a lower tank, from which it is pumped to an upper tank, where again, by gravity, it is distributed to the consumption points. In the second scheme, collected rainwater is stored in the lower tank and distributed directly to the consumption points using a pressuriser. Details about the two configurations can be seen in Figure 1.



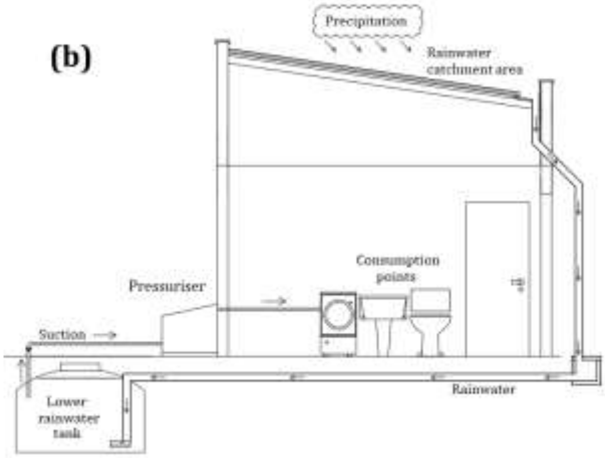


Figure 1. Indirect (a) and direct (b) rainwater distribution schemes

2.2. Initial outlay procedure

The design considered the requirements of NBR 15227 (ABNT, 2019) and represents the minimum requirements related to RWH systems in Brazil. Based on the reference design with indirect and direct distribution of rainwater, as well as the design conventions adopted in this research, quantitative surveys of materials and labour were developed. Tank costs were collected for each city via telephone, e-mail, or online consultation with local suppliers. At least three different suppliers were consulted, and the lowest price found was used in the analysis. The Brazilian Federal database (SINAPI, 2020) corresponding to each location was used as a reference for the remaining items.

2.3. Computer simulation of RWH systems

Generic RWH systems were simulated for eight Brazilian cities based on local rainfall time series. Cluster analysis of rainfall parameters was mainly used for selecting the cities. Further details on such methodology can be found in the study by Istchuk and Ghisi (2020).

The Netuno computer program (version 4) was used in the simulations (Ghisi and Cordova, 2014a). The software employs a daily water-balance model based on design inputs to estimate the potential for potable water savings in the system and define the ideal tank size. The software's user manual contains details about the simulation procedure (Ghisi and Cordova, 2014b). Ideal tank sizes were used to compose the list of materials for the systems, and the potential for potable water savings was used to determine the operational cost. Design parameters were chosen to describe generic configurations of residential RWH systems. The total water demand was defined as 165 L/inhab/day, corresponding to the average consumption observed among the eight cities. Table 1 shows the input data used for the computer simulations.

Table 1. Input data used for the computer simulations

Variable	Unit	Input data
Rainfall time series	-	Daily data for eight cities
Rainwater distribution	-	Indirect [1], Direct [2]
Runoff coefficient	%	80
Catchment area	m²	100, 200 and 300
Number of dwellers	inhabitant	2, 4 and 6
Total water demand	L/inhab/day	165
Rainwater demand (% of total water demand)	%	30, 50 and 70
First-flush discharge	mm	2
Upper tank size	L	[1] variable, [2] zero
Lower tank size	L	1,000 – 50,000 (at intervals of 1,000)

2.4. Operational costs

Operation and maintenance costs were considered for a comprehensive description of the expenses expected for a typical RWH system. Electricity tariffs were considered according to each location (ANEEL, 2021). According to the literature surveyed by Vieira et al. (2014), 0.80 kWh/m³ was used as a reference for the RWH systems with indirect rainwater distribution, and a cost reduction of 25% (0.60 kWh/m³) was assumed for all direct RWH systems. Maintenance costs were assumed as 1% of the initial outlay yearly, which meets the recommended practice (Severis et al., 2019). Disinfection costs were also considered. It was assumed that 1L of sodium hypochlorite (NaClO) treats up to 60 m³ of water (Severis et al., 2019) at R$ 3.19 per litre of disinfectant.

3. RESULTS

Based on the cluster analysis described in the work by Istchuk and Ghisi (2020), the cities chosen for this study are: Belém-PA, Recife-RN, Campo Grande-MS, Salvador-BA, Brasília-DF, Florianópolis-SC, Belo Horizonte-MG, and São Paulo-SP. A total of 432 scenarios were simulated (54 for each city) to obtain ideal tank sizes and potential for potable water savings. All costs corresponding to March 2021. Results from other studies were also corrected to March 2021 according to Brazil’s National Index of Civil Construction (INCC, 2021).

3.1. Initial outlay

The highest average initial cost was obtained for the city of São Paulo (R$ 15,785 and R$ 15,360 for systems with indirect and direct rainwater distribution, respectively). The lowest cost was observed for Belém-PA (similarly, R$ 12,094 and R$ 11,904). Systems with direct rainwater distribution presented initial outlays between 0.30% (Salvador) and 2.69% (São Paulo) below the outlays of systems with indirect rainwater distribution. RWH systems with direct distribution tend to have lower initial costs due to the absence of an upper rainwater tank. However, higher costs for pressurisation equipment tend to make such savings less significant. Table 2 presents the average initial outlays among all cities for both rainwater distribution schemes evaluated herein.

Table 2. Average initial outlays (R$)

Rainwater	Catchment area (m²) – indirect			Catchment area (m²) – direct		
tank (L)	100	200	300	100	200	300
3000	10,999.18	12,077.02	12,885.18	10,749.30	11,872.14	12,680.30
4000	11,565.93	12,643.77	13,451.94	11,361.05	12,438.89	13,247.06
5000	12,157.43	13,235.27	14,043.43	11,952.55	13,030.39	13,838.55
6000	13,134.95	14,212.78	15,020.95	12,930.07	14,007.90	14,816.07
7000	14,130.44	15,208.27	16,016.44	13,925.56	15,003.39	15,811.56
8000	15,143.90	16,221.74	17,029.90	14,939.02	16,016.86	16,825.02
9000	16,175.34	17,253.17	18,061.34	15,970.46	17,048.29	17,856.46

Ghisi and Oliveira (2007) evaluated initial outlays of RWH systems with indirect distribution in two single-storey houses in Palhoça, Santa Catarina. Tanks with 5000 L of rainwater provided potable water savings of around 50% with a catchment area of around 200m². Initial outlays between R$ 6027 and R$ 7512 were obtained. Such costs correspond from 44.3% to 55.2% of the outlays obtained herein in similar systems according to prices surveyed in Florianópolis.

Materials and labour were considered in the outlays. However, as Teston et al. (2018) pointed out, the significant difference observed between the costs obtained herein and those of other authors may be related to different design conventions. Higher initial costs may indicate that a more comprehensive list of items has been considered herein when compared to results obtained by Ghisi and Oliveira (2007) and Carvalho (2010).
Severis et al. (2019) evaluated larger systems and indirect rainwater distribution. The authors obtained an initial cost of R$ 14,372 for a system with 139.2 m² of catchment area and a 12,000 L tank. The cost

corresponds to 88.9% of the average cost obtained herein for a similar system with 100m² of catchment area and a 9,000 L tank. Considering the greater proximity between the costs compared, it can be assumed that the authors considered a similar level of detail in the cost surveys.
Initial outlays were also distributed into categories representing different component groups of RWH systems. Table 3 presents the average results among all cities. Systems with a catchment area of 200 m² were taken as a reference.

Table 3. Initial outlay distribution for systems with a catchment area of 200m²

Tank size (L)	Tanks (%)		Plumbing (%)		Civil works (%)		Rain collection (%)		Electrical system (%)	
	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct
3000	15.6	14.1	24.6	16.0	15.8	23.4	31.4	14.5	12.6	31.9
4000	17.3	16.0	23.5	17.4	17.1	22.3	30.0	13.8	12.1	30.5
5000	18.9	17.7	22.5	18.7	18.4	21.3	28.7	13.2	11.5	29.1
6000	22.8	21.7	20.9	19.1	18.8	19.8	26.7	12.3	10.7	27.1
7000	26.2	25.3	19.6	19.5	19.2	18.5	24.9	11.5	10.0	25.3
8000	29.2	28.3	18.3	19.9	19.7	17.3	23.4	10.7	9.4	23.7
9000	31.8	31.0	17.2	20.3	20.1	16.3	22.0	10.1	8.9	22.2

As tank size increases, costs relative to tanks and civil works also increase. In this study, most civil works correspond to underground tank installation. For the other items, the representative cost decreases as the capacity of the tanks increases. Despite having similar outlays, systems with indirect and direct rainwater distribution presented different cost distributions. Although systems with direct distribution require less capital for tanks, the costs of electrical installations tend to be higher due to the significant cost difference between the motor pump and the pressuriser.

3.2. Operational costs

RWH systems with indirect rainwater distribution presented monthly operational costs between R$ 4.31 and R$ 5.32. The cheapest operational costs were observed in Belém while the most costly operation was observed in Belo Horizonte. On average, the operating costs obtained for systems with direct rainwater distribution were only 3.1% lower than those obtained for indirect rainwater distribution, mainly due to the lower electricity costs attributed to the pressuriser.

4. CONCLUSION

Initial investment costs of RWH systems resulted in a coefficient of variation of 24% among all simulated scenarios. On average, systems with direct rainwater distribution presented initial costs 1.4% lower than indirectly distributed rainwater harvesting systems. In such cases, the higher cost of the pressuriser is equivalent to the savings obtained by not using the upper tank. The average initial costs of indirect RWH systems varied between R$ 10,999 and R$ 18,061, depending on the catchment area and tank size. The greater the tank capacity, the greater the cost relative to the total investment.

Operating costs of RWH systems showed a coefficient of variation of 40% among all scenarios. This variation is influenced by the initial costs of the systems and the different water and energy tariffs practised in each location. Among the eight cities, the average operating costs for systems with indirect rainwater distribution varied between R$ 4.31/month and R$ 5.32/month. On average, systems with direct distribution of rainwater presented operating costs 3.1% lower than systems with indirect rainwater distribution.

Our study obtained initial outlays coherent with what was found by other researchers. As such, the information generated herein can provide reliable information regarding the costs of installing and operating RWH systems in Brazil. Moreover, the proposed initial outlay categorisation helps direct comparisons between studies while also serving as a reference for future studies or other locations.

Considering the importance of financial feasibility and valid public policies to promote the adoption of RWH systems at a larger scale, the information generated herein is suitable for both consumers and policymakers.

REFERENCES

ABNT - Associação Brasileira de Normas Técnicas. NBR 15527: Aproveitamento de Água de Chuva de Coberturas para Fins não Potáveis – Requisitos. [NBR 15527: Rainwater harvesting from roofs for non-potable uses - Requirements]; ABNT: Rio de Janeiro, Brazil, 2019. (In Portuguese)

Amos, C., Rahman, A., & Gathenya, J. M. (2016). Economic analysis and feasibility of rainwater harvesting systems in urban and peri-urban environments: A review of the global situation with a special focus on Australia and Kenya. *Water*, 8(4), 149.

ANEEL - Agência Nacional De Energia Elétrica. Ranking das Tarifas. [Tariff Ranking]. Brasília, 2021. https://www.aneel.gov.br/ranking-das-tarifas in Portuguese.

Cáceres, P. S., Ramos, S. R., & Sant'Ana, D. R. (2019). Potencial de redução da exploração dos recursos hídricos locais pelo aproveitamento de água pluvial em residências no Distrito Federal. [Potential to reduce exploitation of local water resources through the use of rainwater in residences in the Federal District] *Paranoá: Cadernos de Arquitetura e Urbanismo*, v. 23, p. 11-19. (In portuguese)

DTU - Development Technology Unit, *Recommendations for Designing Rainwater Harvesting System Tanks*. O-DEV Contract No. ERB IC18 CT98 027 Milestone A6: Report A4. School of Engineering, University of Warwick, 2001.

Ghisi, E., Cordova, M. M., Netuno 4. Software. Federal University of Santa Catarina, Department of Civil Engineering. Florianópolis. 2014a. http://www.labeee.ufsc.br/downloads/softwares/netuno

Ghisi, E., Cordova, M. M., Netuno 4: User Manual Federal University of Santa Catarina, Department of Civil Engineering. Florianópolis. 2014b. http://www.labeee.ufsc.br/downloads/softwares/netuno

Ghisi, E., & de Oliveira, S. M. (2007). Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil. *Building and Environment*, 42(4), 1731-1742.

INCC – Índice Nacional de Custos da Construção. 2021. [National Index of Construction Costs]. Fundação Getúlio Vargas. https://portalibre.fgv.br/incc

Istchuk, R. N.; Ghisi, E. Agrupamento de regimes pluviométricos para dimensionamento de sistemas de aproveitamento de água pluvial. [Rainfall time series clustering for rainwater harvesting system design]. *Proceedings of the International Congresso f Environmental Engineering and 10th Meeting of Envirionmental Studies*. 1., 2020, Porto Alegre, 2020. p. 87 – 106.

Lima, G. N., Lombardo, M. A., & Magaña, V. (2018). Urban water supply and the changes in the precipitation patterns in the metropolitan area of São Paulo–Brazil. *Applied Geography*, 94, 223-229.

Severis, R. M., Simioni, F. J., Moreira, J. M. M., & Alvarenga, R. A. (2019). Sustainable consumption in mobility from a life cycle assessment perspective. *Journal of Cleaner Production*, 234, 579-587.

SINAPI. Sistema Nacional de Preços e Índices para a Construção Civil [National System of Prices and Indexes for Civil Construction]: Brasília, Brazil, 2021. https://www.caixa.gov.br/Downloads/sinapi-composicoes-aferidas-sumario-composicoes-aferidas/SUMARIO_DE_PUBLICACOES_E_DOCUMENTACAO_DO_SINAPI.pdf

Teston, A., Geraldi, M. S., Colasio, B. M., & Ghisi, E. (2018). Rainwater harvesting in buildings in Brazil: A literature review. *Water*, 10(4), 471.

Vieira, A. S., Beal, C. D., Ghisi, E., & Stewart, R. A. (2014). Energy intensity of rainwater harvesting systems: A review. *Renewable and Sustainable Energy Reviews*, 34, 225-242.