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# RAINWATER HARVESTING AUTOMATIC SYSTEM

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***Abstract.*** *The rainwater harvesting is known as an alternative water supply to reduce the drinkable water used in gardens, toilets and floor cleaning, can be done in an easy way, in different social levels and in any locations with a roof catchment area, but to do so, is necessary to discard the first millimeters of rain to perform the roof cleaning which could contain debris, animal faeces and leafs. That said, an electronic pluviometer capable of measuring the amount of rain to be discarded has been developed, as well as a flow separator device. This device receives an electric signal from the pluviometer, through a microcontroller, and depending of the amount of rain, the water flow is diverted to the discard pipe or to the tank pipe. Validation tests on the pluviometer and flow rate of the flow separator were performed to determine the device's usage band and viability. Besides that, methods to calculate the capacity of the tank are presented to help dimensioning the system accessories. The results of cost and level of system controlling on the process were good, showing the devices viability, as a low cost commercial product to be used in rainwater harvesting systems.*

***Keywords:*** *rainwater harvesting, automation, discard system, first flush*

## 1. INTRODUCTION

The total volume of water on the planet is around 1,4 billion km³, but the volume of freshwater sources is around 35 million km³, or 2,5% of the total volume. Approximately 24 million km³ or 70% of the freshwater sources are in the form of ice and permanent snow in the mountainous regions, and in the polar ice caps of the Arctic and Antarctic, approximately 30% are in underground springs and only 0,3% available in rivers and lakes (UN, 2014).

The United Nations Educational, Scientific and Cultural Organization (UNESCO, 2016) reports that there is increasing concern about available potable water resources, aggravated by the climate change effects. While the rate of exploitation of underground springs has increased by 1% per year since 1980, the global population is estimated to grow by 33% between 2011 and 2050, in addition to the demand for food, with an estimated growth around 70% in the same period. This projection of crisis in water supply will require unconventional water resources, such as rainwater harvesting, recycled wastewater and urban drainage, to gain greater visibility. Besides that, the use of alternative water sources will provide new jobs for research, technology development and in results application.

World water use has more than doubled the rate of population growth in the last century. It is estimated that, by 2025, 1.8 billion people will be living in regions with total water shortages, and that two-thirds of the world's population will face supply crises (UN, 2013).

With these current informations and worrying predictions about the water resources available to the population, it is necessary to seek alternative and renewable sources of potable water. One of the ways to achieve this is through the use of rainwater, which is a very accessible resource for the general population. As rain is a free natural resource, it only takes a catchment area, gutters, pipes and a tank. The sustainability, the direct impact on reducing treated water consumption and reducing the risk of flooding are some of the positive points attributed to the use of rainwater harvesting systems.

It is necessary to use a device capable of removing the debris present on the surfaces of the roofs, which can be carried by the rainwater to the tank, contaminating the stored water. Currently, there are systems which use filters and screens inside the pipe, preventing the debris flow. Others, use systems that discard the initial water runoff, promoting roof cleaning and ensuring that debris is not carried to the tank.

The aim of this work is to offer a low cost system, which the main objective is to discard the initial flow of rain in an automatic and independent way, using an electronic pluviometer capable of detecting the presence of rain and the amount of precipitation that is desired to discard, promoting the activation of a device that performs the separation between stored and discarded water.

The developed device, or flow separator, was constructed with pvc parts, rod and a servo motor. The separator operates by electric activation and depending on the signal it receives from the pluviometer, the water flow is alternated between the two outputs of the separator. The device has one inlet for the rainwater collected on the roof, one outlet for the discard pipe and another outlet for the storage pipe. When the pluviometer indicates the presence of rain, the separator remains in the "discard" position and the initial rainfall is discarded, when the pluviometer indicates the precipitation of 2 or 4 mm of rain, according to the user's choice, the separator changes the flow direction to the "storage" position and the rainwater is stored.

This work is justified by the attitude of developing and evaluating the efficiency of a rainwater harvesting system in order to reduce the consumption of treated water in a house by replacing drinkable water used for sanitary discharges, garden and washing floors, by the stored rainwater. In addition to presenting electronic and automatic devices that require minimal human intervention for its operation. The results, arguments and discussions present in this work can help in the implementation of other similar activities, and help the dissemination of the water saving culture that is very important for facing water crisis.

## 2. THEORETICAL FOUNDATIONS

### 2.1 Rainwater harvesting systems historical

To understand the impending water crisis and the potential impact that climate change can have on our lives, it is worth looking at how water management was of utmost importance to ancient civilizations. Rainwater harvesting and management were popular techniques, already developed thousands of years ago, by different peoples in different parts of the world, especially in the arid and semi-arid regions (GNADLINGER, 2015).

2,000 years ago there was an integrated rainwater harvesting and management system for agricultural purposes of the Hasmonean people, located in the Negev desert, now Israel and Jordan. The Romans were known for the water transport system to their cities through the famous aqueducts, but they also used large-scale rainwater harvesting, especially in North Africa and Minor Asia. In the region of Constantinople, today Istanbul, Turkey, there are more than 150 Byzantine cisterns, the most famous of which, called Basilica Cistern, has a capacity of 80,000 m³ (GNADLINGER, 2015).

Encouraged by the scarcity of water the planet is about to face in the coming years, water recycle systems will certainly come to the fore with even more importance, and present themselves as a sustainable alternative in the drinkable water saving.

In Germany, since 1980, rainwater is always used for non-potable purposes, intended for the discharge of sanitary basins, gardens irrigation, washing machines and commercial and industrial use (TOMAZ, 2010).

### 2.2 Rainwater quality

Rainwater is not safe to drink, on its way to the storage, it can be contaminated by the atmosphere, the collection surface, and the tank. For this reason, collected water should only be used for non-potable purposes.

Depending on the sampling site, rainwater composition may vary according to local weather conditions (wind regime, intensity, duration and type of rainfall and season). Other factors that may influence, are the presence of vegetation and the polluting burden of the local atmosphere (TOMAZ, 2010).

Roofs are usually the most common collection points in rainwater harvesting systems and depending on the materials used in their preparation, the water contamination may be even bigger. Birds, rats and other animal’s faeces, as well as dust, tree leaves, roof coatings and paints are some examples of sources of contamination (TOMAZ, 2010).

In non-potable activities in the house such as garden watering and floor cleaning, a better treatment than the initial disposal or filters is dispensed. But, for use in discharges of toilets, it is recommended to take greater care with water quality due to the risk of contamination (HAFNER, 2007).

The Brazilian association of technical standards ABNT NBR 15527 reports the possibility of installing devices capable of removing debris in the collection systems, which may be grids and screens, or device to discard the first flush of water. It is recommended to be automatic, and when used, should be sized by the designer. In the absence of data, it is recommended to discard 2 mm of initial precipitation. In order to guarantee a better roof cleaning, the system developed in this work has an alternative to discard 4 mm of precipitation beyond the 2 mm suggested by the technical standard.

### 2.3 Rainwater harvesting system stages

The rainwater harvesting system has different stages, such as: collection, transport, storage and supply. Collection is the roofs and terraces, the surfaces where the rainwater is normally collected because, is the largest impermeable area of the occupied land is the easiest and closest way to collect the water, allowing less contamination (RODRIGUES, 2009).

In order to obtain the amount of water collected in a given rainy season, it is necessary to know the rainfall precipitation. ABNT NBR 10844 defines this as the volume of precipitated water per unit of horizontal area.

For each 1 mm measured in the pluviometer, it is assumed that the amount of precipitation is equal to 1 L/m². Therefore, to know the amount of rainwater collected in a certain period, in liters, simply multiply the number of millimeters precipitated by the collection surface area.

The system of transport of the collected water is composed by gutters, vertical and horizontal conductors. The storage system is composed by the tank and has the objective of storing rainwater. After the water is stored in the tank, the last stage of the system begins: the supply or conduction, where the water is sent to the point of use.

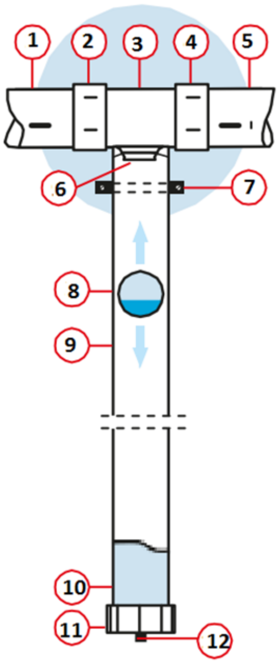
### 2.4 First flush diverters

There are several constructive types of disposal devices for the first flow of rainwater. According to Campos (2004) the discarding is often done manually, causing numerous inconveniences, such as poor operation of the mechanism, which can cause unnecessary losses or contamination of stored water, caused mainly by the inconvenience of rainfall schedules.

A type of automatic valve, quite common in domestic applications, makes the use of a floating ball to promote the separation of the first flow, figure 1.

Harvesting Brasil (2016) explains that the product uses a ball and seat system to promote system sealing in a simple and automatic way of operation without mechanical parts or manual intervention. The operation of the device occurs as follows: when the rain starts, water enters the aperture (1) and is directed to the bypass chamber (9 and 10), where the sealing ball (8) is, when the chamber is full the ball fits into the seal seat (6), directing the clean water into the tank through the outlet pipe (5). At the base of the tube is placed a flow control valve (12) which automatically empties the bypass chamber, leaving the system ready for the next rain.

The system also has a clamp (7) for wall mounting, drain valve (11), chamber inlet (2), chamber outlet (4) and tee junction (3).




(1) aperture
(2) chamber inlet
(3) tee junction
(4) chamber outlet
(5) outlet pipe
(6) seal seat
(7) clamp
(8) sealing ball
(9) bypass chamber
(10) bypass chamber
(11) drain valve
(12) control valve

Figure 1. First Flush diverter with floating ball (Harvesting Brasil, 2016)

The disadvantage of this type of device is that for the disposal of 2 mm of rain it would be necessary to size the diverter chamber for each specific catchment area.

The DesviUfpe is another first flush discard system developed at the Federal University of Pernambuco, figure 2.

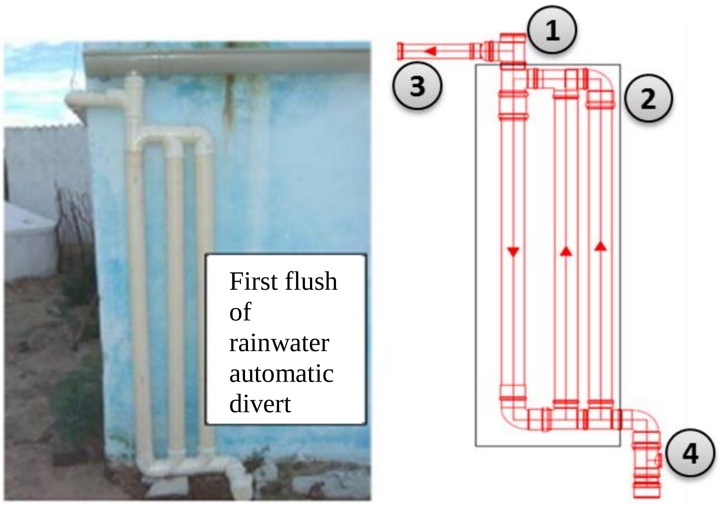



Figure 2. DesviUfpe (Adapted from Lima, 2012)

According to Lima (2012) the operation of the device used for storage and discard of the first flush of rainwater, built and installed in Pesqueira-PE, is based on the physical principles of communicating vessels and water storage. As the roof is washed, the water enters the inlet pipe (1) accumulates in the upright pipes (2) and only after being completely filled, the water is directed into the tank by the outlet pipe (3). It is essential that after each rainy event the device must be emptied through the opening of the discharge valve (4), and closed again leaving the device ready for the next rainy event.

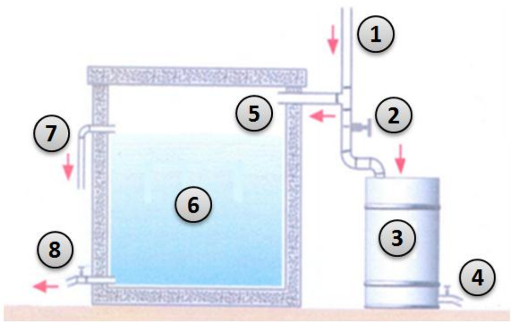



Figure 3. Device with water closure using barrel (adapted form Dacach, 1981 apud May, 1990)

According to Dacach (1981), the discharge tank works as follows: the rainwater is collected by the collecting surface, carried by the rails to the inlet pipe (1), reaching the barrel (3), a small orifice (4) is responsible for regulating the flow. When the rainwater arrives at the barrel, a volume smaller than the inlet volume is discarded by the orifice, so the water level in the barrel gradually increases until reaching the pipe of the rainwater tank (5) and accumulates in the tank (6).

The system also has a cleaning valve (8), an overflow pipe (7) and valve (2) in case the user do not want to do the separation of the first flush of rainwater,

The disadvantages of systems that use secondary tanks are the difficulties of maintaining a standard dimension for the tank, because for each roof area, the size of the adequate tank should be dimensioned. In addition, leaks, the need to perform the discard manually and constant maintenance are some of other negative points.

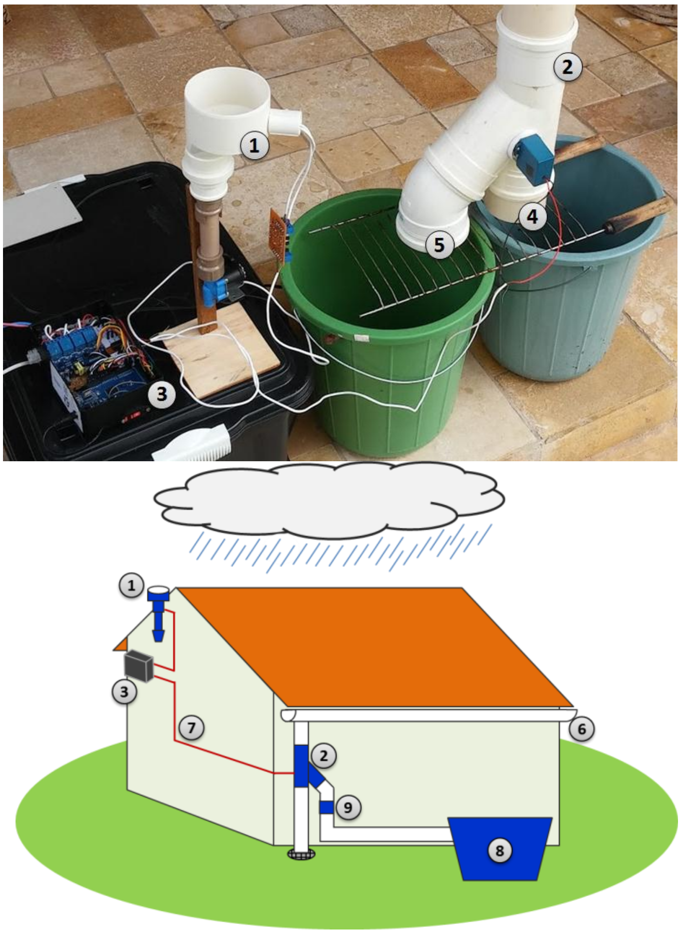
## 3. METHODOLOGY

The rainwater harvesting system developed in this work has as main characteristic to minimize the need for human intervention in its operation, and increase the control over the amount of collected water, using electromechanical equipment controlled by a microcontroller.

Assuming that the first rainwater flow cannot be stored, it was necessary to measure the value of this first volume and create a device that would do the dispose of it.

Therefore, two items of the standard ABNT NBR 15527, which manages the use of rainwater, served to guide the construction of the system's devices. Item 4.2.4 says that a device for the discard of the initial runoff water can be installed in the rainwater harvesting system, and for that purpose, a flow separator has been developed. However item 4.2.5 says that in the absence of data, it is recommended to discard 2 mm of the initial precipitation, and to meet this item, an electronic pluviometer with level sensors and capable of detecting the amount of precipitation was developed.

The system works as follows: the pluviometer is installed in a suitable location near the roof of the house, the flow separator is installed in the vertical conductor that bifurcates the plumbing, one of them is responsible for the discard that directs the water to the ground, the other is responsible for directing the water to the storage that can still rely on a filter to remove debris before the water reaches the tank. The system installation scheme can be seen in figure 4.



(1) pluviometer
(2) flow separator
(3) microcontroller
(4) discard outlet
(5) storage outlet
(6) gutter
(7) wires
(8) tank
(9) filter

Figure 4. Harvesting system scheme

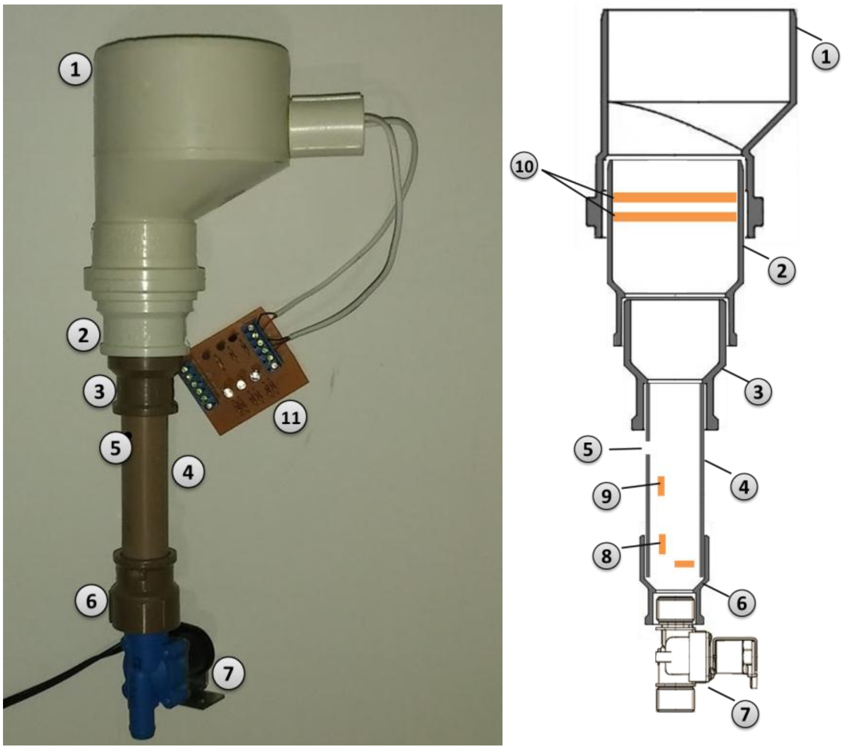
When the rain starts, the pluviometer (1) sends the signal to the flow separator (2) by the microcontroller (3) which directs the water to the discard outlet (4) as soon as the rain reaches the precipitation of 2 or 4 mm, depending on the user's choice, the pluviometer sends a new signal to the flow separator that changes the direction of the water flow to the storage outlet (5), the water still passes through the filter (9) to remove debris before reach the tank (8).

When the rain stops, the pluviometer again sends a control signal to the separator which returns to the discarding position. In order to the pluviometer does not hold water inside of it, a solenoid valve is opened allowing the water to flow and again resetting the pluviometer. The two main components of the automatic rainwater reuse system are presented in details below.

### 3.1 Electronic pluviometer

The main components of the electronic pluviometer developed are the collecting aperture, responsible for the rainwater collecting, the rain sensor, which sends a signal to the microcontroller when there is rain or not, level sensors, which inform the moment when precipitation reached 2 or 4 mm, and a solenoid valve, responsible for its emptying.

As in the other devices that make up the system, cost was one of the primary factors, and for the pluviometer, pvc pieces were used for its construction. The assembly scheme of the developed pluviometer can be better understood in figure 5.



(1) pvc eccentric reduction
(2) reducer 50x40
(3) reducer 40x25
(4) 25 mm pipe
(5) overflow
(6) reducer threaded
(7) solenoid valve
(8) 2 mm sensor
(9) 4 mm sensor
(10) rainwater sensor
(11) circuit board

Figure 5. Electronic pluviometer shceme

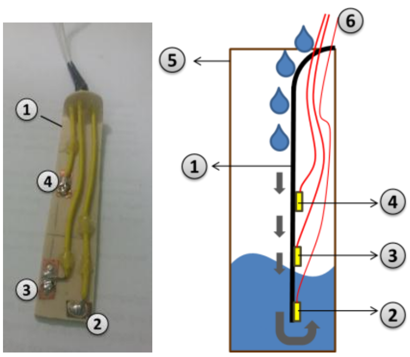
The collection area is composed of pvc eccentric reduction of 100x50 mm (1), which has an internal diameter of 95 mm. Equation 1 shows how to calculate the volume of water collected by this area. It is necessary to multiply the desired precipitation height (h) (2 and 4 mm) by the area (A) corresponding to the diameter of 95 mm.

$$V = Ah \tag{1}$$

Solving equation 1 for a diameter of 95mm and precipitation height of 2 mm, we have a volume of 14.176,44 mm³ or 14,18 ml, and for a height of 4 mm, 28.352,87 mm³ or 28,35 ml. These values in milliliters were used for the validation of the pluviometer.

In order to enable the emitted values of the sensors to be read by the microcontroller, it was necessary to make a circuit board (11) which receives direct 5-volt feed from the microcontroller making possible the electronic part of the pluviometer to function satisfactorily.

Using the electric conductivity property of the water, it was possible to construct a simple level sensor for the pluviometer. It is formed by a piece of pvc with three small bands of copper tape which works as electrical terminals, figure 6.



(1) pvc piece
(2) base terminal
(3) 2 mm sensor terminal
(4) 4 mm sensor terminal
(5) 25 mm pipe
(6) wires

Figure 6. Pluviometer level sensor

The base terminal (2), located at the bottom of the pvc piece, serves as a basis for closing the circuits. The other two bands are located at the heights referring to the volume of 2 and 4 mm accumulated inside the 25 mm pipe. When the interior of the tube accumulates 14,18 ml, the base and 2 mm sensor terminal (3) are submerged and the water closes the circuit by sending an electrical signal to the microcontroller and to an LED, signaling a precipitation of 2 mm of rain. The same happens with the 4 mm sensor terminal (4), when the pluviometer accumulates 28,35 ml of water.

The rainwater sensor used in the pluviometer follows the same principle as the level sensors. Two rings made of copper adhesive tape were installed on the inner walls of the reducer 50x40, forming two terminals that conduct electrical signal when a raindrop passes through the rings, closing the circuit, figure 7.

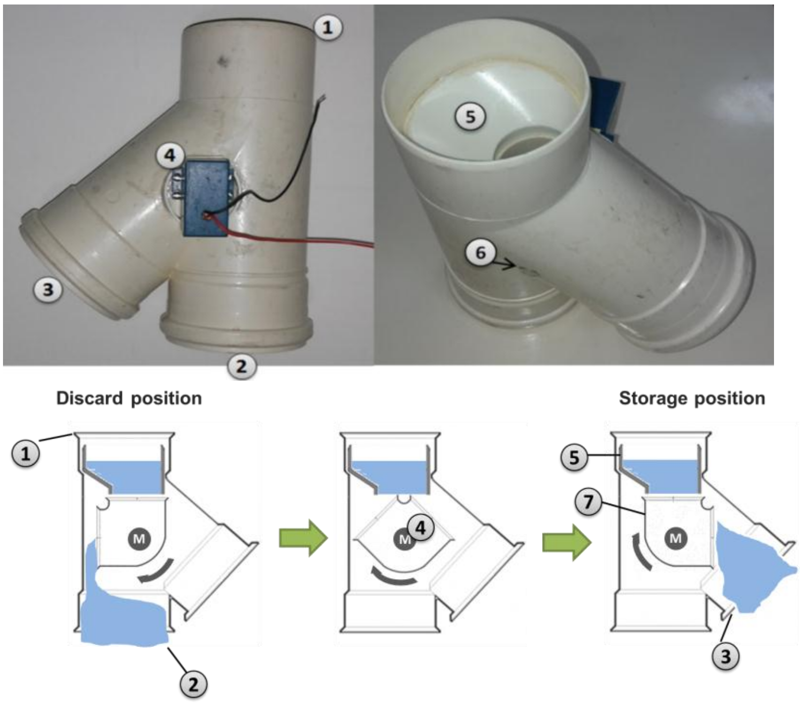
Figure 7. Rainwater sensor

The two copper tape rings were covered with tin in order to protect the tape against possible corrosion. And for each ring, a wire was welded and connected to the pluviometer circuit board.

The solenoid valve (number 7 in figure 5) used in the pluviometer is normally closed, and will receive a signal from the water sensor through the microcontroller, to empty the water stored.

### 3.2 Flow separator

This is the device responsible for separating the stored water from the discarded water. The separator was constructed using a "Y" junction with 100 mm diameter in the three apertures, figure 8.




(1) upper aperture
(2) discard outlet
(3) storage outlet
(4) servo motor
(5) pvc eccentric reduction
(6) shaft
(7) guide gutter

Figure 8. Flow separator

The upper aperture (1) receives the rainwater captured on the roof by through the gutter, which then passes through the pvc eccentric reduction of 100x50 mm (5). By the discard outlet (2) the water is directed towards to be discarded, whilst the flow directed to the storage, passes through the storage outlet (3). The change of position of the separator between the discard and storage positions is performed by the servo motor (4) coupled to the “Y” junction, the servo motor rotates a shaft (6) attached to a guide gutter (7) inside the junction alternating the flow between the outlets.

The flow separator can be easily installed in the piping, even in buildings that already have rainwater harvesting system. The fact of being made from a standard "Y" junction, coupling in the piping occurs quickly and easily, using only connection elements such as pvc joints.

It is important to remember that due to its operating principle, this separator can only be used on the vertical conductor, always with the upper aperture facing upwards.

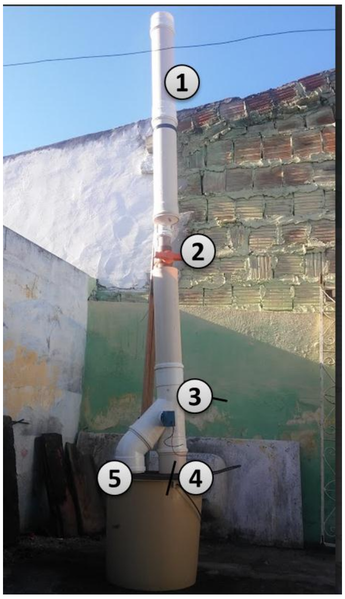
## 4. RESULTS

The level sensor was validated by inserting water into the pluviometer until the sensor was activated, using a syringe graduated in 0,2 ml and recording the value of the inserted volume. Five measurements were made for the 2 mm and 4 mm sensor.

For 2 mm of precipitation, the amount of water that should trigger the sensor is 14,18 ml, and for the 4 mm sensor, this value is 28,35 ml. Table 1 shows the measured values.

Table 1. Measurements for the electronic pluviometer validation

| Measurements | Volume to activate 2 mm sensor (ml) | Volume to activate 4 mm sensor (ml) |
|---|---|---|
| 1st | 14,20 | 28,80 |
| 2nd | 14,00 | 27,80 |
| 3rd | 14,40 | 28,60 |
| 4th | 14,20 | 28,40 |
| 5th | 13,80 | 29,00 |
| Average | 14,12 | 28,52 |




(1) upper aperture
(2) valve
(3) flow separator
(4) discard outlet
(5) storage outlet

Figure 9. Flow separator test

For the flow separator test, figure 9, the volumes of 2, 4, 6 and 8 liters were placed in a storage pipe (1) of 100 mm diameter above the flow separator, and for each volume three measurements were taken. A valve (2) of 50 mm diameter was opened manually and the time the water took to go through the flow separator was noted.

The Table 2 shows the values of the flow rate measurements for the flow separator, for each volume the corresponding water column was also calculated in order to know the accumulated water height in the storage pipe.

Table 2. Flow rate measurements for the flow separator

| Liters | Time 1 (s) | Time 2 (s) | Time 3 (s) | Average Time (s) | Average flow rate (L/min) | Water Column (m) |
|---|---|---|---|---|---|---|
| 2 | 1,05 | 1,14 | 1,12 | 1,10 | 108,76 | 0,28 |
| 4 | 1,44 | 1,31 | 1,88 | 1,54 | 155,51 | 0,56 |
| 6 | 2,44 | 2,19 | 2,22 | 2,28 | 157,66 | 0,85 |
| 8 | 2,86 | 2,72 | 2,65 | 2,74 | 174,97 | 1,13 |

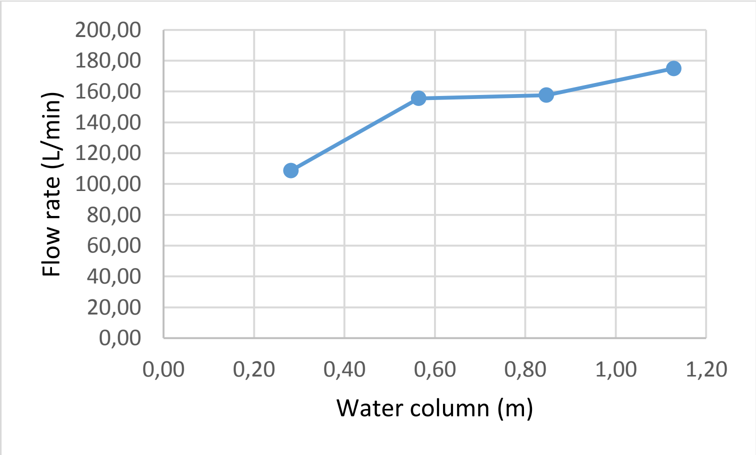



Figure 10. Diagram of flow rate versus water column

During the test some sources of error were perceived, such as the difficulty in judging the exact moment when the strong water flow ended and the small time interval between the beginning and the end of the flow that could suffer interference in the reaction time of the operator when starting and stopping the chronometer.

Another important factor was the verification of a small leak when the separator is subjected to high flow rates. As the flow was directed to the discard exit, in the 8-liter test, approximately 15 ml (0,18%) of water was leaked to the storage exit aperture, and while the flow was directed to leave by the storage exit, using the same 8 liters, there was a leakage of approximately 400 ml (5%) to the discard exit.

It is important that in the installation the lower outlet is intended to the discard, and the lateral outlet is intended for storage, ensuring that less than 0,2% of the initial runoff water is carried into the tank by leak during the first few moments of rain and preventing the contamination of stored water.

## 5. CONCLUSION

In view of the imminent water supply crisis that the population is about to face, it is essential to search for alternative ways to replace the use of potable water in purposes that do not require potability, by reusable water or rainwater.

Following the Brazilian technical standards, this work aimed to create an automatic low cost rainwater harvesting system composed of an electronic pluviometer and a device for separating the first flush of water, produced mostly with pvc parts easily found on the market.

It is important to remember that leaks in the flow separator were small relative to the amount of water, and that the separator is only a prototype made from pvc parts, while the leakage of the device can be ensured with a final device designed and built for the market.

Both the pluviometer and the flow separator are promising prototypes, and can serve as the basis for the creation of a final marketable product. They have the attractiveness of being electronic, of simple use and installation, being able to be acquired even by users who already have rainwater harvesting systems, but do not have a device to discard the first flow.

The possibilities of use are many, for example, through a mobile application connected to the microcontroller of the system, the user can choose whether the pluviometer should discard the first 2 or 4 mm of rain, or skip the first millimeter discharge step and directly control the position of the flow separator for direct storage.

This possibility of manipulating the system remotely, mastering and monitoring the steps of the process is the great advantage of the system developed in this work, compared to the mechanisms of harvesting already in the market, which are often purely mechanical and require constant human intervention to carry out the discard.

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