Portable Green Unit

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ABSTRACT

We propose two rainwater electric system concepts that use a small hydro turbine to generate electrical power to supplement other more common sources of renewable energy such as solar and wind. The first concept is designed for high precipitation density locations and consists in attaching a turbine assembly unit to a building's existing gutter/ drainage system. The second concept stores the run-off rain water in a tank before passing through a turbine, making this design less dependent on precipitation density and able to generate a more stable power output. Both can be adapted to most homes or building gutter/drainage systems, and can serve as a low cost means of harnessing the natural energy produced by falling rainwater. We also describe the Green Energy Unit which is an off-grid portable and self-contained renewable energy system that is being developed at FIU for providing aid in emergency situations, such as disaster response, and remote locations where there is no access to shore line power. The rainwater system will be implemented as part of the Green Energy Unit, expanding its capability to provide electrical power in most climates, maximizing the use of each energy source while minimizing the need to run fossil fuel generators.

Keywords: Renewable energy, water harvesting, disaster response

1. INTRODUCTION

Most modern buildings have some sort of roof drainage system to remove water-runoff after heavy rains and storms. These practices are also implemented in highways, such as bridges and overpasses. Drainage systems consist in piping that channels excess water from the roof to the ground. The water at the top of the roof has an associated potential energy which is directly related to the height of the structure. Our idea is to attach a small hydro turbine to the lowest point of a standard residential rain gutter or building's rain drainage system to generate electrical power. As the rotor spins, mechanical power is transformed to electrical power by means of a small turbine. The energy produced is then used to charge a battery bank.

The rainwater turbine system will be part of a self-contained renewable energy emergency unit consisting in photovoltaic cells to capture solar energy, and small wind turbines to use the wind's kinetic energy. The rain run-off, which has minimal kinetic energy after passing through the rotor, can be stored in tanks or cisterns that can be later used for irrigation and other applications where non-potable water can be used (Hari, 2005). By harvesting different forms of energy, the Green Energy Unit will be able to provide electrical power in most climates, maximizing the use of each energy source while minimizing the need to run fossil fuel generators.

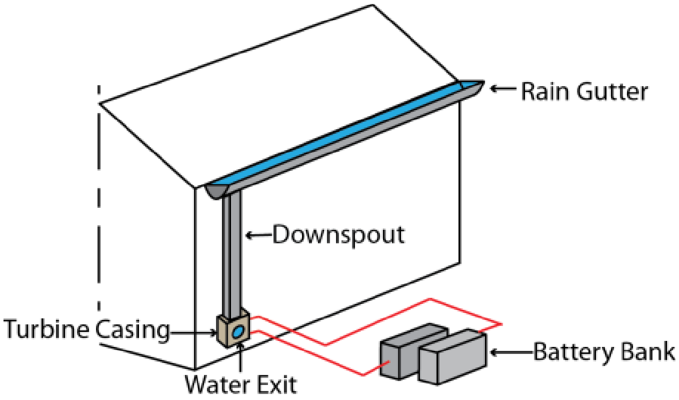

Figure 1: Sketch of the gutter turbine energy system

Figure 1 shows a sketch of the proposed energy system. Water is collected by the rain gutter and travels to the downspout due to the roof's pitch angle. Water flows down the downspout, building kinetic energy. Water exiting the downspout through a nozzle spins a runner inside the turbine casing turning a magnetic alternator to generate electricity. The voltage is rectified to 12 / 24 VDC and used to charge a battery bank. After the water leaves the turbine, it can be harvested and stored for other applications. In section 2.1 we propose a second design that uses the rain collected in a storage tank to run the turbine instead of directly connecting the turbine to the downspout exit.

The reminder of the paper is divided in three sections. In section 2 we describe how to use rainwater as an energy source, providing potential energy estimations, system design concepts and theoretical power output limits. In section 3 we describe current work in the area of renewable energy and describe our Green Energy Unit. Finally in section 4 we give our conclusions.

2. Precipitation and Potential Energy

The total potential energy that could be extracted from rain water depends on precipitation levels. Figure 2 shows the average global precipitation levels for 2008 (Rudolf, 2005), (Beck, 2005). The highest levels of precipitation occur in tropical and temperate climate zones, such as Central Africa, the Caribbean, the Amazon basin and most of southern Asia. It is in these zones that rainwater potential energy is the greatest.

The gutter turbine system will be built and tested in the Engineering campus at Florida International University, hence all precipitation data is taken from the Miami-Dade County. We will consider a flat roof building located at the Engineering campus with a surface area of 2300m^2 and height of 25ft (7.62m) measured from the roof to the downspouts exit point.

Figure 3 shows the average annual Rainfall in the United States from1961 to 1990; for Southern Florida this value is 50-70 inches per year. We will use 60in of rain in our calculation. Table 1 shows statistical data on the annual average rain patterns for the Miami-Dade area. In a year, the Miami-Dade area receives 129 days of rain, where about 50% of it occurs from June to September.

Using the precipitation data from the Miami-Dade area and the building dimensions mentioned before we can establish a relationship to estimate the energy that could be extracted from rain water using Equation 1

$$P = Ah\rho_{water} g \Delta z, \qquad (1)$$

here P is the potential energy, g is gravity , Δz is the height of the building, A is the roof surface area, ρ is the density of water and *h* is the height of water given from the data on table 1 and figure 3.

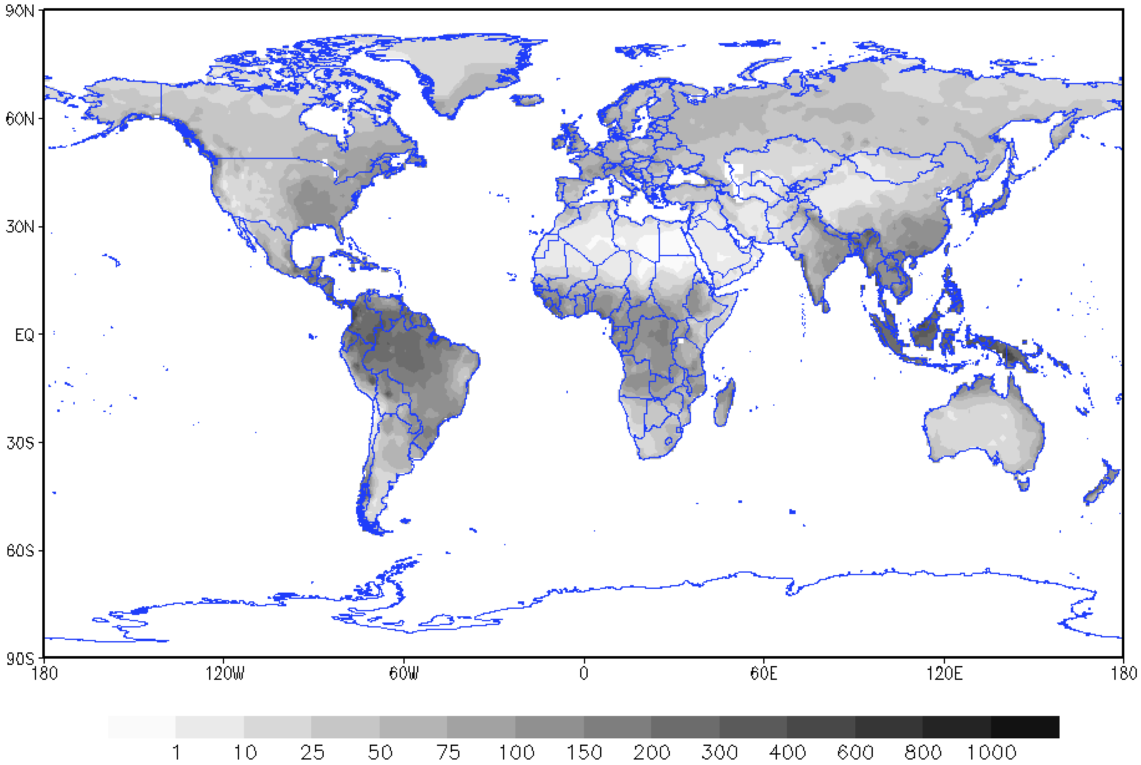

Figure 2: Precipitation for year 2008 (Jan-Dec) in mm/month

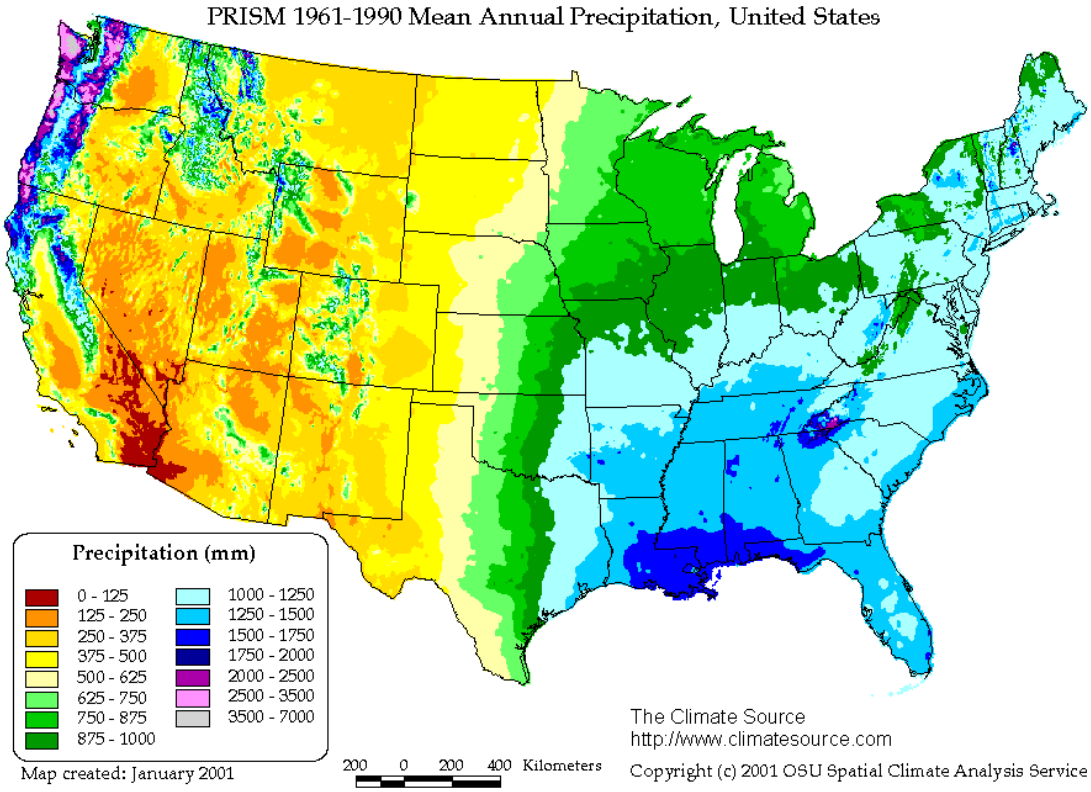

Figure 3: United States Average Rainfall Map

Table 1: Number of Rainy Days in the Miami-Dade area

	Annual	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Days	129	7	6	6	6	10	15	16	17	17	14	9	6

Using equation 1, the total yearly rainwater potential energy is 262MJ, or 73kWh. Assuming evenly distributed levels of precipitation throughout the 129 rainy days, this would account to 0.57kWh of energy per day. This energy value is equivalent to using a 114W solar panel for 5 hours.

2.1 Power Analysis

In this section we will estimate the maximum power that can be obtained by a turbine given the flow characteristics associated with rainwater behavior. For high head low flow conditions, as the case with our rainwater design, impulse turbines would be the most efficient choice. In impulse turbines, water traveling through a penstock (in our case the downspout) exits trough a nozzle forming a high velocity jet that strikes a runner making it rotate. This exit velocity will depend on the nozzle geometry and the available hydraulic head. For steady, incompressible flow the power output for an impulse turbine is given by Equation 2

$$\dot{W} = \rho Q U\left(U - V_j\right)(1 - cos\beta), \tag{2}$$

where $\dot{W}$ is the power at the runner (rotor), ρ is the density of water, Q is the flow rate, U is the bucket speed, V_j is the velocity exiting the nozzle and β is the deflection angle. The maximum power is given when the bucket speed is equal to half the nozzle velocity, $U_{max} = V_j/2$ (Fox, 2006). The flow rate at the downspout expressed in gallons per minute (gpm) can be written as equation 3, where the diameter of the downspout, d, is in inches.

$$Q = \frac{vd^2}{0.4085} \tag{3}$$

From the energy equation, the velocity at the nozzle is given by equation 4,

$$V_j = \sqrt{2g\Delta z - H_f}, \tag{4}$$

where g is gravity, Δz is the height of the downspout and H_f is the head loss. Table 3 shows the power output at the runner, given different nozzle diameters after solving equations 3 - 4 iteratively, here we ignore minor losses. Table 2 summarizes the parameters used in the simulation.

Table 2: Simulation parameters

Variable	Units	Value
Gravity, g	m/s^2	9.8
PVC pipe roughness, ε	ft	$5x10^{-6}$
Defection angle, β	degrees	180
Water Density, ρ	Kg/m^3	1000
Downspout diameter, d	in	4

Table 3: Simulation results for different nozzle diameters

Nozzle Diameter (in)	Flow rate (gpm)	V_j (ft/s)	Power at runner (w)	Rotor Angular Velocity (RPM)				
				4 in	5 in	6 in	7 in	8 in
0.5	25	40	53	1146	917	764	655	573
1.0	100	40	211					
1.5	210	38	400					

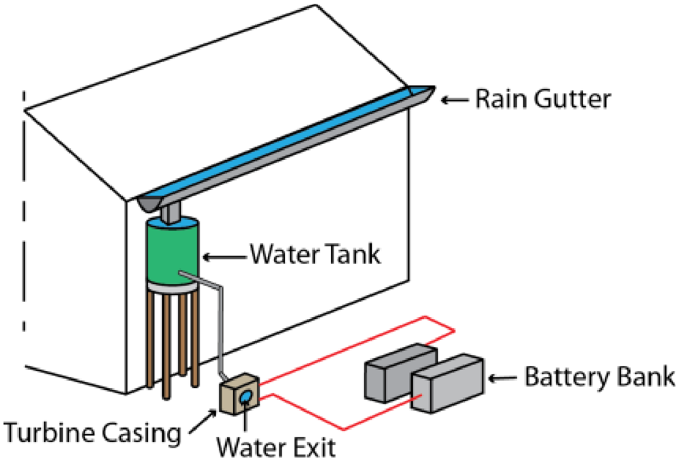

Figure 4: Sketch of the alternative rainwater electric system

In ideal conditions an 8in diameter runner would have an average rotational speed of 500 to 650 RPM. The available maximum power at this rotational speed would vary from 200W to 400W using a 1.0-1.5in nozzle. The calculations in this section assume a steady water column traveling through the downspout, but since rainwater density is not constant it will be difficult to maintain steady flow rates. This strong transient restriction limits the achievable power quality and general power output. Low flow would result in a weak water jet leaving the nozzle; with little kinetic energy, the rotor speed might not reach the required angular velocity to generate electrical current, or the output voltage would be too low to charge a battery bank. Under these conditions we would expect the output power to vary between 0W and 100W.

Given the restrictions and high dependence on precipitation density, we propose a second alternative system design seen on Figure 4. Instead of attaching the turbine directly to the downspout, we first collect the runoff water in a storage tank with a control valve attached at its base. The tank location should be as close to the gutter as possible, allowing the greatest distance (head) between the bottom of the tank and the intake point of the turbine. A tube, penstock, is attached from the control-valve to the turbine inlet. When the tank is full the control-valve is opened allowing water to travel down the penstock and into the turbine inlet. With this design the rainwater is stored in a large enough reservoir in order to maintain constant flow of water to the turbine, following results summarized on table 3 more closely. Another advantage of this design is that it makes the system more accessible to locations with lower precipitation levels since the water used to run the turbine can be stored over time.

Figure 5 shows a three-dimensional conceptual model of the runner Pelton wheel and the rainwater turbine housing system.

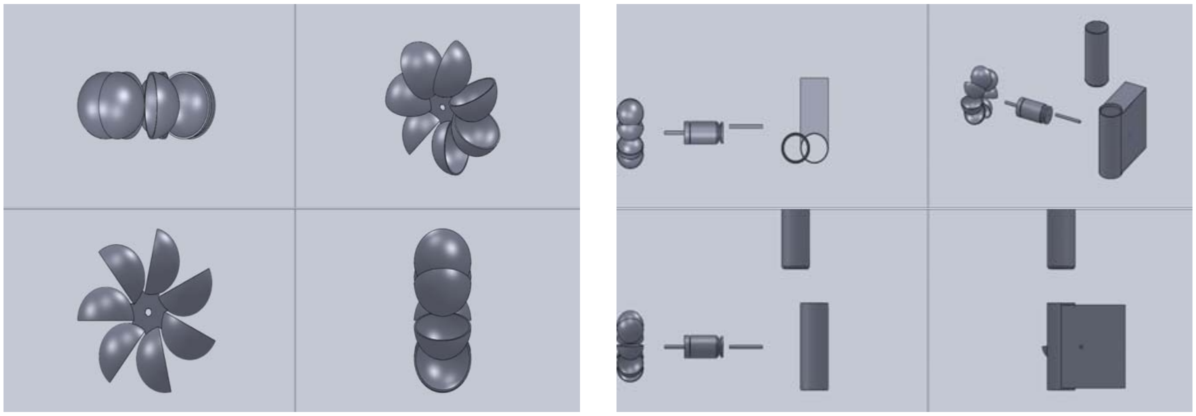

Figure 5: Three-dimensional model of runner the Pelton wheel and the rainwater turbine housing system

Figure 6: The Green Energy Unit located at the FIU Engineering and Computing Campus

3. Portable Green Energy Unit

The Green Energy Unit, shown in figure 6, is an off-grid portable, self-contained unit that can use grid power and/or solar and wind renewable energy sources to charge a battery bank. The unit uses two multi-crystalline 210W solar panels and a 400W small wind turbine for a total of 820W of rated power. It can fit four deep cycle batteries, a 3kW inverter/charger, a 60A MPPT charge controller and all the safety disconnects needed to operate. The Green Energy Unit primary use is for emergency situations, such as disaster response; and remote locations where there is no access to shore line power. It can supply enough power to maintaining small to medium refrigeration system; provide a means of communication, lighting and overall general electrification.

Figure 7 shows the solar and wind energy contribution for the portable renewable energy unit using insolation and wind speed data for the Miami-Dade (NREL, 2007) area found on table 4. The solar component can generate 47kWh to 63kWh of energy per month, roughly translating to 1.8kWh of energy per day. These energy values were calculated using a derating factor of 0.7 which accounts for system losses due to panel efficiency, electronic equipment and voltage losses. Initially a 10 meter tower was considered for the wind component but this would limit deployability and compactness of the unit which was an important design factor. A tower height of approximately 3 meters (10ft) was used. The wind contributions at this height and geographical location are small, accounting for 13.4% of the total energy production. Locations with better wind profiles would benefit the most from this component.

The design goal for the Green Energy Unit was (is) to build a portable and modular unit with the capacity to use all available energy sources to generate the maximum amount of energy possible. By including multiple energy sources the unit can efficiently be deployed to a wide range of geographical locations with different climate characteristics.

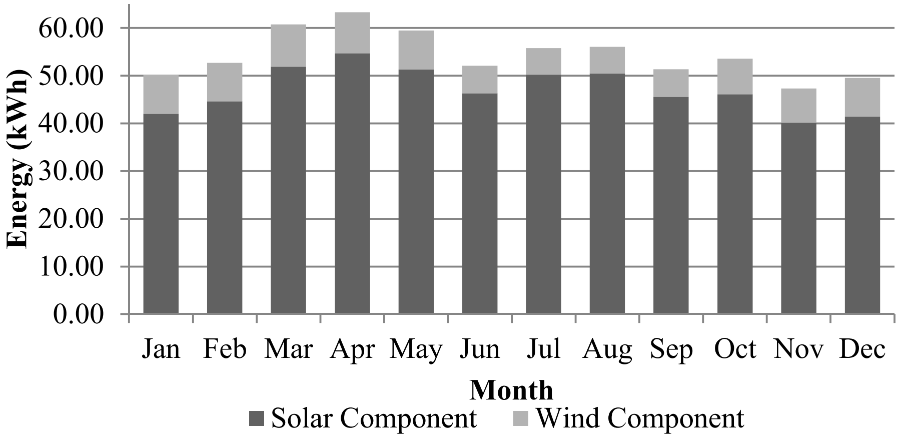

Figure 7: Shows the solar and wind monthly energy contribution for the portable energy unit using Miami-Dade insolation and wind speeds.

Table 4: Solar and Wind (at 3m) Component Energy Contribution

		Solar Contribution		Wind Contribution		Total
Month	**Days**	**Insolation ($Wh/m^2/day$)**	**Avg. Energy (kWh)**	**Wind Speed (Mph)**	**Avg. Energy (kWh)**	**Energy (kWh)**
January	31	4.61	42.02	10.5	8.18	50.20
February	28	5.42	44.62	11.0	8.06	52.68
March	31	5.69	51.86	11.5	8.93	60.79
April	30	6.20	54.68	11.4	8.64	63.32
May	31	5.63	51.31	10.5	8.18	59.50
June	30	5.25	46.31	9.00	5.76	52.07
July	31	5.51	50.22	8.80	5.58	55.80
August	31	5.54	50.49	8.80	5.58	56.07
September	30	5.17	45.60	9.00	5.76	51.36
October	31	5.06	46.12	10.1	7.44	53.56
November	30	4.55	40.13	10.0	7.20	47.33
December	31	4.54	41.38	10.8	8.18	49.56

4. Conclusion

This paper presented two design concepts to harvest energy from rainwater using a building's water run-off drainage system. The first was simple to implement but was strongly influenced by location and precipitation density, while the second would be less dependent on precipitation density, but would require some sort of infrastructure to keep the water storage tank at a height above ground. Both designs can be adapted to fit most homes and buildings, supplementing other renewable energy sources such as solar, wind, micro-hydro, biodiesel, etc. The rainwater electric system will be implemented as part of a portable and self-contained off-grid Green Energy Unit that utilizes solar and wind renewable energy sources to provide electrical energy in emergency situations, such as disaster response; and remote locations where there is no access to shore line power. By harvesting different forms of energy, the Green Energy Unit will be able to provide electrical power in most climates, maximizing the use of each energy source while minimizing the need to run fossil fuel generators.

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