Aquaponics - a test case for the Van Gendt halls in Amsterdam

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ABSTRACT

The Netherlands needs three times its area to provide itself with enough food - and this is when we would use that area purely for food production. The growing population needs to be fed. Instead of relying on import, there is an alternative that could add to the food production: urban farming. There are many forms of urban farming, but here aquaponics is chosen. Aquaponics uses a lot less water and is less intensive than soil-based farming. It's a combination of aquaculture and hydroponics: the fish deliver the nutrients for the plants and the plants clean the water in return.

The general objective is to place aquaponics in such a setting that it can contribute to the local market and raise awareness with regard to the food-cycle. In this paper the focus lies on the in- and output of an aquaponic system and what it can mean for a building.

The overall structure of this paper covers three parts: an explanation of aquaponics, some examples of large-scale aquaponic ventures and a test case for the Van Gendt halls. Within this test case the following subjects are taken into account: produce, water, waste, energy and fish production.

The test case is defined as follows: an area of 2240 m² with 462 m³ water, 9240 kg of fish, 25200 leafy plants and 6720 fruiting plants. If a basic salad comprising of lettuce, tomatoes, eggplant and peppers is defined as daily output, it gives 67 kg of lettuce, 22 kg of eggplant, 32 kg of tomatoes and 26 kg of peppers per day. It means that it would be possible to make 73 full salads, serving a total of 292 people per day.
Using the same numbers the crop residue was calculated. This resulted in a total of 69632 kg of crop residue from which 27852 m³ methane gas can be produced with an anaerobic bioreactor. A microturbine uses the methane gas to generate energy, which results in 278529,2 kWh. This means that 529 light bulbs of 60 Watt can be lit all year round (24 hours a day).
Another source of energy can be the sun. An average commercial solar panel has an output of 200 W. When half the roof is taken as a minimum coverage, and the entire roof as maximum coverage, electricity between 1317600 kWh and 2635200 kWh can be generated. This means that min 2500 and max 5000 light bulbs of 60 Watt can be lit for 24 hours a day for an entire year.

It should be possible to supply the aquaponic system with rainwater: the system would lose somewhere between 1.686.300 litres and 5.058.900 litres water per year. Catching all the rainwater on the roof results in a total water volume of 9.926.592 litres per year - more than enough to resupply the system.

For fish production the species 'tilapia' was chosen. Tilapia reaches maturity at an approximate size of 0,5 kg. For a necessity of 9240kg of fish this means that 18480 fish are needed to keep the system running. Since tilapia can be harvested twice a year, this means that a total of 36960 tilapia are harvested in one year.

Keywords: aquaponics, test-case, Van Gendt, water, energy, food production, architecture

BACKGROUND

The problem

The Netherlands is a major export factor in the food industry globally and in Europe. Despite this business, most of our food production is destined to go outside of our own country, and we still import tons and tons of food to provide our people with nutrition.
The Netherlands needs two times its area to provide itself with enough food - and this is when we would use that area purely for food and fodder production. One person needs about 0.6 ha of food production to be sufficiently fed (see Figure 1). Of course, in the countryside this would not be so hard to achieve. But what about the cities?

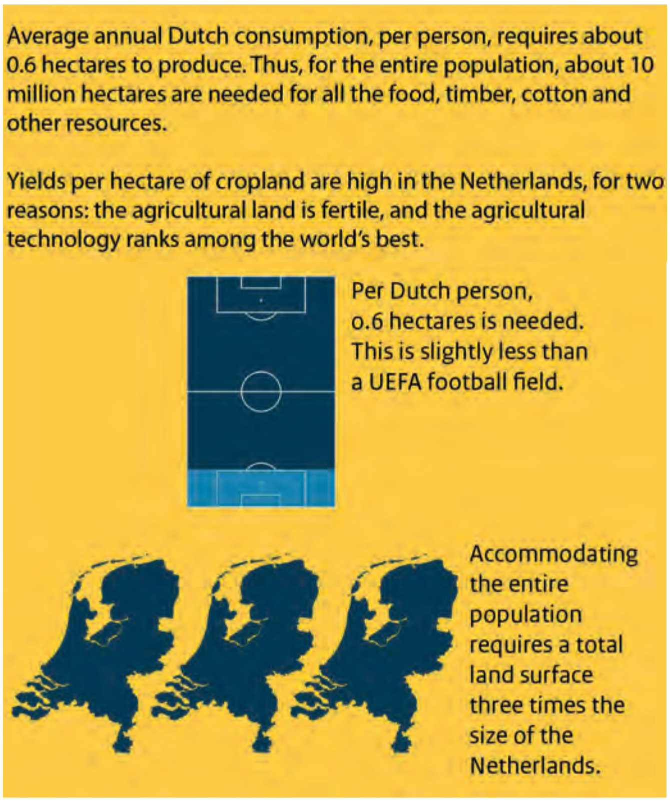


Figure 1 Average Dutch consumption, PBL, 2014b

In Amsterdam there are 800.000 (over 2 million in the Amsterdam greater-area) people, who all need to be fed. Right now, all of this food is imported, be it in- or outside of our country.
I believe it is an important moment in time to invest more in urban farming. This way, the food can be grown locally, hopefully organically, and be better available to people, cafés and restaurants. Rooftops, empty buildings, parks – there can be urban farming. It can be horizontal as well as vertical; which opens up a whole new dimension to the production of food. Food miles can be reduced significantly, awareness concerning food and where it comes from can be raised. Note that urban farming is not the absolute solution to the food problems of the future, but I believe it can add to the solution on a city-scale impact.
There are many forms of urban farming but I am not going to discuss them here, I am solely interested in aquaponics.

Aquaponics

Aquaponics is a way of soil-less farming where aquaculture is combined with hydroponics. Aquaculture is the farming of fish, and hydroponics is soil-less vegetable and fruit farming with all the nutrients added to the water. By combining both systems it becomes a closed loop where the fish provide the nutrients for the plants, and the plants clean the water in return. Since it uses no soil it is very suitable for the urban environment; either inside old buildings or areas that have a non-suitable surface (concrete, stone, tile,...).
Aquaponics uses a lot less water and is less intensive than soil-based farming. If combined with a greenhouse the yield can increase significantly due to all-year round growing. The downside is that the system has to be set up properly in the beginning, nutrient values have to be measured regularly and constant and proper monitoring is necessary.

The design objective

The general objective is to place aquaponics in such a setting that it can contribute to the local market and raise awareness with regard to the food-cycle. It should illustrate that produce is not an object in a plastic wrapping in the supermarket, but a real thing that can grow organically and fresh close-by.
I formulated the design-question as follows:

"Can large scale aquaponics provide effective integrated food production to add to the local market and to raise food awareness within the Van Gendt halls?"

As said before, the chosen system to achieve this goal is aquaponics. To illustrate the subject as complete as possible a few sub-questions are defined as such:

- What is aquaponics exactly?
- What systems exist within aquaponics?
- What can and can't be produced and what would be the yield of it?
- What is the water demand of a system and can rainwater caught by the building suffice?
- What would be an approximate yield of fish?
- What are the possibilities with the waste products such as crop residue?
- What are the possibilities for the Van Gendt-halls and its surroundings?

It is relevant to explain the subject of aquaponics because it explains what will be worked with for the remainder of the paper. Without knowledge pertaining the system one cannot fully understand what the ramifications will be for the Van Gendt halls and Amsterdam.

The production of food can be more integrated with other functions so it can be a bigger part of our lives and thus play a bigger role in the awareness of food. I myself never really stood still at the consequences of importing food long-distance and how little we actually know about it. This rolled into a fascination of aquaponics because of its efficiency and possible high yields. This means it is no longer a community-level vegetable garden, but a fully functioning source of produce for the city.
Particularly interesting to me were the numbers concerning the output and what the possibilities are with those numbers.

Acknowledgments

My thanks to Job Schroën for his guidance and always believing in me, to Ulf Hackauf for his guidance and enthusiasm and Edwin Roelse from De Groene Lelie for his info and enthusiasm pertaining aquaponics.

METHOD

Way of working

The biggest part of the research was done by literature research and a smaller part through research by design. For the literature research I directed my attention to urban farming, aquaponics and food to acquire sufficient background knowledge on these subjects. Then I went a little deeper into aquaponics and agriculture to get to know more about crop yields, crop residues, water needs and biomass energy values. For the research by design a basic aquaponic setup is defined and basic input (water, fish, plants) and output (crop yield & residue, fish) is calculated and discussed for the van Gendt halls.

The overall structure of this paper covers three parts: an explanation of aquaponics, some examples of large-scale aquaponic ventures and a test case for the Van Gendt halls.

The result is an understanding of the benefits and consequences of an aquaponic setup in an urban environment such as the Van Gendt Halls in Amsterdam. This will be used in the design phase of the project and can be related to other urban settings. There will be an excel file where one can input square meters and type of plants and get an estimate of needs and yields.

Circumstances and limits

The most important notion concerning this paper is that although aquaponics is the main focus, I do not attempt to tweak/improve/change the aquaponic system itself. This paper is meant to put it in a more architectural setting and discuss the consequences and possibilities of the system for a large scale operation in an urban setting such as the Van Gendt-halls. Most of the assumptions, calculations and conclusions are made for this specific site. My reasoning, formulas and excel sheet are not bound to the site and can be used freely on another place.

RESULT LITERATURE RESEARCH

What is Aquaponics?

In short, aquaponics is the combination of aquaculture and hydroponics. Aquaculture is the cultivation of fish and hydroponics is soil-less farming. With aquaculture the problem is the waste water from the fish, whereas in hydroponics you have to add all the nutrients manually to the water. When these two are combined both of their problems go away. The plants get the necessary nutrients from the fish water and clean the water so it can be returned to the fish tank. A big plus for aquaponics and hydroponics is the lack of soil which significantly reduces the risk for diseases and pathogens because of sterile conditions.

Figure 2 is a simple setup for aquaponics. The bottom tank is for the fish, on top a planter is placed. A pump makes sure that the water is evenly fed to the plants. After being filtered through the media in the bed and absorption by the plants, the cleaned water is returned to the tank. Figure 3 shows the schematic components for an aquaponic unit.

Figure 2. Aquaponic Unit, photo by Edwin Roelse

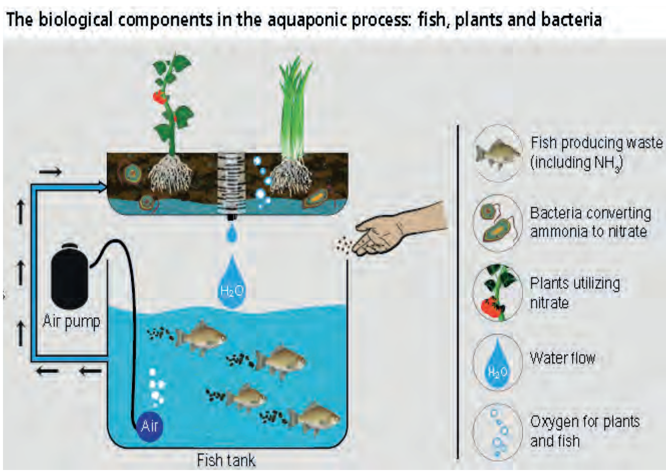


Figure 3. Components in Aquaponics. Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014, p.11

The production of plants and fish is the most visible output and the easiest to understand, but aquaponics is very reliant on another factor: bacteria. In essence aquaponics is the management of plants, fish and bacteria. The bacteria make sure that the fish waste is converted to nutrients that the plants can absorb and use.

This cycle is called nitrification and goes as follows: the fish produce waste (ammonia NH_3, toxic!) which is broken down by ammonia-oxidizing bacteria into nitrite (NO_2). This nitrite is unfortunately also toxic, so the next bacteria comes into play: the nitrite-oxidizing bacteria. These break down the nitrite into nitrate (NO_3) which the plants can use. This is illustrated in Figure 4.

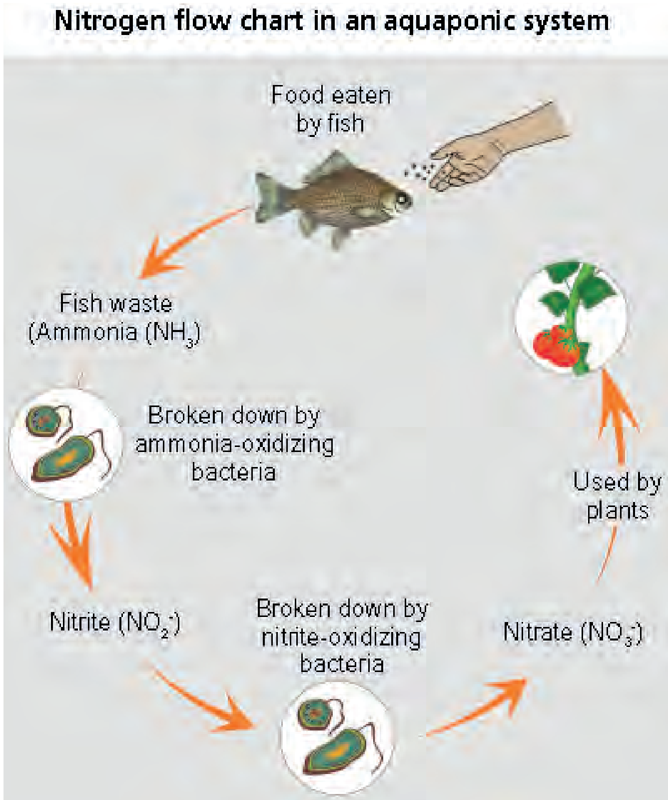


Figure 4. Nitrogen flow in an aquaponic system. Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014, p.13

It is important to have a healthy bacterial colony at all times to keep the ammonia levels as low as possible. Because these bacteria live in the water, there are a few other aspects to keep in mind: water temperature, pH levels and dissolved oxygen (DO = oxygen in the water).
Optimal values for these aspects, for plants, fish and bacteria combined are: temperature = 18 - 30 C°, pH = 6-7 and DO = >5 mg/litre.

Three common systems

There are some aspects that all aquaponic systems share: the fish tank, a mechanical filter, a biofilter and hydroponic containers. For the hydroponic containers three common systems are discussed: media bed, nutrient film technique (NFT) and deep water culture (DWC).

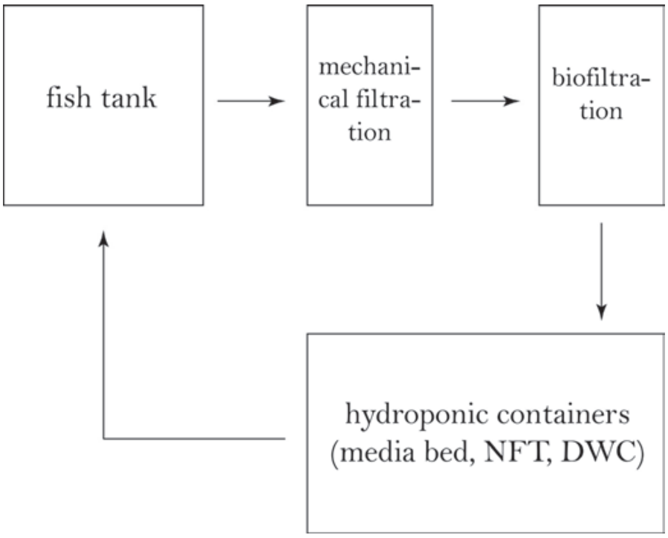


Figure 5. Aquaponic Structure

THE FISH TANK

For the material of the fish tank, plastic or fiberglass is recommend because they are convenient to install and are light and maneuverable; metal is not possible because of rust. The shape can be anything, although round tanks are recommended because of optimal water flow. A cover such as a shade cloth is necessary in relation to algae growth, jumping fish and leaves/debris. Also, the water must never be drained because then the fish will die (Somerville et al., 2014, p.43-44).

Figure 6. Example fish tank from http://aponicbuild.blogspot.nl/

Figure 7. Example fish tank from http://aquaponicfun.com/

THE MECHANICAL FILTER

The mechanical filter is important to get rid of solid waste. In NFT and DWC it is very important because otherwise the waste will clog up the drains and pipes. The simplest method is a screen or filter located between the fish tank and the grow bed. This is usually sufficient for smaller systems, but for larger systems a mechanical separator is recommended, such as a swirl clarifier (Somerville et al. 2014, p.44-45). For more info on this subject please refer to "Small scale aquaponic food production - integrated fish and plant farming" by Somerville et al. page 44-45.

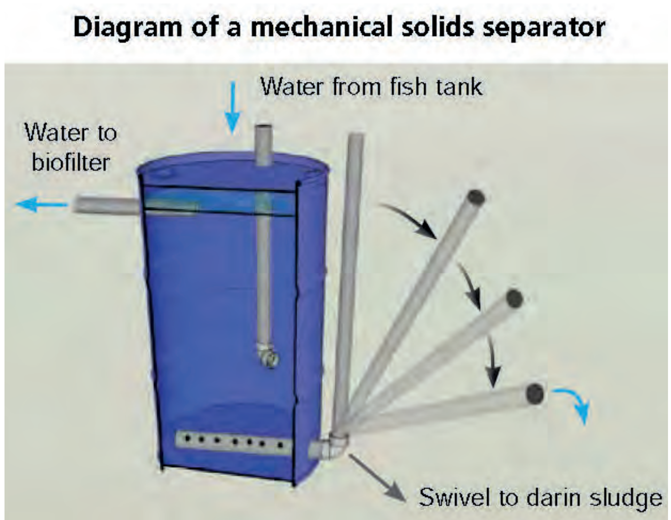


Figure 8. Example of a mechanical filter. Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014, p.45

THE BIOFILTER

The biofilter is where the nitrification process takes place. In a NFT and DWC system it is beneficial to add a biofilter to the system. In a media bed it is not necessary since the grow beds are a perfect biofilter. A biofilter is basically a tank with

added medium such as Bioballs, plastic bottle caps or PVC shavings on which the much needed bacteria can grow.
For more info on this subject please refer to "Somerville et al. page 45-46.

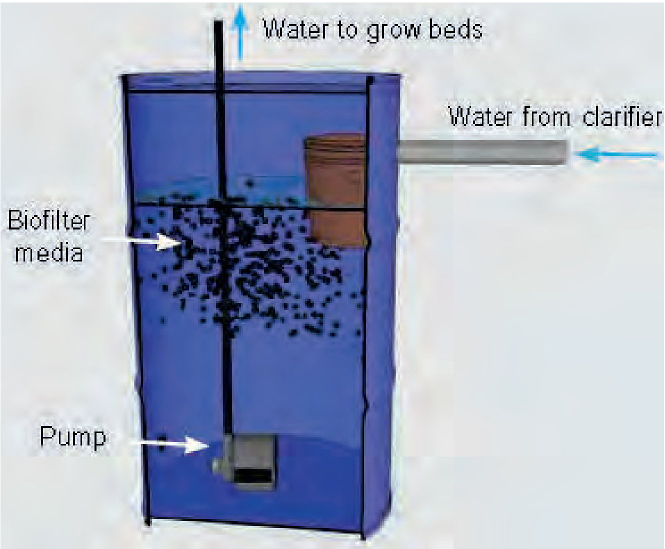


Figure 9. Example of a biofilter. Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014, p.46

Figure 10. Example of plastic biofilter medium. Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014, p.46

In the case of NFT and DWC, a media bed can be used both as mechanical and biofiltration. It cannot however be used as an intensive growing bed because then the plants would take all the nutrients away from the NFT or DWC.

<u>THE HYDROPONIC CONTAINERS</u>

1) THE MEDIA BED TECHNIQUE

Media beds (example see figure 2) can be made from different materials as long as they are strong enough to hold the water, medium and plants; are made from materials that are safe for the fish, plants and bacterias; and they can be placed closely to the other components such as the fish tank. The depth of the bed is very important because this determines the root space for the plants. Larger plants need more root space, so a bigger depth. Usually a depth of 30 cm should do it.

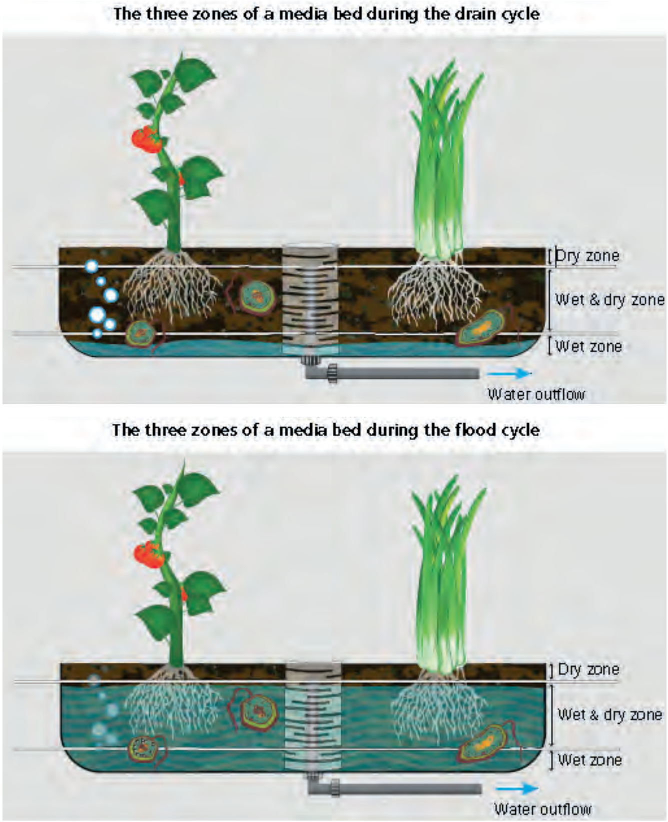


Figure 11. Three zones in a media bed system during flood and drain cycle. Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014, p.60

The medium itself should allow the bacteria to grow, the water to flow and the roots to breathe. A few common media are: volcanic gravel, limestone, clay aggregate or rockwool.

Three zones can be identified within the media bed (see Figure 11). The dry zone keeps the light from getting to the water, preventing evaporation and algae growth. The second zone is the dry/wet zone, where the media bed floods and drains. Here the bacteria, micro-organisms and roots do their thing. The third and last zone is the wet zone where the organisms that do the most mineralisation are present.

The most common method of irrigation is flood and drain combined with a bell siphon. The principle of a bell siphon is explained in figure 12.

1)Water flows at a constant rate into the media bed and fills it with water

2)Once it reaches the top of the siphon it starts to dribble down the pipe

3)As more water flows down, and airlock (vacuum) is created.

4)The siphon fills up with water thanks to the airlock

5)The siphon drains the media bed until it reaches the bottom.

6)Air flows back in to the siphon and the rest of the water inside the siphon drains away. After this it starts back at step 1.

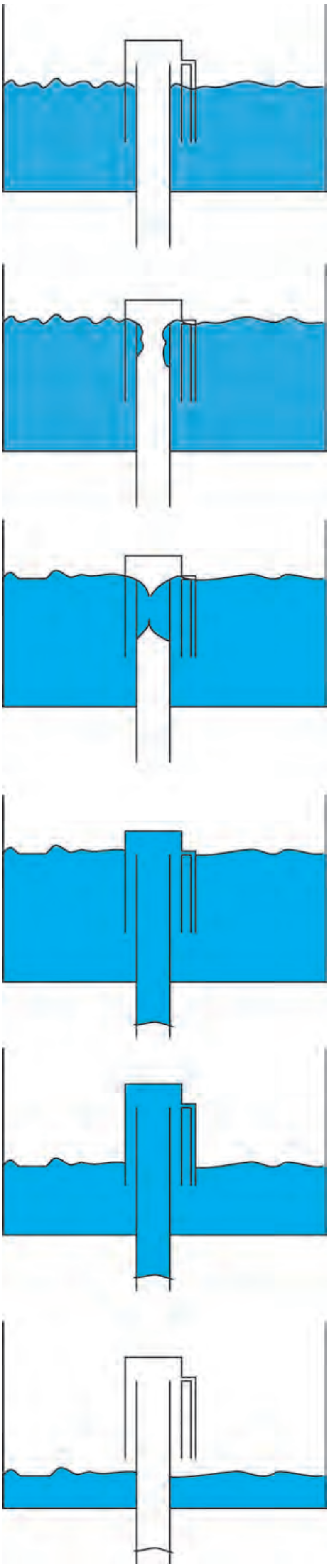


Figure 12. Bell siphon diagram

2) THE NUTRIENT FILM TECHNIQUE

NFT is a hydroponic method where shallow water flows through horizontal pipes with holes (figure 8). In these holes the plants are placed and their roots use the thin film of water to absorb the necessary nutrients (figure 9).

Fig 13. Example of NFT from backyard aquaponics

Fig 14. Plant in NFT from Flickr

The NFT method is more viable for commercial operations or urban environments where vertical space or weight-limitations play a role.

The water flow occurs naturally thanks to gravitation, with an advised slope of 1cm per meter. Just like a media bed the water is afterwards pumped back to the fish basin to reload with nutrients. As said before, mechanical and biofiltration is important with this method to prevent clogging.

When using rectangular pipes, the width should be larger than the height to ensure that the roots reach a large surface of water. For round pipes, the diameter should lie between 7,5 cm (leafy vegetables) and 11 cm (fruiting vegetables or multi-culture). The advised length for both rectangular and round pipes is around 12 m, after that the water is stripped too much of nutrients to be of use.

The preferable plant cup is the plastic net cup. If these are not available or too expensive, one can also use regular plastic drinking cups. If so, enough holes should be made to allow the roots to grow towards the water. The plant cups can be filled with volcanic gravel, rockwool or LECA.

3) DEEP WATER CULTURE TECHNIQUE

Fig 15. DWC unit from systemsbiology.net

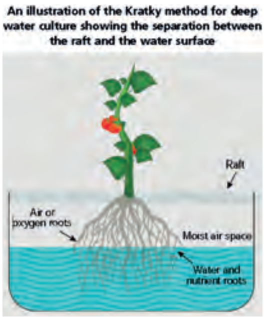


Fig 16. Kratky method, Somerville et al, 2014, p.70

DWC is a technique where plants grow in polystyrene sheets floating on a basin with water. The method is similar to NFT, but instead of pipes the plants are suspended in large basins of water. Just like media beds the recommended depth is about 30 cm (for the basin) to allow for sufficient space for the roots.
To have enough oxygen for the roots, either a lot of dissolved oxygen needs to be in the water or a space between the plant and the water has to be there (Kratky method, figure 16).

Common plants in aquaponics

Just like Somerville et al I have two categories for plants: leafy plants and fruiting plants. The difference lies in the part that is eaten. For leafy plants this is (obviously) the leaves of the plant. For example lettuce, spinach and pak choi. For fruiting plants this is the fruit of the plant, for example broccoli, tomatoes, cucumbers and eggplants. Plants that are not commonly grown in aquaponic units are the plants that need lots of underground space such as potatoes, sweet potatoes, onions and carrots.

The leafy plants that I included in my research are: basil (A), lettuce (B), swiss chard (C), parsley (D), coriander (E), pak choi (F), celery (G) and spinach (H). The fruiting plants are: beans (I), cauliflower (J), cucumber (K), eggplant (L), peppers (M), tomatoes (N), head cabbage (O), broccoli (P) and okra (Q). To get the necessary info on all these plants I scoured the internet on forums such as gardenweb, backyardaquaponics and harvesttotable and read a few articles such as Somerville et al., and "*Hydroponics - the solution to the food problem*" (Willis, 1992).

Common fish in aquaponics

Since there is not much more to the fish in aquaponics than growing them and eventually eating them, I only went with the info from "*Small-scale aquaponic food production*" to use in my research.
It seems that the most common species grown in an aquaponic unit are common carp (R), nile tilapia (S), channel catfish (T), rainbow trout (U), flathead mullet (V), giant river prawns (W) and barramundi (X).

Additionally some people make use of shellfish such as mussels (Y) or oysters (Z) to help clean the water of harmful particles. However I have not found a successful working system with them but forum talk about the subject.

All vegetables and fish are visible on the next page in figure 17.

Figure 17 (right). Vegetables and fish visualized


A


B


C


D


E


F


G


H


I


J


K


L


M


N

O


P


Q


R


S


T


U


V


W


X


Y


Z

AQUAPONICS EXAMPLES

UF001 LokDepot - The first commercial aquaponic rooftop farm worldwide

Since 2013, we operate UF001 LokDepot as our first commercial aquaponic rooftop farm. Based in the Dreispitz area south of Basel, just a few tram stops from the heart of the city, we operate a 250m^2 rooftop greenhouse with fresh fish and healthy vegetables.

UF001 LokDepot is our pilot for rooftop farming, leading on to more sizeable, and commercially viable business models for our customers. During 2013, we are running a series of R&D test

together with the University of Applied Sciences (ZHAW) in Wädenswil in order to test functionality, robustness and quality of our production processes as well as to ensure delivery of our Fresh.Revolution.Basket.Pro allotments to leading restaurants in town. Everything we do from seeding to harvest is supported via the UF Controller, our proprietary farm control software.

UF001 LokDepot can be visited for **private & corporate tours**. Check out our Tour Packages. **Directions** to UF001 LokDepot can be found here.

Main Facts

Address	UF001 LokDepot c/o Christoph Merian Stiftung Frankfurtstrasse 21 4053 Basel
Greenhouse	250m²
Annual production volume	5 tons of vegetables, 850kg of fish

From http://sustainablecitiescollective.com/david-thorpe/426096/worlds-first-commercial-rooftop-aquaponics-farm & http://urbanfarmers.com/projects/basel/

ECF FARMER'S MARKET

The aquaponic-system used by ECF is very resource- and climate-friendly, because it combines the breeding of fish with the cultivation of vegetables.

Due to a closed water and nutrition cycle the farm saves 90% of water compared to conventional fish and vegetable production.

Furthermore, it needs 70% less cultivation area than conventional farms. CO_2 emissions are very low, because the farm produces and sells its products close to the customers so that transport routes and cold chains are reduced.

On an area of 1,800m² ECF City Farm produces about 25 t of fish and 30 t of vegetables. From May onwards the greens will be available in form of weekly vegetable boxes for a total of 300 customers – reservations can already be made. The sale of perches will start in October.

From http://www.ecf-farmsystems.com/en/ & http://www.climate-kic.org/news/successful-launch-europes-biggest-city-farm-fish-vegetables-berlin/

RESULT DESIGN RESEARCH

Basic set-up

NOTE: In this chapter I calculate a test case for the van Gendt halls. To illustrate the full possibilities of the halls I will include the result for the entire halls , always indicated in a square just like this note.

To get a grasp on the m² that is best used for aquaponics in the Van Gendt Halls I made a quick analysis of the area that would be suitable for a greenhouse. The best position would be on the south, west or east side. I combined all three into an area that looks like this:

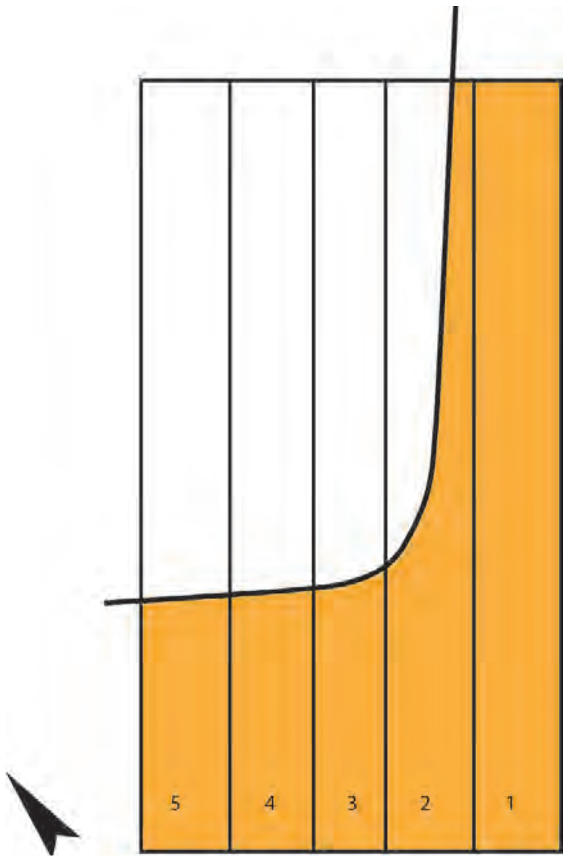


Figure 18. Optimal aquaponic area for the Van Gendt halls in Amsterdam - floorplan

This gives me an approximate area of 6400 m². Now, say that about 50% is actually used. That leaves me with an area of 3200 m² to utilise for aquaponics. Because not all of that space will be used for planting (there is also space needed for pumps, fish tanks and other stuff) I estimated that about 70% of the remaining area will actually be planted. That gives me approximately 2240 m² of plantable area.

From the calculation in appendix A I got following numbers:

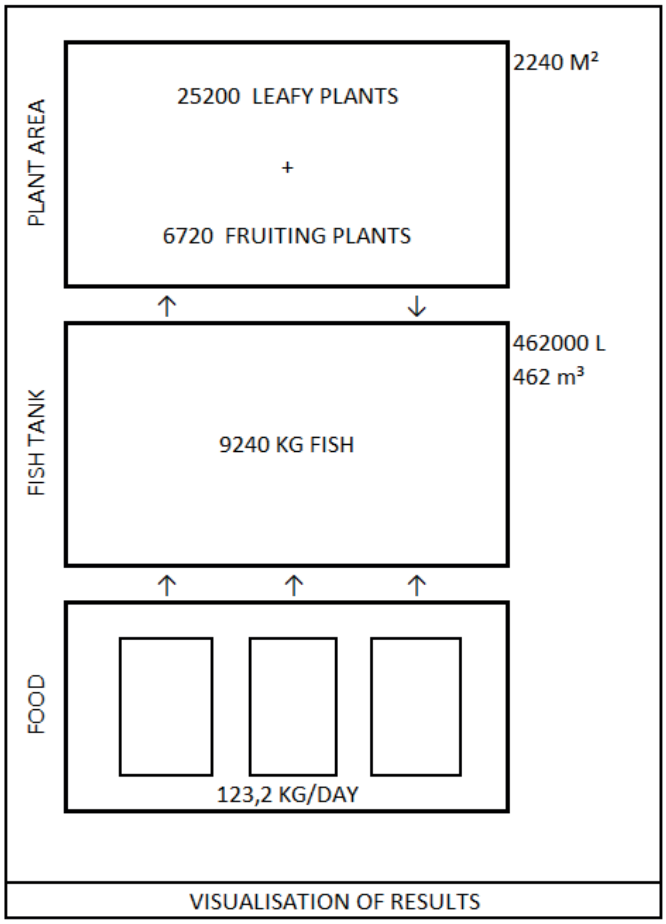


Figure 19. Visualization of the results

This means that for 2240 m² of plantable area I can plant an average of 25200 leafy plants and 6720 fruiting plants. To provide the necessary nutrients I'd need 9240 kg of fish in 462 m³ water and 123,2 kg of fish feed per day. To show the effect of these numbers for the location I tried to visualize them in a diagram.

This means that for ±12000 m² of plantable area I can plant an average of 135000 leafy plants and 36000 fruiting plants. To provide the necessary nutrients I'd need 49500 kg of fish in 2475 m³ water and 660 kg of fish feed per day.

x 9000 = all the fish

x 120 = all the feed per day

As you can see, one hall would be completely filled with plants. No aisles or anything, pure planted area. The fish would reside in an area of about 18 x 25 m and 1m height. Now, if you imagine a fish at an average size of a sugar pack of 1kg, there would be 9000 of those packs floating in the water. To feed those fish, you'd need about 120 packets. That means for 75 fish (or packets of sugar) you would need another packet of sugar PER DAY to feed them.

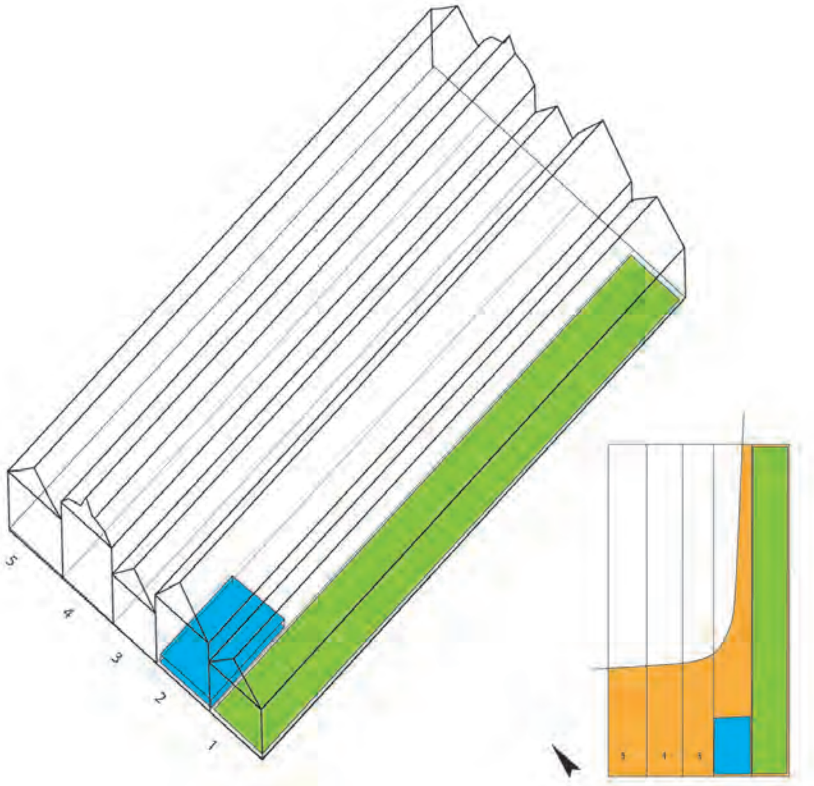


Figure 20. Diagram of space the system would need

All these amounts are huge. To bring it all down to a human level, the output values for a simple salad are calculated. I'm assuming that (only) these plants are grown: lettuce, tomatoes, eggplants and peppers. For the data I put together on these plants please refer to appendix C.

To find the total yield per plant per year this formula was used:

yield (kg/m^2) x area (m^2) x times of harvest

	yield kg/m²			m² of plants	times of harvest per year	yield kg per year
PICK A LEAFY PLANT	min	max	avg			
lettuce	1,80	4,50	3,15	560,00	7,00	12348,00
lettuce	1,80	4,50	3,15	560,00	7,00	12348,00
PICK A FRUITING PLANT	min	max	avg			
eggplant	3,00	8,00	5,50	373,33	4,00	8213,33
tomato	6,00	15,00	10,50	373,33	3,00	11760,00
peppers	2,20	8,16	5,18	373,33	5,00	9669,33

Figure 21. Calculation of yield

The yields per year are as follows: 24696 kg for lettuce, 8213 kg for eggplants, 11760 kg for tomatoes and 9669 kg for peppers. Per day this would average on 67 kg of lettuce, 22 kg of eggplant, 32 kg of tomatoes and 26 kg of peppers.

A tomato weighs on average 100 grams (wikipedia), an eggplant 300 grams (answers.com), a pepper 120 gram (answers.yahoo.com) and a lettuce head 700 grams (ask.com). This means that on average per day there would be 320 tomatoes, 73 eggplants, 216 peppers and 95 lettuce heads.

Say there is a recipe for a salad with eggplant, tomatoes and peppers for four people that goes as follows:

- 1 lettuce head
- 4 tomatoes
- 1 eggplant
- 2 peppers

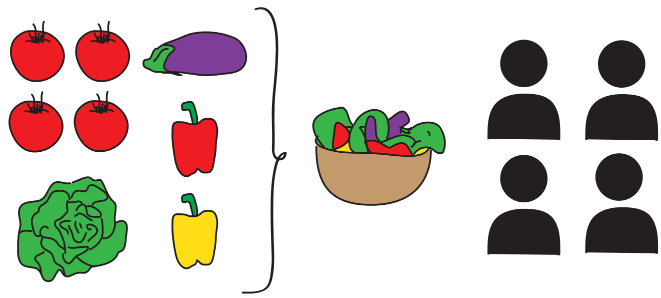


Figure 22. Composition of a salad for four people

This means that it would be possible to make 73 full salads (with leftover 22 lettuce heads, 28 tomatoes and 70 peppers), serving a total of 292 people.

For the big calculation this means that it would be possible to make 400 full salads, serving a total of 16000 people.

Another very important input is water .The 462000 litres of water from the basic setup are not endless. Although aquaponics has a very small percentage of water loss per day(1 to 3%), it is still a considerable amount: between 4620 litres and 13860 litres per day.

For the 2475000 litres this means that between 24750 and 74250 litres per day go to waste.

"*Small-scale aquaponic food production*" (Somerville et al., 2014) lists four types of water that can be used to replenish the aquaponic system. Rainwater, cistern or aquifier water, tap water and filtered water. My interest lies with rainwater and filtered water.

RAINWATER

According to Somerville et al, rainwater is usually perfect as a supply of water for aquaponics. It normally has a neutral pH, low concentrations of hardness and almost zero salinity. It is a good idea to buffer the rainwater (store it for a while), then it will definitely work.

Between 4620 litres and 13860 litres per day is lost due to evaporation and splashing. For the timespan of a year this means that between 1686300 litres and 5058900 litres is lost per year.

The average rainfall in Amsterdam is 776 mm or 776 l/m^2 per year (KNMI, 2011). The area of the roof is roughly 12792 m^2. That means that about 9.926.592 litres per year can be caught from the roof.

This means that it should be possible to supply the aquaponic system with rainwater.

Between 24750 litres and 74250 litres per day is lost due to evaporation and splashing. For the timespan of a year this means that between 9.033.750 litres and 27.101.250 litres is lost per year.

Since about 9.926.592 litres per year can be caught from the roof, this means that it is not possible to supply the entire system with rainwater.

FILTERED WATER

Filtered water is very safe to use. It is not possible to use crops as a filter medium because the harvest would become inedible (Rana et al., 2011). If wanted a separate plant-track could be set up where the plants filter grey water coming from surrounding buildings and the Van Gendt halls themselves.. This method of cleaning water is for example used in the zoo in Emmen, Netherlands. They have a system called "De Waterfabriek" (The Waterfactory) (see appendix D) where the water management of the zoo takes place (Smits, 2012).

Another important input factor is energy. All those pumps, lights and fans need electricity. The system itself could generate electricity. How? Biomass. The leftovers from harvest and plants could be used in a bioreactor combined with a microturbine to generate electricity ,just like in Villa Flora in Venlo. Another solution would be solar energy. Both are discussed and calculated (see appendix B & C)

BIOMASS

The residue from harvest can be used to generate electricity. For example, in poor regions in China leftover from crops is burned in a stove as an alternative to wood for heating/cooking (Henderick, 2000). It is not a very efficient method though.

Another way to get energy from harvest residue is with an anaerobic bioreactor. In this machine a process called anaerobic digestion takes place. This process involves a series of metabolic reactions such as hydrolysis, acidogenesis and methanogenesis (Khalid et al., 2011). Basically the harvest residue is broken down inside this bioreactor and one of the main components that come out of it is methane (CH_4). Methane gas can be burned to generate energy, this has to be done in a microturbine (for more information see Appendix B).

So, the combination of bioreactor and microturbine can be a source of energy for the Van Gendt halls. To calculate the crop residue I needed specific crop types, so I used the same setup that was used to calculate the salads (see figure 23).

From a total of 69632 kg of crop residue , 27852 m^3 methane gas can be produced. This means that 529 light bulbs of 60 Watt can be lit all year round.

x 529

for 24 hours a day

for 365 days

	yield kg/m²			crop residue kg/m²			energy value of average crop residue (Mj/kg)	m² of plants	plants/m²			times of harvest per year	yield kg per year	crop residue kg per year	energy value crop residue Mj
PICK A LEAFY PLANT	min	max	avg	min	max	avg			min	max	avg				
lettuce	1,80	4,50	3,15	0,89	2,22	1,56	18,00	560,00	20,00	25,00	22,50	7,00	12348,00	6095,60	109720,80
lettuce	1,80	4,50	3,15	0,89	2,22	1,56	18,00	560,00	20,00	25,00	22,50	7,00	12348,00	6095,60	109720,80
PICK A FRUITING PLANT	min	max	avg	min	max	avg									
eggplant	3,00	8,00	5,50	6,09	16,24	11,17	18,00	373,33	3,00	5,00	4,00	4,00	8213,33	16673,07	300115,20
tomato	6,00	15,00	10,50	6,00	15,00	10,50	18,00	373,33	3,00	5,00	4,00	3,00	11760,00	11760,00	211680,00
peppers	2,20	8,16	5,18	6,60	24,48	15,54	18,00	373,33	3,00	4,00	3,50	5,00	9669,33	29008,00	522144,00
													TOTAL	69632,27	1253380,80

Figure 23. Calculation of crop residue per year

From a total of 373030 kg of crop residue , 149212 m³ methane gas can be produced. This means that 2838 light bulbs of 60 Watt can be lit all year round.

x 2838

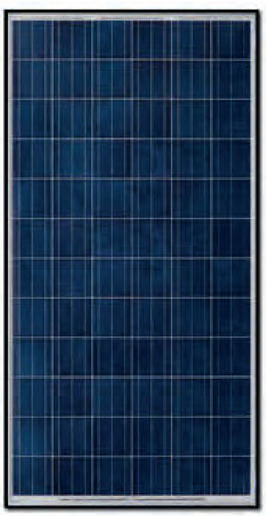
for 24 hours a day

for 365 days

SOLAR PANELS

Another source for energy would be solar panels. Since this form of energy is not dependent on the size of the aquaponics system, I decided to go with a calculation where the minimum would be half the roof covered with solar panels and the maximum would be the whole roof (see appendix C).

The minimum amount of solar panels comes down to 3000 panels, and the maximum is 6000 panels.



This means that a minimum of 2500 and a maximum of 5000 light bulbs of 60 Watt can be lit for 24 hours a day for an entire year.

Fig 24. Commercial solar panel from sunmetrix.com

FISH PRODUCTION

Since the fish in aquaponics only have output, namely themselves, they are discussed last. The topics discussed before all had a role in the input involving the system.

In reality it is possible to have multiple cycles to accommodate weekly or even daily harvests. But since I want to know the possible output in a time-span of one year where a full cycle takes place, I chose tilapia as the fish species. Tilapia has a maturity time of 6 months, which means it is possible to harvest twice a year. From earlier calculations we know that 9240 kg of fish is needed for a system of 2240 m².

Tilapia reaches maturity at an approximate size of 0,5 kg. For a necessity of 9240kg of fish this means that :

$$\frac{9240 \text{ kg}}{0{,}5 \text{ kg}} = 18480 \text{ fish}$$

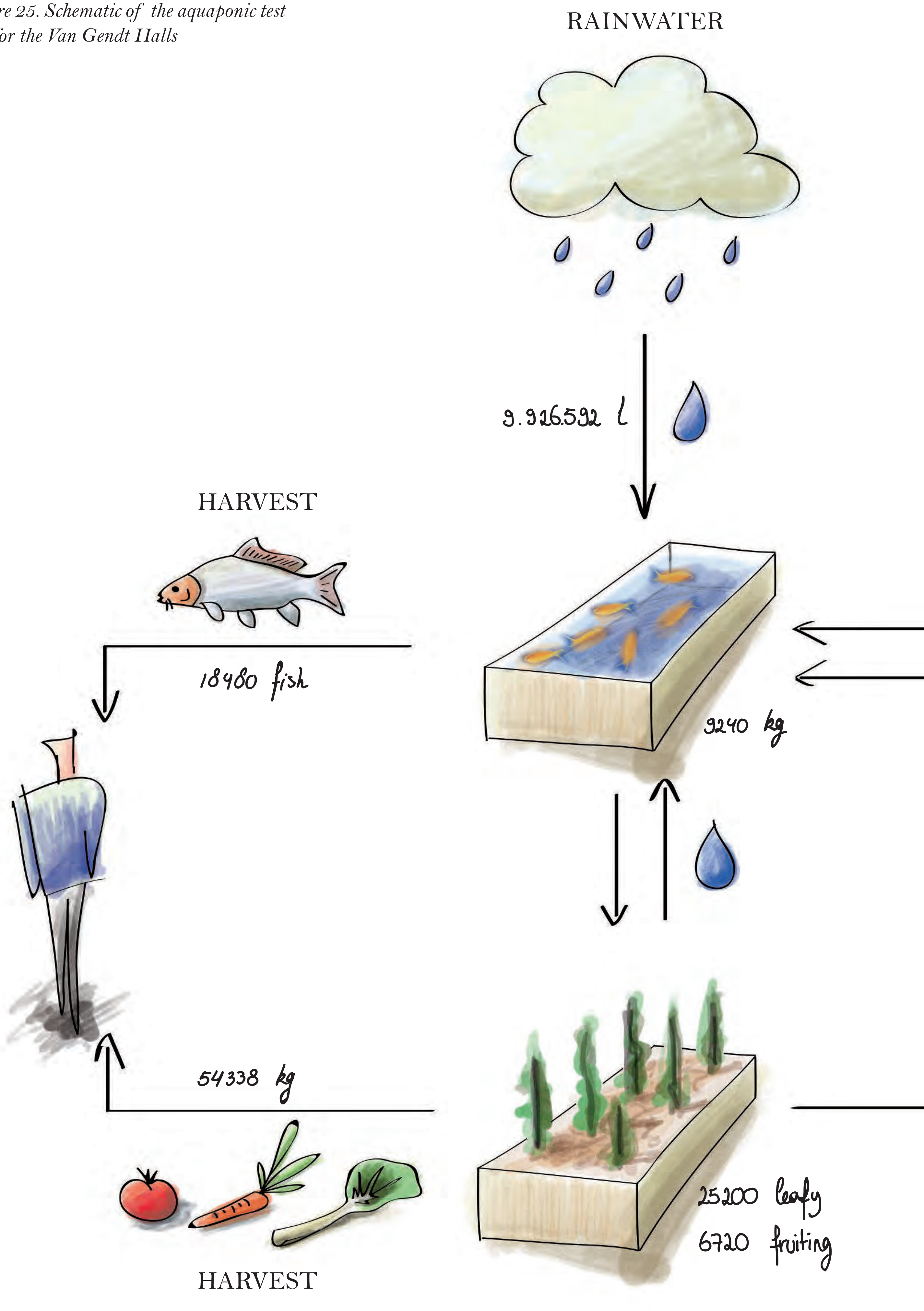
So 18480 fish are needed to keep the system running. Since tilapia can be harvested twice a year, this means that a total of 36960 tilapias (0,5 kg per tilapia) are harvested in one year.

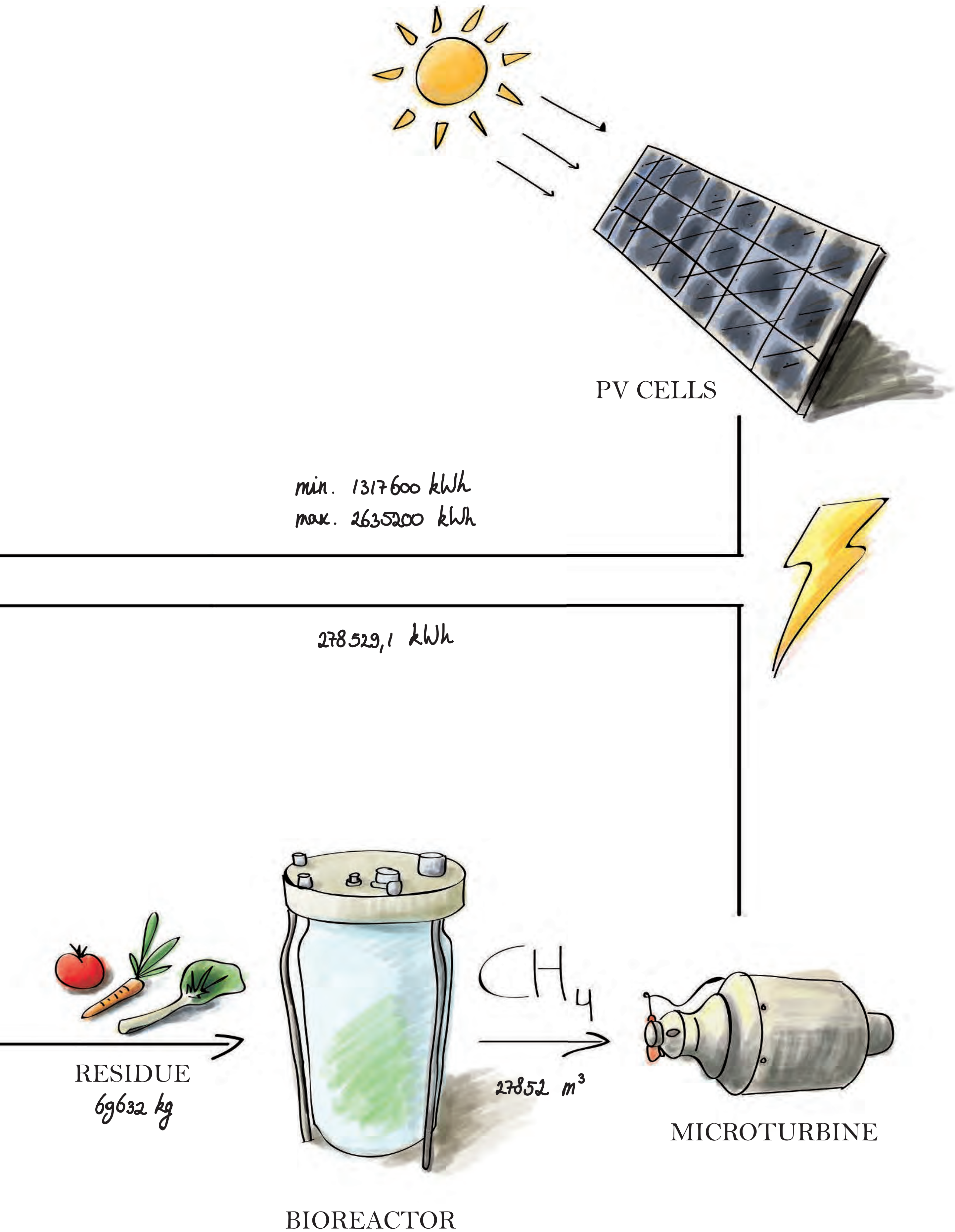
From earlier calculations we know that 49500 kg of fish is needed for a system of 12000 m². This means that:

$$\frac{49500 \text{ kg}}{0{,}5 \text{ kg}} = 99000 \text{ fish}$$

So 99000 fish are needed to keep the system running. Since tilapia can be harvested twice a year, this means that a total of 198000 tilapias (0,5 kg per tilapia) are harvested in one year.

Figure 25. Schematic of the aquaponic test case for the Van Gendt Halls




PV CELLS
min. 1317600 kWh
max. 2635200 kWh
278529,1 kWh
CH4
RESIDUE
69632 kg
27852 m3
MICROTURBINE
BIOREACTOR

CONCLUSION

The aim of the design is to achieve integration between aquaponic production and actually experiencing it. Instead of being a separate, closed-off unit located in the countryside, it can be a valuable addition to the city and provide green space and a supply of food. The research for the graduation design is focused on the aquaponic system and what it can mean for a building. The in- and output of the system is quantified and put in perspective, whether it be from aquaponics to building or the other way around.

First, thorough knowledge on a few subjects was gathered: aquaponics, agriculture and biomass. The result is focused on aquaponics: a short but informative chapter about aquaponics, what is it and what can it do. The second part takes all three subjects into account with a short addition on rain- and filtered water. From this an aquaponic test case is made for the Van Gendt Halls. Now we understand what such a system on such a scale can produce, and what it needs (for a schematic summary, see figure 25 on page 16-17).

If you look at the energy possibilities of the bioreactor + microturbine and the solar cells it is certainly an idea to strive towards energy neutrality. Since there was only a calculation made to illustrate how many light bulbs could be lit, this idea deserves further exploration and perhaps calculation.

The idea is to combine functions with the aquaponic system so that people are involved to a certain degree. This can be simply seeing it, or even helping in harvest. A few obvious functions to combine with food production are a restaurant or café and a supermarket/farmers market. There is also a possibility to create an educational program on aquaponics or even cooking. Plants could be grown and sold. Because of the greenery and the fish, it could also become a place to relax with for example a book. Perhaps a small library could be part of the program.

The building could give back even more to the city by adding a water treatment facility just like in Emmen Zoo. From calculations it is not necessary for the aquaponic system, but it could be a great addition to aid water treatment of the city and show the possibilities of green in the city.
There are also a few drawbacks to aquaponics at this location. The whole system (water and plants) is very heavy. It might not be possible to really go into the height of the halls or even just the ground floor without extra support needed within the foundations.

It also needs proper care and knowledge to keep an aquaponics system running. For a system this large it is essential that the correct staff is hired. Of course, this means that there will also be job possibilities which might be beneficial for the area.

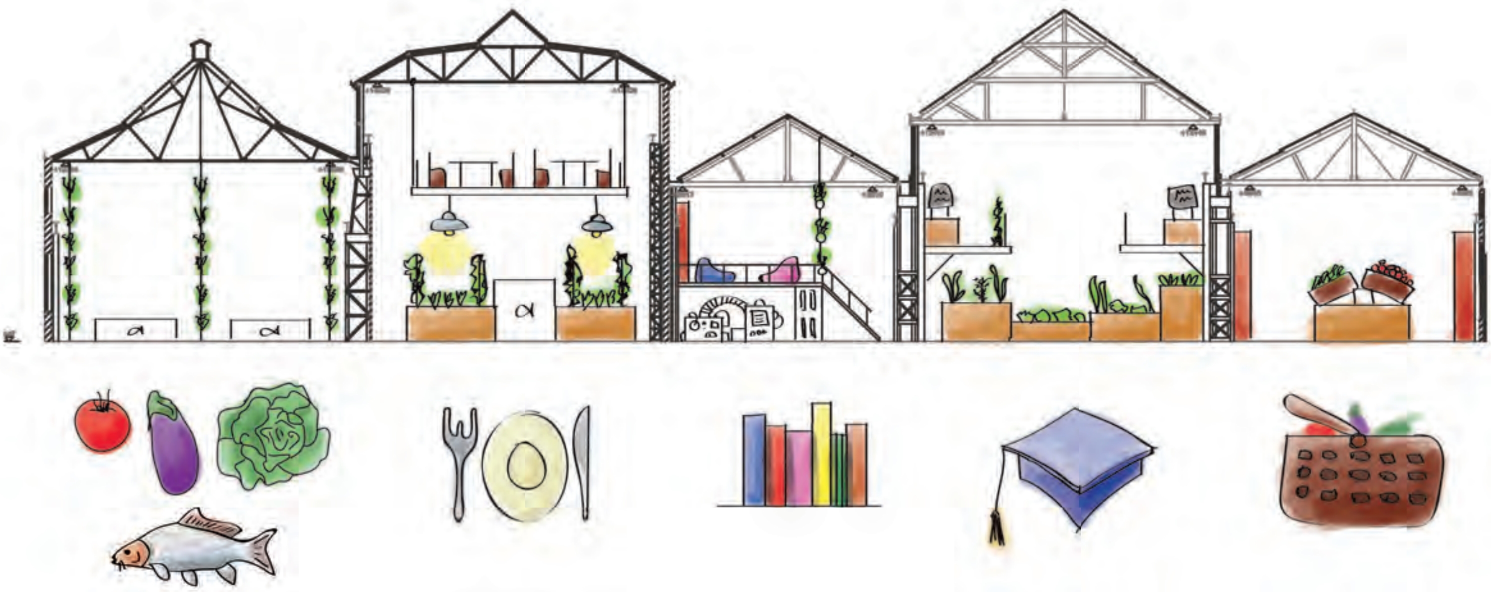


Figure 26. Conceptual section of the Van Gendt halls

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LIST OF FIGURES

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APPENDIX A: AQUAPONICS CALC.

To calculate the aquaponic system these numbers were used (Somerville et al., 2014):

- leafy plants can be planted at an average of 20 to 25 plants per m^2
- fruiting plants can be planted at an average of 4 to 8 plants per m^2
- 40 to 50 grams of fish feed per m^2 per day for leafy green plants is needed
- 50 to 80 grams of fish feed per m^2 per day for fruiting plants is needed
- the fish feeding rate is 1 to 2% of their body weight per day
- fish stocking density for beginners is a maximum of 0,02 kg per litre
- biofiltration volume is 1l per gram of daily feed for cinders in media beds or 0,5l per gram of daily feed for bioballs in NFT and DWC

So for a system with a desired $m^2 = 2240\ m^2$ (see page 12) the following calculations were made:

step 1: determine the % of leafy/fruiting plants. I chose for 50% leafy and 50% fruiting
step 2: calculate the min and max amount for the plants

formula: $x = \dfrac{a \cdot b}{\left(\frac{100}{c}\right)}$ where x = amount of plants
$a = m^2 = 2240$
b = amount of plants per m^2
→ leafy 20 to 25
→ fruiting 4 to 8

FORMULA $X = \dfrac{a \cdot b}{\left(\frac{100}{c}\right)}$ WHERE X = AMOUNT OF PLANTS
$a = m^2 = 2240$
b = AMOUNT OF PLANTS PER M^2
→ LEAFY 20 TO 25
→ FRUITING 4 TO 8
c = PERCENTAGE OF PLANTS

LEAFY MIN $X = \dfrac{2240 \cdot 20}{\left(\frac{100}{50}\right)} = 22400$

MAX $X = \dfrac{2240 \cdot 25}{\left(\frac{100}{50}\right)} = 28000$

FRUITING MIN $X = \dfrac{2240 \cdot 4}{\left(\frac{100}{50}\right)} = 4480$

MAX $X = \dfrac{2240 \cdot 8}{\left(\frac{100}{50}\right)} = 8960$

step 3: calculate the min and max amount for the fish feed

FORMULA $X = \dfrac{a \cdot b}{\left(\frac{100}{c}\right)}$ WHERE X = AMOUNT OF FISH FEED

$a = m^2 = 2240$

b = FISH FEED PER M^2

→ LEAFY 40 TO 50

→ FRUITING 50 TO 80

c = PERCENTAGE OF PLANTS

LEAFY MIN $X = \dfrac{2240 \cdot 40}{\left(\frac{100}{50}\right)} = 44800$

MAX $X = \dfrac{2240 \cdot 50}{\left(\frac{100}{50}\right)} = 56000$

FRUITING MIN $X = \dfrac{2240 \cdot 50}{\left(\frac{100}{50}\right)} = 56000$

MAX $X = \dfrac{2240 \cdot 80}{\left(\frac{100}{50}\right)} = 89600$

step 4: calculate the min and max amount for the average biomass of fish

FORMULA $X = a \cdot \left(\frac{100}{b}\right)$ WHERE X = FISH BIOMASS

a = AMOUNT OF FISH FEED

b = MIN 1, MAX 2

FOR AVERAGE: $X = \dfrac{a \cdot \left(\frac{100}{b_1}\right) + a \cdot \left(\frac{100}{b_2}\right)}{2}$

gr ↓ kg

AVERAGE: $X = \dfrac{\left[\dfrac{a \cdot \left(\frac{100}{b_1}\right) + a \cdot \left(\frac{100}{b_2}\right)}{2}\right]}{1000}$

LEAFY MIN $X = \dfrac{\left[\dfrac{44800 \cdot \left(\frac{100}{1}\right) + 44800 \cdot \left(\frac{100}{2}\right)}{2}\right]}{1000}$

$= 3360$ kg FISH BIOMASS

$$\text{LEAFY MAX} \quad X = \frac{\left[\dfrac{56000 \cdot \left(\frac{100}{1}\right) + 56000 \cdot \left(\frac{100}{2}\right)}{2}\right]}{1000}$$

$$= 4200 \text{ kg FISH BIOMASS}$$

$$\text{FRUITING MIN} \quad X = \frac{\left[\dfrac{56000 \cdot \left(\frac{100}{1}\right) + 56000 \cdot \left(\frac{100}{2}\right)}{2}\right]}{1000}$$

$$= 4200 \text{ kg FISH BIOMASS}$$

$$\text{FRUITING MAX} \quad X = \frac{\left[\dfrac{89600 \cdot \left(\frac{100}{1}\right) + 89600 \cdot \left(\frac{100}{2}\right)}{2}\right]}{1000}$$

$$= 6720 \text{ kg FISH BIOMASS}$$

step 5: calculate the min and max amount for the water

$$\text{FORMULA} \quad X = \frac{a}{b} \qquad \text{WHERE} \quad a = \text{FISH BIOMASS}$$

$$b = \text{STOCKING DENSITY}$$

$$\rightarrow \text{MAX } 0{,}02 \text{ kg}/\ell \text{ FOR BEGINNERS}$$

$$\text{LEAFY MIN} \quad X = \frac{3360}{0{,}02} = 168000 \text{ litres}$$

$$\text{MAX} \quad X = \frac{4200}{0{,}02} = 210000 \text{ litres}$$

$$\text{FRUITING MIN} \quad X = \frac{4200}{0{,}02} = 210000 \text{ litres}$$

$$\text{MAX} \quad X = \frac{6720}{0{,}02} = 336000 \text{ litres}$$

step 6: calculate the biofiltration volume cinders in media bed

FORMULA $X = a \cdot b$ WHERE X = BIOFILTRATION VOLUME CINDERS MEDIA BED

a = 1 l/daily feed

b = FISH FEED

LEAFY MIN $X = 1 \cdot 44800 = 44800$

MAX $X = 1 \cdot 56000 = 56000$

FRUITING MIN $X = 1 \cdot 56000 = 56000$

MAX $X = 1 \cdot 89600 = 89600$

step 7: calculate the biofiltration volume bioballs in NFT and DWC

FORMULA $X = a \cdot b$ WHERE X = BIOFILTRATION VOLUME bioballs IN NFT / DWC

a = 0,5 l / daily feed

b = FISH FEED

LEAFY MIN $X = 0{,}5 \cdot 44800 = 22400$

MAX $X = 0{,}5 \cdot 56000 = 28000$

FRUITIN MIN $X = 0{,}5 \cdot 56000 = 28000$

MAX $X = 0{,}5 \cdot 89600 = 44800$

Summary of the results from excel:

AVERAGE FOR A SYSTEM OF 2240 M²	leafy plants	fruiting plants	TOTAL
amount of plants	25200	6720	31920
fish feed per day in gram	50400	72800	123200
average fish biomass in kg	3780	5460	9240
average amount of water in l	189000	273000	462000
biofiltration volume cinders in media bed in l	50400	72800	123200
biofiltration volume bioballs in NFT and DWC in l	25200	36400	61600

The entire calculations are also in excel, where only the desired m² and percentage of leafy plants have to be put in. To download the excel file, scan the QR-code on the right or go to:

https://www.dropbox.com/s/z5ln4q9v7r070oy/SHEET%20AQUAPONICS.xlsx?dl=0

APPENDIX B : PLANTS + BIOMASS

LEAFY PLANTS											
name	plants/m² min	plants/m² max	yield (kg/plant)	yield (kg/m²)		category	harvest index	crop residue (kg/m²)		energy (heating) value of average crop residue (Mj/kg)	times harvest per year
basil	8	40									
lettuce	20	25	0,09 - 0,18	1,8	4,5	vegetable	0,67	0,89	2,22	18,00	7,00
swiss chard	15	20	0,2	3,6	5,4	vegetable	0,38	5,87	8,81	18,00	7,00
parsley	10	15									
coriander	8	40									
pak choi	20	25	0,09 - 0,18	1,8	4,5	vegetable	0,67	0,89	2,22	18,00	7,00
celery	15	20	0,3	4,5	6	vegetable	0,75	1,50	2,00	18,00	3,00
spinach	20	25	0,125	1,8	3,17	vegetable	0,67	0,89	1,56	18,00	7,00

FRUITING PLANTS											
name	plants/m² min	plants/m² max	yield (kg/plant)	yield (kg/m²)		category	harvest index	crop residue (kg/m²)		energy (heating) value of average crop residue (Mj/kg)	times harvest per year
cauliflower	3	5	1	3,6	4,5	vegetable	0,33	7,31	9,14	18,00	6
cucumber	2	5	1 - 2	3,6	4,6	vegetable	0,2	14,4	18,4	18,00	6
eggplant	3	5	1 - 2	3	8	vegetable	0,33	6,09	16,24	18,00	4
peppers	3	4	0,7 - 2	2,2	8,16	vegetable	0,25	6,6	24,48	18,00	5
tomato	3	5	3	6	15	vegetable	0,5	6	15	18,00	3
head cabbage	4	8	1,5	6	12	vegetable	0,67	2,96	5,91	18,00	5
broccoli	3	5	0,6	1,8	2,7	vegetable	0,33	3,65	5,48	18,00	5
okra	3	4	0,5	2,2	4,5	vegetable	0,38	3,59	7,34	18,00	6
beans/peas bush	20	40	0,1 - 0,05	1,3	2,2	legume	0,2	5,20	8,80	18,00	6,00
beans/peas climbing	10	12	0,2	1,3	2,3	legume	0,2	5,20	9,20	18,00	5,00

The tables above show all the gathered information on different kinds of plants suitable for aquaponics. The image below shows all the information and calculated output for the salad setup used in the calculations.

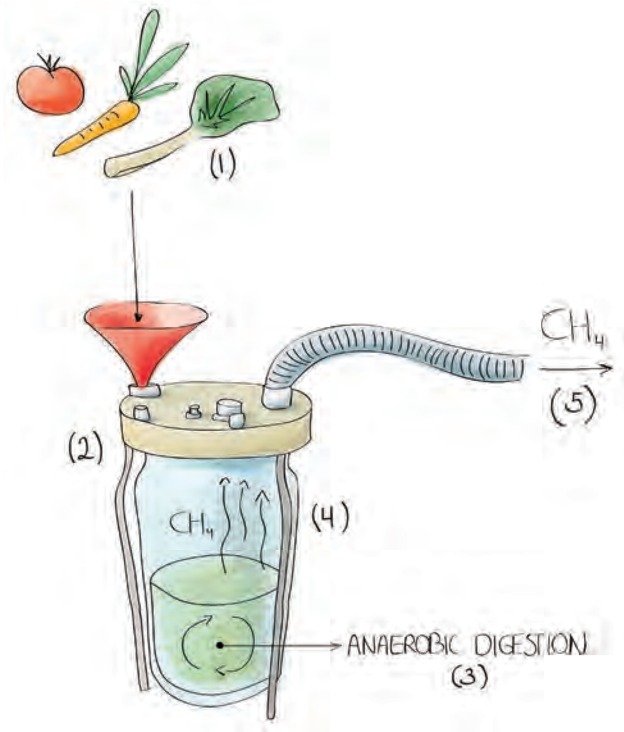
	yield kg/m²			crop residue kg/m²			energy value of average crop residue (Mj/kg)	m² of plants	plants/m²			times of harvest per year	yield kg per year	crop residue kg per year	energy value crop residue Mj
PICK A LEAFY PLANT	min	max	avg	min	max	avg			min	max	avg				
lettuce	1,80	4,50	3,15	0,89	2,22	1,56	18,00	560,00	20,00	25,00	22,50	7,00	12348,00	6095,60	109720,80
lettuce	1,80	4,50	3,15	0,89	2,22	1,56	18,00	560,00	20,00	25,00	22,50	7,00	12348,00	6095,60	109720,80
PICK A FRUITING PLANT	min	max	avg	min	max	avg									
eggplant	3,00	8,00	5,50	6,09	16,24	11,17	18,00	373,33	3,00	5,00	4,00	4,00	8213,33	16673,07	300115,20
tomato	6,00	15,00	10,50	6,00	15,00	10,50	18,00	373,33	3,00	5,00	4,00	3,00	11760,00	11760,00	211680,00
peppers	2,20	8,16	5,18	6,60	24,48	15,54	18,00	373,33	3,00	4,00	3,50	5,00	9669,33	29008,00	522144,00
													TOTAL	69632,27	1253380,80

But the plant output can be used for more than salad-ingredients. The crop residue in kg per year that is calculated can be converted into methane by a bioreactor. This methane can produce a certain amount of kWh. Then, the standard kWh for a 60 Watt light bulb is calculated. If one divides the kWh from the methane with the kWh needed for one light bulb, the result is the amount of light bulbs that can be lit with the methane.

Again, all these calculations were made in excel. If you are interested in the excel file, please refer to the QR-code mentioned in appendix A.

Total crop residue	69632,27	kg	
methane yield	400	l/kg	
total methane yield	27852907	l	crop residue x methane yield
total methane yield	27852,91	m³	l -> m³
1 m³ methane is 10 kWh	278529,1	kWh	m³ -> kWh
a standard light is 60 Watt or 0,06 kilowatt			
so 0,06 kW * 24 hours * 365 days = 0,06 kW * 8760 hours = 525,6 kWh energy to light a bulb all year round			
amount of bulbs all year round	529,9259		kWh methane / 525,6 to light a bulb

What is a Bioreactor?



A bioreactor is where a chemical process takes place. This can be water cleaning, methane gas production or even algae growth. In this case I'm talking about the production of methane gas.
The crop residue from the aquaponic system (1) is loaded into the bioreactor (2). Under controlled circumstances the waste goes through the anaerobic digestion (3). This process involves a series of metabolic reactions such as hydrolysis, acidogenesis and methanogenesis (see "*chemical cycle of anaerobic digestion*"). One of the products is methane gas (4). This is what we want, since it can be transported to a microturbine which will use it to generate electricity.

Chemical cycle of anaerobic digestion

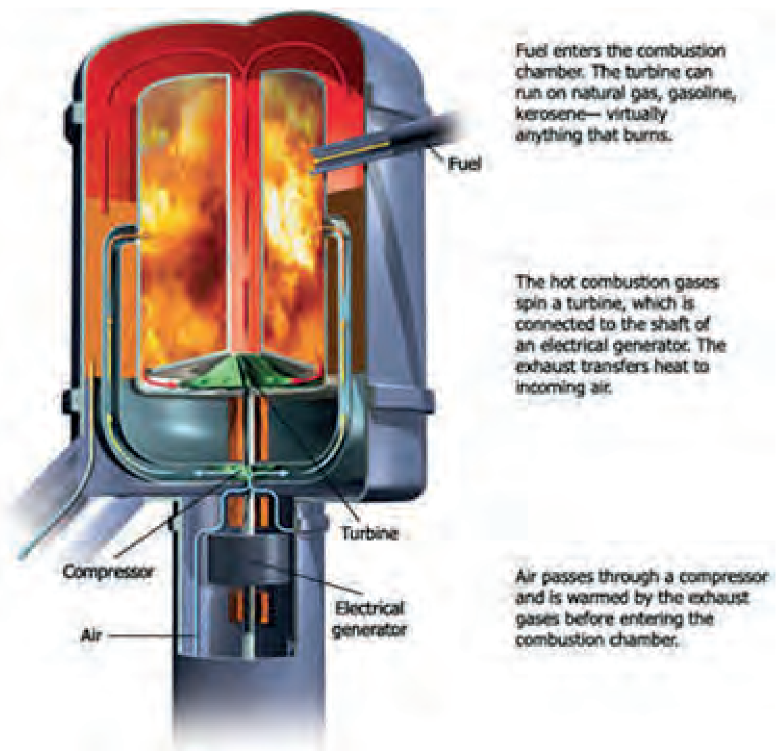
Fruit and vegetable waste (cellulose, fat, protein, lignin and sugars)	Hydrolysis →	Amino acids, alcohols, sugars and acids	Acidogenesis → Acetogenesis	H_2 CO_2 Acetate	Methanogenesis →	H_2O CO_2 CH_4

What is a Microturbine?

Microturbine Overview:

Commercially Available	Yes (Limited)
Size Range	25-500 kW
Fuel	Natural gas, hydrogen, propane, diesel
Efficiency	20-30% (Recuperated)
Environmental	Low (<9-50 ppm) NOx

Microturbines are small combustion turbines approximately the size of a refrigerator with outputs of 25 kW to 500 kW. They evolved from automotive and truck turbochargers, auxiliary power units (APUs) for airplanes, and small jet engines. Most microturbines are comprised of a compressor, combustor, turbine, alternator, recuperator (a device that captures waste heat to improve the efficiency of the compressor stage), and generator. The figure to the right illustrates how a microturbine works.



Taken from: http://www.wbdg.org/resources/microturbines.php

APPENDIX C: SOLAR ENERGY

CONCERNING SOLAR PANELS

Length and Width – Although length and width varies slightly, most companies are manufacturing solar panels in standard sizes. The most typical size used for residential installations is 65 inches by 39 inches, while the common size for commercial applications is 77 inches by 39 inches. The smaller size is a better fit for residential projects to maximize available roof space. Most commercial projects have hundreds of panels and this is why the slightly larger panel is a more ideal choice.

Taken from: http://brightstarsolar.net/2014/02/common-sizes-of-solar-panels/

Solar panel size http://sunmetrix.com/solar-panel-size-for-residential-commercial-and-portable-applications/

What's the typical solar panel output?

The average solar panel output ranges from about 175 W to about 235 W, with an exceptionally powerful solar panel measuring 315 W. Among the top ten manufacturers, the average wattage of a panel is about 200 W.*

Taken from: http://pureenergies.com/us/how-solar-works/solar-panel-output/

From the information above it is known that a common commercial solar panel has a size of about 100 cm by 195 cm (= +- 2 m²) and a wattage of 200 Watt. From the table to the right I calculated the hours of sun in a year in Amsterdam (*http://www.holiday-weather.com/amsterdam/averages/*).

month	days	total hours of sun
jan	31	93
feb	28	140
mrt	31	186
apr	30	300
may	31	310
jun	30	330
jul	31	310
aug	31	248
sept	30	210
oct	31	186
nov	30	90
dec	31	93
TOTAL		2496

So one panel of approximately 2 m² has an energy output of 0,2 kW x 2496 hours = 439,2 kWh per year. As said a few times before, the roof has an area of about 12000 m². To give an idea of a minimum and maximum output I decided to take half the roof as the minimum and the entire roof as a maximum. From the calculation below the results are as follows:

- with 6000 m² filled with panels of 2 m² and an output of 0,2 kW, 1317600 kWh can be generated in an entire year. This means that 2506 light bulbs of 60 Watt can be lit, all day, all year.
- with 12000 m² filled with panels of 2 m² and an output of 0,2 kW, 2635200 kWh can be generated in an entire year. This means that 5013 light bulbs of 60 Watt can be lit all day, all year.

$\frac{1}{2}$ ROOF = 6000 m²

$\frac{\text{TOTAL AREA}}{\text{PANEL AREA}}$ = AMOUNT OF PANELS

$\frac{6000\ m^2}{2\ m^2}$ = 3000 panels

3000 panels x 439,2 kWh = 1.317.600 kWh

1 BULB LIT FOR ONE ENTIRE YEAR = 525,6 kWh

$\frac{1.317.600}{525,6}$ = 2506 light bulbs

ENTIRE ROOF = 12000 m²

$\frac{\text{TOTAL AREA}}{\text{PANEL AREA}}$ = AMOUNT OF PANELS

$\frac{12000\ m^2}{2\ m^2}$ = 6000 panels

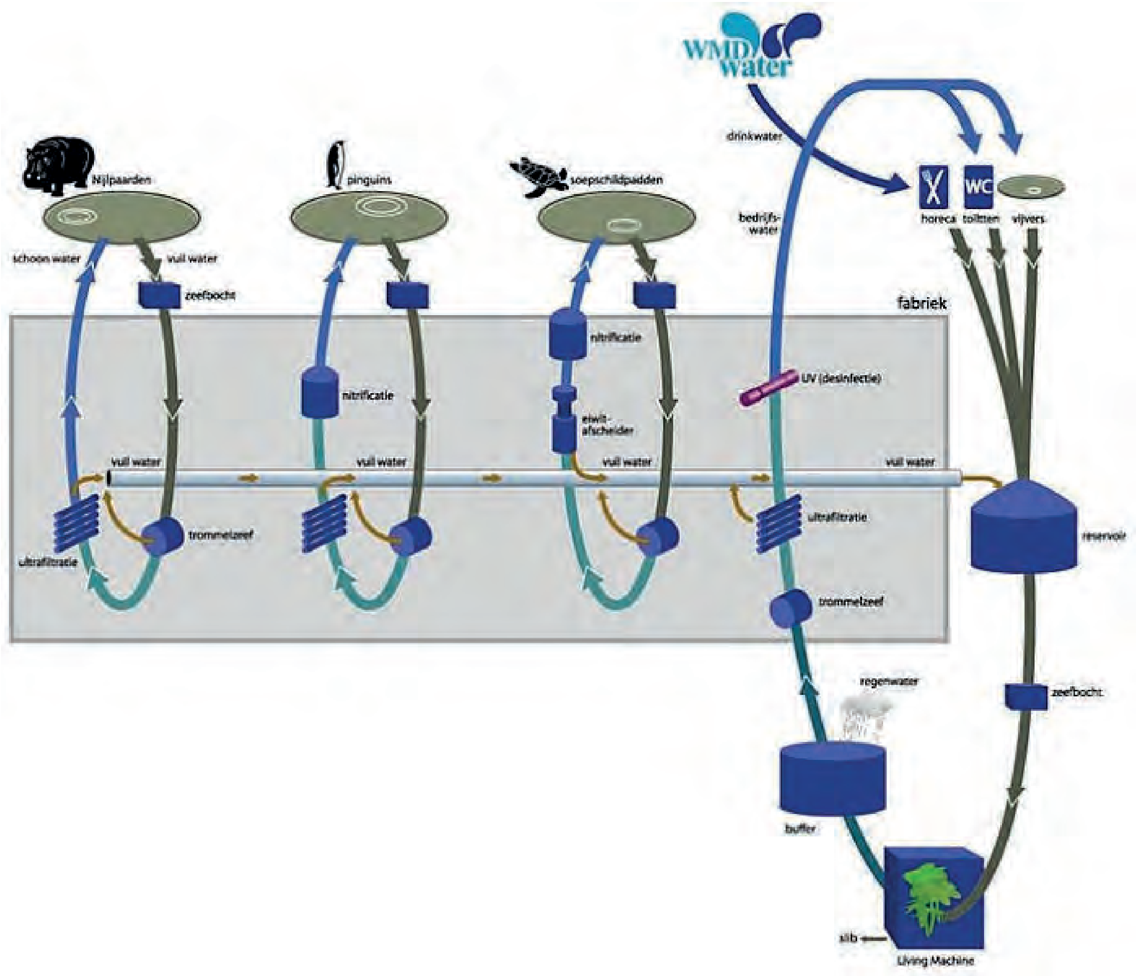
6000 panels x 439,2 kWh = 2635200 kWh

1 BULB LIT FOR ONE ENTIRE YEAR = 525,6 kWh

$\frac{2.635.200}{525,6}$ = 5013 light bulbs

APPENDIX D: THE WATERFACTORY

http://www.groenblauwenetwerken.com/uploads/Waterfabriek-001B-Waterleidingmaatschappij-Drenthe-1300x650.jpg



http://www.dierenparkemmen.nl/uploads/lightbox/d9acc66f-4f2c-45a6-881e-cd7e2926b961