Water is Life 2016

Sustainable Rainwater

School Research

Kees van de Sanden
Niek van Huijkelom
Titus Naber

April 2016

Index

Introduction

Nowadays, sustainability is one of the top priorities of many organisations and the government. Therefore, it is one of the most important subjects of the 21st century. With our research we hope to be able to improve the way people treat their rainwater and how they could reuse it. Knowing that we are more interested in the scientific and practical side of research, we have chosen to perform a research and do an experiment based on this research.
Water management, something which is immediately associated with the Dutch, is our source of inspiration for this project. We will limit ourselves to rainwater management and how we could use it as a sustainable energy source. But why rainwater? In our opinion, rainwater is still something people take for granted, instead of using it to create energy. With our research we hope to help in the search for sustainability and we hope to inspire other people in discovering ways of sustainable water management. We hope you have a good read!

Kees van de Sanden
Niek van Huijkelom
Titus Naber

Preface

First of all we would like to thank a few partners who helped us to make this project. Fablab 013 helped us with printing the parts that were needed to practically experiment with our project. Even when we broke our first model, Fablab helped us making a new one in only one day. Without the help of Fablab, we would not have been able to test our model and practically measure it's possibilities. The models we used for our project were made by Leapfrog. This company, and especially Mr. Pim Rutgers helped us in making a design of our model. So a special thanks for both companies. A special thanks to Prof. Dr. Ir. M.C.M. van de Sanden, who helped us in calculating and building our system. And also a special thanks to Mr. Harrie van Harssel for the guidance.

Chapter 1: The Research

Research Questions

Main question:
How can we deal with rainwater in a sustainable way?

Theoretical sub-questions:
1. In which way can we use rainwater to generate electricity?

- 1.1 What is the maximum amount of energy we can produce using a turbine in a drainpipe?
- 1.1.2 What is the most practical way to maintain 280 litres of water on a roof for a longer period of time?
- 1.2 How can we use a UV-system to help us produce (more) energy?

2. Is it possible to transform rainwater into drinking-water in a domestic environment?
3. In what ways can we reuse water within our household?

- 3.1 What are the different kinds of wastewater within our household?
- 3.2 What are the best options to reuse this water?
- 3.3 How much could we save up on water?

Practical sub-questions:
1. Is it possible to produce energy from rainwater?

- 1.1 How can we use a turbine to make electricity?
- 1.2 How do we construct a reliable setup?
- 1.3 How much energy can we produce in this setup?
- 1.4 Could we make a system that is profitable when using such a setup?

Hypotheses

We think that with some adjustments in the water treatment system, sustainable use of rainwater is within our reach.

Theoretical Hypotheses

1.1 **In which way can we use rainwater to generate electricity?**
We expect that we could generate energy with rainwater falling through a drain. We expect that the most efficient way to do this is to install a turbine in the drain and connect it to a generator. In this way we could transfer the energy in the water through our turbine into a generator and create electricity. We expect that the output of this system would not be very big, because of the irregular downpour.

1.2 **How can we use a UV-system to help us produce (more) energy?**
The UV-system might be a system that could help us to generate more energy. The system is based on creating a lower pressure in the tube with water, which causes the water to go faster through the tube. This could help us to generate energy in a more constant way.

2. **Is it possible to transform rainwater into drinking-water in a domestic environment?**
We expect that it is possible that rainwater is purifiable at home. Rainwater is already quite clean so the process will not be very complex and can be easily used in a household. A few possibilities for purification are: cleaning with chlorine, cleaning with UV-light and purification through adding bacteria. We hope to create an energy efficient way of cleaning the water and eventually reusing the water as rinse water or maybe even drinkable water.

3 **In what ways can we reuse water within our household?**
Our expectation is that we will have a large range of possibilities in reusing wastewater. The average Dutch person does not pay much attention to the amount of water they use in daily activities and this creates a lot of unnecessary waste. The purification of the water is done by the government, but putting this in the hands of citizens would create more efficiency. Creating small water treatment plants at homes would create more awareness and efficiency. Not only could the rainwater be treated, but also the wastewater of showering and flushing the toilet. A drawback of this system could be that the chemical compounds in certain cleaning materials are not degradable. Changing to biodegradable cleaning agents could solve this problem.
Another way of reusing the water, is by using it to water a garden.

Practical Hypothesis

1. **Is it possible to produce energy from rainwater?**

1.1 How can we use a turbine to make electricity?

We expect that it is possible to create a generator at low cost and convenient size, and we are going to try this. We expect that a bicycle dynamo is the most suitable solution. The dynamo will be powered by a turbine which is mounted in the drain. It will generate an induction voltage which will power our LED-light. The LED-light is the most convenient, because it has the biggest output. The LED-light will give a flickering light, because it is a diode and it does not work on alternating current.

1.2 How do we construct a reliable setup?

In school we have optional IT lessons and our teacher has a 3D printer in the classroom. This was our first real contact with a 3D printer. We have seen how simple it is to print exactly the product that we are looking for. Therefore, we think that to create a reliable setup, 3D printing is a great option. We can construct this model to our liking so that it fits perfectly. We also need a dynamo, we think that a bicycle dynamo will do the job, because we think it will suffice and will not have too great a resistance and we can easily get hold of such a dynamo.

1.3 How much energy can we produce in this setup?

The energy depends on the amount of water which flows through the drain and the pressure it can deliver on the turbine. This determines the speed of the turbine and eventually the amount of energy produced by the dynamo. So if we could create circumstances that give a constant flow of water, we expect that the amount of energy will be enough to power small electrical devices.

1.4 Could we make a system that is profitable when using such a setup?

We expect that the system will be profitable, but only during rainy days. We might have to construct a water supply on the roof to create enough pressure.

Implementation and Results of the Research

Theoretical Implementation and Results

1. In which way can we use Rainwater to generate electricity

1.1.1 What is the maximum amount of energy we can produce using a turbine in a drainpipe?

Because of the enormous height, the potential energy in one single raindrop is really high. We want to use this potential energy for, for example, creating an electric flow. We will transform the potential energy in height into kinetic energy using for example a water wheel. The kinetic energy can be transformed into electric energy, which we can use to illuminate a light bulb. The potential height energy can be calculated by using the height, the gravitation and the mass of the object. $E_z = \Delta h \cdot g \cdot m$ In this situation we are looking at a roof of $10 m^2$, which is 3 meters in height. We constructed our system, or water wheel, in the drainpipe at about 1 meter above the ground. The average rainfall in the Netherlands is 28 mm per month. When we are looking at this case, the roof will, when there is no drainage, contain an amount of water for a month's worth of rain. The volume of water will then be $28mm \cdot 10\,m^2 = 280\,l$. The mass of 280 litres of water is 280 kg. This is calculated by using the density of water, which is 1. Then we calculate the potential energy in height: $E_z = \Delta h \cdot g \cdot m \rightarrow E_z = 2 \cdot 9{,}8118 \cdot 280 \rightarrow E_z = 5494{,}608\ J$. So this is the potential energy of height which the water contains in one month.

Studies from the university of Twente points out that the efficiency of turbines in small scale water-electric systems is on average not higher than 50%. The efficiency of a bike dynamo, which we will use in our experiment, is around 25%.

So in conclusion we can use our rainwater for electricity. If we stick to our case we can calculate the amount of energy: $E_{total} = \eta_{dynamo} \cdot \eta_{LED} \cdot E_{potential} = 0{,}25 \cdot 0{,}66 \cdot 5494{,}608 = 906{,}610\,J$. In another case, this number may rise due to a larger building or a bigger surface. Something that is important to keep in mind is that in this case, we discuss the average rainfall per month, collecting this, and then afterwards, draining everything at once.

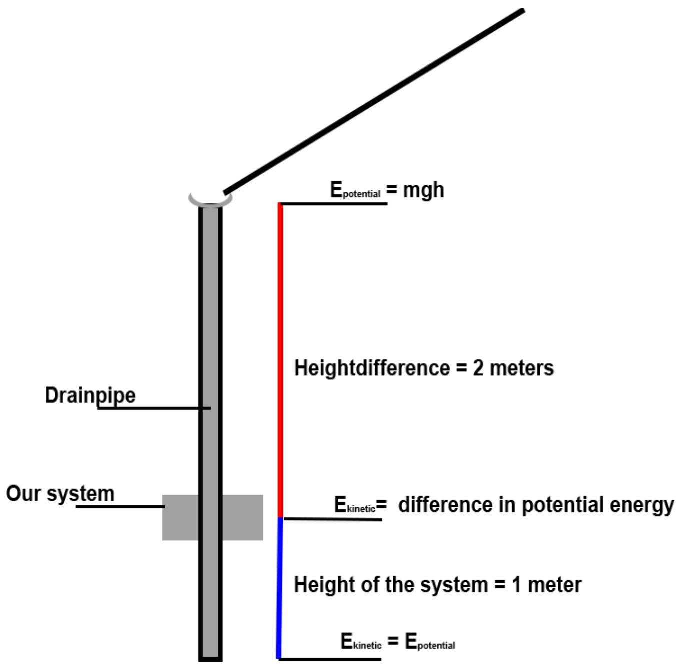

Figure 1: Calculations of the energy produced in our system.

In our experiment, we want to illuminate our LED with U = 2,0 volt and I = 20 mA. This means our power is $P = U \cdot I = 2 \cdot 0{,}020 = 0{,}04\ W$. We calculate the time in which we want our 280 litres of water to flow through the system. This can be calculated with a formula: $t = \frac{E}{P}$. We know the amount of Joules which flows through the LED, and we know our LED can maintain 0,04 watt. $t = \frac{906{,}610}{0{,}04}$ so this gives us: $t \approx 22665{,}25\ s$. In conclusion, the 280 litres of water has to fall through the drainpipe in 23000 seconds. If this is the case, our LED will illuminate the given time.

Furthermore, we are going to calculate the maximum power we can get by letting water drop in a turbine. The formula we use is $P = \rho \cdot \eta \cdot g \cdot \Delta h \cdot \upsilon$. In this formula, ρ is the density of water (1,0 kg/L), η the turbine efficiency, we will get back on that, g the gravitation in Tilburg (9,8118), h the height in meters (2,0) and υ the flow rate. For the efficiency of the turbine we take 50%. The flow rate is $\upsilon = \frac{V}{t} = \frac{280}{22665{,}25} \approx 0{,}0124\ l/s$. We can now easily calculate the formula: $P = 1 \cdot 0{,}50 \cdot 9{,}8118 \cdot 2 \cdot 0{,}0124 \approx 0{,}0122\ W$.

If we take a turbine efficiency of 25%, it seems to look like we can illuminate our LED for $0{,}25 \cdot 22665{,}25 \approx 5666{,}3$ seconds. So we could enjoy 5666,3 seconds of light in a month.

We would also like to calculate the speed of the water column. This is possible by firstly calculating the surface of our drainpipe. Our drainpipe has a diameter of 7 cm. The surface of the drainpipe is: $r^2 \cdot \pi$. So, $Surface = 3{,}5^2 \cdot \pi \approx 38{,}485\ cm^2$. The flow rate is $12{,}2\ cm^3/s$. we now divide the flow rate by the surface of the drainpipe. This brings us $\frac{12{,}2}{38{,}485} \approx 0{,}317\ cm/s$. This means our water column falls with approximately 0,317 cm per second.

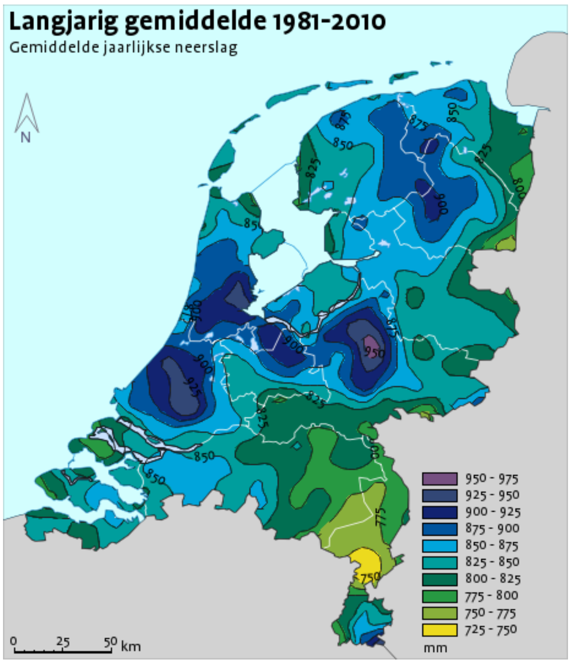

**Figure 2: The average rainfall in the Netherlands.*

Magnitude	Unit	Amount
Potential energy (E_z)	Joules (J)	5494,608
Height difference (Δh)	Metres (m)	2,0
Gravitational constant (g)	Metre / second squared (m/s^2)	9,8118
Mass (m)	Kilograms (kg)	280
Surface (A)	Metre squared (m^2)	0,003845
Volume (V)	Litres (l)	280
Voltage (U)	Volt (V)	2,0
Power (P)	Watt (W)	0,040
Time (t)	Second (s)	22.665,25
Amperage (I)	Ampere (A)	0,020
Density (ρ)	Kilogram / litre (kg / l)	1,00
Turbine efficiency (η)	Percentage (%)	25
LED-efficiency (η)	Percentage (%)	66
Flow rate (υ)	Litre / second (l / s)	0,0124
Radius (r)	Metre (m)	0,035

**Table 1: Glossary of scientific symbols and standards.*

1.1.2 What is the most practical way to maintain 280 litres of water on a roof for a longer period of time?

The first idea that comes to mind is a major collection tank on the roof. The tank would empty its water when the month is over. However, time cannot be the qualification for opening the drain pipe.
The first issue we have to deal with is how to regulate the flow of water during a period of time. The amount of water needs to be the qualification. Which means that we have to install a device that reads the amount of water on the roof. So first we will have to build a container on top of the roof. A container with the exact same surface as the roof it will be installed on. The second thing we will have to do is to make an electric device that sends a signal to a gate in the drainpipe which will make it accessible to water. In conclusion, there needs to be a device which constantly measures the amount of water on the roof.
This could be done using a kind of pressure plate which we could install on the roof. This device will measure the weight on top of it, and if the weight of 280 litres is reached it will send the signal to open the drainpipe.
Another option is to install a device which measures the height reached in the tank. When the water reaches the height of 280 litres, it will send an electric signal to the port at the drainpipe which will allow water to flow through the drainpipe.
A manual system would be possible too, in fact it would even be the simplest solution to this problem. However, it will take a person to go outside and pull the switch every time he thinks the roof is full of water.
The second issue we will have to take care of is the construction. If we store 280 litres on a roof of an old shed, it will most likely collapse under the weight. The weight of 280 litres of water is 280 kilograms. This means that our roof will have to be able to support 280 kilograms plus the amount of weight the roof itself weighs and the tank. If we use an aluminum tank of 5 meters by 2 meters, (which gives us the $10m^2 \text{litre}$) and we use a thickness for the walls of around 2 centimeters, we can calculate the weight of the aluminium container. $m = v \cdot \rho \rightarrow m = v \cdot 2{,}70$. For the volume of the tank we calculated $0{,}207795\, m^3$. So the mass of this object will contain: $m = 0{,}207795 \cdot 2{,}70 \rightarrow m \approx 0{,}5610465\, kg$. Which will make our tank weigh half a kilogram. So the total weight increase on the roof will be the tank plus the water. $280 + 0{,}561 = 280{,}561\, kg$. This is a lot of weight on our small building.

An average building will be able to support up to 30 kg per m^2 more than it normally holds. Our roof consists of $10m^2$. Which means we could add a maximum of 300 kilograms. The total weight of our tank plus the water is 280,561 kilograms. It will be near the maximum weight, making it a dangerous wager, but it should be possible to install the tank on top of our building.

1.2 How can a UV-system help us to produce (more) energy?

First of all, what is a UV-system? A UV-system is a pressure-based system that makes the water in a drainpipe flow faster. It is a relatively new system and not that well known. The system can be built in a drainpipe and will allow air to get out of the drainpipe. The pressure in the drainpipe will decrease and the demand of water will increase. As a result, the flow of water will increase through the drainpipe. This also works for horizontal drainpipes or gutters. In this way it is possible to regulate the point of drainage. The figures show what is stated. Horizontal drainpipes usually do not flow fast enough or not at all. This system provides a low pressure, making sure water flows constantly, even in horizontal drainpipes.

When we are able to regulate at which point the water will be transported away from the roof, we can build our system in this particular drainpipe and make sure all the water will flow through our water-energy system.

- The system depends on air pressure and this means that it does not rely on the irregular flow of water during a downpour, so the energy it gains because of the pull of the air pressure is added to the potential energy. The speed of the flowing water will be constant and putting our generator in it will create a power source that delivers its energy in a continuous and regular way. The total energy at the point at which the generator is installed could be defined as $E_{kin} + E_{potential\,2} = E_{potential\,1} + E_{air\,pressure}$, according to the law of conservation of energy. Defining $E_{air\,pressure}$ as $W = Fs$ with $F = pA$, $p = \rho gh$ and together $E_{air\,pressure} = \rho ghAs$. Knowing that the kinetical energy of the water is the only useful energy in the water the formula becomes $E_{kin} = E_{potential\,1} - E_{potential\,2} + E_{air\,pressure}$. This can also be written as $E_{kin} = \Delta E_{potential} + E_{air\,pressure}$. This converts into formulas as: $E_{total} = mg\Delta h + \rho g\Delta hAs$. Mass m = 280 kg, just like in §1.1, gravitational speed g= 9,8118 m/s^2, density ρ= 1,0 kg/L, surface A = πr^2 = $3{,}5^2 \cdot \pi \approx 38{,}485\, cm^2 = 0{,}0038485\, m^2$, the difference in height Δh = 2,0 meters, and the distance between the two points s = 2,0 meters. The energy stored in the water at the moment it hits the turbine in the system should be the same as the energy stored in the water at the point it gets into the drain. This gives that the total energy in the water is equal to $E_{total} = mgh + \rho ghAs = 280 \cdot 9{,}8118 \cdot 2{,}0 + 1{,}0 \cdot 9{,}8118 \cdot 2{,}0 \cdot 0{,}0038485 \cdot 2{,}0 = 5494{,}759\, J$.The amount of energy the UV-system produces is negligible and taking the effectivity of the turbine in account it will produce about the same amount of energy as a regular drain with our system.

Furthermore, using the UV-system enables us to use drainpipes with a smaller diameter. This is also convenient because of the limited drainpipe we have in the system. A UV-system will help us make a more convenient drainage system. It will definitely be a beneficial system to our project.

2. Is it possible to transform rainwater into drinking-water in a domestic environment?

Changing rainwater into drinkable water is usually done by letting the water flow through the drainage system towards a water treatment plant. In the past, the water was added to the sewage system, but nowadays it is required that the water is transported separately. Rainwater is in comparison with sewage very clean and only needs little treatment. Transported together would mean that the rainwater is being polluted unnecessarily. This is not an efficient way of cleaning the water, because the sewage will get diluted and it will be harder to purify it.

Rainwater is quite pure and with little treatment it can become drinkable water, as long as it is filtered from any kind of dirt. This can be done by collecting all the water in a tank and letting all the dirt sink to the bottom of the tank. The negative effect of this method is that while the bigger particles of dirt are sinking, water can not be added. Another problem that occurs when we use this method is that bacteria will be able to multiply easily. Concluding, it would be easier when the dirt is filtered while the water is still in the drainpipe. However, this will bring some problems as well. The filter will have to be replaced once in a while, otherwise the flow of water can be obstructed.

One of these purification methods which is good for the environment is filtering the water with UV-light. UV-light kills most of the bacteria that can do harm to a human being, the percentage being 99,9. If we used the energy created in our generator described in 1.1 and filter the water with UV-light, we would be using a downpour in the most efficient way possible. The water can be filtered to be used as water for showering, flushing toilets or it can be used as drinking water.

Having purified the water with UV-light, how clean is it actually? Ultraviolet light purifies the water by affecting the DNA of bacteria and microorganisms. This makes the organisms incapable of reproducing or infecting other cells. The ultraviolet light is also dangerous for people, as it causes skin burns. However, this will only become dangerous in large doses and long term exposure. In that case it can cause skin cancer. The purification of water with ultraviolet light does have a few advantages. One of these advantages is that there is no need to add chemicals to the water for cleaning purposes. Another advantage is that ultraviolet light does not affect the colour and taste of the water. Many organisations and individuals make use of this system, particularly in the United States of America. Keeping the safety aspect in mind, this system is a safe way to kill pathogens. In conclusion, this system seems to be perfect for our domestic water treatment plant.

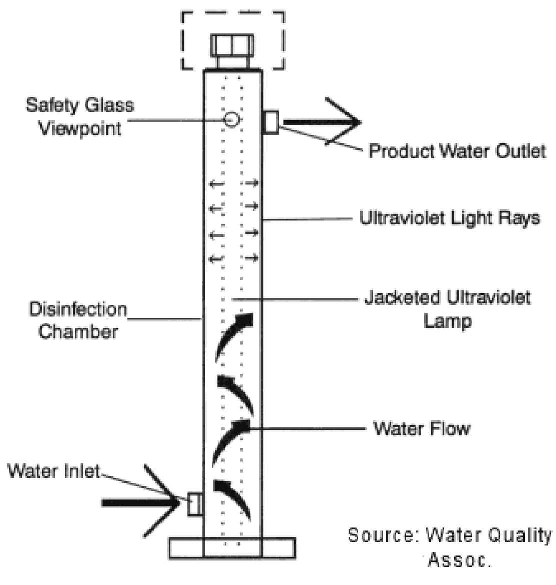

**Figure 5: The UV-filter: Functions of a UV-filter.*

However, this system does have some problems we have to keep in mind. To create UV-light with the right dose and intensity, a UV-lamp is necessary. To power this lightbulb throughout the day, the amount of energy needed would be enormous. A solution to this problem could be installing an electrical circuit which only powers the bulb if the hatch on top of the drain is opened. This means that as long as the water flows and the UV-light passes, the light will be on. This would be a solution, but this means that only the water that has been used to generate energy could be purified. It would be more efficient if we could purify all the water which pours down on our lot and eventually reuse it as rinse water.

Another problem with radiating the water with UV-light is the quality of the water. UV-light kills the microorganisms, but some inorganic substances will still be in the water. Research from the TU/e from 2001 has shown that rainwater is drinkable when you catch it. The only statistic that was above the set Dutch average was the ammonium concentration. The storage of rainwater causes the bacteria and the other pathogens to reproduce. The main problem to solve is the ammonium concentration. Ammonium filters do exist, but they are primarily made for the cleaning of ponds. These filters are only useful at very high ammonium concentrations. There is not a lot of information about these kinds of filters. So we do not think it is very trustworthy. Another method of clearing the ammonium from the water is by letting it pass through alges. Plants need a lot of nitrates for their growth and they will collect the NH4+. However, there might be an extra step needed in which nitrogen bacteria convert NH4+ into nitrates.

Another way to extract the ammonium out of the water is to add nitrifying bacteria and denitrifying bacteria. These bacteria are part of the nitrogen cycle. Nitrifying bacteria convert ammonium into nitrite and nitrate, the denitrifying bacteria convert the nitrate into nitrogen gas. Converting ammonium into nitrite and nitrite into nitrate is an aerobic process, air is necessary to get the reaction going. Oxygenating water is a very energy inefficient process in large water treatment plants. The water which comes through the drain is already well oxygenated because of the irregular waterflow. The nitrifying bacteria could convert the ammonium into nitrate in the drain. Unfortunately, this process is very slow and the use of a water storage is necessary to completely convert the ammonium into nitrate. However, the denitrifying bacteria work in an anaerobic environment, they only work in an environment without air. If we create another water storage underneath the first water storage, we could create an anaerobic environment. This would cause the bacteria to work. The next problem would be the drainage of the nitrogen gas. A separate drain for the nitrogen would make it possible to let the gas out. The water which comes out of the last tank does still have the bacteria in it, but filtering the water with the UV-light should kill them. This means that the UV-light treatment should happen after clearing the water of the ammonium. The tanks for the water storage do need to have the capacity to store enough rainwater to get the bacteria working.

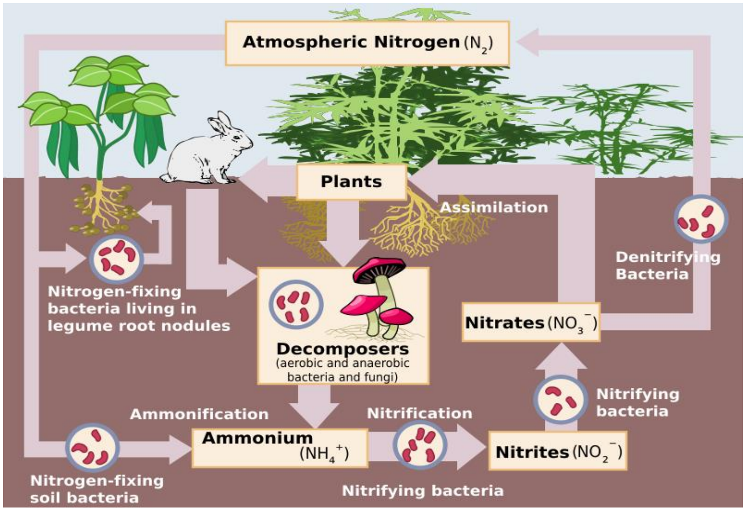

**Figure 6: The chain of the Nitrogen compound.*

3. In what ways can we reuse water within our household?

3.1 What are the different kinds of wastewater within our household?

A single household produces a lot of wastewater, which can be divided into two categories. The first category is blackwater which is typically created by toilets and can contain faeces and urine. The second category is less polluted water named ‘greywater’, this water can contain traces of dirt, food, grease, hair, household cleaning products and other materials that typically go down the drain. For instance, when taking a shower, we produce a grave over-abundance of water. Therefore this water should be recycled and used again. Recycling water is important for the environment and will lower the yearly costs of the individual’s water bill.

There are multiple reasons to reuse used water. When living in a dry country, a person might have to be careful with how much water they consume. With a filtration system this problem would be solved. Filtering your own chemicals out of the water will reduce the impact they have on the environment. Finally, lowering the amount of water an individual uses in total is a great way to save some money.

3.2 What are the best options to reuse this water?

When trying to recycle this “greywater” there are a few different options. We are going to create an overview of these options and look at two different main criteria. How clean can we get the water with that specific kind of filter and is it affordable to do so? Furthermore, we have to take into account that we can only use filters that are small enough to be build in a normal household.

The principle of a greywater system is as follows: Bathing water, wastewater from the washing machine and the shower are examples of greywater. The wastewater coming from, for example, the toilet is absolutely not greywater. This water is extremely polluted and therefore does not qualify anymore for being reused. Therefore, this kind of water is called “blackwater”. Greywater and blackwater are separately collected. In contrast to the blackwater, the greywater is stored in a large

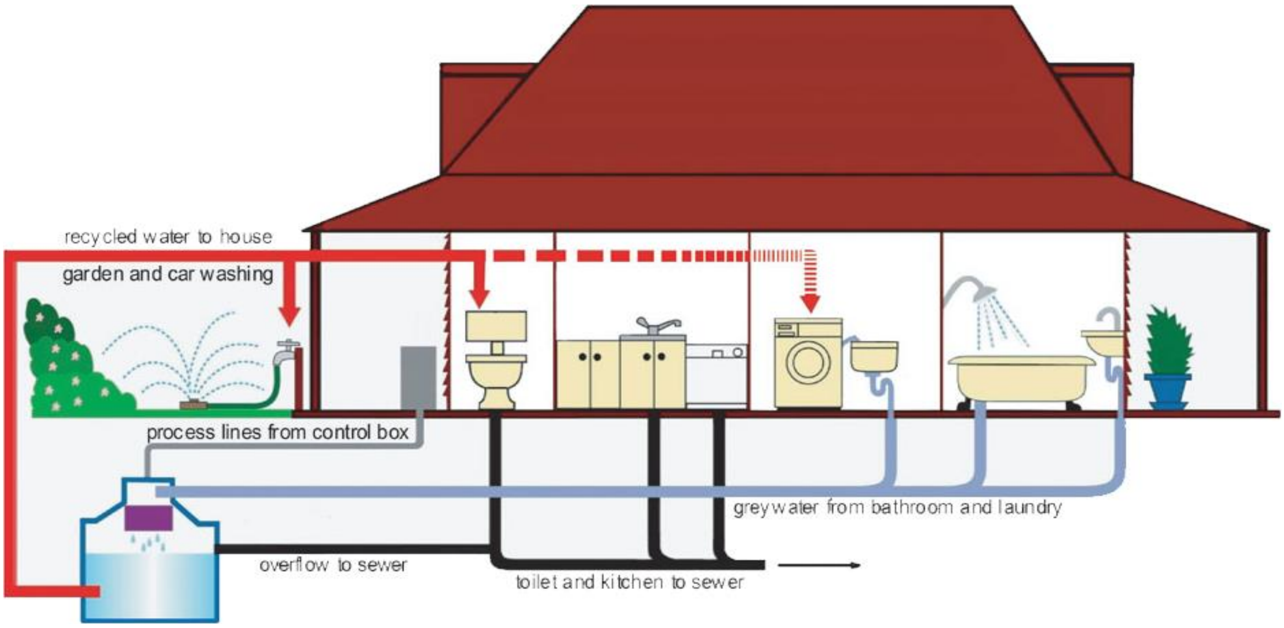

**Figure 7: Waterflow in a household. Possible waterflow of reusable water.*

tank which can be hidden under the house. When there is too much greywater this water will be forwarded to the sewers along with the blackwater. In this tank the greywater will not be stored for longer than 24 hours because after a day the oxygen is resolved from the water and without the oxygen anaerobic bacteria will have the opportunity to multiply. These anaerobic bacteria will pollute the water and a nasty smell will arise. In case there is no other opportunity but to store the water for more than 24 hours, a disinfectant can be used, for example, chloride.

The stored water from this tank will be filtered and there are different filters that can be used for performing this task. The filtered water is, after this process, ready to be reused within the household. Depending on the filter the water is cleaned to a certain degree though drinkable water is rarely achieved. Therefore, the best way to reuse this water is to water the garden and flush the toilet. If the water is clean enough, it can again be used in the washing machine and with the appropriate filter, it might even be reused as drinkable water.

After having collected the water in the tank in the filtering stage, there are two kinds of systems. The two categories are mechanical systems and organic systems. A prime example of an organic filter is a helophyte filter and a prime example for the mechanical system is the earlier discussed UV-filter or a sandfiltersystem.

Organic Filter

In the Netherlands there are houses that have these kinds of greywater filter systems, the most-used system in the Netherlands is the helophyte filter. A helophyte filter is also known as a “swamp filter”, as this structure filters the water using helophytes. A helophyte is a kind of plant which is exceedingly good at living in symbiosis with bacteria that are needed for this process.

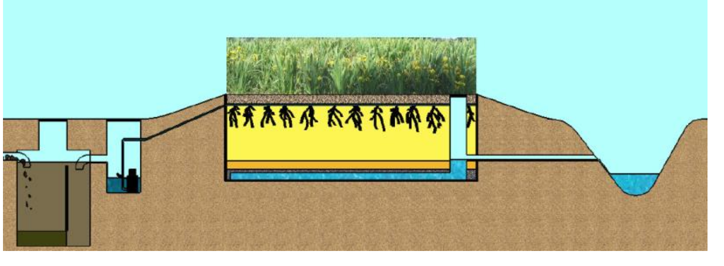

**Figure 8: A helophytes filter.*

There are three kinds helophyte filter: the sewage farm, the horizontally through flowing helophyte filter and the vertical flow through filter. The principle in these three systems is more or less the same but it will be explained using the vertical filter as an example of this is the most-used system in the Netherlands.

The top layer of the helophyte filter consist of a layer of gravel, beneath which there is a layer of sand of 1 meter. The helophytes are placed on top of the gravel with their roots running deep into the sand. Water is spread over the top layer multiple times a day. The bacteria that are able to live there because they can live in symbiosis with the helophytes, filter the water. Deeper into the layer of sand it can be noticed that there is less oxygen present. Denitrifying bacteria solve this problem by releasing oxygen from molecules in the lower level of the sand. In some systems this is not enough and to solve this problem there is the option to pump additional oxygen into the system. After this process, the filtered water leaks into a tank beneath the system, and as a result the water is than much cleaner and is separated from about 99% of its pollution.

The main advantage of this system is that it uses about 1/10 of the energy used by a normal (mechanical) system. Additionally, this system barely needs maintenance, with no maintenance the efficiency of this will only decrease after two years.

A second organic filter system is the slow sand filter, which relates closely to the helophyte filter and makes use, just like the helophyte filter, of the biomass built up within the system. In contrast to the helophyte filter this sandfilter relies heavily on the filtering that happens when the water flows through the fine sand. When the greywater sinks through the sand under influence of gravity the bigger particles will get stuck between the grains of sand. The size of these grains of sand varies from about 0,1mm to about 1,0mm. In figure 9 you can see why this does not only mean that particle between 0,1mm and larger will get stuck, the small grains of sand have even smaller openings between them. The most polluting particles cannot flow through these small openings whereas water can.

Within the sand filter there are three layers: fine sand, coarse sand and gravel. The fine sand builds up the top layer, this gradually changes to coarse sand and transitions into gravel making up the final and bottom layer. This gradual decrease in particle size is done so that the fine sand will not be taken into the drain along with the water. The fine sand does most of the filtering, after this first filtering the coarse sand and gravel will make sure no sand will come into the cleaned water. Just like the helophyte filter, this system barely uses energy. In fact, no energy needs to be added externally, not taking into account the energy that might be used for pumping the water. In contrast to the helophyte filter, this filter is an easy to make at home system.

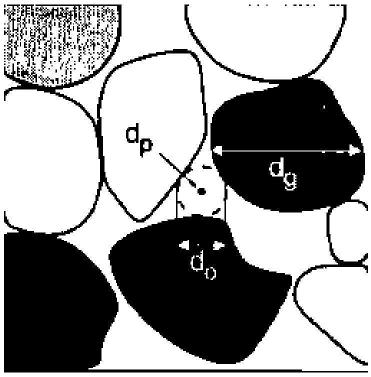

Figure 9: The picture shows how the holes between two sand particles can even be smaller than the diameter of the particle.

Unfortunately, this system has too many disadvantages. The first disadvantage is that it needs a relatively high maintenance. Because the sand filters out the filth, this filth becomes stuck in the sand, therefore, after a while, the sand needs to be replaced. Luckily, this is not hard to do, just remove the top layer and refill the filter with cheap fine sand. The second disadvantage is the low waterflow ($v = \frac{V}{t}$ in: $L\,s^{-1}$), in itself this does not need to be a big issue as biomass has time to develop which improves the quality of the final water. However, this biomass needs to be balanced and a constant flow of water is vital. So when using this system the individual has to constantly flow water through the system.

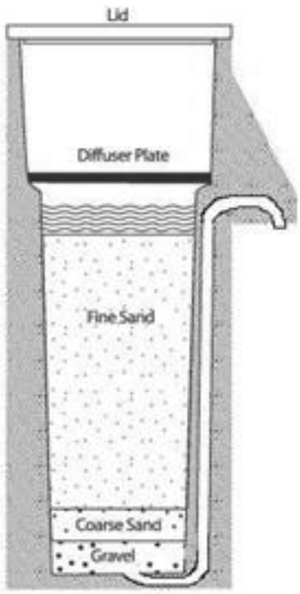

Figure 10: An example of a sand filter.

A third, relatively unknown, kind of filter is the lava filter. This system is based on micro-organisms growing on the lava pebbles. On these pebbles will, as a result, grow a kind of bio membrane, which is an optimal environment for denitrifying bacteria. These bacteria can easily multiply in this environment. The bacteria are aerobic and because of this, the system needs to contain enough oxygen, which is hard accomplish considering these stones will be placed underwater. NH_4^+(ammonium), NO_2^- (nitrite) and some other chemicals are removed in this filter. These lava pebbles are often placed in a pond to keep it clean. However, this filter is extremely slow and is not optimal in a lot of ways, although it would connect extremely well to the problem stated in the second sub-question because this filter can filter out ammonium. This cannot be done by the UV-light filter which is discussed in sub-question 2.

Mechanical Filtersystems

In addition to these organic filters there are also mechanical filtersystems. Defining characteristics for a mechanical system are that these systems use more energy, do not make use of biomass to purify the water and have a higher waterflow ($L\,s^{-1}$). However, these systems will assumably be a lot less affordable because of their much higher price range. Mechanical systems are the kind of systems that are used in official water treatment plants, which means it will not be better for the environment than normal and it will cost a lot of money to install these kinds of systems on such a small scale.

There are a few options we have when choosing mechanical filters as the way to go. The earlier-discussed UV-filter is a widely used mechanical filter. The main advantage of the UV-filter is that it purifies water in such a way that it is actually drinkable. However, this filters uses a lot of energy which we are trying to prevent, because we want to create a household that is sustainable. Therefore, we should not try to filter water at the cost of using more energy. Another option might be the fast sand filter. In contrast to the organic slow sand filter, this is a mechanical filter. This filter uses the same principle as the slow sand filter with the exception of the biomass that is used to purify the water. The water in a quick sand filter is also filtered exploiting the property of the pollution being bigger than the water itself. Because the quick sand filter cannot make use of the biomass, another solution to compensate this problem needs to be found. By using specific property of really small sand grains, this problem can be solved. In extremely fine sand 'van der Waals' force can be used to make the filth stick to the tiny sand grains. The result of this small force is adhesion, even the molecular salts will stick to the grains and are filtered out. In this system the water is hardly transported by using gravity, instead, water is in a closed room under extreme pressure which presses the greywater through the sand. As a result, purification can be done within minutes.

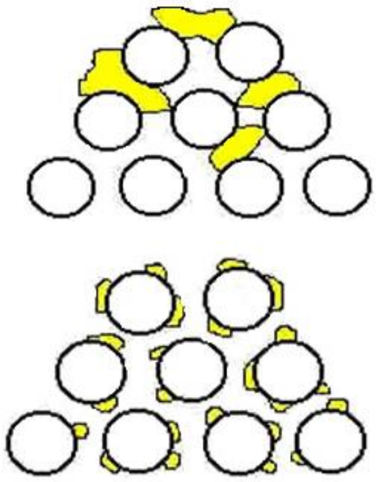

**Figure 11: A picture of the method of filtering using a mechanical filter.*

Although this system cleans the water thoroughly, it does not produce drinkable water. Drinkable water can only be produced in this system if there is an extensive prefiltering at the beginning and a second disinfection stage at the end. This has to be done because this system lacks the power of biomass, which cannot arise in these conditions. Therefore this system is a lot more vulnerable to harmful bacteria, viruses, organic matter and even some additional salts.

To sum up, the next page shows a table. This table displays the different options we have discussed and which might be suitable to use in a modern house.

Filter \ Abilities	Clean Water	Drinkable Water	Mainte-nance	Bio-mass	Energy Useage**	Time
UV - filter	✓	✓	+	x	--	++
Helophyte filter	✓	✓	+	✓	+	-
Slow sand filter	✓	✓	-	✓	+	-
Lava filter	✓	x	++	✓	++	--
Quick sand filter	✓	x	-	x	-	++

** Table 2: When a '✓" is used the water is drinkable and satisfies the requirements for drinkable water in the Netherlands*

*** A lower energy usage results in a better score*

3.3 How much could we save up on water?

After looking at how a greywater system works and which options we have to make such a system efficient, we have to look at whether we can use this system to save on costs. On average, a single person spends €9,75 monthly on water usage. This means €117,- per year. If we could make a system with which we could use our water a second time, this will mean a cost reduction of half the price, so a saving of €58,50 annually. In a household with 5 people, this would mean a saving of nearly €300,- per year. For this, we will have to use some fixtures. (All these averages are Dutch averages.)

Average annual water consumption per household:	*182 m^3 (182000 L)*
Average costs water (per litre):	*€ 0,0015 (1 cent ~ 7 litre)*
Total water consumption per person (per day)	*119L*

<u>Amenities (average per day per person):</u>

Shower	51,17 L
Bath	2,38 L
Sink	4,76 L
Toilet flush	33,32 L
Washing machine	14,28 L
Dishwashing (hand)	3,57 L
Dishwasher	2,38 L
Additional Kitchen water	3,57 L
Drinking water	1,4 L

The greywater is the water which comes out of the shower, the bath, the sink, the washing machine and the kitchen. If this water consumption is added up, it will come down to: (51,7 + 2,38 + 4,76 + 14,28 + 3,57 + 2,38 + 3,57 =) 82,11L per day, in an average household of five people this comes down to 410,55 L per day. Annually, this would be 150 m^3 of water with a cost of €224,80 of greywater. The rainwater can be added to the greywater, which has a volume of 280 L monthly, which means 9,0 L (with a roof surface of 10m^2) added to the water which can be reused on a daily base. The average roof surface is 60m^2, according to the Ministry of VROM, this could add up to 54 L daily with a maximum collection.

Out of the numbers we can conclude that drinking tap water is just a small percentage of the daily water consumption, which is 1,04 L. When one takes a bath or a shower, or uses the washing machine, the water does not have to be drinkable, but a purification level of 99% would be enough. This does not meet the Dutch standards for drinkable water. With flushing the toilet, the second biggest water consumer, the water also does not have to be drinkable. This is convenient, as none of our filter systems can purify up to Dutch standards for drinkable water. The numbers show us that a regular person uses around 119 L on a daily base, 82,11 L of this is eventually reusable in an optimal system. If we add up the volume where the greywater can be reused it will be 119 L - 1,4 L = 117,6 L, because the greywater cannot be used as drinkable water. Knowing that the water cannot be filtered forever, because some of the dangerous substances which cannot be filtered will grow in concentration, the water can only be reused a few times. When new greywater gets into the system, the purification percentage of the water would be 99%. If this greywater is used again and refiltered, the percentage of the pollution will be doubled from 1% to 2%. This will lower the purification percentage of the water to 98%. The purification percentage may not go lower than 98%, as this might cause it to become dangerous. Therefore we state that greywater may only be used twice in the system. This results in the next scheme (the scheme is on a daily basis, because greywater can only be kept in a tank for 24 hours):

Day 1: 119L (tap water, TW) gets in the system → resulted in 82 litres (greywater, GW)

Day 2: 82L (GW1, first time) + 37L (TW) → total 119 litres

Day 3: 82L (GW2, second time) +37L (TW) → total 119 litres

The greywater from day 1 is now totally used, the system has to be refilled.

Day 4: The calculations start again: 119L (tapwater, TW) gets in the system → resulting in 82 litres (greywater ,GW)

Etc.

**37L is the amount of water which is added into the system to get the total amount of 119L we use per day. (119L - 82L = 37L)*

In this system, a consistent saving of 2 times 82 litres in three days can be seen, with a total usage of 357 litres. This is: $Savings\ Percentage = (164L\ /\ 357\ L) * 100\% = 46\%$. So by using this greywater system we could possibly save 46% of our water usage. 46% means a yearly cost per person of €63,18. In a household of 5 people, this means that $5 * €53{,}82 = €269.10$ can be saved.

Implementation and Results of the Research

Practical Implementation and Results

1. Is it possible to produce energy from rainwater?

1.1 How can we use a turbine to make electricity?

Generating energy with water can be done in a few ways, with chemical reactions or with a turbine. The turbine seemed a more logical solution to us, because chemical reactions need the minerals in water, but their density is very low, especially in rainwater. The turbine takes the kinetical energy and the generator converts it into electrical energy.

There are a few options in installing a turbine in a drainpipe. The factors we need to take into account are the output of the turbine; the cost to produce it; it has to be easy in use, and replacing broken parts should not be expensive or difficult. Having these factors in mind, we have come up with a turbine installed into the drainpipe at about the height of 1 meters above the ground, to make certain that it is accessible, and we connected the turbine with a bike dynamo to generate the energy. A turbine is a big wheel that will turn under the force of water. Consequently, this movement is converted into electricity using magnetic flux, which is the principle of a dynamo. In our setup we will use a dynamo to convert the water flow into electricity. Being students, we have limited resources so we have to use a bicycle dynamo to convert this flow in our setup. Sadly, the bicycle dynamo has a few disadvantages, the main concern is that the dynamo has a resistance which is much too high and not at all suitable for the experiment that we tried to perform.

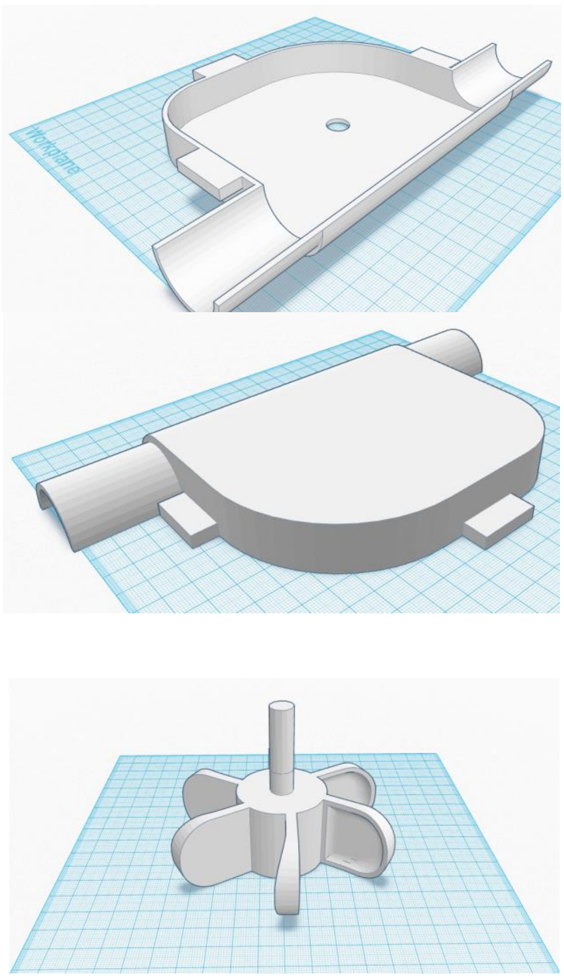

**Figure 12: Pictures of the 3D-models we used in our research.*

1.2 How do we construct a reliable setup?

To start with, we had to get our hands on a 3d model that would be suitable for what we were trying to accomplish, so what we needed is a casing with a spinning wheel within, which will be rotated by the flow of water. We also had to be able to connect this wheel to our dynamo outside the casing.

A 3d model is suitable for this experiment, because if this idea is manufactured in the future, a simple model like this will be an easy form of production. A great advantage of 3d printing is that the model can be created exactly in the fashion the individual would like it to be. For instance, we want a longer axis in the middle of the wheel so we can have a better connection between the wheel and the dynamo. This is why we chose to use 3d printing for our project. Our model consisted of three parts, two of which are the casing, and the main part, of course, is the waterwheel. The parts are displayed in the pictures on the right. The printing of all these parts took approximately 9 hours in total using a 3d printer. This might seem long but it is well worth it when looking at the results. The material was solid and it all fitted perfectly.

The next step was assembling these parts. Because it is risky to use screws on plastic material, we put the material together using duct tape. This tape had to be extremely tightly fitted or the model would not have been watertight. The dynamo had to be connected to the axis outside the casing, and again we used duct tape. This setup worked but was not stable so we built a wooden structure to support this setup. This structure is shown in the picture below. Alongside this photo there is a QR code which you can scan to watch a video in which the setup is working to power a led light. As you can see, there are wires connected to the dynamo, which in turn lead to a led which lights up when the wheel is turned.

By scanning this QR code with your phone you will be brought to a video in which we demonstrate our setup.

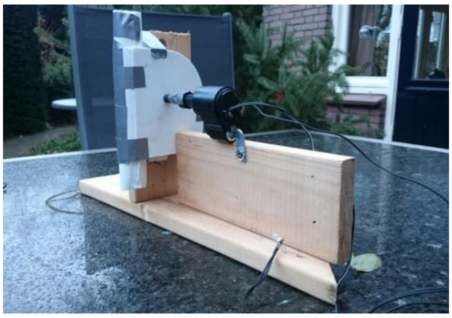

**Figure 13: A photo of our prototype.*

1.3 How much energy can we produce in this setup?

For collecting our data we used a timer, a voltage and current meter. We used the timer to measure the flow in our system, we tested four times how much time it took for the water to flow through our system and fill a bucket of 10L, then we took the average time it took. We are going to use this time as our final result.

Measuring the voltage and current was a more difficult task. To measure the voltage, we had to install our voltage meter in parallel in our enclosed system. You can see this in the sketch on the right.

We also did an Ampère measurement and for this measurement we had to place the meter and LED-light in series. Again, we made a sketch of this situation on the right.

In both situation there is a QR code implied which you can scan, this will bring you to videos in which we perform that specific measurement.

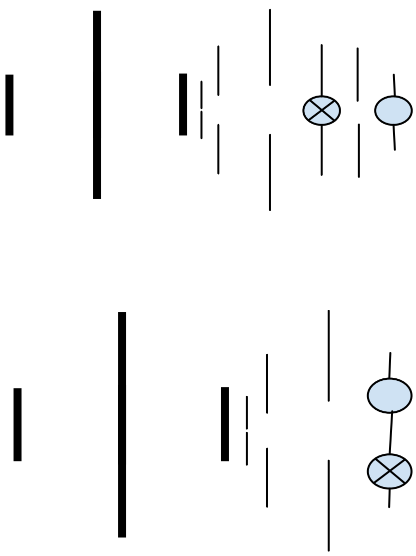

**Figure 14: A drawing of the two set-ups in which we calculated the ampère and the voltage.*

Testing our system has given us the following results:
I = 0,7 mA
U = 0,18 V
d = 2,8 cm
The time 10 litre takes to go through the system: 42,5 s.

The following results can be calculated with the results from the experiment:
r = 1,4 cm
A = 6,15· 10^{-4}

$$\upsilon = \frac{V}{t} = \frac{10}{42,5} = 0,24\ l/s = 0,00024\ m^3/s$$

But $\upsilon = A \cdot v$ so $v = \frac{\upsilon}{A} = \frac{0,00024}{6,15 \cdot 10^{-4}} = 0,39\ m/s$

$$p = \frac{F}{A} = \frac{ma}{A} = \frac{m}{A} \cdot \frac{\Delta v}{\Delta t} = \frac{10}{6,15 \cdot 10^{-4}} \cdot \frac{0,39}{42,5} = 149,2\ Pa$$

This is the pressure necessary for the turbine to let the led-light be a constant source of light. In this case, we can determine what the constant amount of water in the drain should be. The pressure could also be defined as $p = \rho g h$ so the height would be $h = \frac{p}{\varrho g} = \frac{149,2}{1,0 \cdot 9,81} = 15,2\ m$.This is not applicable in a regular household. We could lower the height by giving the drain a funnel shape. The opening towards the system would have the same size, but the opening at the top would be wider. In this way you still have the same mass and the same pressure, according to the law of Bernoulli. This law states that the pressure in different places in an amount of water is constant. This way, we could lower the height of the amount of water in the drain. This should make the system compatible with more regular households.
The power of this system could be defined as $P = UI = 0,18\ \cdot 0,007 = 0,00126\ W$. This is the energy over the LED-lights. The energy created with 10 litres of water would be $E = Pt = 0,00126 \cdot 42,5 = 0,05355\ J$. The energy consumption of the two LEDs is very low, but they have a high output of about 66%. The dynamo has a low output of about 25%. This way we can determine the total potential energy of the water. $E_{\ potential} = 0,05355 \cdot \frac{100}{66} \cdot \frac{100}{25} = 0,325\ J$. This is the potential energy created by letting 10 litres through the turbine. So, for 280 litres the potential energy would be $E = 0,325 \cdot 28 = 9,1\ J$.

1.4 Could we make a system that is profitable when using such a setup?
We could make a system that is profitable when using such a setup, by having a drain filled with at least 15,2 meters of water. The height of the water could change if we change the width of the opening of the pipe and make a funnel in it. With a regular drain diameter of about 7,0 cm, the minimal height of the water should be between 5-10 meters. This is a reasonable height and is applicable in most of the buildings which have at least two stories. The pressure has to be constant, so in tropical climates this system could be very useful during the rain season, because of the huge downpour. In dry climates this system will not be profitable. The system would be the most profitable in large buildings for industrial purposes or big offices, because most of them have a great surface of roof and have multiple stories.

Conclusion

1. In which way can we use rainwater to generate electricity?

1.1 What is the maximum amount of energy we can produce using a turbine in a drainpipe?

We have seen in our calculations that with a month's worth of rain water, we can illuminate our LED for more than 6 hours. This is possibly not the *maximum* amount of rainwater. If we had a better turbine with a higher efficiency, the amount of water might be higher. We calculated the maximum amount of rainwater which will become available if we used the situation we sketched in 1.1. This means that in other circumstances, for example, a higher building with a larger surface, the maximum energy conducted from the water could be higher.

1.1.2 What is the most practical way to maintain 280 litres of water on a roof for a longer period of time?

We concluded that storing approximately 280 litres of water on a roof is to contain it in a tank. We used an aluminium tank because aluminium has a low density and is not expensive, and still remains a strong element. We found out that using this method of storing, we would be able to store our 280 litres of water on the roof of 10 square meters.

1.2 How can we use a UV-system to help us produce (more) energy?

We found that a UV-system could not help us produce more energy out of our system. The difference will only depend on the pressure the column of water above our drain produces. This pressure is so low that the difference in energy will be neglectable. However, this UV-system will be helpful in regulating the drainage system. With a UV-system we will be able to position our system perfectly and make sure all the rainwater goes through our intended pipe. This is demonstrated in the two pictures used in 1.2.

2. Is it possible to transform rainwater into drinking-water in a domestic environment?

It is possible to produce your own drinking-water out of rainwater in a domestic environment. However, this will also produce a lot of problems. Every filtering system has a negative side and neither one has potential to, by itself, help us create drinking-water easily. We think that using UV-light to purify water is a great idea. However, it seems that using a UV-light purifier only kills organisms and does not remove elements or dirt from the water. To get rid of the high percentage of ammonia, we could use an ammonia-filter. However, these filters are perhaps not reliable when it comes to relatively small doses of ammonia. To really purify our water at home, we may need a combination of both a UV-light system and a filter to really make drinkable water.

3. In what ways can we reuse water within our household?

3.1 What are the different kinds of wastewater within our household?
In our household we have two different kinds of wastewater, the first one is greywater and the second one is blackwater. Greywater is water that has the option to be reused because it has not been as open to contamination as black water. For instance, greywater is the water that comes out of your dishwasher. In contrast, there is also blackwater. Blackwater is highly polluted and might, as an example, come from the toilet.

3.2 What are the best options to reuse this water?
After extensive research we have come down to a short list of different options this list consists of two kinds of systems: mechanical filtration systems and organic filtration systems. When taking a look at the 3.2 sub-question these systems are listed in this table.

Filter \ Abilities	Clean Water	Drinkable Water	Mainte-nance	Bio-mass	Energy Useage**	Time
UV - filter	✓	✓	+	x	--	++
Helophyte filter	✓	✓	+	✓	+	-
Slow sand filter	✓	✓	-	✓	+	-
Lava filter	✓	x	++	✓	++	--
Quick sand filter	✓	x	-	x	-	++

** When a '✓" is used the water is drinkable and satisfies the limit for drinkable water in the Netherlands*

*** A lower energy usage results in a better score*

The benefits and drawbacks are clearly visible, when taking an objective look at the filter that has the most benefits it would be the helophyte filter. When coming to a conclusion, the helophyte filter would be the best system to use. However, this might not always be what one is looking for. If someone is looking for a smaller filter, the slow sand filter is a suitable option. For a quicker filter we would choose the quick sand filter. Although this system uses a lot of energy, the UV-filter is recommended when someone is looking for a quick and fast filter.

3.3 How much could we save up on water?
In our calculation we came to a sum of money that might lead up to about €269.10 annually for a family with 5 people. This might seem like a lot of money, and it will be, but only after the filter has been built. According to a Dutch source, verbouwkosten.com, the costs of a helophyte filter system might add up to about €5.000. With these costs it would take 19 years to earn this investment back. When looking at a mechanical system this would cost even more and the chance of profitability is eliminated. The third option would be a slow sand filter, and this system is profitable. This system is easy to install and everybody can make one right at home. Additionally, this filter has really low maintenance and a small layer of sand might have to be removed once in a while, which is cheap and easy to do. However, this system also has a lot of drawbacks. The biggest disadvantage of this

system is that it can only be used on a small scale, the water flow is really low in this system. This results in a system that can barely be used to take care of the water supply for one person in a household. If someone wanted to upscale this system, it would make it incredibly expensive.

Discussion

We think that our conclusions are reliable and correct. We have been careful with our calculations and conclusions and have taken a bit of a margin in saying what is correct and what is not. There is a difference between numbers we find in our theoretical part and the practical part of the project but those are simple to explain. In our calculations the models were perfect without any friction. This is not the case in the practical part. Moreover our generator did not perform, as we calculated it would. It was a lot harder to produce energy with the generator because it was a low cost, low efficiency bike generator. This explains why the practical part differs from the theoretical part. Furthermore, some calculations might not be very precise for example, the flow rate. We calculated the flow rate, using a stopwatch and a bucket. When the bucket reached the 10L mark, we stopped the stopwatch and wrote down the time. Unfortunately, this might not be precise because this is based on the reaction speed of a person, and this increases the amount of time. Furthermore, the scale we used was a scale on the "praxis" bucket. We do not know for sure if this scale was really accurate.
Something that is noticeable is that our potential energy in the practical part is much lower than the energy we calculated in the theoretical part. This is perhaps caused by the enormous loss by friction and turbine efficiency. This is something we really regret. Another fault that could result in a lower potential energy is the fact that the 3D model is actually not perfectly printed. The two tubes on top and bottom were not printed well, so the pipe that was above the whole system did not connect perfectly. This caused some water to escape between the connecting pipe above the system and the pipe on top of the system. Sadly this made our system less profitable.
We regretted not making a UV-system. It would have been useful to develop a UV-system by ourselves and to use it in the system we build. We chose not to because of limited time and resources.

Hypotheses

1.1 Our hypotheses were partly correct. We are able to generate energy from our 3D-modelled system. The output was, relatively speaking, not huge. However, this system can deliver more energy when used on bigger and higher buildings. As we mentioned in the hypotheses, the system is not always working, not only because of the irregularity of the downpours, but mainly because of a lack of height and too small a surface.
1.2 The UV-system did not help us to make more energy. However, it did solve some problems in logistics as it enabled us to make one collecting point and to let water flow horizontally. Our hypotheses were not correct because the pressure above the drainpipe was so low, it did not make any difference. Had we thought it through properly, we would not have made such a hypotheses.
2. We are eventually able to purify the water at home. However, it will be a whole process and is not realistic to see it happening in the future. Most of all, not every person in the Netherlands will have time nor money to be able to, firstly, filter the water, then purify it with UV-light and lastly filter out the ammonia. This is not a realistic target for people at home. However, it is possible.
3. We have seen that (Dutch) citizens can easily reduce their water usage and save up money by using greywater as toilet water. Another way to reduce water waste is to use the greywater as part of the garden watering.

Suggestions for further research

For further research we could try to find out how turbines work and how we can determine the efficiency of turbines in the world. In our research we used a model which was made by Pim Rutgers. However, Mr. Rutgers is not a scientist on the turbine efficiency and therefore could not possibly have developed a perfect turbine.

Another interesting thing we could further do research into is the cost-benefit analysis. Following our research, people could save up a lot of money. It would be interesting to find out how much money the state and the total population could save per year by using greywater to flush their toilets.

The topic

Kees: “I personally think that the topic we chose was brilliant! I really liked working with the water and the turbine system. The 3D printing part was very convenient as well. I learned to make a 3D model and to adjust it to the situation. It was interesting to cooperate with other developers like Fablab and Leapfrog. I really liked the way we had contact with them and the way they responded. I think I learned a lot of communication skills in that part. Furthermore, I think we learned a lot about energy. We learned that power is not that easily generated and that it costs a lot of money to purify water. I personally wonder more about how to use energy and water in the near future. It is a slight concern that worries most of us but this project made me realise the importance of being sustainable. I hope that in the near future citizens can generate their own green energy by using systems like ours or other nature-born recourses like wind and sun. I hope that one day my children will live in a sustainable world which I helped maintain.”

Niek: “The topic we chose had a good balance between practical work and theoretical work. This made it great fun to work at it, because you were not only working on something on paper, but you actually saw it coming to life. It has also shown me that if something works in theory, it does not have to work the same in reality.
Water management has always intrigued me, from playing with sluices in models to the Deltaworks. Working on this project gave me a more scientific approach to the management of water and the production of energy.”

Titus: “To be honest we had a lot of trouble choosing the topic, two factors played a big role in obstructing the selecting process. The first factor was that we had a narrow area in which our interests overlapped a little bit. I might have been the one who had the most different interests, for I am personally more interested in the IT directions. This was a little unfortunate for Niek likes physics and Kees interests himself mostly in biology. However, we could find common ground on the physics side, especially when it came to waterworks. To compromise all these different interests, we first wanted to research on the Panama canal but all of us did not really feel satisfied with this topic. Our second idea was, luckily, much better. A 3D model that we could place into a drainpipe to create energy combined our different views and interests. The 3D printing part was the part I was most interested in. Obviously this is because I love to see how our computers can accomplish so much. Kees was interested in the waterworks and Niek liked the physics calculation most. In the end I realised how much fun this topic actually was and the more I got into it, the more exciting it was.

The learning process

Kees: “Perhaps we learned more than we expected. That is a statement I am willing to defend. We did not expect to have a few fallbacks in our project. Luckily we managed to solve all problems we had and make a amazing project. I the most important things we learned are not the physical knowledge. Perhaps the most valuable lesson in this project is communication. I really learned to work in an team. I am not always that keen on group projects, however, I think I learned a big deal in communicating with the other group members and also outside school. The communication with for instance the companies were a great learning opportunity. Luckily that opportunity has not gone to waste as they all reacted positively. I hope that the readers of our project enjoyed themselves and are willing to change their way of living to ensure a suitable earth for the rest of days.”

Niek: “One of the most important things I learned is solving problems as a team. Every group member had their own task in the project and in this way their own expertise. When we were brainstorming on how the system might work and during the building process, everyone had their own view. Combining these views gave very surprising results and I think that in this way we learned a lot from each other. In this way, we were able to overcome some setbacks during our project. In other words, together we were able to improvise in situations that did not look so promising. I also gained some experience in the planning and organisation of a group project, the main factor in this is good communication.”

Titus: “Group project are for me always a good way to learn. The amount of new things I learn in a group project are immensely more than I do in a normal day of school. The main skills that I improved by doing this research were my planning and my basic understanding of physics. Specifically the area of physics about electricity, I have always had a hard time wrapping my mind around how exactly the electricity flow work. I always confused ampere, volts and watts with each other and did not really understand how exactly these ‘worked’ together. After having done our own research and measurements I must say that I now understand it much better. I can see the difference and know what role al these different elements play within a ‘machine’. Planning was the next which has improved, every group project I learn how important planning is. For example, our prototype broke 2 weeks before our deadline, because we planned the experiment on time we had enough time to make a new 3D print without having to panic.
Of course with such a project you gain a lot of experience, I learned about 3D printing, about experimenting and how to measure simple flows of electric energy. Also I got a better view of how much energy a system can create and how hard it actually is to create a balanced source of energy. Additionally, I have made calculations of how much money we could save by filtering our own water and got a more realistic view of how much water actually costs and how hard it is to filter out drinkable water.
After reading Kees and Nieks evaluations I realised we wrote a bare minimum about how our teamwork went, this is because the teamwork went perfect. I can even say without doubt that our teamwork always goes flawless. We have been friends for six years and when we are annoyed by each other or think that someone in the group is doing actually doing excellent we just say it, I have not felt any tensions during this project. I am extremely happy to have these two friends of mine as my peers in this project.”

Bibliography

Sources sub-question 1:

- http://www.wot.utwente.nl/publications/cde/waterkracht.pdf
- https://nl.wikipedia.org/wiki/Hydraulische_turbine
- http://www.klimaatatlas.nl/klimaatatlas.php
- https://www.amsterdam.nl/toerisme-vrije-tijd/groen-amsterdam/groene_daken/dak-geschikt/
- http://www.uv-system.com/technical.html
- http://oddity.quirkdesign.co.uk/2010/08/10/drain-pipe-generator/
- http://dangerousprototypes.com/docs/Basic_Light_Emitting_Diode_guide LED
- http://www.linetec.nl/electronics/leds/led_1.html
- https://nl.wikipedia.org/wiki/Fietsdynamo#Rendement_en_weerstand

Sources sub-question 2:

- http://web.tue.nl/cursor/bastiaan/jaargang43/cursor35/onderzoek.shtml
- http://www.velda.nl/producten/filtratie__beluchting/filtermaterialen/ammonium_filtermedium
- http://www.harvesth2o.com/filtration_purification.shtml#.VmB9vIQmUtI
- https://en.wikipedia.org/wiki/Nitrogen_cycle#/media/File:Nitrogen_Cycle.svg
- http://www.milieufocus.nl/factsheets/d/denitrificatienitrificatie.html
- https://nl.wikipedia.org/wiki/Nitrificatie

Sources sub-question 3:

- http://www.reuk.co.uk/Sand-Filters-for-Greywater.htm
- https://nl.wikipedia.org/wiki/Zandfilter
- http://www.nzdl.org/gsdlmod?e=d-00000-00---off-0fnl2.2--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-00&cl=CL2.7.4&d=HASH010cd6fcdbf2f1e7865ac229.8.3&gt=1
- http://www.sswm.info/category/implementation-tools/water-purification/hardware/semi-centralised-drinking-water-treatme-14
- http://www.duurzaamthuis.nl/water/grijs-water
- https://nl.wikipedia.org/wiki/Helofytenfilter
- http://www.kilianwater.nl/helofytenfilters/hoe-werkt-het.html
- www.vitens.nl/vragen/Paginas/Wetenswaardigheden-Hoeveel-water-verbruiken-we-per-dag.aspx
- http://greywateraction.org/contentabout-greywater-reuse/
- https://en.wikipedia.org/wiki/Greywater
- http://oasisdesign.net/greywater/
- www.verbouwkosten.com
- http://www.nibud.nl/consumenten/energie-en-water/
- http://gemiddeldgezien.nl/
- www.vitens.nl/vragen/Paginas/Wetenswaardigheden-Hoeveel-water-verbruiken-we-per-dag.aspx

Glossary

Potential (gravitational) energy: The energy an object gains when it is lifted, the work that has to be done to lift an object to a certain height because of the gravitational pull. Defined in formulas as $E_{potential} = mgh$.

Kinetic energy: The energy an object has because of the motion it is in. It depends on the speed and the mass of the object. Defined in formulas as $E_{kinetic} = \frac{1}{2}mv^2$.

3D printing: Printing a model using a liquid form of ABS, which after a time of stolling, becomes a solid.

UV-light: Electromagnetic radiation just outside the visible spectrum. With a wavelength from 10 nm to 400 nm. High energetic UV-light ionizes atoms and could kill bacteria in this way.

Filtration System: A system that filters water. Out of this system will flow cleaner water.

Biomass: Organic matter derived from living, or recently living organisms.

Greywater: Lightly polluted water with the potential to be reused.

Blackwater: Heavily polluted water.

UV-system: A system that creates a low pressure state in the lower drainpipes which allows water on top to flow horizontally.

Nitrates: Oxidized forms of N-compounds, NO_3^- or NO_2^-.