Article

Rainwater Harvesting for Irrigation of Tennis Courts: A Case Study

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Abstract: It has become evident that, during this century, climate change will continue, affecting all regions of the planet. The expected impacts over the next few decades may differ from region to region, with some areas becoming humid and others drier. In regions such as the Mediterranean basin, the main expected impacts of climate change will be prolonged droughts and an increase in the intensity and frequency of heavy rains. Measures of mitigation and adaptation are particularly important in urban environments, where more than half of the population lives, and rainwater harvesting systems (RWHS) are considered to be a very suitable solution to these problems. However, the published studies have mainly focussed on buildings, with very limited references to the interest of its application in large urban infrastructure. Based on consumption and precipitation data, this article presents a study on the implementation of an RWHS in a large-scale sports infrastructure located in the city of Cascais (Portugal) intended for the practice of tennis, with 12 brick dust fields, some of them covered. The average annual consumption of potable water for watering the tennis courts is 5500 m³, and the results show that the RWHS can reduce this consumption by >50%, in addition to other expected benefits, such as the known effect of these systems in reducing flood peaks in the area.

Keywords: rainwater harvesting; climate change; water efficiency; tennis courts

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1. Introduction

It has become evident that, during this century, climate change will continue, with an extent that will depend on the emission mitigation policies that are implemented [1]. By the end of this century, the global average temperature will rise by 2.6–4.8 °C from its current value [2], and more frequent and intense extreme weather events will result in a higher incidence of floods and droughts around the planet [3,4].

Variations in precipitation characteristics because of climate change are expected to differ from region to region on the planet, with some areas becoming humid and others drier, increasing precipitation in high latitude regions and decreasing it in most subtropical areas [5–8]. Regarding the European continent, southern and central Europe will face increasingly frequent heat waves and droughts. The Mediterranean area, in particular, is gradually becoming dry and, therefore, it is becoming even more vulnerable to droughts [9–11].

Regardless of the reduction in annual precipitation, an increase in the intensity and frequency of heavy rains is another important impact of expected climate change in the coming decades, and this trend will also affect the Mediterranean regions [12–17].

According to the United Nations, about 54% of the population on the planet currently lives in cities, but this percentage is expected to increase to 66% by 2050. Therefore, the impact of climate change on cities will be very significant in the future and will drive measures to improve adaptation and greater resilience to more extreme weather conditions [1,18].

More frequent and intense winter rains could lead to exceptional flooding that would substantially impact urban areas [19–25]. Extreme precipitation events can cause, within urban areas, the overflow of interior water lines, affecting riverside areas, and can also cause flooding in non-marginal areas due to the lack of capacity of urban stormwater drainage systems, which generally have not been dimensioned for exceptional scenarios. The frequency with which this insufficiency of public stormwater drainage networks occurs can be further increased by using inadequate regulatory return periods, given the current reality of climate change, in the design of public systems. These situations can cause, among other consequences, the occurrence of excessive surface runoff, causing damage to urban infrastructure, eventually with greater impact after prolonged periods of drought.

It has been recognised that rainwater harvesting systems (RWHS) in buildings can be an important measure of adaptation to the urban environment, as they can contribute not only to the interception and storage of rainwater, significantly dampening flood peaks, but also for the conservation of potable water, as these systems allow the alternative use of rainwater for non-potable purposes [7,26]. It is important to note that the use of rainwater in cities can be considered not only in buildings but also in other infrastructure and urban equipment. This article presents a case study regarding the possibility of installing an RWHS in a large urban facility, the Estoril Tennis Club (ETC), intended for sports activities (tennis and paddle). This sports complex (Figures 1 and 2) is located in Portugal (Cascais) near the capital, Lisbon.

Figure 1. Aerial view of the Estoril Tennis Club (ETC).

It should be noted that Portugal is a Mediterranean country which, according to forecasts, will be one of the most affected by climate change and will suffer not only prolonged droughts, but also extreme rainfall events. Indeed, official forecasts indicate that, in the period of 2040–2070, an average annual temperature increase of 2–3 °C and an annual precipitation decrease of 20–25% may occur in Portugal, despite the incidence of more frequent and extreme precipitation events, implying greater risks of flooding. Under these conditions, the use of RWHS in Portugal is an adaptive measure of great interest because it addresses both problems.

With regard to the installation of RWHS in large public sports facilities, there are some studies in Portugal and in other countries [27] that have shown, in general, the great interest and feasibility of these solutions. However, the studies carried out have focussed essentially on stadiums, without any known application in large infrastructure dedicated to tennis, such as in the present case study.

Figure 2. The Estoril Tennis Club (ETC) plan with the location of the rainwater harvesting system (RWHS) covers and installation site.

2. Materials and Methods

2.1. General Aspects

The ETC is internationally known as the headquarters of the ‘Estoril Open’, a professional men’s tennis tournament belonging to the Association of Tennis Professionals (ATP) circuit. The ETC has 12 operational tennis courts in brick dust (six more that are not in use), eight of which are uncovered and four of which are covered with a metallic roof (Figures 1 and 2). It also has four covered paddle courts.

It should be noted that in brick dust fields, as in this case, the watering needs are much higher than those for other types of fields. In fact, brick dust fields need to be swiped with a net every hour and to be watered systematically to keep the playing surface aggregated and to prevent the dust from drying out completely. Upon drying, the dust becomes lighter and is removed by the wind.

In the case of the ETC, the annual water consumed in the fields is, on average, 5500 m³; it is supplied by the local public network. The local water authority is responsible for the metring and periodically communicates the consumption values (on the invoices) to the ETC, but it should be noted that the measurement periods are variable. This situation does not allow the invoice values to be used in this analysis, but the water authority performs an annual consumption adjustment, which makes the annual amount accurate. The value of 5500 m³ has had little variation in recent years, which is why it was considered adequate as a basis for this study.

The installation of an RWHS allows, in addition to significant savings in operating costs for the ETC, a more sustainable use of drinking water; it can also provide awareness for citizens and companies regarding the implementation of this type of sustainability measure in urban areas. This study was based on the European Standard EN 16941-1 [28] and the

Technical Specification ETA 0701 [29] adopted in Portugal for the design, dimensioning, construction, and maintenance of these systems.

2.2. Rainwater Availability

The ETC has two large covers that are permanently closed (in green in Figures 1 and 2), whose use was considered in this study: a cover for four tennis courts and a smaller, more recent cover for the paddle tennis courts (four courts). These covers are arched roofs of metal plate, which discharge rainwater in trapezoidal side gutters, presently connected to the public stormwater drainage system outside of the facility through a network of pipes.

The tennis court cover has an area of 3500 m², and the paddle court cover has an area of approximately 1400 m², which totals an area of 4900 m². The harvesting of this rainwater in a single place can be done without great complexity and can take advantage of the existing gutters, downpipes and drains in the covers.

For the development of this study, it was necessary to know the average monthly rainfall in the region. Data from the nearest meteorological station (S. Julião do Tojal) were used, accessible on the website of the National Water Resources Information System (SNIRH; apambiente.pt). Monthly data were used because (1) the official data available in Portugal are only monthly or annual and (2) ETA 0701, used in Portugal for the design of RWHS, recommends the use of monthly timesteps in sizing the cisterns. Hence, monthly timesteps were considered appropriate in this case study.

Regardless of the reasons mentioned that led to the choice of monthly timesteps, it should be noted that these timesteps have been used commonly in prior research [22,27,30–33] and that EN 16941-1 refers to the use of daily or annual time steps in the dimensioning of tanks, depending on the characteristics of the rainwater demand, the desired detail in the dimensioning of the tank, etc., while not also rejecting the use of monthly timesteps.

Based on the values provided by the SNIRH website, Table 1 was constructed and organised according to the hydrological year (beginning in October). The data in this table indicate that the total availability on average is 713 mm/year, which corresponds to 0.713 m³/(m² × year). For a total roof area of 4900 m², this value corresponds to a total rainwater volume of:

$$\text{Total availability} = 4900 \times 0.713 \approx 3500 \text{ m}^3/\text{year}. \quad (1)$$

Table 1. Average monthly rainfall in Estoril (from the SNIRH website).

Month	Average Monthly Precipitation (mm) or (L/m ²)
October	75
November	106
December	105
January	103
February	93
March	77
April	56
May	45
June	16
July	3
August	5
September	29
TOTAL	713

This value would be affected by coefficients related to the efficiency of the filters and the runoff coefficient in the roofs, as mentioned later, so the useful value is 2830 m³. Recalling that the needs are around 5500 m³/year, it can be noted that, at this stage (the ETC intends to carry out other coverage later and, in a second stage, increase the harvesting of rainwater), it will be possible to satisfy approximately 52% of the requirements for watering. In any case, in Mediterranean climates that are characterised by long droughts during the

hot season (≥ 3 months), it is generally not viable to supply all watering needs with an RWHS, as this would require large-volume cisterns and long retention periods, which are not feasible from technical, economic, and sanitary points of view.

2.3. Storage Tank Characteristics and Volume

In terms of investment, the storage cistern constitutes the main component of an RWHS. It is known that for large volumes, concrete cisterns that are built in situ are more economical than prefabricated cisterns. Nonetheless, the ETC opted for prefabricated high-density polyethylene (HDPE) cisterns that are easy to install, to avoid the disturbances necessary for the construction of a large concrete cistern that would impact the normal operation of this sports facility.

The sizing of rainwater cisterns is generally done based on the same methods traditionally used for sizing water reservoirs; it is based on supply–consumption differences during reference periods (daily or monthly), such as by the Rippl method [29]. In the present case, however, where the amount of rainwater is insufficient for almost every month, complex optimisation methods are not justified, and simplified methods can be adopted, according to ETA 0701. This specification is based, for example, on intended maximum retention periods. A volume corresponding to about 2 weeks of watering at the average annual flow was considered for the cistern, which led to the installation of two prefabricated 52 m³ cisterns. The total volume was 104 m³, which is compatible with the space available for this purpose, located next to the paddle area (Figure 2).

3. Results and Discussion

As mentioned above, the complex has 12 operational tennis courts in brick dust, eight of which are uncovered and four of which are covered with a metallic roof. The estimated average annual consumption for the irrigation of the fields is 5500 m³ (≈ 460 m³/month, on average).

To estimate monthly needs, days with precipitation were discounted in the fields that are not covered, as shown in the graph in Figure 3; data were also obtained from the SNIRH website. Thus, a weighting was carried out that considered the number of fields not covered and the days without precipitation (*DWP*), which led to the values shown in Table 2.

Figure 3. Rainfall days (*RD*) in the Lisbon region.

Table 2. Monthly consumption for irrigation estimated for an average year.

Month	Rainfall Days	Days without Precipitation (DWP_M)	Weighting Factor (WF_M)	Required Watering Volume (WV_M) (m^3)
October	12	19	9.07	437.05
November	12	18	8.80	424.04
December	17	14	7.73	372.48
January	15	16	8.27	398.50
February	7	21	9.60	462.59
March	10	21	9.60	462.59
April	13	17	8.53	411.03
May	12	19	9.07	437.05
June	4	26	10.93	526.68
July	3	28	11.47	552.70
August	3	28	1.47	552.70
September	9	21	9.60	462.59
TOTAL	-	-	114.14	5500.00

In the construction of Table 2, the weighting factor for the month M (WF_M) and monthly watering volume needed (WV_M) were determined by the following formulae (where N_M is the number of days in month M):

$$WF_M = [4 + 8 \times (DWP_M/N_M)] \quad (2)$$

and

$$WV_M = WF_M \times (5500/\sum WF_M) (m^3/month). \quad (3)$$

A question that can be raised in relation to the values in Table 2 regards the possibility that they will be different in the future as a result of climate change. In fact, an increase in periods without precipitation is expected for Portugal in the short/medium term, among other consequences of climate change, which may imply an increase in the values for irrigation shown in Table 2. This effect, however, does not invalidate the present study, as it will mainly be reflected in an increase in the payback period, which, as will be seen, is relatively low for the current values. It should also be noted that the ETC intends to cover other fields in the future and to increase the use of rainwater, as mentioned above, so the situation will have further adjustments and optimisation over time.

According to ETA 0701, the volume of usable rainwater in a given period of can be determined by the expression:

$$Va = C \times P \times A \times \eta_f, \quad (4)$$

where Va corresponds to the volume of rainwater in the reference period that can be used (litres), C is the runoff coefficient (dimensionless), P refers to the average precipitation accumulated at the site in the reference period (mm), A is the catchment area measured in horizontal projection (m^2), and η_f (dimensionless) considers the hydraulic filtering efficiency. In the present case, $P = 713$ mm and $A = 4900$ m^2 , as previously mentioned. The value of 0.9 can be adopted for both C and η_f , according to ETA 0701.

In the simulation shown in Table 3, an initial volume of the cistern of approximately one third of its total volume was assumed, but it should be noted that a lower value has no influence on the results, as can be easily seen.

ETA 0701 imposes the use of upstream filters and recommends checking, in each case, the interest in diverting the first flush. The need to divert the first flush must be weighted according to the environmental pollution at the site (for example, roofs in low-polluted urban areas may eliminate the first flush diversion, but roofs in industrial areas with a large amount of dust must have this diversion) and also with the intended uses (for example, the quality of rainwater for washing floors is less demanding than for use in washing machines). In the present case, an upstream filter for leaves was foreseen, but the diversion

of the first flush was considered unnecessary, given the localisation of the ETC and the intended use for the water; this was deemed especially important in order not to reduce the available volume of water.

Table 3. Rainwater harvesting system cistern simulation.

Month	Monthly Precipitation (mm)	C	η_f	Available Rainwater Volume (m ³)	Monthly Consumption (m ³)	Availability—Consumption (m ³)	Cistern Volume (m ³)	Water Volume at the End of the Month (m ³)	Public Network Supply (m ³)
October	75	0.90	0.90	297.68	437.05	−139.38		0.00	139.38
November	106	0.90	0.90	420.1	424.04	−3.33		0.00	3.33
December	105	0.90	0.90	416.75	372.48	44.27		44.27	0.00
January	103	0.90	0.90	408.81	398.50	10.31		54.58	0.00
February	93	0.90	0.90	369.12	462.59	−93.47		0.00	38.89
March	77	0.90	0.90	305.61	462.59	−156.98	2 × 52,000	0.00	156.98
April	56	0.90	0.90	222.26	411.03	−188.77	= 104,000	0.00	188.77
May	45	0.90	0.90	178.61	437.5	−258.45		0.00	258.45
June	16	0.90	0.90	63.50	526.68	−463.18		0.00	463.18
July	3	0.90	0.90	11.91	552.70	−540.79		0.00	540.79
August	5	0.90	0.90	19.85	552.70	−532.86		0.00	532.86
September	29	0.90	0.90	115.10	462.59	−347.49		0.00	347.49
TOTAL	713			2829.91	5500.00				2670.12

The rainwater collection network was sized for the peak flow, in accordance with the Portuguese General Regulation, and corresponded to a rainfall time of 5 min and a return period of 5 years. The value obtained was:

$$I = 56.6 \text{ mm/h} = 0.016 \text{ L/(s} \times \text{m}^2\text{)}. \quad (5)$$

The formula applied to determine the tip flow Q (in L/s) was:

$$Q = I \left(\sum C_i \times A_i \right), \quad (6)$$

where C_i is the weighted (dimensionless) runoff coefficient of the area A_i (m²), and I is the intensity of precipitation. In this case, the regulatory value of 1.0 was adopted for the roof runoff coefficient. Thus, for a total coverage area of 4900 m², the flow rate obtained was:

$$Q = 0.016 \times 1.0 \times 4900 = 78.4 \text{ L/s}. \quad (7)$$

Although industrial filters up to 6000 m² (≈ 100 L/s) are available on the market, it was considered preferable to install two commercial filters for flow rates of up to 50 L/s that were upstream of each cistern.

Variable speed pumping groups were installed in the tanks and considered a flow rate of 1.15 L/s (4.140 m³/h) for a head of about 400 kPa. The value of 1.15 L/s was sufficient for the simultaneous operation of three irrigation hoses, in accordance with the Portuguese General Regulation, and the head was determined based on the existing terrain unevenness and on the residual pressure recommended in the taps and in the head losses in the pipes.

The pumping group was specific for this use and contained automatic switching to the drinking water network in case of a lack of water in the cistern, ensuring the necessary sanitary safety. The catchment inside the cistern was done through a flexible hose to keep the aspiration below the free surface (for better water quality).

The cisterns had an overflow with a siphon, allowing the excess water to be discharged. On the other hand, to promote periodic cleaning and maintenance activities, bottom discharges or another total emptying solution were installed. The possibility of access to the interior of the cisterns through the respective cover (DN 650) was also guaranteed. A system of valves upstream of the cistern was provided so that the system could be connected/disconnected in case of the detection of anomalies or for its maintenance.

The investment in this RWHS was estimated at approximately €105,000, according to the budget summarised in Table 4. Given that the price of water paid by the ETC is €1.6/m³ (it should be noted that this is a low tariff that is applied by the water authority to institutions considered to be of public interest) and considering the average annual consumption of 5500 m³, the estimated payback period for this investment is 11.9 years. Considering that the average useful life of these installations is around 40 years [34], this payback period is very interesting from an economic point of view.

Table 4. Budget summary.

Components (Installed)	Cost (€)
-Drainage pipes and accessories, including utility access holes and the watering network	15,000
-Two 52,000 L prefabricated cisterns, complete, including accessories and connections	70,000
-Two pumping systems, complete, including a water power grid, with water management (from cistern or mains)	8000
-Two industrial leaf filters (DN 300)	12,000
TOTAL (€)	105,000

It was not the intention of this article to study the effect of this RWHS in reducing flood peaks in the area, as they do not represent a serious problem in the city of Cascais at the present, but this additional advantage will undoubtedly exist and will be relevant, as highlighted in several scientific publications on the effects of RWHS in urban environments [35–42].

4. Conclusions

Dealing with climate change is one of the major challenges facing mankind in the 21st century, especially in urban environments, where around two thirds of the world population will reside in 2050. In some parts of the world, such as the Mediterranean basin, where the likely effects of climate change will be prolonged droughts and extreme precipitation events, RWHS in buildings seem to be an adaptation measure of great interest in urban environments because they provide a simultaneous response to these two situations. Therefore, these solutions should be widely generalised, possibly through a mandate in some regions. RWHS can be considered not only for buildings, but also for other urban infrastructure with high water consumption.

In this article, the implementation of an RWHS in a large-scale sports infrastructure that is intended for the practice of tennis and located in the city of Cascais, Portugal, was studied. The ETC has two large covers with a total area of 4900 m², and the average annual consumption of drinking water to water the tennis courts at this facility is 5500 m³. The RWHS reduces this consumption by >50% because it provides about 2830 m³/year, in addition to reducing flood peaks in the area. In economic terms, the study predicts a payback period of around 11.9 years, which is clearly shorter than the useful life of the installation and proves the viability of this solution. It should be noted that, considering the average per capita value in Portugal of 127 L/(inhabitant and day), that is 46 m³/(inhabitant and year), the drinking water saved with this system (2830 m³/year) corresponds to the annual consumption of approximately 62 inhabitants.

RWHS could constitute a relevant solution for adaptation to climate change in urban environments. Not being an unprecedented solution in buildings or football stadiums, for example, its application could be extended to other urban infrastructure, although in each case it would be necessary to analyse its technical, economic, and environmental interest. The present case study contributes to this context, demonstrating that the application of an RWHS in a large urban sports infrastructure dedicated to tennis presents high feasibility from all points of view.

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