ISBN: 978-628-95207-4-3. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2023.1.1.245

Clean Energy from Rainwater

Luz E Torres Molina [1], PhD, Samir J Cajigas Soto[1], Diego Matias Laguna[1]
Osvil Lopez[1] Maria Torres Barajas[2]

[1]Department of Civil Engineering Universidad Ana G Méndez, Gurabo, PR, [2] Sykes College of Business, University of Tampa
TORRESL6@uagm.edu, scajigas2@email.uagm.edu, dmatias11@email.uagm.edu, olopez86@email.uagm.edu,
maria.torresbarajas@spartans.ut.edu

***Abstract* – Demand for clean energy production arises worldwide from solar, wind, and water sources. The small islands are Prone to power outages frequently due to global warming and constant exposure to atmospheric phenomena such as hurricanes that worsen the generation and distribution of weak energy systems.**

The research aimed to evaluate a rainwater harvesting system to generate energy from roof housing in urban and rural areas in Puerto Rico. It considered the current climate in Puerto Rico using precipitation data for wet and dry periods and precipitation produced by Severe weather events. The motivation is to find the feasibility of generating power using a small turbine. The system contemplates collecting all the rainwater from flat and pitched roofs using a gutter connected to a downspout at a lower roof level. Another alternative considered is the use of greywater, that combined with the rainwater, maximizes the amount of water content through the turbine.

A water flow sensor sits in the gutter to measure the flow rate. The sensor has a type of pinwheel to measure the quantity of liquid that goes through it. The selection of the best turbine depends on any specific characteristic, such as the head and flow available. Other considerations, such as whether the turbine is expected to produce power under part-flow conditions, that is, when it just rains or the combination of rain and greywater, also play an essential role in the turbine selection.

***Index Terms* -Energy, precipitation, turbine, greywater, Puerto Rico.**

I. Introduction

Hydropower has been used for many centuries to obtain energy, and it began with wooden waterwheels. Various types of these were used in many locations in Europe and Asia, mainly for the milling of grains. Waterwheel technology was developed during the industrial revolution and produced up to 70% efficiencies. Benoit Fourneyron developed the first hydro turbine in France in the 1820s. [1]
During the first half of the 20th century, large-scale hydropower development was driven by dams and hydropower stations were built rapidly in North America and Europe. Since the 1960s, large hydropower manufacturers and equipment suppliers have flourished by exporting to developing countries. The most well-known impulse hydro turbine design is the Pelton Wheel. It is name after Lester Pelton, credited with developing the split bucket design. Although others patented similar configurations, Pelton tested a range of bucket shapes in 1878 and eventually patented the design that became known as the Pelton Wheel [1] Hydropower is not just limited to Pelton Turbines. Impact Turbines, such as Pelton, Turbo, and Cross Flow, are small and easy-to-handle hydropower used to produce energy.

Turgo Turbine was developed in the 1920s, a variant of Pelton; the difference is in their cups, where turgo turbine uses single cups instead of double cups on the wheel. Another characteristic is the cup's form; for Turgo turbines, the cups are shallower. The water in a Turgo turbine is moving quickly, impulsing the turbine and producing energy from the water, in this case, from the precipitation.

Turgo turbines can handle higher flow rates than those a Pelton turbine can handle. This ability to deal with large volumes of water gives the Turgo turbine an advantage when used with vast quantities of water, such as in hydroelectric plants. However, in this case, it is optional the use a turbine with a high capacity to manage enormous water quantities.

On the other hand, a Turgo runner is more challenging to make than a Pelton, and the vanes of the runner are less sturdy than Pelton buckets.[2].

Although they can better manage high flow rates, Turgo turbines are slightly less efficient. The design and operation of a Turgo turbine are very similar to that of a Pelton turbine. In the Turgo turbine, high-speed water jets emerge from the turbine's nozzles. These nozzles are arranged so the water jet will hit the buckets on one side at around 20° while the water jet in Pelton is sprayed directly at a 0° angle. This shallow angle allows the water stream to exit on the other side instead of diverting backward. Since the incoming and outgoing jets do not interfere as they do in Pelton turbines, this type of turbine can accommodate a higher flow rate. [3]

Water is essential for power generation, as well as for all living things on earth. Solar energy is radiant light and heat from the Sun Solar energy is essential as a renewable energy source. Photovoltaic solar panels absorb sunlight as a source of energy to generate direct-current electricity.

However, finding other Sources of energy with the capacity to use in small structures such as housing is fundamental. Capturing and storing rainwater is particularly important in dry, hilly, urban, and coastal areas. The widely used technique for capturing rainwater is rooftop rainwater harvesting. It is a simple way of storing water and has many advantages. Mainly it will meet the increasing demand for water in urban areas. Rainwater harvesting will avoid flooding roads, increase groundwater storage, and control the decline of water levels. It will supply domestic water requirements during summer, drought, and other. [4]

According to U.S. Energy Information Administration (eia.gov), Puerto Rico consumes about 27 times more energy than it produces. The Commonwealth's energy consumption per capita is roughly one-third of the average in the 50 U.S. states. Petroleum products account for about two-thirds of Puerto Rico's total energy consumption.

However, the island's per capita petroleum consumption is about half the U.S. average. Puerto Rico Energy Public Policy Act mandates that the Commonwealth obtain 40% of its electricity from renewable resources by 2025, 60% by 2040, and 100% by 2050. Puerto Rico has no proven reserves or production of fossil fuels. The Commonwealth has some renewable resources in the form of solar, wind, hydropower, and biomass but relies primarily on imported fossil fuels to meet its energy needs.

For the fiscal year 2021 (July 2020 to June 2021), fossil fuel-fired power plants generated about 97% of Puerto Rico's electricity. Natural gas-fueled about 44%, petroleum about 37%, and the island's one coal-fired power plant about 17%. Renewables accounted for about 3% of the island's electricity generation. The commercial sector consumes nearly half of Puerto Rico's electricity sales, the residential sector accounts for two-fifths, and the industrial sector makes up about one-tenth. In 2020, Puerto Rico's average electricity price was higher than in all but two U.S. states, Hawaii, and Alaska [5].

The advance in the generation of power from rainwater is water reuse. Harvested rainwater can be stored in external tanks to meet household needs. The Main Objective of rooftop rainwater harvesting is to make water available for future use. This project is based on searching for alternatives that help reduce fossil energy consumption. At the same time, the water is stored and reused, and the development of the possibility of generating electricity using a small turbine.

II. Local Climate

The Caribbean's climate is subtropical, with relatively dry winters and wet summers. The dominant large-scale atmospheric influence on the climate is the North Atlantic subtropical high (NAH). In 2021, the average temperature at the San Juan, Puerto Rico station was 80.74°F. Recent data shows an annual temperature increase between 2000 and 2018 for January and September. An average slope of 6% was founded for September data and 13% for January data.

On the other hand, the amount of rainfall varies considerably throughout the study area. Most of the rainfall occurs during August, with 7.15 inches on average for the last 20 years. February is considered the dry season, with 2.32 inches [6].

The amount of rainfall varies considerably throughout the island. The precipitation in Puerto Rico changes substantially according to the region. In Puerto Rico western area is considered high in the rain compared with the southern area.
An ANOVA Analysis was made using precipitation data from 1900 to evaluate the relationship between the Amount of precipitation in the September and February months And to study the theory that September is the month with higher rainfall and February is the driest month [12].

The evaluation was proposed for the town in the north, southwest, and east areas, but principally was centered in the metropolitan area and south area.

The region with the lowest precipitation rates in Puerto Rico is the south, where the towns of Ponce, Guayama, Santa Isabel, and others are located; for this region, a recurrence analysis was elaborated where precipitation values were found to be lower than in the San Juan area.

The most rainfall in urban areas such as San Juan occurs during September; analysed data for 100 years found that the precipitation through the month has been higher to 17 inches. Figure 1 shows the amount of rainfall and frequency for 100 years in September, and the most recurrence precipitation is between 3.49 to 5.49 inches, and the second place is 5.49 to 7.49inches.

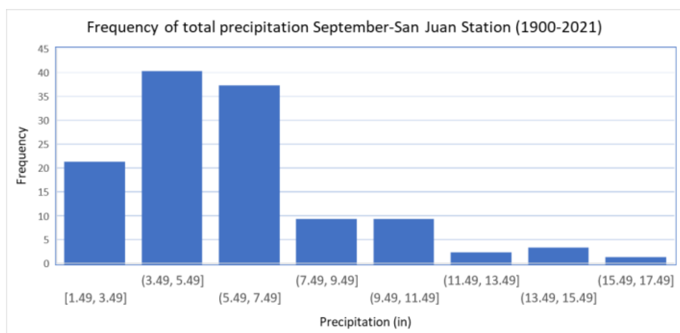

Fig. 1 Frequency of total precipitation September – San Juan Station (1900-2021).

Figure 2 shows the total precipitation of February from 1990-2021. February is considered the month with less precipitation on the island. The most recurrence precipitation in February is in the range of 1.65-2.45 inches, and the second recurrence is 0.85-1.65 inches.

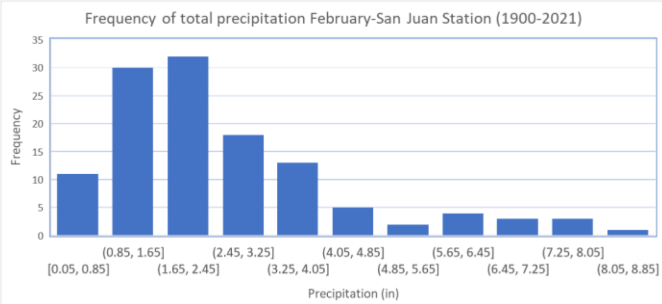

Fig. 2 Frequency of total precipitation February – San Juan Station (1900-2021).

The Puerto Rico area with the Lowest precipitation all year is the south coast. For Guayama town, a recurrence analysis was elaborate where the precipitation with more frequency in February is between 0.05-2.05 inches see Figure 3. September reached values of between (4.51-6.51) inches of precipitation, see Figure 4.

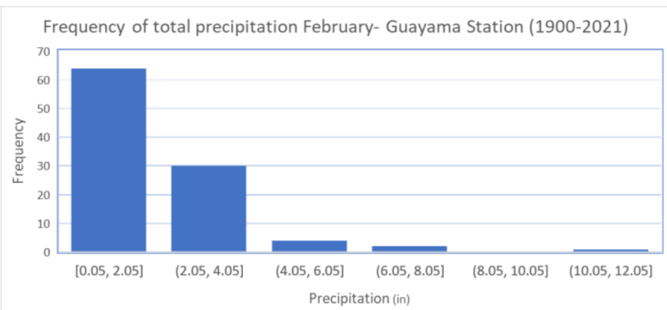

Fig. 3 Frequency of total precipitation February – Guayama Station (1900-2021).

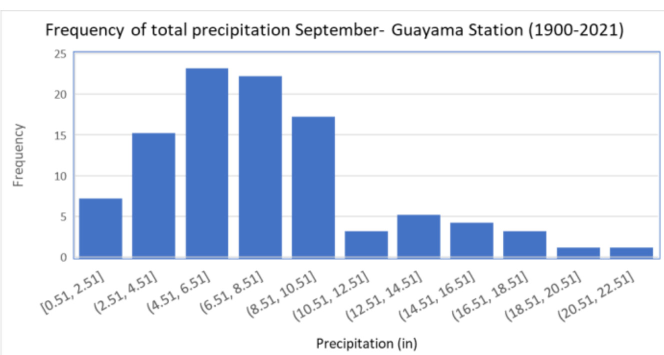

Fig. 4 Frequency of total precipitation September – Guayama Station (1900-2021).

Table 1 shows the summary data for precipitation in the San Juan station for February and September from 1900.

Table. 1. 100 years Precipitation Analysis-San Juan Station

Groups	*Count*	*Sum*	*Average*	*Variance*
FEB	122	313.4	2.568852459	3.026036689
SEP	122	724.37	5.937459016	7.902171176

An ANOVA test was used to determine the relationship between the precipitation in February and September. The purpose of this one is to show the difference in precipitation quantities according to what was planned previously.

To determine whether any differences between the means are statistically significant, compare the p-value to its significance level to assess the null hypothesis. The null hypothesis states that the precipitation between February and September is equal. Usually, a significance level (denoted as α or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that a difference exists when there is no actual difference. P-value ≤ α: The differences between some of the means are statistically significant. If the p-value is less than or equal to the significance level, the null hypothesis is rejected and concludes that not all the population means are equal. Table 2 shows the ANOVA test for precipitation in San Juan Station, where the P-value is 6.53334046598818E-24, considering the rejection of the null hypothesis.

Table. 2. ANOVA February and september precipitations San Juan Station

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	692.1981	1	692.1981	126.68	6.53334E-24
Within Groups	1322.313	242	5.464104		
Total	2014.511	243			

In the same way, other ANOVA tests were used for stations in the north, south, east, and Puerto Rico western area. Table 3 presents the test ANOVA result to compare the months' precipitation for Guayama Station, where the P value is less than or equal to 0.05. The null hypothesis is rejected, concluding that precipitation estimation differs for the months.

Table. 3. ANOVA February and september precipitations Guayama Station

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	1669.6	1	1669.6	166.3141	4.34E-28
Within Groups	2007.8	200	10.039		
Total	3677.4	201			

In this case, ANOVA was used to compare differences in means among two precipitation groups. September and February rainfall, September is the month with the most precipitation, and February is the month with less precipitation.

The analysis determines the variations in the data and where that variation is found. The result indicates that the precipitation amounts are different between these months; this conclusion is essential to evaluate the energy in these two seasons.

III. Study Locations

For this research, the complete area of the roofs was determined for both rural and urban areas. Floral Park Urbanization, the Israel neighborhood, and the Country Club were measured using Arc Gis, which allowed precision when analyzing the roof catchment area. Figure 5. helps visualize the process of how ArcGIS was used.

Figure 5. Israel neighborhood rooftops catchment area

It was determined that the average catchment area for houses in said locations is approximately 160 square meters or 0.04 acres. Figure 6 shows the two most common roofs in Puerto Rico, the flat and the pitched roofs.

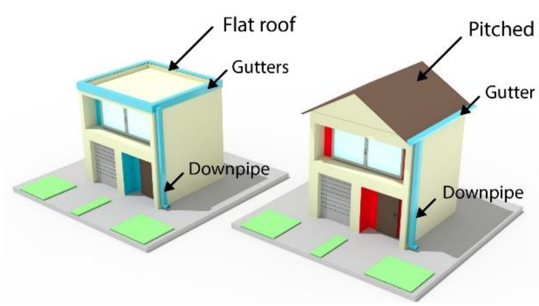

Figure 6. Puerto Rico typical roofs

Flat roofs are considered those with a minimum slope of one-fourth inch vertical to twelve inch horizontal (¼:12 or 2 percent), and roofs with lateral slopes greater than 3:12 are considered roof pitch or a steep roof.

It is known that most roofs have two downspouts on each side, a roof with only one downspout would not have the capacity to handle the flow of water over its surface, and this would cause flooding and roof collapse. Therefore, the catchment area to determine the flow is divided into two, as shown in the following Figure 7

Figure 6. roofs catchment area

There are three components outside the scope of the project: the roof, the gutter, and the runoff coefficient. The system proposed begin with the roof. And this is directed to low-income families living in Puerto Rico. The concert roof will provide a smooth and impervious surface for the Water to flow down to the gutter. The roof has a minimum of slope even if they are considered flat to ensure the flow of water.

The scope of the research is mainly focused on the transformation of rainwater into energy. Therefore, the study will focus on the gutter form, texture and availability, downspout system, and turbine. Additionally, the water that goes through the turbine can be reused, such as irrigation and toilets, without a filtration system to save energy because the objective is “save energy.”

Another important property is the runoff coefficient. The runoff coefficient refers to the amount of resistance the surface imposes over the water flow. The following Table 4 shows the runoff coefficient for different types of surfaces. There is a coefficient of friction of 0.9 for the roofs of the residences, where most of these constructions are constructed in concrete.

Table 4. runoff coefficients for different types of surfaces

Land Use	C
Downtown areas	0.7-0.95
Neighborhood areas	0.50-0.70
Asphaltic	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Roofs	0.75-0.95
Drives and Walks	0.75-0.85
Unimproved areas	0.10-0.30

Once the precipitation intensity data had been calculated, the data were used to determine how much power could be generated using the Pelton and Turgo turbines. The first step was to select the rainfall data with more significant value precipitation during the periods of 15-, 30-, 45-, and 60 minutes. Afterward, it was necessary to calculate the average flow using the data provided and the turbine's estimated characteristics. Figure 7 shows a sketch of the future system

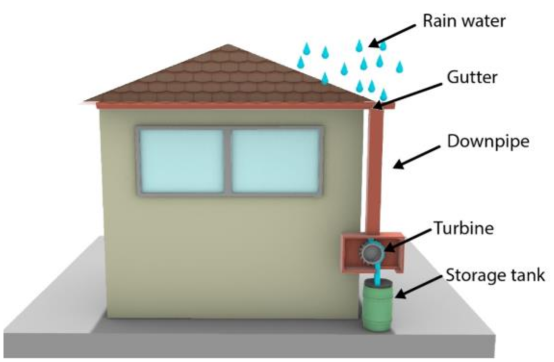

Figure 7. Sketch future system

To determine the flow generated by precipitation falling on the roof was used the Rational Method equation to determine the average water flow.

$$Q = CiA$$

Where Q is the peak rate of runoff in cubic feet per second, C is the friction coefficient (direct relationship between rainfall and runoff), i is the average precipitation intensity in inches per hour, and A represents the watershed area. An area of approximately 80m^2 was used, and a coefficient between 0.9 and 0.99. The intensity depends on the precipitation and duration of every event.

To determine the velocity of the water falling through the roof was necessary an analysis with the Bernoulli equation

$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma_w} + h_1 = \frac{V_2^2}{2g} + \frac{P_2}{\gamma_w} + h_2$$

$$\frac{V_2^2}{2g} = h_1$$

$$V_2 = \sqrt{2gh_1}$$

h_1 = 3-4m

V_2 =Velocity exiting the pipe

Figure 8 shows the location of the parameters for the analysis.

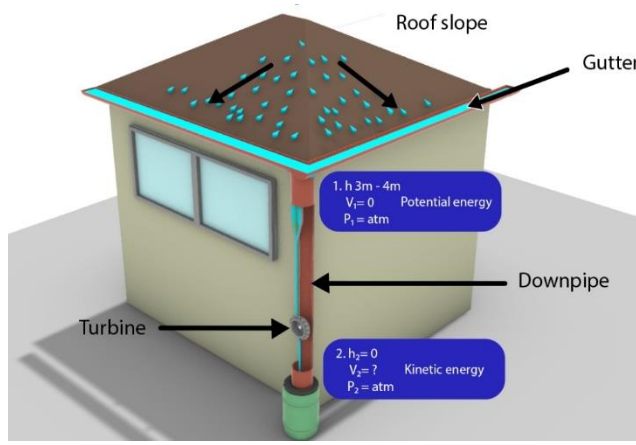

Figure 8. Parameter for Bernoulli Equation

If gutter speed is low, Y will be neglected. Manning equation was used to obtain the gutter velocity, the gutter used was a U-style or half-round gutter of 5 to 6 inches; these are known as European Profile, and these rounded gutters have a classier style. Manning equation coefficients n=0.014 and gutter slope of 1%, assumed water height into the gutter of 50 to 75% of the radius where the diameter is 5 inches, then the height is between 1.25 to 1.875 inches. Finally, the gutter velocity found was 0.6 m/seg.

$$V = \frac{1}{n}\left(\frac{A}{P}\right)^{\frac{2}{3}} (S)^{1/2}$$

IV. TURBINES CHARACTERISTICS

The Two types of turbines generally used with water are turbines of reaction and impulse. The impulse turbines use the water speed to rotate the shaft; this turbine is adequate for low flow and a high head. For this research, the headwater was considered 4 to 3 meters; this head is adequate for a small turbine of impulse.

The Impulse turbines are classified into 3: the Pelton wheel, Turgo, and Crossflow turbines. Another kind of turbine is a Reaction turbine, which can generate power from the combination of pressure and movement. This turbine is suitable for a high flow such as the water in a river or dam. Given the characteristics, reaction turbines are not recommended to generate energy using the flow from the precipitation with a small watershed, such as the roof of a house.

For this research, the alternative selected was the turbine of impulse. In this case, there are three types: Pelton Wheel, Turgo Turbine, and Crossflow. Pelton wheels consist of multiple bucket-shaped blades, known as impulse blades, and often have jets directed tangentially to the turbine.

The Turgo turbine is a modification of the Pelton wheel, except that it uses only half of the blade or just one "bucket" The Crossflow turbine is designed with tangential rectangular-shaped blades that allow the water to flow through the turbine twice, flowing through the inside of the runner.

In general, the impulse turbine powers the runner and uses the water speed to produce kinetic energy. The stream of water reaches each bucket on the racer. There is no suction on the low side of the turbine because the water flows out of the base of the turbine box as it hits the runner. An impulse turbine is usually ideal for high-head, low-flow applications [7].

Several features distinguish Pelton Wheels from other turbines, which can be seen in the layout of the turbine and how the water jet strikes the buckets. The nozzle that directs the water jet at the wheel is in the
same plane as the wheel's buckets. Each bucket is also spilled in half by a ridge that forms two elliptically shaped cups inside each bucket.

The notch in each bucket allows the water jet to hit the tangential bucket's center for a longer duration without interference from the edge of the next bucket on the wheel. Efficiencies of large Pelton turbines are typically over 90%. Micro-hydro Pelton impellers commonly have simpler designs that typically have efficiencies ranging from 75% to 85%, Figure 9 shows the buckets of the Pelton Turbine.

Figure 9. Buckets of Pelton Turbine

Turgo Turbines are like Pelton Wheels but with several key differences. The water jet of the Turgo turbine is positioned at an angle from a plane through the rotating impeller causing the jet to impinge on the bucket at an angle. The jet enters one side of the impeller and then exits the other. There are no notches in Turgo buckets.

This configuration keeps water exiting the impeller separate from the water jet entering the bucket on the other side of the wheel. Eliminating this interference allows a Turgo impeller to be more compact and operate at faster speeds when compared to Pelton Wheels operating in the same conditions.[8]. Figure 10 shows the buckets of the Turgo Turbine.

Figure 10. Buckets of Turgo Turbine

This study used parameters of Pelton and Turgo turbines to calculate the power generated from both turbines. The effects of blade orientation angle and jet impact location on efficiency are a function of each parameter above and their interactions. The effects of blade orientation angle and jet impact location on efficiency are also considered.

This study aims to establish a practical design that Supports the creation of an alternative way to generate energy from typical houses in Puerto Rico. Where the design is low-cost, takes advances the constant precipitation in the tropic at a high rate, and reuses water using a passive harvesting system

Before selecting the turbine's final decision, A theoretical analysis of the two types was done to determine the maximum potential power.

The equation used to determine the estimated wattage generated by the water flow in a 60-minute interval for the Pelton turbine is as follows:

$$P = \rho QU(U - V)(1 - \cos\beta)$$

$$\rho = water\ density\ (kg/m^3)$$
$$Q = Flaw\ Rate\ (m^3/s)$$
$$u = Blade\ Speed\ (m^3/s)$$
$$V = Pipe\ water\ velosity\ (m/s)$$
$$\beta = recomemded\ angle\ (degree)$$

Where P is power in watts, ρ represents water density, Q is the flow rate, U is the turbine’s blade speed, V is velocity and β is the exit angle.

The second equation is used to determine the estimated wattage generated by the waterflow in a 60-minute interval for the Turgo turbine:

$$PH = \rho g Q H$$

Where ρ represents water density, g is the force of gravity, Q is the flow rate, and H is the total head.
With the implementation of the rational method to calculate the flow, we proceeded to determine the daily rainfall for February and September during an annual period of 10 years. The 15, 30, 45, and 60 minutes with the highest daily rainfall were determined for each day. It should be noted that since Puerto Rico is located in the Caribbean, the rain tends to be of high intensity and short duration due to its geographic location and geography, in which convective precipitations predominate.

Once the precipitation data were obtained every period, the procedure to calculate power could be generated using the Pelton and Turgo turbines based on the data collected.
Table 5 shows the power obtained using the Pelton Turbine and Turgo turbine for precipitation in February with 15 minutes in an urban area, specifically Guaynabo city.

Table 5. Power using Pelton and Turgo Turbines for 15min of precipitation in Guaynabo City (February)

2021									
USGS 50049620									
18°24'55.9", 66°06'12.1"									
Guaynabo									
February	15 min. (in)	15 min. i(in/hr)	15 min. Q(cfs)	L/M 2 slope	m^3/seg 2 slope	Power (w) (Pelton)	Power (w) (Turgo)	Wh (Pelton)	Wh (Turgo)
1	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.80003021	0.19660031	0.20000755
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0.02	0.08	0.00288	2.4465744	4.078E-05	1.5728024	1.60006043	0.39320061	0.40001511
5	0	0	0	0	0	0	0	0	0
6	0.05	0.2	0.0072	6.116436	0.0001019	3.9320061	4.00015107	0.98300153	1.00003777
7	0.02	0.08	0.00288	2.4465744	4.078E-05	1.5728024	1.60006043	0.39320061	0.40001511
8	0	0	0	0	0	0	0	0	0
9	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.80003021	0.19660031	0.20000755
10	0.08	0.32	0.01152	9.7862976	0.0001631	6.2912098	6.40024172	1.57280245	1.60006043
11	0.14	0.56	0.02016	17.126021	0.0002854	11.009617	11.200423	2.75240428	2.80010575
12	0.12	0.48	0.01728	14.679446	0.0002447	9.4368147	9.60036258	2.35920367	2.40009064
13	0	0	0	0	0	0	0	0	0
14	0.02	0.08	0.00288	2.4465744	4.078E-05	1.5728024	1.60006043	0.39320061	0.40001511
15	0.03	0.12	0.00432	3.6698616	6.116E-05	2.3592037	2.40009064	0.58980092	0.60002266
16	0	0	0	0	0	0	0	0	0
17	0.04	0.16	0.00576	4.8931488	8.155E-05	3.1456049	3.20012086	0.78640122	0.80003021
18	0.06	0.24	0.00864	7.3397232	0.0001223	4.7184073	4.80018129	1.17960184	1.20004532
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.80003021	0.19660031	0.20000755
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0
27	0.09	0.36	0.01296	11.009585	0.0001835	7.077611	7.20027193	1.76940275	1.80006798
28	0.06	0.24	0.00864	7.3397232	0.0001223	4.7184073	4.80018129	1.17960184	1.20004532

Para zona urbana	
Area (acres)	0.04
coeficiente de friccion	0.9
Gravity (m/seg^2)	9.81
Potential Energy(m)	4
Velocity downpipe	8.8588938
density (kg/m^3)	1000
Blade speed (m/s)	4.4294469
the angle of the exit edge of the blade	165
Storm duration (min)	15

Table 6 shows the same power but now uses the data from September, the month with more precipitation in Puerto Rico.

Table 6. Power using Pelton and Turgo Turbines for 15min of precipitation in Guaynabo City (September)

2021									
USGS 50049620									
18°24'55.9", 66°06'12.1"									
Guaynabo									
September	15 min. (in)	15 min. i(in/hr)	15 min. Q(cfs)	L/M 2 Slope	m^3/seg 2 slope	Power (w) (Pelton)	Power (w) (Turgo)	Wh	Wh
1	0.08	0.32	0.01152	9.7862976	0.0001631	6.2912098	6.4002417	1.57280245	1.60006043
2	0	0	0	0	0	0	0	0	0
3	0.09	0.36	0.01296	11.009585	0.0001835	7.077611	7.2002719	1.76940275	1.80006798
4	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.8000302	0.19660031	0.20000755
5	0	0	0	0	0	0	0	0	0
6	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.8000302	0.19660031	0.20000755
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0.79	3.16	0.11376	96.639689	0.0016107	62.125697	63.202387	15.5314242	15.8005967
10	0.1	0.4	0.0144	12.232872	0.0002039	7.8640122	8.0003021	1.96600306	2.00007554
11	0.55	2.2	0.0792	67.280796	0.0011213	43.252067	44.001662	10.8130168	11.0004155
12	0.19	0.76	0.02736	23.242457	0.0003874	14.941623	15.200574	3.73540581	3.80014352
13	0.13	0.52	0.01872	15.902734	0.000265	10.223216	10.400393	2.55580398	2.6000982
14	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.8000302	0.19660031	0.20000755
15	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.8000302	0.19660031	0.20000755
16	0	0	0	0	0	0	0	0	0
17	0.05	0.2	0.0072	6.116436	0.0001019	3.9320061	4.0001511	0.98300153	1.00003777
18	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.8000302	0.19660031	0.20000755
19	0.1	0.4	0.0144	12.232872	0.0002039	7.8640122	8.0003021	1.96600306	2.00007554
20	0.63	2.52	0.09072	77.067094	0.0012845	49.543277	50.401904	12.3858193	12.6004759
21	0.16	0.64	0.02304	19.572595	0.0003262	12.58242	12.800483	3.1456049	3.20012086
22	0.01	0.04	0.00144	1.2232872	2.039E-05	0.7864012	0.8000302	0.19660031	0.20000755
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0.22	0.88	0.03168	26.912318	0.0004485	17.300827	17.600665	4.32520673	4.40016618

Para zona urbana	
Area (acres)	0.04
friccion	0.9
Gravity (m/seg^2)	9.81
Potential Energy(m)	4
Velocity downpipe	8.85889384
density (kg/m^3)	1000
Blade speed (m/s)	4.42944692
the angle of the exit edge of the blade	165

V. PRECIPITATION ANALYSIS

Based on the precipitation data obtained in the Guaynabo and Anasco weather stations, the monthly precipitation sum, average, and standard deviation were calculated for February and September in 15, 30, 45, and 60-minute intervals. Table 7 presents the 60 minutes of average precipitation for one decade between 2010 and 2021 for September in two locations.

The Figure 11 is compared the stations of Anascos (Puerto Rico's western area) and GUaynabo (Puerto Rico metropolitan area).

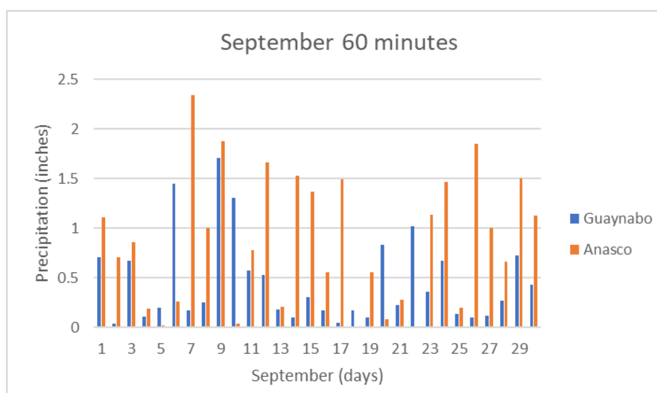

Figure 11. 60 minutes of precipitation for Guaynabo and Añasco.

Añasco, located in the western area of Puerto Rico, is considered one of the rainiest areas of the island. As seen in the graph, the Añasco station exceeds the precipitation rates observed in the Guaynabo station.

Several precipitation data were analysed, to Examine the 60-minute period as the period where constant precipitation can be observed, necessary for the turbine to be constantly in motion.

VI. TURBINE SELECTION

The turbine selection took into account multiple criteria, in which different turbines were evaluated. During this initial research, we considered three essential turbines: Crossflow, Pelton wheel, and Turgo. Reaction turbines were eliminated based on background research because they require a fully submerged pipe to operate at the highest efficiency.

The test used 2 microturbines to determine if the amount of precipitation was sufficient to generate energy in small-magnitude turbines.

Hydroelectric Generator, model DB-168: turbine with a built-in generator. It is responsible for generating energy from the water flow provided by the rainwater. This particular model has an output voltage of 5V DC and a current of 150mA. Its operating range is a flow of around 2.5~25L/min. The openings that let the water in are half an inch in diameter, see Figure 12.

Figure 12. Hydroelectric Generator, model DB-168

And the second one is the Micro Hydro Generator, model F50: this turbine also has an integrated generator. The diameter of the openings is also half an inch in diameter. What distinguishes the F50 turbine from the DB-168 turbine is the threshold voltage and current. The maximum output voltage is 12 V.

The maximum charge current it can handle is 220mA. Hence this turbine has a higher potential in energy production. Nonetheless, it is still not a significant amount, judging by the limits of the component. See Figure 13.

Figure 13. Micro Hydro Generator, model F50

The components were connected via pipes to simulate the downpipe of a household. The sensors and the turbines were connected in series to obtain more accurate readings. A ball valve was used to control the water pressure, represented by the handle's angles. The angles considered were 0, 45, 60, and 90.

The distance between the components measures one foot to avoid the turbulence of passing through components. The first sensor had a diameter of ¾ of an inch, while the second sensor had a diameter of ½ an inch. Hence, different adapters were used to install these components in the characterization system. Once connected, the water hose was opened, and the sensors were wired to an Arduino with the water flow sensor code uploaded onto it. This allowed for the measuring of the sensor's data via the Arduino. Figure 14 close up of the turbine connection in a pipe system simulating the downpipe

Figure 14. Closeup of turbine connected in a piping system

VII. WATER PRECIPITATION REUSE

The reuse process involves a series of stages, from the catchment area to the storage method for later use. The catchment considered for this experiment is that intercepted in the roofs of single-family homes in Puerto Rico, as shown in the precipitation analysis. The captured precipitation is guided to tanks using a K-style gutter. The selection of these gutters is for their easy handling and purchasing accessibility.

For storage, tanks or cisterns were used, each with different colors, materials, and installation locations. This aspect complicates the choice of the correct one, but the number of options allows us to adjust to the need and objective. Tanks are designed to store several chemical substances, including water. Its design is intended for use on the surface. These come in different sizes, materials, and colors

The color of the container is one of the most important factors when storing drinking water. Light colors allow sunlight to pass through, creating a favorable environment for photosynthesis, which feeds the growth of algae in the water. Algae can cause water to have an unpleasant color, taste, and smell [9]. It can also be harmful since it can produce toxic chemicals for animals and humans.

Dark colors reduce the possibility of light entering and reflecting, which helps prevent the reproduction of algae inside the tank. The most used colors are white, black, blue, and gray [10]. The color must be chosen according to the need since this infers not only the water quality but also the temperature. From the albedo effect, we know that pigments absorb sunlight and convert the energy into heat. The darker the color, the more excellent heat absorption.

According to EPA, some of the main chemical hazards are pH and lead, which are acquired in the catchment area. Some physical characteristics of rainwater can be color due to the presence of pigmented matter, odor, and taste due to organisms on the surface [11]. The alternative is to opt for a simple, passive filtration system. Meshes that can prevent the passage of leaves, limiting their use to irrigation and cleaning tasks.

This research recommends using a barrel with a minimum capacity of 200 liters, that is, small volumes lacking additional treatment, not for potable uses. The passive system requires only minor maintenance at little or no cost. The US Department of Energy highlights the specific services of rainwater harvesting for irrigation, cleaning applications, and toilet flushing, among others. Rain barrels are typically small volume (50-200 gallon) systems designed to capture rooftop runoff. Rain barrels are commonly used in residential applications, and the most common is plastic, as shown in Figure 15.

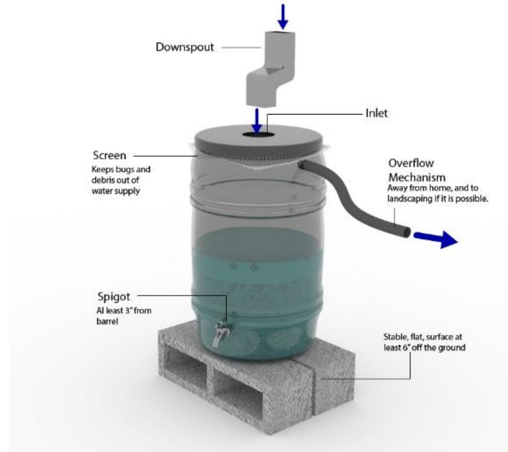

Figure 15. Typical Rain Barrels

During the passage of Hurricane Maria through Puerto Rico in 2017, a large part of the community lost power and water services for long periods. Rainwater harvesting helped mitigate the water shortage in various sectors of the island. Many people used rainwater with the help of a screen to eliminate some little particles or suspended solids. Rainwater was used for cleaning bathrooms and floors and even washing sidewalks and cars.

VIII. CONCLUSION

Having obtained all the necessary data, precipitations of 60 minutes of duration were taken, and the highest Wh that would be produced in the best case per month/year was selected. With results between (24 - 46) Wh, it can be theoretically determined that energy can be produced to light two energy-saving light bulbs while there is precipitation.

Table 7 summarizes the energy produced during 60 minutes of continuous precipitation for the stations of Juana Diaz, Guaynabo, Dorado, Fajardo, and Añasco. These towns cover the island's north, south, east, and west areas. The precipitation estimate was based on an average of 10 years. Precipitation from atmospheric events such as storms or hurricanes was not considered.

Table 7. Summary Energy obtained in 60 minutes of precipitation

Summary (60 min)															
Juana Diaz															
2021				2020				2019				2018			
February		September		February		September		February		September		February		September	
Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Maximum	8.25721285	Maximum	27.1308422	Maximum	8.25721285	Maximum	34.798254	Maximum	7.47081163	Maximum	17.6940275	Maximum	0	Maximum	17.6940275
Guaynabo															
2021				2020				2019				2018			
February		September		February		September		February		September		February		September	
Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Maximum	5.40020395	Maximum	22.8008611	Maximum	16.1212251	Maximum	33.618652	Maximum	14.7450229	Maximum	28.5070444	Maximum	10.8130168	Maximum	8.84701377
Dorado															
2021				2020				2019				2018			
February		September		February		September		February		September		February		September	
Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Maximum	6.6844104	Maximum	30.4730474	Maximum	11.7960184	Maximum	13.5654211	Maximum	10.0266156	Maximum	31.84925	Maximum	0	Maximum	26.1478407
Fajardo															
2021				2020				2019				2018			
February		September		February		September		February		September		February		September	
Maximum	24.77	Maximum		Maximum	10.22	Maximum	25.16	Maximum	17.69	Maximum	24.57	Maximum		Maximum	11.99
Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0
Anasco															
2021				2020				2019				2018			
February		September		February		September		February		September		February		September	
Maximum	5.11	Maximum	37.35	Maximum	11.79	Maximum	36.37	Maximum	6.29	Maximum	46	Maximum		Maximum	36.56
Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0	Minimum	0

The Five weather stations (USGS) shared decreased daily precipitation in the month of February, with larger intervals of drought (that is, more days in a row without precipitation). Up to 4 days without precipitation were observed at the Dorado station, ten days without precipitation at Juana Diaz and Fajardo, 13 days at the Añasco station, and nine days at Guaynabo.

In addition, the 60-minute intensity of the observed rainfall across all five stations did not reach the one-inch benchmark in February. For September, all stations reported one-hour rainfalls with intensities over the 1'' benchmark at least once per month each year. With the recorded precipitations in the month of February, it would be unlikely to generate electricity since the precipitations are lower than 1 inch and have many days between each precipitation event.

However, flash floods during the Atlantic Hurricane Season are less uncommon, according to the rainfall intensity analysis performed in Puerto Rico. The month of September shows potential for generating electricity.

The goal of this project was to Generate energy from rainwater to charge batteries for light in areas with much rainfall but minimal electricity. San Juan was a case study area for our implementation due to its yearly rainfall rate. Using estimates for Puerto Rico rainfall rates, our system could produce 118800 Joules of energy in only a 60-minute rainstorm with a flow of 44.34 liters per minute; this is enough to charge a cellphone, approximately 13%.

Several investigations mention the importance of each of these turbines. In this case, Pelton has been selected because of the ease that the water can go down the downpipe and crash directly against the cups without the need to have a specific inclination angle, as in the case of the turgo; This makes construction more efficient and more manageable. In addition, a nozzle is unnecessary, which could increase friction losses, causing a decrease in speed.

However, power generation using precipitation could be feasible in regions where long periods of constant precipitation can be experienced, at least four continuous hours of precipitation. Puerto Rico's geographic location and geography determine the type of precipitation, where the predominant ones are short-duration and high-intensity precipitation. One advantage is that you can accumulate large amounts of rainwater for reuse, but within a short period, it is impossible to have a constantly moving turbine. Another viable alternative would be to change the capture scheme and store a large amount of precipitation in elevated tanks that can give a high headwater where there is an orifice at the bottom of the tank, and the turbine can be placed there.

IX. Acknowledgment

We would like to thank PREC, and UAGM for giving us this opportunity to participate in the Year long program investigation. This material is based upon work supported by the department of Energy/National Nuclear Security Administration under Award Number(s) DE-NA0003982

X. References

[1] Paish, O., 2002, "Small Hydro Power: Technology and Current Status," Renewable and Sustainable Energy Reviews, 6(6), pp. 537-556.

[2] G. Boyle. Renewable Energy: Power for a Sustainable Future, 2nd ed. Oxford, UK: Oxford University Press, 2004.

[3] David Darling. (August 26, 2015). Turgo Turbine [Online]. Available: http://www.daviddarling.info/encyclopedia/T/AE_Turgo_turbine.html

[4] Rashmi V. Patil, Nikhil S. Mhetre, Ashitosh A. Varkale, Pramod P. Darade. Automatic power generation using rainwater harvesting and solar energy, International Journal of Advance Research, Ideas and Innovations in Technology, www.IJARIIT.com.

[5] www.eia.gov

[6] L. E. T. Molina, S. Morales, and L. F. Carrión, "Urban Heat Island Effects in Tropical Climate", in Vortex Dynamics Theories and Applications. London, United Kingdom: IntechOpen, 2020 [Online]. Available: https://www.intechopen.com/chapters/71293 doi: 10.5772/intechopen.91253

[7] L. E. T. Molina, D. Matias, and M. Moreno, "A feasibility analysis of energy harvesting coming from Puerto Rico's rivers", 20th LACCEI International Multi-Conference for Engineering, Education, and Technology: "Education, Research and Leadership in Post-pandemic Engineering: Resilient, Inclusive and Sustainable Actions", Hybrid Event, Boca Raton, Florida- USA, July 18 - 22, 2022.

[8] Harvey, A., Brown, A., Hettiarachi, P. and Inversin, A., 1993, "Micro-Hydro Design Manual: A Guide to Small-Scale Water Power Schemes", Practical Action Publishing, Warwickshire, United Kingdom.

[9] Help California's drought by preparing to collect rainwater this winter. Sierra Club. (2021, August 28). Retrieved February 11, 2022, from https://www.sierraclub.org/san-francisco-bay/blog/2021/08/help-californias-drought-preparing-collect-rainwater-winter.

[10] Centers for Disease Control and Prevention. (2021, July 15). Making water safe in an emergency. Centers for Disease Control and Prevention. Retrieved February 11, 2022, from https://www.cdc.gov/healthywater/emergency/making-water-safe.html.

[11] Why are black water storage tanks preferred over white ones? Hunker. (n.d.). Retrieved February 17, 2022, from https://www.hunker.com/13417300/why-are-black-water-storage-tanks-preferred-over-white-ones

[12] Rosa, R. , Perez, J., Ortiz, D. & Rodriguez, R. (2022). Headcount optimization using discrete event simulation at Flower Shop, Inc.. 10.18687/LACCEI2022.1.1.666.