Hygrow Aquaponics

A system that combines aquaculture with hydroponics in a symbiotic environment

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Abstract

This Final Report summarises the research, study and work on the Aquaponics system at Novia University of Applied Sciences in Vaasa, Finland. The team continues the project started by the group of students in the winter semester 2019. The Hygrow Aquaponics 2020 Team has been tasked with creating the sustainable aquaponic system together with the greenhouse benefiting from the achievements of the previous team.

The report is divided into chapters devoted to significant parts of the project. The subjects of the project study were aquaponics system operation, controlling unit, system design, energy, greenhouse design as well as finance and public relations. Each chapter includes the research, design or solution implementation, conclusions and recommendations. Building parts are present in the Aquaponics and Greenhouse chapters.

The research resulted in designing a system that fits the size of the greenhouse to be placed on the university roof. It was also decided to establish the ecosystem with leafy vegetables, herbs along with Koi Carps, shrimps and nitrifying bacteria.

After the research, the team worked on designs. The aquaponics modular model consists of two Deep Water Culture units, Vertical Towers unit, fish tank, biofilter tank, settling tank and water storage containers. The greenhouse project comprises the construction of walls and floor corresponding to climatic conditions in Finland during spring and summer. Both the greenhouse and the aquaponics system are equipped with devices to monitor and control their operation in order to automate their performance. Moreover, the energy part focuses on energy consumption and production.

Afterwards, the building process is explained to give a full insight into the stages of modules development. Simultaneously, the greenhouse and the aquaponics system were built. All the systems we built were described and documented with photographs.

The summary of each chapter and the whole report are our conclusions and recommendations. The conclusions describe how the objectives were achieved. The recommendations give our advice to the future project group, who can improve our designs and implement unfinished ideas.

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Foreword

This Report was written by 8 European students from different countries, namely: Germany, Belgium, France, Poland and Italy. During the presentation of the different projects at the beginning of the semester, we found the Aquaponics Hygrow project the most interesting.

The project is a very innovative project, that provides new insights in the field of sustainable entrepreneurship. The old food production model is being reinvented. With this model you can save on ground surface as well as raw materials and transportation costs. This makes it interesting for economic and sustainable interested parties.

During the spring semester, all the resources have been made accessible by Novia UAS, were available on the Technobothnia campus. Furthermore, the Svenska Kulturfonden has provided us with a budget, that we will use to build for the future of the Aquaponics project. Therefore, we would like to thank them. We would also like to acknowledge the previous team working on this project. The knowledge we were given as well as their own work helped us significantly in developing the project.

In particular, we would like to thank our coaches Mikael Ehrs and Rayko Toshev for their insights and advice. We would also like to thank Roger Nylund for the Project Management courses and Hanna Latva for the English courses. They made us better writers and managers.

Sponsors

Abbreviations

Abbreviation	Explanation
AC	Alternating current
ADC	Analog to digital converter
ATP	Adenosine triphosphate
BSA	Bacterial Surface Area
COP	Coefficient of Performance (efficienty of the heat pump)
CPU	Central Processing Unit
CSS	Cascaded Style Sheet
DAC	Digital to analog converter
DBMS	Database Management System
DC	Direct current
DNA	Deoxyribonucleic acid
DO	Dissolved Oxygen
DWC	Deep Water Culture
EC	Electrical conductivity
etc	Et cetera, and the rest
gH	General Hardness
GPU	Graphic Processing Unit
G^r	The total grams of feed given daily to the fish
HSA	Hydroponic Surface Area
ISO	International Organization for Standardization
KB	Kilobyte
KH	Carbonate Hardness
LED	Light-emitted diode
MHz	Megaherz
MQTT	MQ Telemetry Transport
N.S.	Not specified
NFT	Nutrient Film Technique
nRCA	Raincoast Aquaponics
OS	Operation System
PAR	Photosynthetically Active Radiation
pH	Power of hydrogen
ppm	Parts per million
RAM	Random-Access Memory
RFS	Radial Flow Separator
SATA	Serial ATA
SBC	Single-Board Computer
SQL	Structured Query Language
TDS	Total Dissolved Solids
UAS	University of Applied Sciences
UV	Ultraviolet
WBS	Work Breakdown Structure
WR	Water resistant
ZDEP	Zero Discharge-Extra Production

List of chemical compounds

Formula	Chemical compound
B	Boron
Ca	Calcium
$Ca(OH)_2$	Calcium hydroxide
$CaCO_3$	Calcium carbonate
CO_2	Carbon dioxide
Cu	Copper
Fe	Iron
K	Potassium
K_2CO_3	Potassium carbonate
KOH	Potassium hydroxide
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N.S.	Not specified
N_2	Nitrogen
NH_3-N	Undissolved ammonia nitrogen
NH_4^+	Dissolved ammonium
NH_4^+-N	Undissolved ammonium nitrogen
NO_2^-	Nitrite
NO_3^-	Nitrate
O_2	Oxygen
TAN	Total ammonia nitrogen (NH_3-N + NH_4^+-N)
WR	Water resistant
Zn	Zinc

List of Units

Unit	Meaning
%	Percentage
°C	Degree Celsius
cm	Centimetre
g	Gram
kg	Kilogram
kWh	Kilo Watt Hour
L	Litre
m	Metre
mA	Milliampere
m^2	Square metre
m^3	Cubic metre
mg	Milligram
mg/L	Milligram per litre
mm	Millimetre
ppm	parts per million
V	Volt
W	Watt

Table of contents

1 Introduction

This chapter explains the aim of this project together with the motivation of the team as well as interested stakehlders. Final report is the result of teamwork on the aquaponics project during the European Project Semester. The project is being carried out at the Novia University of Applied Sciences in Vaasa, with the support of the Svenska Kulturfonden and the University of Vaasa.

The final report comprises the most essential parts of the project including the summaries and conclusions. Additional information and more detailed descriptions can be found in the "Handoff package".

1.1 Stakeholders

1.1.1 Novia UAS

Novia University of Applied Sciences is situated in the west of Finland. It is the largest Swedish-speaking University in Finland with over 4000 students and 300 personnel. The history and traditions of the UAS goes back to 1813. Novia University offers multidisciplinary higher education with a practical orientation. The school trains students to become experts and developers based on the requirements of working life. High quality degrees provide students with a proper platform for their future careers. (NoviaUAS, 2020)

1.1.2 University of Vaasa

The University of Vaasa is as the name states also located on the west coast of Finland. It consists of 4 schools for research and teaching: management, accounting and finance, marketing and communication and of technology and innovations. The school has over 5000 students and more than 450 personnel. (Univaasa, 2020)

1.1.3 Svenska Kulturfonden

The mission is to support and strengthen the culture and education of the Swedish-speaking minority in Finland, by supporting education, arts and culture and social growth through non-profit organisations. They invest around 36 million euro each year coming from 490 individual funds. They provide grants for individuals, working groups and projects who work on educational and cultural purposes and activities. (Kulturfonden, 2020)

1.1.4 Others

Indirectly other parties will also benefit from the information of our project. Like the agricultural sector can benefit from the advantages linked to doing aquaponics. Also, other schools who are focussing on an efficient and effective way of addressing today's problems like food supply, availability of clean water and air pollution. In one way or another the aquaponic system contributes to these problems.

1.2 Project Goals

1.2.1 Vision

The subject of our project is to create a sustainable way of growing plants and fish in an almost closed loop, called an aquaponic system. By creating fish and vegetables in compact and often vertical systems, there is no need for large pieces of land. This way of growing food can be implemented close by the supermarkets which results in a reduction in CO_2-emissions due to less transport. By using the water from the fish, which contains a lot of nutrients, these systems use up to 80% less water than classic agricultural models.

Vision: **"Make a thriving aquaponic system that can persuade and inspire people to rethink about the classic models of food production in a sustainable way."**

1.2.2 Mission

We will be the second group that will be working on this project and therefore we will have to take, the work from our previous colleagues to the next level. Also, after us there will be a next group working on the aquaponic system. Therefore, we will have to build for the future.

During our semester (spring semester 2020) the focus will lay on creating stand-alone aquaponic systems where we can benefit from. With this we mean getting knowledge for educational reasons and making it more profitable for economic reasons.

The system must be sustainable in the first place but also flexible. It should be modular and be able to be reassembled. We will enlarge the existing system according to a 'plug and play' system and focus on the controlling part to get more data, where we can extract information from to learn about the different pros and cons from the different systems. All of this will consume energy, that we will try to compensate with the production of renewable energy.

Mission: **"Build for the future by making a flexible aquaponic system setup where we focus on learning from different stand-alone systems by collecting automated data and powering it with renewable energy."**

1.3   The Team

The project team consists of a multi-disciplinary and multi-cultural team. Team members possess the knowledge from the fields of study such as biotechnology, energy management, electrical engineering, industrial engineering and product development.

During the project, team members have to combine their competences to complete different tasks in the project. This smaller teams can change during the project because of the different tasks. The overall goal is to achieve the mission of our semester together by combining the different competences of the group. This can be seen in Table 1.

Table 1.1 Team Knowledge (Hygrow Aquaponics, 2020)

Field of expertise	Project members
Biochemical Engineering	Natalia
Electrical / Electronic engineering	Stefan, Karina, Filippo
Management	Karina, Sascha, Felix
Informatics	Stefan, Karina, Filippo
Mechanics Engineering	Maxime
Energy Management	Felix, Sascha
Marketing	Arthur, Natalia, Karina
Accounting	Karina, Sascha

2   Aquaponics

2.1   Introduction

The aim of this chapter is to introduce the concept of aquaponics, explain how it works and show the system as an environmentally friendly model of agriculture. Following discussion would give an insight into the reasons why the aquaponics project is beneficial for agriculture and further study. The full scope of research can be found in Handoff Package.

2.1.1   Hydroponics

Hydroponics is defined as a system of growing plants without soil. Crops are grown using rich in nutrients water flowing through the system and lighting provided by lamps or sunlight. Benefits of hydroponics method include elimination of factors that handicap plants cultivation. Soilless farming eliminates pests, fungi and diseases as well as weeds and stray seedlings. There is no need for usage of herbicides, pesticides thus labour costs are reduced. Furthermore, hydroponic farming increases yield of production and shortens crop maturation cycle. *(Roberto, 2001)*

2.1.2   Aquaculture

National Oceanic and Atmospheric Administration identifies the aquaculture as the breeding, rearing and harvesting aquatic organisms including fish, shellfish, algae and all other organisms in the controlled water environment. It is a method used to produce food as well as other commercial products, restore habitat or rebuild population of endangered species. Aquacultures can be cultivated in all types of water environment such as ponds, rivers, lakes, the ocean and man-made tanks. It is one of the fastest growing forms of food production covering the seafood demand on a worldwide scale. Basic division of aquaculture is based on the type of water in which organisms are raising. We distinguish marine aquaculture focusing on saltwater fish, oysters and algae production, and the freshwater aquaculture including trout, catfish and tilapia.

The aquaculture uses large amount of the resources. Growing fish involves frequent changes of large amounts of water, disposing quantities saturated with waste and harmful chemicals. Aquaponic farming takes advantage of fish farming while improving this technique by cooperation with plant growing, providing farmers with cost effective and water saving system.

(What is aquaculture?, 2020) (What is aquaculture? | National Oceanic and Atmospheric Administration, 2020)

2.1.3   Aquaponics Technology

According to Southern and King (2019), aquaponics is a combination of hydroponics and aquaculture. It is a system in which the plants grow in symbiosis with fish or other aquatic creatures. Since the system uses hydroponics technology, the aquaponic growing methods are soilless thus cultivation of the plants is possible due to the highly oxygenated, nutrient-rich water.

Aquaponics is a solution for the problems of hydroponics and freshwater aquacultures. The main issue that the aquaculture faces is increasing level of toxic ammonia in water caused by continuously produced fish waste. Too high concentration of ammonia kills all the living creatures in a water tank.

Aquacultures deal with this problem in two ways. First includes constant supply of fresh water while the other one uses expensive filtration systems. These solutions are far from ideal if they waste large quantities of water to run and release high-ammonia toxic water to the ecosystem.

Hydroponics struggle with necessity of large input of fertilizers. Soilless cultivation requires supplying with all nutrients for plants in continuous manner. Certainly, it generates high costs of production. Both chemical and organic fertilizers have disadvantages. Fossil-fuel derived fertilizer are not environmentally friendly and may harm the ecosystem while organic substituents are usually less soluble in water. What is more, hydroponic farms consume large quantities of water which must be replaced to keep a system in a chemical balance.

A combination of hydroponics and aquaculture known as aquaponics can solve the problems of both cultivation methods. Fish waste is converted into plant nutrient, becoming a high value fertilizer while the plants using the minerals created from waste act as a natural cleaner. The symbiosis of fish and plants is effective and environmentally friendly. The third essential part of the system is bacteria. Their role in the aquaponic system is to remove or decompose the metabolic wastes produced by the fish. Nitrifying bacteria serve as a biofilter, decomposing toxic ammonia contained in fish excreta, urine and uneaten fish feed. Removing ammonia from the system is crucial because when its level exceeds 3 ppm, the ammonia becomes harmful and even fatal to the fish. The nitrification process consists of two steps. Firstly, *Nitrosomonas* bacteria oxidize ammonia into nitrites, afterwards *Nitrobacter* genus oxidize nitrites into nitrates. Oxidation of ammonia by bacteria releases nitrates which are a bioavailable form of nitrogen, the mineral element necessary for plant growth. The organic particles are decomposed into their elemental forms by mineralizing bacteria. They source the energy from organic compounds such as fish feces and feed residues.

Jacobson (2016) states that the main advantages of aquaponic system are high productivity, self-regulation, cost efficiency and saving water. The system allows to grow vegetables, fruits, herbs and raise many species of fish. All the crops would be free of pesticides and chemicals used as soil fertilizers thus the aquaponics give us organic and healthy products. The aquaponics mimics the natural ecosystem therefore maintenance requirements are measurably lower in comparison to ordinary agriculture systems. An aquaponics farmer must only feed fish and perform a simple maintenance of the system. Another asset of this type of farming is limited usage of water and energy. In contradistinction to soil-based farming, water consumption in aquaponics may be 90 % lower.

2.1.4   The Types of Aquaponics

We differentiate several aquaponics systems whose names suggest the method of plant cultivation. In all these systems fish raising methods are very similar thus the focus is on way of plants production. Two basic principles must be followed in every kind of system. Water must be cycled between plants and fish tank, secondly bacteria participate in waste conversion. When designing the system, requirements such as providing plants fresh supply of water and nutrients, maintaining high level of gas exchange in the system and preparing the tools for system control must be kept in mind.

2.1.4.1   *Nutrient Film Technique (NFT)*

This concept involves placing the plants in an inverted ''V'' shape channel enclosed in the pipe, through which a film of nutrient solution passes. Roots grow down along the channel receiving water with

nutrients from the film located on the bottom of the pipes. Oxygen is accessible thank to the porosity of foam in which the plants are placed. Pumps and pipes system allow water to flow through, nutrients are collected and recycled for the next usage. *(Roberto, 2001)*

Nutrient Film Technique (NFT)
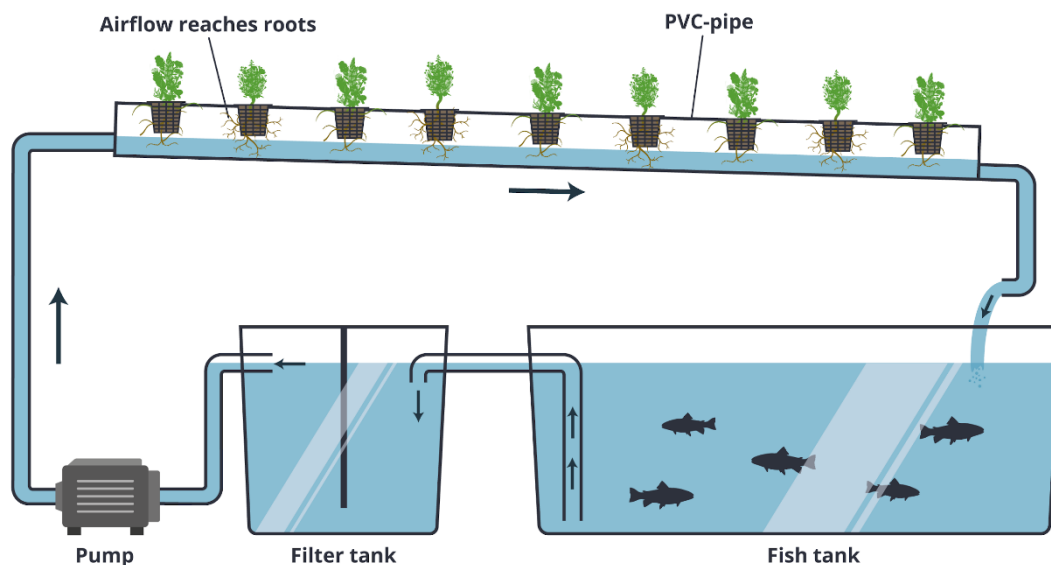
Figure 2.1 Nutrient Film Technique. (Verheyen L., 2019)

Strengths

Channels are enclosed, maintaining 100 % humidity which protects plants against dehydration. The evaporation is limited to the minimum thus the system requires less water. Constant water flow provides fresh nutrients all the time, gaining an advantage over soil-based farming. Furthermore, channel hydroponic infrastructure saves space and is easy to maintain. These features make the NFT system very efficient. This technique is recommended for beginners and due to convenient installation, ease of cleaning and fine adaptation for vertical growing. *(Aquaponics UK - a practical guide to producing fish and plants in a sustainable system, 2020) (Aquaponics.com, 2020) (Goddek et al., 2015)*

Weaknesses

On the other hand, NFT faces some problems making it perfect choice only for small scale gardening. The channel system can't support heavy plants, limiting production significantly. The nutrient film tends to be vulnerable to temperature fluctuations hence better and more expensive pumping systems are required. Another inconvenience is a separate biofilter tank because in the NFT there is not enough water amount and surface for bacteria growth. Very common issue found in this system is excessive root development and solid accumulation causing clogging and weaker nutrient distribution. *(Aquaponics UK - a practical guide to producing fish and plants in a sustainable system, 2020) (Aquaponics.com, 2020) (Goddek et al., 2015)*

2.1.4.2   Media-filled bed

In this system the plants are grown in a tank filled with media working as a plant bed, usually gravel, perlite or Styrofoam. The media bed is repeatedly flooded and washed out with water from the fish tank. All waste material is converted by bacteria living in the media bed. *(Aquaponics.com, 2020)*

Media Bed
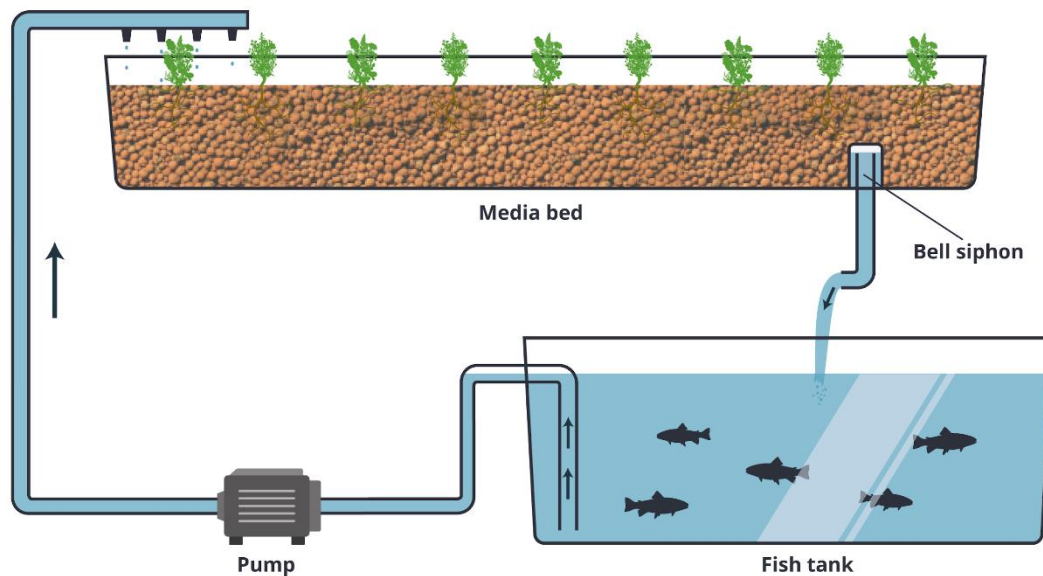
Figure 2.2 Media-filled bed system. (Verheyen L., 2019)

Strengths

One of the advantages in this system is biofiltration occurring in the media which serves substrates for nitrifying and mineralizing bacteria. Additional biofilter tanks are not necessary. The media bed also filtrates solids whereas the optional worm addition enhances decomposition process. Few components and in-system filtration make the media-filled bed system simple to operate. *(Aquaponics.com, 2020) (Goddek et al., 2015)*

Weaknesses

The biggest disadvantage of this system is space inefficiency. The media-filled bed system requires large space which makes maintenance and cleaning time consuming. Flooding the media bed must be provided by strong and reliable pump system, also the hydroponic infrastructure is heavy and inconvenient. In large scale aquaponics, this technique would be very labour intensive while producing less than other hydroponics methods. *(Aquaponics.com, 2020) (Goddek et al., 2015)*

2.1.4.3   Deep Water Culture (DWC)

This technique locates the plants at regular intervals into a floating raft usually made of Styrofoam. Water flows from the fish tank to the separate raft tank, the nutrients and fresh water are provided to plants and then they return to the fish tank. Additional tanks such as sedimentation tank and biofilter tank may be introduced to enhance system cleaning and waste conversion. *(Aquaponics.com, 2020) (Aquaponics UK - a practical guide to producing fish and plants in a sustainable system, 2020)*
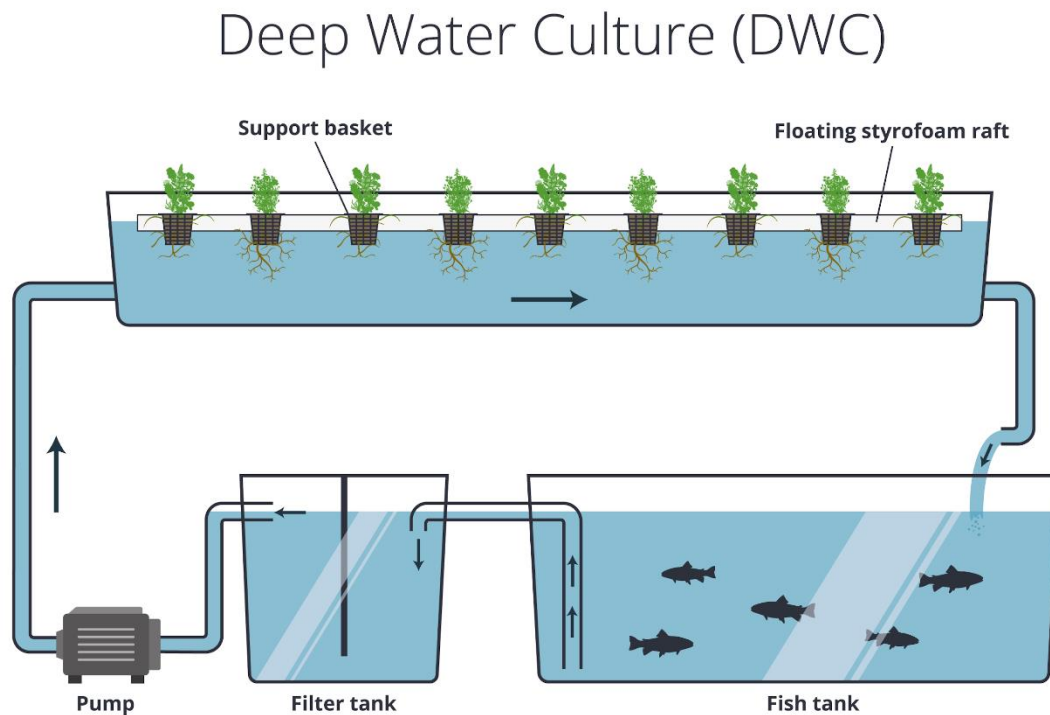
Figure 2.3 Deep Water Culture system. (Verheyen L., 2019)

Strengths

Large volumes of water in the raft tanks serve as a buffer for the fish by reducing stress and water temperature fluctuations. Constant water flow provides fresh nutrient solution and aeration, avoiding water stagnation. DWC is considered as a perfect system because it has a simple and inexpensive design which might be fully automated. Cleaning and maintenance are not labour intensive. What is more, cultivation and harvesting in rafts create a process line. Plant seedlings are transplanted on the one end of the raft, when they are harvested the raft is replanted on the opposite side. Floor space and production efficiency is largely increased by this method. *(Aquaponics.com, 2020) (Aquaponics UK – a practical guide to producing fish and plants in a sustainable system, 2020) (Roberto, 2001)*

Weaknesses

Like the NFT system, deep water culture is less suited for growing large plants with extensive roots which need more support than simple raft. Proper device for roots aeration such as air pump is obligatory in this system since plant roots are immersed in water. The lack of media bed imposes the use of separate filtration tank. Finally, this system requires bigger fish population to obtain more

waste converted into nutrients for plants because of larger water volumes. *(Roberto, 2001)* *(Aquaponics.com, 2020) (Hygrow EPS report, 2019)*

2.1.4.4   Vertical Gardening

This approach to the aquaponic gardening focus on vertical towers. It is a subcategory of NFT system, built of tubes with holes running along the tube length on the its one side. The tubes are suspended vertically in rows. Each tower contains a growing media for the roots to attach while the water flows continuously through the system. This type of hydroponics saves space and has a good aeration system, although water and light distribution tend to be uneven thus control is necessary. *(Hygrow EPS report, 2019)*

Figure 2.4 . ZipGrow Towers system. (ZipGrow, 2019)

2.2   Plant Selection

The primary source of income on the aquaponic farm is the plants. Roberto (2001) defines that it is crucial to maintain proper conditions and make sure the plants grow naturally and have the same phases of growth as in nature. To ensure proper growth of chosen plants, we must know their growing environments. The choice should not be only dedicated by profitability but also by climatic conditions in which we operate our aquaponic system. Before we start choosing plant species it is important to be familiar with requirements for plant cultivation.

Temperature is one of the factors that controls plant growth. Plants' metabolism depends on temperature fluctuations thus keeping the aquaponic garden within the optimum temperature range reduces stress and avoids prolonged maturation.

Humidity is known as an amount of water present in air. High level of humidity minimizes transpiration, the plants do not loose water through their leaves. Although, this condition also leads to preventing

plants from cooling themselves and provides perfect climate for the development of various species of mould.

Light range that stimulates photosynthesis is called Photosynthetically Active Radiation, only these spectra can influence growth rate. PAR light is produced by the Sun, High Pressure Sodium lamps, Metal Halide lamp, recently introduced fluorescent and LED lights.

Carbon dioxide is essential for photosynthesis, its constant supply keeps chlorophyll activity at the same rate and allows plant growing rapidly. Providing fresh air or supplemental CO_2 in the range of 1000-1500 PPM is necessary for proper plant growth.

Oxygen available in the water nutrient solution is called dissolved oxygen. In aquaponic farming we should pay attention on DO values because plants' roots are suspended in water most of the time. Roots require oxygen to perform respiration. If we grow the plants in a soilless system based on flowing water, we should keep in mind that optimum DO value ranges between 5 and 25 PPM. In most cases, the system should be additionally oxygenated to prevent anaerobic respiration which causes the production of toxic levels of ethanol.

Another significant factor in healthy plant growth is pH. The pH measures the relative number of hydronium ions in a solution. It ranges between 0 and 14, the value 7 is a neutral pH while the value 0 is extremely acidic and 14 means extremely alkaline. Neutral pH is determined by the same amount of H^+ and OH^- ions. Acidic solution is dominated by H^+ ions, on the other hand alkaline solution consists of more OH^- ions. The pH in a nutrient solution controls the availability of elemental salts to the plant. When pH drops or increases out of the range, it usually causes nutrient deficiency for plants.

TDS measures total amount of solids dissolved in a solution. The TDS level is lowered when plant uptakes nutrient, less salts are present in a solution. The level increases when water evaporates or is transpired by the plants. Nutrients concentration in a water solution should be controlled for two reasons. If plants do not receive enough nutrients, they would not grow properly. But too high concentration of nutrients can be harmful for plant. Root freeze happens when plant is exposed to way too many nutrients root system stops absorbing them causing the plant damage.

Based on the Somerville et al. (2014) to start with the aquaponic farming we can choose from 150 different species of vegetables, herbs, fruits, flower and small tress that have been successively grown in this system. The easiest plants to cultivate are leafy green plants as well as popular fruiting vegetables such as cucumber, tomatoes and peppers. Fruiting vegetables and flowers are considered to have higher demands. Changing live phases in fruiting plants cause a need for different conditions and nutrient supply. They are recommended for established farms, operating for longer time with adjusted fish stocks. Although, there are some crops which do not grow well in aquaponics for example root crops. Because they require special treatment and can only be grown in deep media beds, root crops are rarely chosen for aquaponics.

Plants cultivated in aquaponics are divided into two groups due to their nutrient requirements. Low- nutrient-demand plants include the leafy greens and herbs for instance chard, lettuce, salad, basil, mint, parsley, coriander, chives, pak choi and rucola. Some species of legumes including peas and beans also belong to low-nutrient-demand plants. To the group of plants with high-nutrient-demand, called nutrient hungry, belong mainly the botanical fruits such as tomatoes, eggplants, cucumbers, zucchini, strawberries and peppers. Representatives of medium-nutrient-demand plants are the family of cabbages: kale, cauliflower, broccoli and kohlrabi. Bulbing plants are more diverse in that matter. Beets, taro, onions and carrots possess medium to high requirements, while radish needs less nutrients

The aquaponic system which we use also influences the choice of crops. Media-filled bed systems are suitable for leafy greens, herbs and fruiting vegetables. Polyculture seeding is common in this case, preventing many pest infections. NFT system allows to grow larger fruiting vegetables provided that they have access to continuous flow of water in large amounts.

Table 2.1.1 Review of the most commonly grown plants in aquaponic cultures with their environmental demands. (Roberto, 2001) (Somerville, et al., 2014) (Brooke and Brooke, 2020) (Hygrow Aquaponics.,2020)

Plant name	Lighting conditions	Favourable temperature	pH	TDS (PPM)	Recommended aquaponic method	Growth time	High market value and short harvest time	Easy for start -up
Basil	High insolation	Warm 20-25 °C	5.5-6.5	700-1120	Media beds, NFT, DWC, Vertical towers	5-6 weeks	Yes	Yes
Lettuce	Medium insolation	Cool 15-22 °C	6.0-7.0	560-840	Media bed, NFT,DWC, Vertical towers	24-32 days	No	Yes
Cucumber	Medium insolation	22-28 °C day, 18-20 °C night	5.5-6.5	1100-1750	Media beds, DWC	55-65 days	No	No
Pepper	High insolation	Warm 22-30 °C day, 14-16 °C night	5.5-6.5	300-500	Media beds	60-95 days	No	No
Tomato	High insolation	Warm 22-26 °C day, 13-16 °C night	5.5-6.5	1400-3500	Media beds, DWC	50-70 days	No	No
Parsley	High insolation with partial shade	Warm 15-25 °C	6.0-7.0	560-1260	Media beds, NFT, DWC	20-30 days	Yes	Yes
Mint	Medium to high insolation	Warm	5.5-6.5	1400-1680	Media beds, NFT, DWC, Vertical towers	80-90 days	No	Yes
Spinach	Medium insolation	Cool to warm	6.0-7.0	1260-1610	Media beds, NFT, DWC	37-50 days	Yes	Yes
Swiss Chard	Medium to high insolation	Warm to hot	6.0-7.0	1260-1610	Media beds, NFT, DWC	25-35 days	No	Yes
Cauliflower	High insolation	Warm 20-25 °C	6.0-6.5	1900-2450	Media beds	2-3 months	No	No

2.3   The role of nutrients

Somerville et al. (2014) indicate that inorganic salts known as nutrients are required for most of the enzymatic reactions, photosynthesis and plant metabolism. In nature they are sourced from the soil. In aquaponic soilless farming they need to be provided by the fish waste. If nutrient deficiencies occur, plants do not grow properly and get sick. In that case, it must be determined which element is lacking and then supplemental fertilizer must be applied.

Nitrogen is a basic component of all amino acids. It is needed for cell growth, metabolic processes, and production of chlorophyll required for photosynthesis. In the aquaponic system it serves as a proxy indicator for other nutrients. Yellowing of older leaves, thin stems and poor vigour are symptoms of nitrogen deficit. However, the overabundance of nitrogen causes excessive vegetative growth, resulting in plants susceptible to diseases.

Phosphorus is mainly present in the DNA structure but also serves as a component of phospholipid membranes and ATP which is an energy storage in a cell. Plants need it to conduct photosynthesis as well as form oils and sugars. Deficiencies result in poor root development caused by poor energy transport connected to the shortages in ATP.

Potassium is responsible for proper cell signalling via the ion flow through cell membranes as well as production and transportation of sugars, water uptake, disease resistance and the ripening of fruits. Deficiency can be concluded from burned spots on older leaves and poor plant turgor. It also manifests in form of interveinal chlorosis or yellowing between the veins of the leaves.

Magnesium cocreates the chlorophyll molecule thus it is a key element in photosynthesis. Deficiencies manifest as yellowing of leaves in older parts of the plant. In the aquaponics it is not considered as a limiting nutrient, supplementation with it is not necessary.

Calcium constitutes a part of cell walls and membranes. Its abundance affects stems strengthening and root development. In the aquaponics calcium deficiency is common and can be always seen in the newest growth because it is immobile in the plant. Tip burns and blossom-end are typical visible features of deficit. Transport of calcium occurs only via xylem transpiration, maintaining proper humidity level is essential in that case. Calcium carbonate or coral sand can be added to the aquaponics as a good source of this element and buffer for the system.

Sulphur is a component of some amino acids such as methionine and cysteine. It regulates photosynthetic enzymes and takes part in chlorophyll production. Yellowing of the entire foliage is a sign of sulphur deficiency, however it happens very rarely.

Microelements such as Mg, B, Fe, Zn, Cu and Mo are present in plants cells only in trace amounts. Iron, manganese, molybdenum and zinc shortages are seen as yellowing of the leaves while copper deficiency causes darkening of the leaves.

Nitrogen in a form of nitrate is provided to the plants after the ammonia from the fish waste is converted by nitrifying bacteria. Other elements are dissolved in the water from the fish waste. However, majority of inorganic nutrients remain in solid state and they need to be broken down by heterotrophic bacteria. The availability of these elements depends on the pH of the water solution and the balance of fish diet. Composition of the fish feed is important both for fish and plants. Although the ratio of nutrients in fish feed may not be perfectly adjusted for the plants which need some nutrients in different concentrations. Deficiencies in iron, potassium and calcium are quite common in aquaponic systems due to their small content in fish feed. Iron can be supplemented in form of chelated iron to reach concentration of about 2 mg/l. Calcium and potassium are added as $Ca(OH)_2$, KOH, $CaCO_3$ and K_2CO_3. They work as a system buffer, correcting the pH and preventing the water solution from acidification caused by nitrification process.

2.4   Plant Health and Disease Control

Somerville et al. (2014) describe the aquaponic system taking advantage of rich microflora inhabiting the system. Complex microscopic ecosystem consisting of bacteria, fungi and other microorganisms makes the system more resistant to infections and diseases. Nonetheless, the aquaponic farming requires preventing actions and proper treatment of plant and fish diseases. Plant health is achieved by capable management of pathogens and pests, providing optimal nutrition, proper planting techniques and environmental management.

One of the biggest threats to the system are pests which carry diseases that plants can contract. They also stun plant growth by secreting toxic liquids. Notwithstanding the presence of beneficial fauna, insect pests such as whiteflies, thrips, aphids, leaf miners, cabbage moths and spider mites cause damage to the plants.

Common practice to deal with them is to use chemical pesticides but in the aquaponics there in no such an option. Any strong chemical can be fatal for fish and bacteria, usage of pesticides is a last resort. Prevention is fundamental step for pest management. One of the methods is netting which separates insects from the seedlings. It is mostly applied in tropical climate whereas cold climate greenhouse does not have to deal with excessive amounts of insects to such an extent. Physical barriers such as rooftop localization provide good ventilation and prevent insects from entering due to large distance from ground level. Additionally, a ring of copper flashing can prevent snails and slugs from climbing up the greenhouse walls or legs of plant container. Sticky traps as well as pheromone-baited traps might be a solution for flying insects. Continuous monitoring allows to identify the species of pests and eliminate them early before they damage all the crops.

Good environmental management including maintenance of optimal light, temperature and humidity level results in growing healthier plants which are less susceptible to pests. Some insects and spiders do not tolerate wet humid conditions, sustaining them would daunt undesirable pests. Another method includes choosing resistant varieties of plants and seeding polycultures. There are plant species which repel insects and protect plants living together with them. Catch plants are planted nearby the aquaponic system in order to attract insects away from the greenhouse unit, e.g. fava beans, petunia flowers and lettuce seedlings. Crops rotation is suggested for reducing pests attacking the monoculture crops. Frequent cleaning, removal of debris and dead leaves from the plant site pace prevent pests spreading. Some botanical pesticides obtained from microorganisms are safe for aquaponic animals because they act specifically on insects' tissue structures. Two most commonly used are *Bacillus thuringiensis* and *Beauveria bassiana*, the toxin extracted from *Bacillus* damages insect's digestive tract. *Bassiana* is a fungus that penetrates insect skin and kills it through dehydration.

Finally, the use of beneficial insects which feed on pests may bring good results. Although, this method never fully eradicates the pests and it must be applied only when we have extensive knowledge about those species.

Table 2.2 The examples of common beneficial insects used to control the pests (Hygrow Aquaponics, 2020) (Somerville, et al., 2014)

PROBLEM PEST	BENEFICIAL INSECT
WHITEFLY	*Encarsia formosa*
SPIDER MITE	*Phytoseiulus persimilis*
APHIDS	Ladybugs, Lacewings
MEALYBUG	*Crytolaemus montrouzieri*
CATERPILLAR	*Trichogramma* spp.
CHAFER GRUB LARVAE	*Heterohabditis perminutus*
CODLING MOTH	*Cydla pomonella*
LEAFHOPPER	*Anagrus atomus*
LEAF MINER	*Dacnusa sibirica*
THRIP	*Amblyselus cucumerls*
SLUG	*Phasmarhabditis hermaphrodita*

Similar to pest prevention and treatment, plant disease management focuses on frequent control, wise plant choice and preventive actions. Optimal temperature and humidity are a key element in environmental control. Development of bacterial and fungal diseases relates to conducive levels of humidity and moisture conditions. In order to reduce the risk of disease outbreak, the aquaponic greenhouse must be equipped with dynamic ventilation system including fans creating horizontal

airflow and enough windows. Continuous airflow reduces humidity and condensation spots, inhibiting fungi development.

Evaporation in water tanks contribute to increasing humidity level thus all the container should be covered and kept dry. When choosing plants, their pathogen resistance should be taken into account. Planting the known resistant cultivars is a good method of avoiding infection. Moreover, applying polyculture is an advantage, when it comes to contraction of one species, the disease would not shift to the other, more resistant varieties. Buying seeds and cuttings from a trusted source also affects plant resistance. Plants which do not suffer any nutrient deficiencies are less prone to infections. It is important to carry out frequent inspections and whenever plants show signs of damage, it is crucial to remove the infected parts to avoid the disease spreading.

Chemical treatment of bacterial and fungal is not recommended for aquaponic systems due to possible harmfulness on beneficial bacteria species and fish. As in pest management, botanical control agents such as *Trichoderma* spp., *Ampelomices* spp. and *Bacillus subtilis* are used to fight the specific diseases. *Trichoderma* spp. protects against soil-borne pathogens, especially *Phytium* spp*. Ampelomices* spp. prove themselves in the fight against powdery mildew.

Table 2.3 The examples of environmental control over plant diseases (Hygrow Aquaponics, 2020)

Disease name	Disease agent	Plants	Target tissue	Temperature (°C)	Humidity
Root rot	*Phytium* spp.	Lettuce	Roots	28-30	Waterlogged soil
Downy mildew	*Pseudoperonospera cubensis*	Cucumber, zucchini, squash	Leaves	27	Leaf wetness for 1 hour
***Verticillium* wilt**	*Verticillium* spp.	Various	Stems	21-27	Moist soil
***Fusarium* wilt**	*Fusarium oxysporum*	Cucumber, zucchini, squash	Stems	25-27	-
Early blight	*Alternaria solani*	Tomato, potato	Leaves	28-30	Free moisture
Powdery mildew	*Sphaerotheca fuliginea*	Cucumber, zucchini, squash	Leaves	20-25	-

More information about the pest control including repellents, soft-chemicals, insecticides and beneficial insects as well as disease control agents such as inorganic chemicals and companion planting charts can be found at http://www.fao.org/3/a-i4021e.pdf *(Roberto, 2001) (Somerville, et al., 2014)*.

2.5   Fish Selection
This chapter focuses on several potential options for species of fish suitable for the project aquaponic system and their nutritional and environmental demands.

2.5.1   Tilapia
Tilapia comprises the family of fish living in East Africa. It is one of the most cultivated species in the aquaponic systems. The popularity of Tilapia is caused by pathogens and stress resistance and wide tolerance for water quality. Moreover, the fish consumes plant-based feed and need approximately

7 months to achieve harvestable growth. The ideal water temperature range varies between 27-30 °C thus water must be heated in the system if it is not established in hot climate. Considering the water temperature condition and availability in Finland, Tilapia might not be the most economic choice for the project aquaponic system. *(Somerville et al., 2014) (Hygrow Aquaponics, 2019)*

Figure 2.5 Tilapia (Tørrissen, 2012)

2.5.2   Rainbow Trout (Oncorhynchus Mykiss)

It is a widespread fish in the world due to the high market price and relatively easy breeding. Trout is an excellent choice for the aquaponics thanks to its fast growth rate. Rainbow trout is distinguished by the pink stripe, an array of black spots and red cover over the gills. It is the strongest type of living trout, making it easier for farmer to grow the fish and maintain the system. Their speed of growth allows to rapidly increase the population and the number of crops which can be grown. The key element to choosing rainbow trout is that they are able to survive in a wide range of temperatures, preferably colder water. The fish diet is based on molluscs, flies and crustaceans which are high in energy, meaning that the fish meat is also highly nutritious. *(Brooke and Brooke, 2020)*

Figure 2.6 Rainbow Trout (Wikipedia, 2020)

Table 2.4 Pros and cons of Rainbow Trout cultivation (Hygrow Aquaponics., 2020)

Advantages	Disadvantages
Low maintenance Keeping rainbow trout in aquaponic system is not labour intensive.	Large area required for cultivation The fish requires fast waterflow rates and high densities. Large systems in which 0.5 kg of fish per 100 L of water are suggested.
Fast growth Marketable size of fish can be reached in approximately 9 months.	Inadaptation for high temperature Trout cannot withstand water temperature above 22 °C. In higher temperatures the digestive system of trout is inefficient thus most of fish feed end up as waste.
Cold resistant Preferable temperature for cultivation ranges between 10 to 20 °C.	Low oxygen levels in the water Fish do not thrive in low oxygenated water; the oxygen dose should be more than 5.5 mg/L.
Nutrient-rich meat Rainbow trout is a good source of protein, omega-3, vitamin B12, vitamin D, selenium and comparably low in calories.	

2.5.3   Carp (Cyprinus carpio)

Carp are omnivorous fish and require moderate levels of protein in comparison to carnivorous salmonids. They are generally more sustainable than trout or salmon as a choice for aquaponics. Their protein demand reaches the level of 35-45 %. Carps are very adaptable and can feed on different types of food. Dry pellet diet may be supplemented with plants grown in aquaponic system. The fish eats little but frequently. A mature carp eats around 2 % of his body mass per day while a fingerling consumes 10 % of its weight per day. Carps tolerate moderate to low waterflow rates. They can survive in warm, static ponds with a company of tilapia and catfish. Their ideal temperature for growth ranges between 24-28 °C but they are able to adapt to temperatures from 0 to 32 °C. The ability to survive in static ponds is a result of comparatively low oxygen demand reaching 4 mg/L. However, it must be considered that under warm water conditions oxygen consumption might be even higher than trout. In common with other fish, the concentration of ammonia should be maintained below 0.02 mg/L for carp to thrive. The perfect stocking density should not exceed 20 kg/m^3. The large advantage of carp fish is high demand on Eastern European and Chinese markets. *(Aquaponics UK - Carp - an excellent species for large systems, 2020) (Somerville, et al., 2014)*

Figure 2.7 Cyprinus carpio. (Wikipedia, 2020)

Table 2.5 Pros and cons of Carp cultivation (Hygrow Aquaponics, 2020)

Advantages	Disadvantages
Small stocking area Carps do not require fast waterflow and high densities. They can be cultivated in relatively small, static water tanks with maximum density 20 kg of fish per cubic meter.	Low market price In comparison with salmonids, carp sales would not bring high income.
Low demand for oxygen In colder water climate they can thrive when the dissolved oxygen concentration is equal 4 mg/L.	Complex breeding techniques In order to obtain to obtain juveniles female carps are induced by hormone injection, a technique requiring additional knowledge of fish physiology and experience.
Temperature adaptability Carps are able to survive and adapt to the temperatures from 0 to 32 °C.	
Low protein diet Lower protein requirements make carps' diet not really demanding	
Easily polycultured Culturing herbivorous grass carp, planktivorous silver carp and omnivorous common carp covers all the food niches resulting in better use of fish feed.	

2.5.4   Koi carp

Koi fish is a popular form of Japanese carp used in ornamental ponds and outdoor water gardens. They are characterized by their attractive, colourful skin and large size. They are very suitable for aquaponics due to their durability and parasite resistance. Koi can withstand wide range of temperatures, ranging from 2 to 30 °C. Thanks to the temperature resistance, the aquaponic system requires less energy for heating the water what reduces cost of maintenance. Another advantage of Koi is their eating habit. They are great algae eaters thus cleaning the system would be less troublesome. Furthermore, in cold water the fish require less frequent feeding resulting in lower amount of produced waste while in warm water Koi can be fed many times a day and produce more waste. The fish may reach lengths of up to 60 cm after four or five years if water conditions and space are optimized, being an excellent source of profit from hobbyists and pet stores. The major drawback is that when Koi gets larger, the production of waste is hugely increased which can cause system overloading. The waste production must be under strict control. *(Brooke and Brooke, 2020)*

Figure 2.8 Koi carp. (Brooke and Brooke, 2020)

Table 2.6 Pros and cons of Koi Carp cultivation (Hygrow Aquaponics, 2020)

Advantages	Disadvantages
Running cost Koi can survive in cold water, saving heating costs. Moreover, they are not fussy eaters, feeding on food waste and algae would be enough for them.	Inedible Fish are not used as a food source. This reduces the harvest possibility from the system.
Resilience Koi are exceptionally resilient to diseases. They require low level of care.	Purchase cost They are not a cheapest option among the fish.
Nutrient producers Koi produce a lot of waste rich in ammonia and nutrients.	Monitoring Ammonia concentration in the water should be controlled because of intense waste production.
High market price Decorative fish are sold to collectors at very high prices.	

2.6   Fish Requirements

2.6.1   Feed and Nutrition

Somerville et al. (2014) suggest fish diet must be composed of balanced amount of proteins, carbohydrates, fats, vitamins and minerals to grow a healthy specimen. Commercially available fish feed pellets covering the fish nutritional demands are recommended for small scale or beginners aquaponics. Homemade feeds require extensive knowledge and special attention to be prepared otherwise it may lack in essential nutritional components.

Protein is the most important component for building fish mass. Omnivorous fish need 25 to 35 % of protein in their diet while carnivores need up to 45 % protein to grow. Protein supply is especially important during the grow-out stage of younger fish. Amino acids combining to form proteins are mainly synthesized by the fishes' organisms. There is a group of amino acids called essential amino acids which have to be obtained from the food. Methionine and lysine are the examples of essential amino acids which are supplemented in vegetable- based feeds.

Lipids are high-energy molecules desired in fish diet. Fish oil, high in omega-3 and omega-6 fatty acids is a common component of fish feed.

Carbohydrates are delivered to fish mainly in the form of starches and sugars. This inexpensive diet component increases energy value of the feed. Starch helps to bind the feed together to make a pellet. However, fish do not metabolize carbohydrates well thus much of the energy can be lost.

Vitamins and minerals are necessary for fish health and growth. Vitamins affect organism development and proper functioning of immune system. Minerals are responsible for synthesis of the body components, vitamins and cellular structures and osmotic regulation.

Whole feed including all the essential components is produced as feed pellets. The size of these pellets depends on the size of fish stock. Fingerling can struggle with too big pellets while adult fish are not fed enough when they receive too small pellets. The size of pellets should be adjusted and changed along with growing fish. Feed pellets are designed to either float on the surface or sink to the bottom. Their choice depends on the feeding habits of the fish. Feed should be stored in dark, dry and cool conditions otherwise the feed can rot. Spoiled feed might be toxic for the fish, then it should be never used. Uneaten food can be harmful for the system. Feed waste is converted into ammonia, increasing the toxicity level in the system. What is more, uneaten pellets can clog filters and piping system.

2.6.2 Water Quality for Fish

Nitrogen

Ammonia and nitrite become toxic for fish above levels of 1 mg/L, though any concentration of these compounds in the system contributes to fish stress. System should be balanced in such a way that there should be close to zero detectable levels of these compounds. Ammonia is especially dangerous in the basic pH thus water tests including total ammonia nitrogen should be made if there are rapid changes in system pH. Symptoms of ammonia and nitrite poisoning are seen as red streaking on the fish body, gills and eyes. On the other hand, nitrate is tolerable at the level equal 400 mg/L. *(Somerville, et al., 2014)*

pH

Fish can tolerate a wide range of pH but thrive at levels of 6.5-8.5. Rapid changes in pH may occur lethal for fish. It is important to maintain stable pH by using the buffers such as calcium carbonate. *(Somerville, et al., 2014)*

Dissolved oxygen

Most fish require 4-5 mg of dissolved oxygen per litre but the more DO is available the better a system works. To maintain the oxygen concentration at the optimal level air pumps providing dynamic water flow must be implemented. The suggested flowrate is 5- 8 litres of air per minute for each cubic metre of water. To avoid low DO level in the tank do not overstock the fish. The optimal fish density in the tank should not exceed 20 kg of fish per 1000 litres of water. Backup aeration systems are a good asset to an aquaponic system preserving the fish during power cuts or equipment failures. *(Somerville, et al., 2014)*

Temperature

Optimal temperatures reduce risk of fish diseases and stress. Thermal isolation, water heaters and cooler can help to achieve a steady temperature condition. General rule is to respect fish optimal temperature range and avoid rapid changes. Tropical fish thrive at 22- 32 °C and cold-water fish prefer 10 to 18 °C. *(Somerville, et al., 2014)*

Lighting

The light level in the fish tank should be as low as it is possible to prevent algae growth. However, complete darkness can make the fish stressed. Delivering indirect natural light through shading would be enough for the fish to grow healthy. *(Somerville, et al., 2014)*

Table 2.7 Water quality parameters, feed requirements and average growth rate for researched fish species. (Hygrow Aquaponics, 2020)

Species	Temperature (°C)		Total ammonia nitrogen (mg/litre)	Nitrite (mg/litre)	Dissolved oxygen (mg/litre)	Crude protein in feed (%)	Growth rate
	Vital	Optimal					
Common carp	4-34	25-30	< 1	< 1	> 4	30-38	600 grams in 9-11 months
Koi carp	2-30	15-25	< 0.5	< 0.25	> 4.5	-	-
Rainbow trout	10-18	14-16	< 0.5	< 0.3	> 6	42	1 000 grams in 14-16 months

2.7 Natural System Cleaners

The aquaponic system mimics a natural ecosystem. It harnesses the power of integrated aquatic life, bacteria and plants. The exchange of nutrients occurs in harmony with nature and does not require any special human influence other than frequent controlling. However, implementing crustaceans, small fish and snails to the system creates a better nutrition cycle. Nutrient conversion rates can be increased by the activity of organisms feeding on fish waste. Additionally, the system would be less prone to algae overgrowth resulting in better water quality.

2.7.1 Shrimps

Freshwater shrimps are beneficial addition for the already fish populated tank or working aquaponic system. They are bottom feeders which means that they eat all organic matter from fish waste. Farmers can keep them in the fish tank, although the juvenile shrimps tend to be eaten by the fish so they must be separated from them using for example nets. They can be kept under the floating rafts or in sedimentation tank. There is very low possibility for them to eat plant roots. It is important to remember that keeping too many shrimps in one area is dangerous for the. When they are hungry, they become territorial and might eat each other. To avoid cannibalism, the shrimps must be provided

with a place where they can hide. They do not require feeding, only if they cannibalize each other the fish food must be supplemented. Having the shrimps in the aquaponic system creates a risk disease. To prevent extensive infection the water quality should be controlled. *(Brooke and Brooke, 2020)*

Table 2.8 Information on cultivating shrimps (Hygrow Aquaponics., 2020)

Parameter	Value
Growth time	4 months to reach market size
Market size	85 g
Temperature range	24-32 °C
Harvest time	3 times a year
pH	7.8-8.5
Space	0.2 m^2 per one shrimp
Aeration	necessary air pump
gH	4-8 PPM
KH	2-6
TDS	100-220

Table 2.9 Pros and cons of shrimp cultivation in the aquaponics (Hygrow Aquaponics, 2020)

Advantages	Disadvantages
Increased yield With the help of shrimps, the system is able to convert organic waste more rapidly resulting in faster plant growth.	*Disease Risk* There is a higher risk of disease by having shrimps in the aquaponics. The system requires careful monitoring to prevent death of the marine life and crops.
Easy Maintenance Shrimps do not have high demands; they can survive on the food available in the system.	
Eco-friendly farming Due to the shrimp's presence in the system, the use of pesticides to kill algae is not necessary.	
Possible retail Market size shrimps can be sold thus you can make profit from keeping them in a system.	

2.8   System Parameters

Establishing sustainable system requires knowing and maintaining all necessary parameters within their optimal ranges. The values that must be measured and controlled in the aquaponics are as follows: pH, temperature, dissolved oxygen, total nitrogen and total water hardness. Optimal values of parameters should be adjusted to the type of aquaponics we aim to operate. While establishing

the aquaponic system we need to compromise demands of fish, plants and bacteria. It is essential to wisely choose the elements of the aquaponics ecosystem. If the choice falls on cold climate aquaponics, warm water fish and warm weather plants should be avoided, otherwise it may cost additional energy and source usage. The following chapter explains the cold climate aquaponics limitations and the dependence between the relevant parameters for fish, plants as well as bacteria. *(Hygrow Aquaponics, 2019)*

2.8.1 Temperature

Water temperature affects all elements of aquaponics ecosystem. According to Somerville et.al (2014, 24-25) generally the aquaponic system temperature ranges between 18-30 °C to keep DO and ammonia concentrations in proper values. Too high water temperature causes heat stress in plants while the cold water may stun plants' growth. The same issue concerns fish. Highly increased water temperature enhances respiration rate thereby raising the oxygen demand. The temperature elevation affects the solubility of both oxygen and nutrients. The key in fish cultivation is to keep stable water temperature within the right tolerance range. It causes proper growth, facilitates efficient feed conversion and decreases the risk of diseases. In conclusion it is the best to choose plants and fish adapted to the local climate as well as preventing the temperature fluctuations. Additionally, the water temperature is also essential for bacteria health. Nitrifying bacteria are most productive in the temperature ranges from 20 to 30 °C. The lower the temperature the less activity they will show. Water hotter than 49 °C and colder than 0 °C would kill all the *Nitrobacter* and *Nitrosomonas.*

The following figure presents the optimal temperature ranges for cold and warm climate aquaponics. It is not possible to provide ideal conditions for all elements present in the ecosystem. If we want to cultivate cool weather plants and fish, their optimal temperature range do not fully correspond to the optimal temperature for *Nitrobacter* bacteria. Furthermore, bacteria efficiency to convert ammonia into nutrients decreases in the cold-water system. To maintain high conversion rates, it is recommended to increase the biofilter size. *(Hygrow Aquaponics, 2019)*
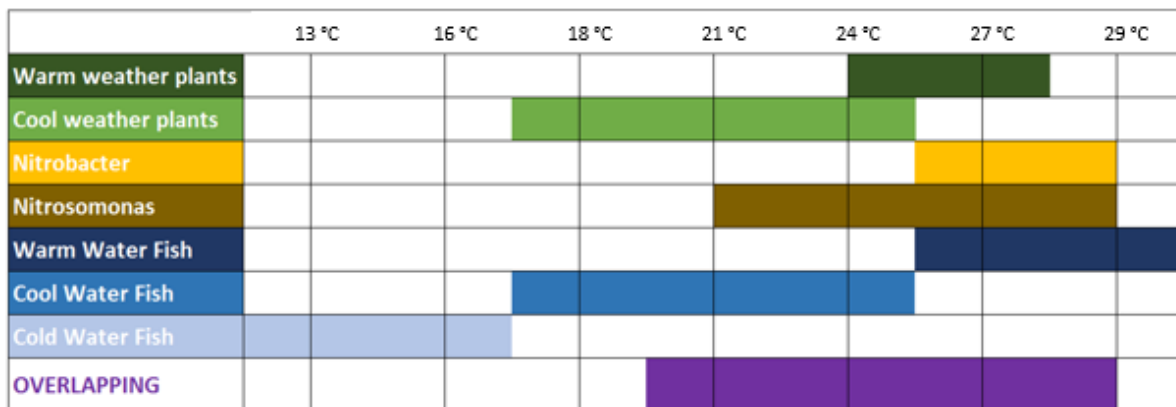
	13 °C	16 °C	18 °C	21 °C	24 °C	27 °C	29 °C
Warm weather plants					■	■	
Cool weather plants			■	■	■		
Nitrobacter						■	■
Nitrosomonas				■	■	■	■
Warm Water Fish						■	■
Cool Water Fish			■	■			
Cold Water Fish	■	■					
OVERLAPPING				■	■	■	■

Figure 2.9 Temperature dependence of plants, fish and bacteria (What is the Optimum Range of Temperature for Aquaponics?, 2020)

2.8.2 pH

Continuous ammonia conversion and mineralization slowly acidifies the water solution. The pH correction in needed to stabilize the system and prevent fish and plants from death. Each group of organisms have different pH tolerance. Plants thrive when the pH ranges between 6.0-6.5 because in this regard the nutrients are most accessible. Nitrifying bacteria work efficiently when pH is higher than 6. Most fish have a pH tolerance range of 6.0-8.5, including the chosen koi carps which have pH tolerance between 6.8 and 8.2. Tolerable pH value for the three components of a system should

be maintained between 6.8 and 7.4. *(Southern and King, 2019) (Somerville et.al, 2014) (Sallenave, 2016)*

Methods of pH management in the aquaponics includes buffering or adjusting the pH. Buffering uses calcium carbonate to resist changes in pH when acid is released by ammonia conversion. It can be added to the system in the form of crushed oysters, eggshells or as a pure chemical tablets. Usage of buffering methods should be supplemented with potassium sulfate (K_2SO_4) having neutral pH. However, this method allows to maintain pH at the levels 7.0-7.5 which might be not acidic enough for plant growth. *(Southern and King, 2019)*

Adjusting method utilizes calcium and potassium in hydroxide forms to gradually adjust the pH value. Only small amounts of highly soluble hydroxides are required for precise adjustment, although they exhaust rapidly thus this method need to be applied regularly. Using the adjusting methods enables maintaining pH ranges more optimal for plant growth and supplies the water with calcium and potassium. The disadvantage of hydroxide usage is requirement for careful control of pH values. Changes in pH can be rapid if the inadequate dosage of hydroxide is added to the system. This method should be applied along with controlling sensors. Calcium and potassium hydroxides should be added in relatively equal concentration to avoid moving chemical equilibrium thus one of the compounds would precipitate and will not be available for plants. *(Southern and King, 2019)*

2.8.3 Water Hardness

The general water hardness measures the number of positive ions in the water. Hard water consisting of Mg^{2+} and Ca^{2+} is a useful source of nutrients for plants and helps fish keeping other salts in organism. *(Somerville et.al, 2014)*

On the other hand, carbonate hardness (KH) described as an alkalinity measures a buffering capacity of water which affects pH. It is a total amount of carbonates and bicarbonates dissolved in water. KH resists the lowering of pH. The carbonates bind to the input H^+ ions preventing the solution from becoming acidic. The buffering role is very important because rapid changes in pH are stressful for the whole aquaponic ecosystem. The process of ammonia oxidation produces H^+ ions which are bind by carbonates resulting in system balance. In the aquaponic system certain concentration of KH must be present all the time. The optimum range for both hardness types is approximately 60-140 mg/litre. *(Somerville et.al, 2014)*

2.8.4 Dissolved oxygen

According to Sallenave (2016) dissolved oxygen is an essential parameter for both fish and nitrifying bacteria. DO level should be maintained above the 5 ppm in the aquaponic systems. It is recommended to measure oxygen levels frequently in a new system. When the system circulation is done, and fish stocking rates standardized it is not required to measure DO so often. Deficiencies in oxygen can be compensated by the additional air pumps or air stones.

2.8.5 Nitrogen

Nitrogen is present in the aquaponic system in the form of ammonia, nitrites and nitrates. Ammonia exists in two forms: un-ionized (NH_3) which is extremely toxic and ionized (NH_4^+) which is toxic in very high concentrations. Temperature and pH affect the ratio of NH_3 to NH_4^+, the toxic ammonia concentration increase when pH and temperature raise. Total Ammonia Nitrogen measures the amount of toxic NH_3 and ionized form. Healthy aquaponic system should be maintained at the level lower than 1 ppm. The concentration of un-ionized ammonia can be determined by following steps. Firstly, TAN must be measured together with water temperature and pH. Afterwards, correction factor

must be find using the Figure 2.10 and finally the TAN value can be multiplied by the found multiplication factor. *(Sallenave, 2016)*

Table 1. Percentage of Total Ammonia Nitrogen (TAN) in Freshwater that is in the Toxic Un-ionized Ammonia Form at different pH values and temperatures (adapted from data presented in Francis-Floyd et al. [2009] and Florida Department of Environmental Protection Chemistry Laboratory Methods Manual [2001])

	Temperature										
	50 (°F)	60.8	64.4	68	69.8	71.6	76.1	78.8	82	86	89.6
pH	10 (°C)	16	18	20	21	22	24.5	26	28	30	32
7.0	0.18	0.294	0.342	0.396	0.425	0.457	0.546	0.607	0.697	0.799	0.95
7.2	0.29	0.466	0.540	0.625	0.673	0.723	0.863	0.958	1.10	1.25	1.25
7.4	0.46	0.736	0.854	0.988	1.06	1.14	1.36	1.50	1.73	1.98	2.36
7.6	0.73	1.16	1.35	1.56	1.67	1.80	2.14	2.36	2.72	3.11	3.11
7.8	0.16	1.82	2.12	2.44	2.63	2.80	3.35	3.68	4.24	4.84	4.84
8.0	1.82	2.86	3.31	3.82	4.10	4.39	5.21	5.75	6.56	7.46	8.77
8.2	2.86	4.45	5.16	5.92	6.34	6.79	8.01	8.75	10.0	11.3	13.2
8.4	4.45	6.88	7.93	9.07	9.69	10.3	12.1	13.0	15.0	16.8	19.5
8.6	6.88	10.5	12.0	13.7	14.5	15.5	17.9	19.4	21.8	24.3	27.7
8.8	10.5	15.7	17.8	20.0	21.2	22.5	25.7	27.8	30.7	33.7	37.8
9.0	15.6	22.7	25.6	28.4	29.9	31.5	35.5	37.7	41.2	44.6	49.0
9.2	22.7	31.8	35.2	38.6	40.4	42.1	46.5	49.2	63.8	56.1	70.8
9.4	31.8	42.5	46.3	49.9	51.8	53.5	58.0	60.5	63.8	66.9	70.7
9.6	42.5	53.9	57.7	61.3	63.0	64.6	68.5	70.8	73.6	76.2	85.9
9.8	53.9	65.0	68.4	71.6	72.9	74.3	77.6	79.4	81.6	83.6	85.9
10.0	65.0	74.6	77.4	79.9	81.0	82.1	84.5	85.9	87.5	89.0	90.6

Figure 2.10 Correction factor data for un-ionized ammonia concentration (Sallenave, 2016)

For example, a measured TAN equal 4 ppm at pH 7 and 20 °C would be

$$4\ ppm \times 0.396\ \% = 0.016\ ppm\ of\ un-ionized\ ammonia$$

If ammonia concentration reaches toxic levels, we should check if feed rate and fish stocking density are not too high for the water volume or the aeration is not sufficient. Low ammonia concentration occurs when the system has too much water or too less fish. The solution is to scale the system by decreasing the water volume or introducing more fish to the system. *(Sallenave, 2016)*

Ammonia oxidized by nitrifying bacteria is present in the water as nitrites and nitrates. Nitrite is less toxic than ammonia, although it still can be lethal for fish. It should not exceed 1 ppm. If the level of nitrites is higher, water should be diluted or changed. Nitrate is tolerable up to 300 ppm, with some fish being resistant to 400 ppm. Plants would suffer negative effect if the nitrate levels reach 250 ppm. When nitrate level is too high additional plants should be added to the system. *(Somerville et.al, 2014)*

2.8.6 Parameters suggestion for cold climate aquaponics

The following table presents the optimal parameters for an aquaponic system in colder climate countries such as Finland. It is a summary of the current chapter and serves as a recommendation for designing the sustainable system.

Svenska
kulturfonden
University of Vaasa
FINLAND
NOVIA
UNIVERSITY OF APPLIED SCIENCES
HyGrow
Aquaponic System

Table 2.10 Parameters for the aquaponic system (Hygrow Aquaponics, 2020)

Parameter	Cool water Fish	Koi Carps	Cool weather plants	Bacteria	Cold water Aquaponics	Unit
Temperature	10-24	2-30	16-25	20-30	18-22	°C
pH	6.0-8.6	6.8-8.2	5.5-7.0	6.0-8.5	6.5-7.0	-
Dissolved Oxygen	>5	>4.5	>3	4-8	>5	ppm
TAN	<1	<0.5	-	<3	<0.5	
Nitrite	<0.1	<0.25	<1	<3	<0.1	
Nitrate	<300	<60	-	<300	50	

2.9 Aquaponic Design

2.9.1 Design Calculations

In order to scale up the aquaponic system properly the essential parameters and ratios must be calculated and determined in this chapter.

2.9.1.1 Daily Feed Rate

The dimensional design of aquaponic system should start from determining the system ratio. It is calculated using the method suggested by Southern and King (2019).

$$G^r/m^2/Day$$

Where G^r is the total grams of feed given daily to the fish and m^2 means the total Hydroponic Surface Area (HSA) in square meters. HSA describes the surface area devoted to the plant growth. The aim of the ratio is to obtain the balance between the input of nutrients to the system and waste conversion. Waste removal in the system depends on the two factors. First one is the capacity of the biofilter to carry out nitrification which is connected to the Bacterial Surface Area. Second factor is the capacity of the hydroponics to assimilate nitrates which is expressed by the HSA. The ratio values differentiate between aquaponic systems. The DWC generally have low BSA/m^2 of HSA, usually less than 2 m^2 of BSA per m^2 HSA. The vertical tower system can achieve 150 m^2 of BSA per m^2 HSA, although capacity for denitrification is almost the same as in DWC system thus the ratio should be applied to design both DWC and vertical tower systems.

To design sustainable aquaponics the climate factor must be considered. In cold-water system the nitrifying bacteria grow slower than in warm-water system thus more BSA is needed for sufficient oxidation of ammonia to nitrates. What is more, nutrient uptake by plants decreases in cold-water systems thus the denitrification is also carried out slower. In conclusion, the input of fish feed per m^2 of plant area should be smaller for cold-water aquaponics. The recommended ratio for cold-water aquaponics ranges between 25-35 g/m^2/Day.

Using the optimal ratio allows to calculate the daily feed amount and the total fish biomass which help determining the fish tank size and amount of water that must be delivered.

$$8\ rafts \times (0.6 \times 0.4)m^2(size\ of\ each\ raft) + 12\ towers \times (0.0018 \times 10)m^2 = 2.14\ m^2\ HSA$$

The daily feed rate can be estimated, following the cold-water system ratio.

$$25 \ g \ \times 2.14 \ m^2 = 53.5 \ g \ of \ feed \ per \ day$$

$$35 \ g \ \times 2.14 \ m^2 = 74.9 \ g \ of \ feed \ per \ day$$

The amount of fish feed that can be safely added to the system without going beyond nitrifying bacteria conversion capacity ranges between 53.5 g and 74.9 g per day. These values can be adjusted to the daily feed rate of specified species of fish and the total fish biomass can be calculated. According to Koi Length and Weight - Ammonia Produced, and Waste Produced *(2020),* the optimal daily feed rate for Koi carp is equal 1.5 % of body weight, therefore:

$$53.5 \ g/0.015 = 3567 \ g = 3.6 \ kg \ total \ biomass$$

$$74.9 g/0.015 = 4993 \ g = 5 \ kg \ total \ biomass$$

The target fish biomass ranges from 3.6 kg to 5 kg. When we know the volume of fish tank and total biomass, we can ensure that the aquaponic system design has sufficient HSA to support chosen biomass range. Tidwell (2012) together with FAO: Feeding methods (2020) describe that in the aquaponic system stocking capacity should not exceed 20 kg/m^3. This density promotes fast fish growth and efficient feed conversion while reducing stress which cause diseases. Purchased fish tank will be filled with 0.5 m^3 of water.

$$20 \frac{kg}{m^3} \times 0.5 \ m^3 = 10 \ kg \ maximum \ biomass$$

Koi fingerlings after a year reach a length of about 25 cm weighing 200 g. Theoretically, a 0.5 m^3 tank can hold 50 young fish. Due to budget limitations and no real experience in fish farming the team decided to buy maximum 20 fish. The average weight of 3 years old adult Koi is around 3.8 kg thus no more than 3 fish should be kept in 0.5 m^3 tank. The older fish should be separated into additional fish tanks. In conclusion, one fish tank was purchased for the needs of the project due to budget and space constraints.

$$20 \ fish \times 200 \ g = 4000 \ g = 4 \ kg \ fish \ biomass$$

The estimated total fish biomass is within the range of 3.6 kg and 5 kg meaning that it fits the calculated biomass ratio.

$$4 \ kg \ of \ fish \times 1.5 \ \% \ (daily \ feed \ rate) = 0.06 \ kg = 60 \ g \ feed \ per \ day$$

$$60 \ g/2.14 \ m^2 \ HSA = 28 \ g/m^2 \ /day$$

The determined daily feed input is equal 60 g. It lies in the acceptable range of the ratio of 25-35 g/m^3/day.

2.9.1.2   The Amount of Ammonia Produced by Feed

Ammonia is a by-product from the degradation of proteins provided to fish in form of the feed. The amount of ammonia in the water does not depend only on the quantity of proteins in fish feed but also on the fish species, the digestibility, temperature and removal of fish wastes from the aquaponic system. About 30 % of proteins supplied by the diet are retained in the fishes' body. The residual 70 % is lost including 15 % of undigested part from which 60 % is taken out by means of settlers and 55 % is

excreted as ammonia. Summarizing, only 61 % of the nitrogen from the feed becomes ammonia which is oxidized to nitrates. *(Somerville, et al., 2014)*

$$60 \; g \; of \; feed \times \frac{32 \; g \; protein}{100 \; g \; feed} \times \frac{16 \; g \; nitrogen}{100 \; g \; protein} \times \frac{61 \; g \; wasted \; nitrogen}{100 \; g \; total \; nitrogen} \times \frac{1.2 \; g \; NH_3}{1 \; g \; nitrogen} = 2.25 \; g \; ammonia$$

2.9.1.3   The Amount of Biofilter Media Needed by Nitrifying Bacteria

Somerville et al. (2014) explains that nitrifying bacteria convert ammonia in range of 0.2-2 g per square metre per day. The removal rate depends on the biofilter design, water load, temperature, salinity, pH, oxygen and TSS. If average rate is equal 0.57 g of ammonia per metre of surface area per day. Knowing the daily production of ammonia in the system we can calculate the BSA.

$$2.25 \; g \; ammonia \times \frac{1 \; m^2}{0.57 \; g \; ammonia} = 3.95 \; m^2 \; BSA$$

The surface area for bacteria can be chosen from wide variety of materials including gravel, sand, foam, fibre mesh pads as well as designed bioballs. Each bacteria surface has specific surface area (BSA), expressed as m^2/m^3. The volume of media needed for ammonia conversion can be calculated using the BSA ratios. In our system we use the foam and bioballs which surface area has the following dimensions, 400 m^2/m^3 for foam and 600 m^2/m^3 for bioballs. We take the average of these two values.

$$3.95 \; m^2 \times \frac{1 \; m^3}{500 \; m^2} = 0.0079 \; m^3$$

The nitrifying bacteria require space equal 0.0079 m^3 to convert the ammonia produced by the input of 60 g of feed per day.

$$\frac{7.9 \; litres \; of \; biofilter \; media}{60 \; g \; fish \; feed} : \frac{1 \; litre \; of \; biofilter \; media}{7.6 \; g \; fish \; feed}$$

According to the calculations 1 litre of biofilter media surface is required to convert the ammonia produced from 7.6 g of fish feed. The minimum volume of biofilter media is 7.9 litres.

The Hygrow Aquaponics 2019 team printed 110 Bioballs including Gyroid-cubes, HyGrow-cylinders and Thingverse-balls. The most economical Gyroid-cubes have the volume of 0.125 dm^3 per each, expensive Thingverse-balls with the volume of 0.113 dm^3 and the team invented HyGrow-cylinders have the volume of 0.04 dm^3. The team produced 10 Thingverse, 40 Gyroid cubes and 60 HyGrow self-made cylinders. The total volume of biofilter media equals 8.53 dm^3. The new aquaponic system requires 7.9 dm^3 of biofilter media thus printing additional Bioballs is not necessary.

2.9.1.4   Water evaporation rate
This equation allows to calculate the amount of water evaporating in given time (hour)

$$g_h = \Theta A (x_s - x)$$

Where

$g_h \; amount \; of \; evaporated \; water \; per \; hour \; (\frac{kg}{h})$

$\Theta \; (25 + 19 \, v) = evaporation \; coefficient \; (\frac{kg}{m^2 h})$

v velocity of air above the water surface $\left(\dfrac{m}{s}\right)$

A water surface area (m^2)

x_s maximum humidity ratio of saturated air at the same temperature as the water surface $\left(\dfrac{kg}{kg}\right)$

x humidity ratio air $\left(\dfrac{kg}{kg}\right)$

Data

Typical range for air velocity indoor does not exceed 0.1 m/s in closed room. During the ventilation process the air velocity increases to 0.3 m/s and above in the summer and 0.15 m/s and above in the winter considering cold climate. Taking into account that the greenhouse windows will be closed most of the time, the velocity 0.1 m/s was assumed. *(Indoor air velocity, 2020)*

$$\Theta = \left(25 + \left(19 \times 0.1\frac{m}{s}\right)\right) = 26.9 \; kg/m^2h$$

The units for Θ don't match because it is an empirical equation which is a result of experience and experiments.

The fish tank will be built from 1000 litre IBC tank which dimensions are $1200 \times 1000 \times 1160 \; mm$, thereby the surface area is 1.2 m². *(webmaster.tanksdirect@gmail.com, 2020)*

Deep Water Culture and Vertical Towers water surface area is equal 2.14 m².

Knowing the volume and shape of settling tank would allow to calculate the water surface area. The settling tank should contain at least 0.218 m³ water. The cylindrical shape was chosen for the target shape of the container due to lower maintenance requirements and shorter retention time for solids settling. *(Voutchkov, 2005)*

$$V = \pi r^2 H$$

$$Surface\; area = \pi r^2 = \frac{V}{H} = 0.218\; m^3 / \, 0.8\; m = 0.27\; m^2$$

Biofilter tank volume depends on the bacterial surface area that must be provided in order to grow sufficient number of nitrifying bacteria. From the BSA calculations it is known that bacteria require space equal 0.0079 m³ to convert the ammonia produced by the input of 60 g of feed per day. The biofilter tank must contain bioballs of volume 0.0079 m³ thus the volume of the tank cannot be less than 0.0079 m³. We decided to reuse the biofilter tank bought by the previous team, which has a volume of 52 L and water surface equal 0.195 m².

$$A = (1.2\; m \times 1m) + (2.14\; m^2) + (0.195\; m^2) + (0.27\; m^2) = 3.8\; m^2$$

Maximum saturation humidity ratio of air (x_s) at water temperature 20 °C is 0.014659 (kg$_w$/kg$_a$). *(Humidity Ratio of Air, 2020)*. Humidity ratio can be calculated using the following equation. *(Water Vapor and Saturation Pressure in Humid Air, 2020)*

$$x = 0.62198\, p_w/(p_a - p_w)$$

x humidity ratio (kg/kg)

p_w partial pressure of water vapour in moist air (Pa)

p_a atmospheric pressure of moist air (Pa)

The assumed air temperature is 25 °C. Partial pressure of water vapour in moist air is *980 Pa at 25 °C and atmospheric pressure of moist air equals* $101325\ Pa.$ *(Humidity Ratio of Air, 2020) (Relative Humidity Calculator - Free Online Tool - ROTRONIC Measurement Solutions, 2020)*

$$x = 0.62198 \times 980\ Pa/(101325\ Pa - 980\ Pa) = 0.00607\ kg/kg$$

Finally, after obtaining all necessary data the evaporation rate can be calculated.

$$g_h = \Theta A(x_s - x) = 26.9 \frac{kg}{m^2 h} \times 3.8\ m^2 \times \left(0.014659 \frac{kg}{kg} - 0.00607 \frac{kg}{kg} \right) = 0.88 \frac{kg}{h} = 0.88\ l\backslash h$$

$$0.88\ l\backslash h = 21.12\ l/day = 147.8\ l/week$$

The water is estimated to evaporate in the amount of 147.8 litres per week. The simplest solution to prevent extensive evaporation is covering the tanks. Deep Water Culture will already have the floating rafts which separate the water surface from the air. The lids will be placed on fish tank, settling tank and biofilter tank. This way, the water would not escape the aquaponic system.

2.9.2 Settling Tank Volume and Design

Thorarinsdottir (2015*)* notes that sedimentation tank also called settling tank separates the waste solids from the water by means of gravity. The sedimentation process results in the solids settling down at the bottom of the tank from where they are drained and discharged. The main factor to be considered when designing a settling tank is the retention time. The recommended retention time should correspond to one third of water flow rate per hour in the system.

Brooke (2020) remarks that the recommendation for water flow in the aquaponic system with a high fish stocking density is to cycle the water two times per hour. Although, lower stocking density does not require such frequent water circulation thus water is cycled one time per hour. The water volume in our designed aquaponic system is estimated at 660 litres including 500 litres fish tank and eight deep water culture containers of volume 20 litres each. In conclusion, the water flow in the system should be 660 litres/hour due to the low stocking density in the fish tank.

$$660 \frac{litres}{hour} \times 0.33\ hour = 218\ litres = 0.218\ m^3$$

The desired volume of sedimentation tank is 0.218 m³. The best choice for small scale aquaponic system is radial flow separator. Its operation is based on the flow of water into the centre of the radial flow separator from where it is forced downwards. Disruption in water flow velocity causes the solids to settle down and water to flow out through an overflow weir. Choosing passive sedimentation system allows reducing costs and maintenance.
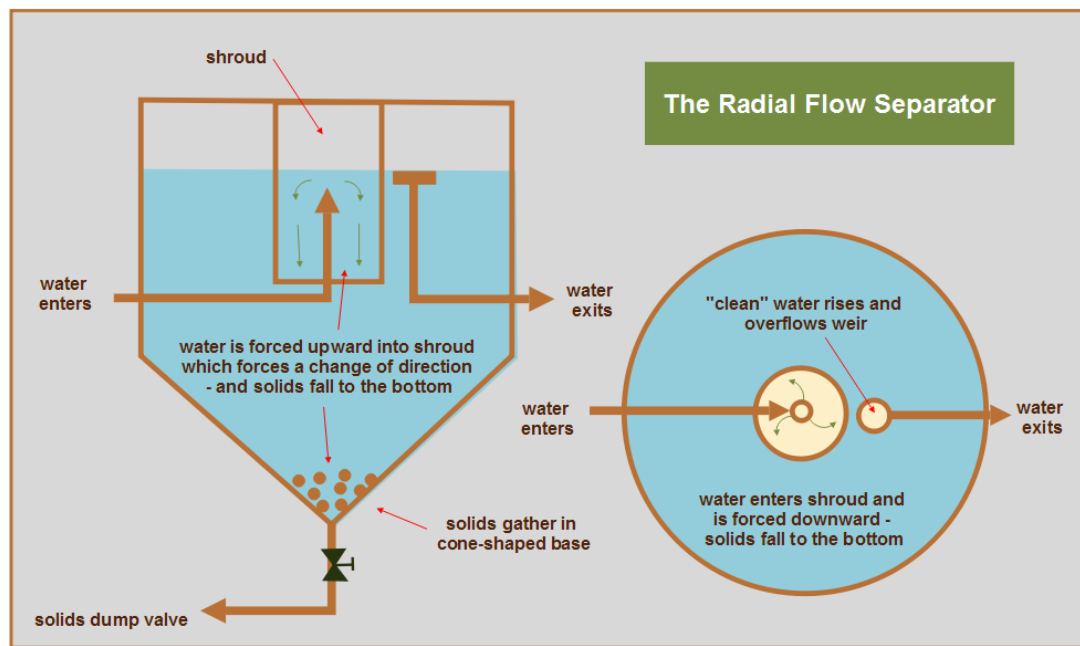
Figure 2.11 The Radial Flow Separator scheme. (Donaldson, 2020)

Designing the settling tank is an essential step in the aquaponic system cycling process. Fish waste which is not converted by bacteria or shrimps should be removed because of harmful effects of solids accumulation. The suspended solids may cause fish diseases, increase oxygen demand and ammonia concentration. Radial flow separator decelerates the water flowing into the sedimentation chamber thus the solids can settle down and be removed from the system. *(DIY Radial Flow Filter for Aquaponics | Ecofilms, 2020)*

The RFS can be built with a use of a plastic barrel, a bucket which redirects and decreases water flow velocity, PVC pipes and seals. The following picture represents the draft of the settling system.

Water from the fish tank flows into the settling tank through the pipe and is slowed by the bucket. Solid waste settles down on the bottom of the barrel. The drainage pipe draws clear water from the surface. At the bottom of the settling tank the pipe should be mounted at a 90° angle. The water on the top puts the pressure on the solids which go through the pipe so they can be discharged easily. *(Brooke and Brooke, 2020)*
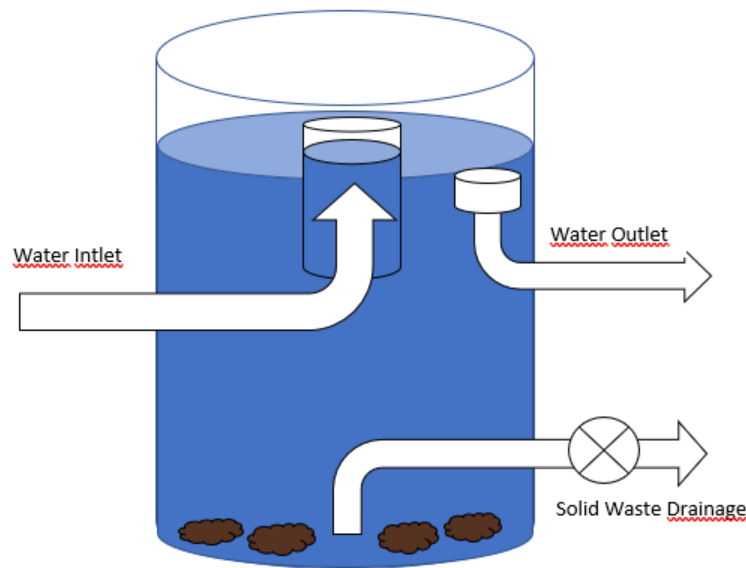
Figure 2.12 Radial Flow Separator Design (Hygrow Aquaponics, 2020)

2.9.3 Lights

Due to budget constraints as well as focusing on other aspects of the project, we did not purchase new lights. We will use the LED strips the previous aquaponic team purchased, which have been programmed for the plants. Two pre-programmed LED strips are used for the Vertical Towers unit while three sets of RGB LED bars were used for the DWC unit.

2.9.4 Ecosystem Choice

2.9.4.1 Hydroponics

This section presents a selection of plants to be implemented in the system. In addition to the plant selection, it will also be discussed which aquaponic systems the plants will be best suited to.

2.9.4.2 Choice of Plants

The factors that determined the choice if plants were the short growth period, adaptation to a cold climate and ease of cultivation. It was also decided to use the seed left over from the winter semester of the project. When selecting the plants, the nutrients and market demand had to be considered. Implementing a large variety of plants is advantageous for the aquaponics. All kinds of crops are susceptible to some parasites or diseases thus polyculture farming reduces the risk of infection. To sum up, the choice fell on locally available, easy to grow and commercially sellable plants.

Table 2.11 Decision on plants (Hygrow Aquaponics, 2020)

Leafy green vegetables	Herbs
• Lettuce • Red Lettuce • Swiss Chard • Spinach • Rucola	• Parsley • Mint • Basil

Vertical towers aquaponics is particularly advantageous for different lettuce varieties as well as certain green herbs. Due to the testing and optimizing purposes lettuce, swiss chard, spinach, mint and basil will be planted both in vertical and DWC systems. Parsley and rucola will be planted in the DWC system because of their lesser adaptation to the vertical towers. The following table shows the requirements of previously selected plants.

Table 2.12 Parameters and requirements for the cultivation of lettuce, spinach, swiss chard, rucola, parsley, mint and basil in the aquaponic system (Roberto, 2001) (Hygrow Aquaponics report, 2019)

Species/ Parameters	Lettuce	Swiss Chard	Spinach	Rucola	Parsley	Mint	Basil
Temperature (°C)	15-22	16-24	16-25	18-24	15-25	13-21	18-30
Growth time (days)	24-32	25-35	37-50	30-40	20-30	80-90	35-42
Germination time (days)	3-7	4-5	5-9	5-7	8-10	10-15	6-7
pH	6-7	6-7.5	6-7	6-7	6-7	5.5-6.5	5.5-6.5
Plant spacing (cm)	18-30	30	2-3	5	15-30	25	15-25
Light exposure	Full sun	Full sun; partial shade > 26 °C	Medium sun	Full sun	Full sun; partial shade > 25 °C	Medium to full sun	Sunny or slightly shade
Totals Dissolved Solids (PPM)	560-840	1260-1610	1260-1610	-	560-1260	1400-1680	700-1120
Aquaponic method	NFT, DWC and media bed						

2.9.4.3 Hydroponic Medium

There are plenty of media available for soilless gardening including coconut coir, perlite, LECA, rockwool. Perlite and rockwool were chosen as a best solution for our aquaponic system. They are both widely available and easy to operate. The advantages of the perlite include excellent oxygen retention and effective support for the roots. On the other hand, it should not be applied in flood and flush type hydroponics thus. Putting the media in 3D aquaponics or baskets situated in the rafts solves the problem of media movement. Besides sufficient ventilation and roots support the rockwool has high absorption and decent drainage properties as well as sterility which prevents contamination. *(Roberto, 2001)*

2.9.4.4 Humidity and Temperature

Plants will be provided with optimal temperature in the range of 18-22 °C due to the greenhouse design. The greenhouse will be properly insulated and supplied with heat by means of heat pumps. Humidity can be controlled by the ventilation system in the greenhouse.

2.9.4.5 Micro and Macro-elements

The measurement of nutrients concentrations is an essential element in maintaining the sustainable aquaponic system. Apart from the ammonia and nitrates measurement, elements such as iron, potassium, calcium and magnesia must be monitored on a daily basis. The effect of nutrient deficiencies is discussed in the section 2.3. The role of nutrients.

2.9.4.6 Seedlings Unit

The first attempts to grow plants have been partly successful. Seed managed to germinate and grow although the roots were not large and strong enough to be put in the aquaponics and thrive. In order to grow strong plants that will survive in the aquaponics, the seedlings need to be cared for in a more comprehensive way.

Seeds need water, oxygen and proper temperature to germinate. Creating the germination chamber would allow the plants to develop strong roots and grow quickly. Germination chamber usually is a separate place in the greenhouse but due to the size limitations there will be a table with seedling trays in our greenhouse. *(Roberto, 2001)*

At first, the seedling trays are prepared. The setup consists of small but deep pots, a plastic tray and a cover to provide the plants with constant temperature and humidity. Second important choice is the starting media. It is a medium in which the seeds are put and may be further replaced with a new medium. The choice fell on the rockwool or perlite as they also will be used in the DWC as a medium. *(Roberto, 2001)*

Figure 2.13 Seedling tray example. (Amazon, 2020)

Planting seeds should be done according to the following steps. The workbench must be filled with trays and pots. Afterwards, the starting media is spread to the pots and watered. Moreover, the water will cause the media to compress thus an additional layer of media would be needed. Second watering is not necessary because the additional media will source the water from the bottom layer. Furthermore, we must drill a small hole in each media unit to create a space for a seed. Although, it

depends on the plant species if it needs light or can be sown under the media. The following table shows seeds requirements for germination. Finally, the seeds must be put in the holes. *(Southern and King, 2019)*

Table 2.13 Sowing depth for chosen plants. (Albert, 2020)

Plants species	Lettuce	Swiss Chard	Spinach	Rucola	Parsley	Mint	Basil
Sowing depth	0.6 cm	1.3 cm	1.3 cm	0.6 cm	0.6 cm	0.6-1.3 cm	0.3-0.6 cm

From the sowing depth we can conclude which seeds prefer darkness and which germinate well having access to the light. Basil, lettuce, rucola and parsley can be sown shallowly while swiss chard, spinach and mint prefer to be more covered with media.

The seedlings should be watered once a day, only in the morning or evening. Watering in the middle of the day is not recommended. The programmed LED lights should light for 16 hours per day. Additionally, adding bio hummus to the water would provide seedlings with nutrients. *(Southern and King, 2019)*

Seedlings must be observed daily. If any weak or slowly growing seedlings appear, they need to be discarded. When the plants establish a root system they can be transplanted into the aquaponics. We do not need to discard the media in which plants have grown. Straightforward transporting to the baskets in the raft is an easy method. After transplanting the system should be slightly adjusted for plants to recover from movement. The plants would need a few days of lower than normal lighting and watering from above to ensure root moisture. *(Roberto, 2001)*

2.9.4.7 Aquaculture

The research of local fish market resulted in narrowing the search for a suitable fish species for the aquaponic system. The common carp proved to be completely unavailable in Ostrobothnia region. Due to the small scale of aquaponics, the choice of rainbow trout was also rejected because of its large space and dynamic waterflow requirement. The only fish accessible and suitable for the system occurred to be Koi carp. As a low-demanding fish, the Koi will work well in the beginner's system. Unlike the other proposals, the Koi is not an edible species, but a decorative one, making it highly marketable. The benefits of Koi cultivation are described in section 2.5. Fish selection.

Table 2.14 The summary of parameters and demands of Koi carp. (What are the ideal water conditions for healthy koi?, 2020)

Temperature (°C)	2-30
Optimal temperature (°C)	15-25
DO (ppm)	> 4.5
pH	6.8-8.2
Carbonate hardness (ppm)	90-120
Ammonia (ppm)	< 0.5
Nitrites (ppm)	< 0.25
Nitrates (ppm)	< 60
TAN (ppm)	< 0.5
Diet	Omnivore
Water quality	Medium
Salinity (ppt)	5
General Hardness (ppm)	60-160

The implementation of shrimps has a positive effect on the balance of the system. If they are treated as an addition to fish farming, the shrimps are excellent waste reducers. However, a suitable place for shrimps should be considered before putting them into the system in order to avoid the fights between them or being eaten by fish. For these reasons it is recommended to keep the shrimps in a separate tank such as settling tank or deep-water culture containers. Section 2.7. Natural system cleaners describes the shrimps requirements and benefits from keeping them in the aquaponics.

2.9.5   Cycling the System

Southern and King (2019) explain that cycling is considered as establishing the biofilter and incremental introduction of living organisms. In order to create robust, sustainable aquaponic system following steps must be performed. Firstly, the system must be filled with water and checked for possible leaks. If water is chlorinated it must be circulated for at least 24 hours with UV lighting to remove all the chlorine before introducing the bacteria. Secondly, the parameters such as ammonia, nitrites, nitrates, calcium and water hardness must be measured and recorded. In case of too low calcium concentration or pH value, the system must be provided with small amounts of calcium hydroxide. When the pH value increases too high, addition of phosphoric acid is necessary.

Table 2.15 The baseline inorganic molecules concentration in the system at the beginning (Hygrow Aquaponics, 2020) (Somerville, et al., 2014)

Parameter/ Value	Ammonia	Nitrite	Nitrate	Calcium
Concentration (ppm)	0	0	0	> 40

Furthermore, the ammonia in amount of 2-3 ppm is added to the system. The source of ammonia may be implemented in form of pure ammonia or fish generated ammonia. Pure ammonia input is easier to control precisely and suggested. The ammonia concentration in the system should reach 1-2 ppm. Higher levels of ammonia require complete water change. Afterwards, the nitrifying bacteria are implemented into the system. The bacteria cultures colonize biofilter surfaces. The next step

involves feeding the bacteria with ammonia thus the ammonia concentration should be maintained at the same level. When the ammonia concentration decreases below 1 ppm it is a sign of bacteria conversion. Another indicator of the biofilter establishment is a slow decrease in nitrites and increase in nitrates. Ammonia must be continuously added, and the system should be frequently monitored. Once the concentration of nitrates is stabilised the biofilter is successfully established. In small-scale aquaponic systems the fish can be added in one cohort and then the plats may be put into the hydroponics.

It is important to maintain the calcium concentration at the optimal level. Calcium is essential for bacteria to function. Deficiencies in calcium may result in bacteria disfunction which lead to system unbalance. Before transplanting the seedling, nitrates concentration needs to rise above 50 ppm. Supplementation with iron and magnesium is necessary in system cycling.

2.10 Aquaponic System Design Ideas

The aim of this section is to explain and present the projects of the aquaponic system, which are the result of joint brainstorming and designing. The various project alternatives will be described in order, ending with a final decision on the system choice. Furthermore, the final project will be explained step by step to understand thoroughly the way it operates. The main idea behind the system design is to create sustainable, remotely monitored and modular system which will be scaled up to the size of a greenhouse. The picture underneath illustrates the process of collecting concepts for system design.
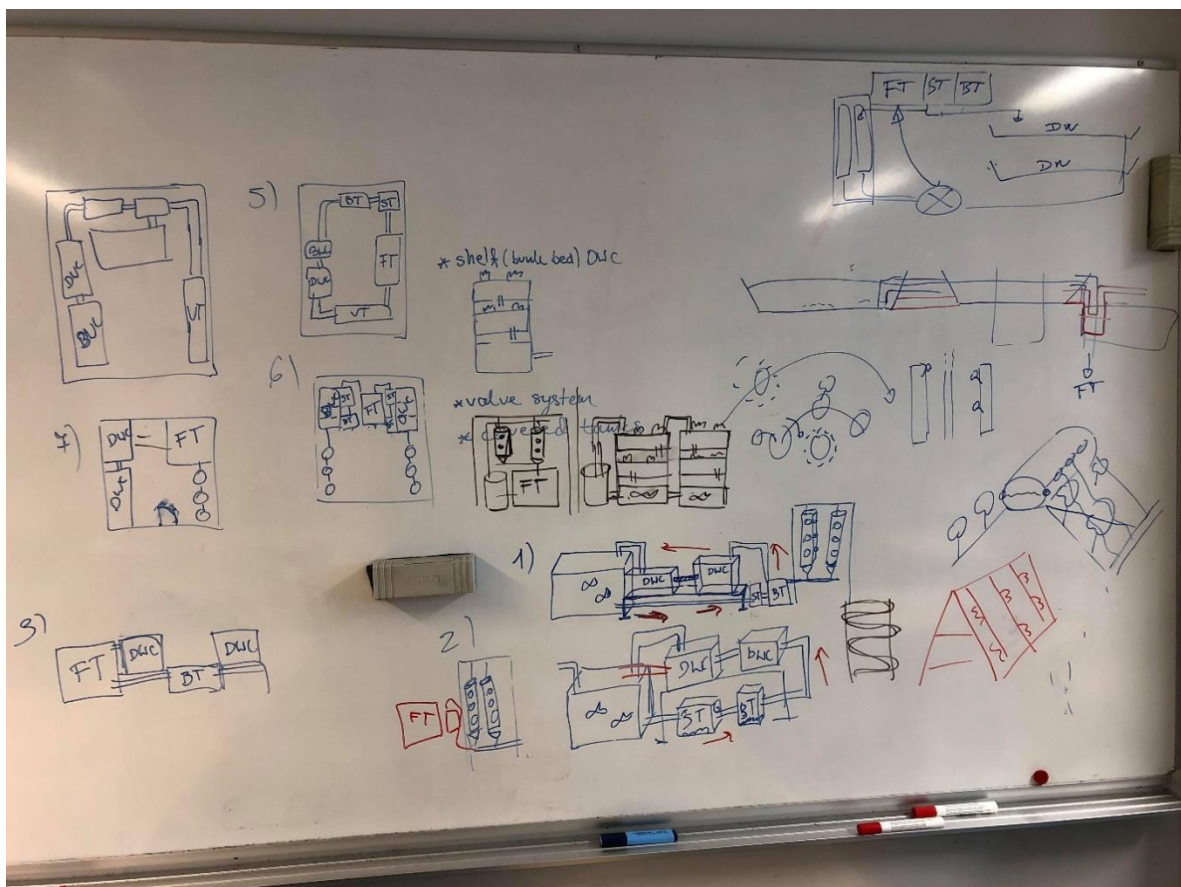
Figure 2.14 System Design brainstorming session. (Hygrow Aquaponics, 2020)

2.10.1 First Design

The first idea is based on the existing aquaponic system made by EPS Team in 2019. This system combines two types of hydroponics, DWC and vertical towers including the NFT towers and 3Dponics. The system is composed of a fish tank, sedimentation tank, biofilter tank, hydroponics, water storage, lighting system and piping system. One of the essential elements is a settling tank. It was decided to choose radial flow separator which conical shape simplifies drainage. Two water pumps are located in the biofilter tank to distribute water to both hydroponic systems. There is a water storage tank on the top of vertical towers system. The pump provides water to the storage tank for a certain period, then it is delivered to the towers via nozzles. Therefore, the operating time and thereby the energy consumption is reduced. Water from the hydroponic section is discharged into the fish tank. The piping system transfers water from fish tank to the sedimentation tank where waste solids settle down, thereafter water flows to the biofilter tank where the dissolved ammonia is converted to nitrates.
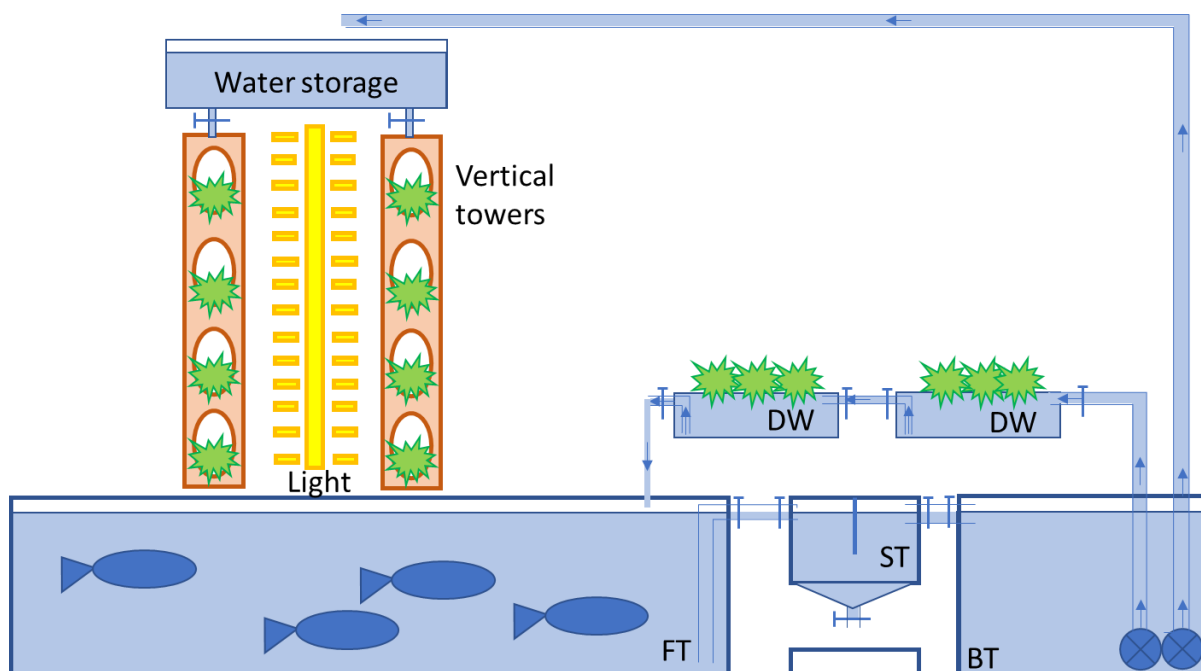
Figure 2.15 First aquaponic system scheme (Hygrow Aquaponics., 2020)

2.10.2 Second Design

Another idea was to create two separate aquaponic systems. This solution would enable the study and comparison of which system is more efficient in production and easier to maintain. Vertical towers unit has a relatively simple architecture. It involves the fish tank, hydroponics, settling and biofilter tank. Water circulates through the system with the use of pump. Deep water culture unit works on a similar principle, basically differing in the type of hydroponics. The hydroponic system is arranged in a shelf structure. Water delivered by the pump flows to the highest level of shelves and from there it is transported to lower levels through the dripping system. Positioning the plant containers at different heights saves space in the greenhouse.
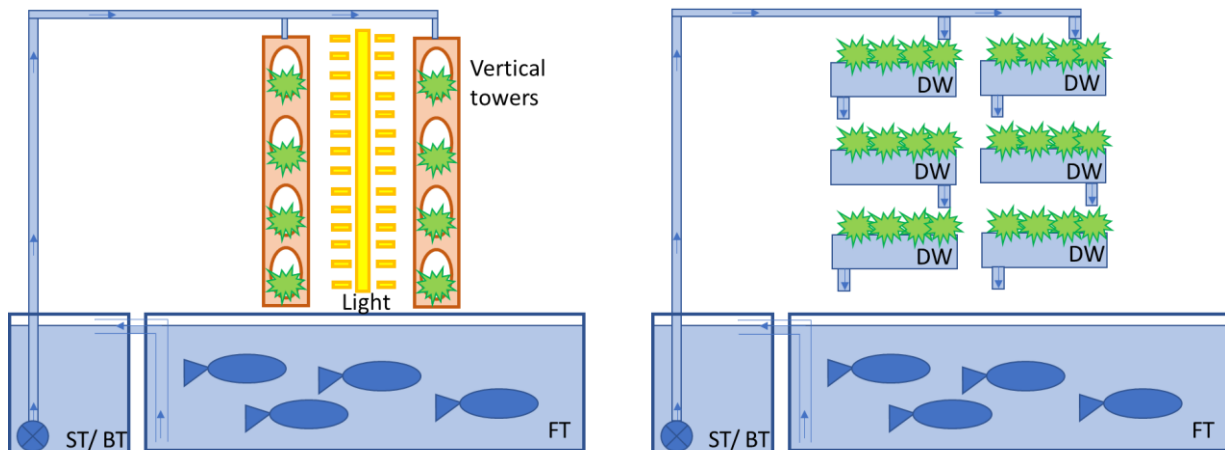
Figure 2.16 Second aquaponic system scheme (Hygrow Aquaponics.,2020)

2.10.3 Third Design

This project is an alternative to classical aquaponics architecture. The water wheel inspired system uses water flow to rotate the plant containers. The advantage of this system is constant availability of oxygen for plants and space saving. An interesting appearance of the system can serve educational purposes. However, due to the rarity of such a system, it is difficult to estimate its efficiency.
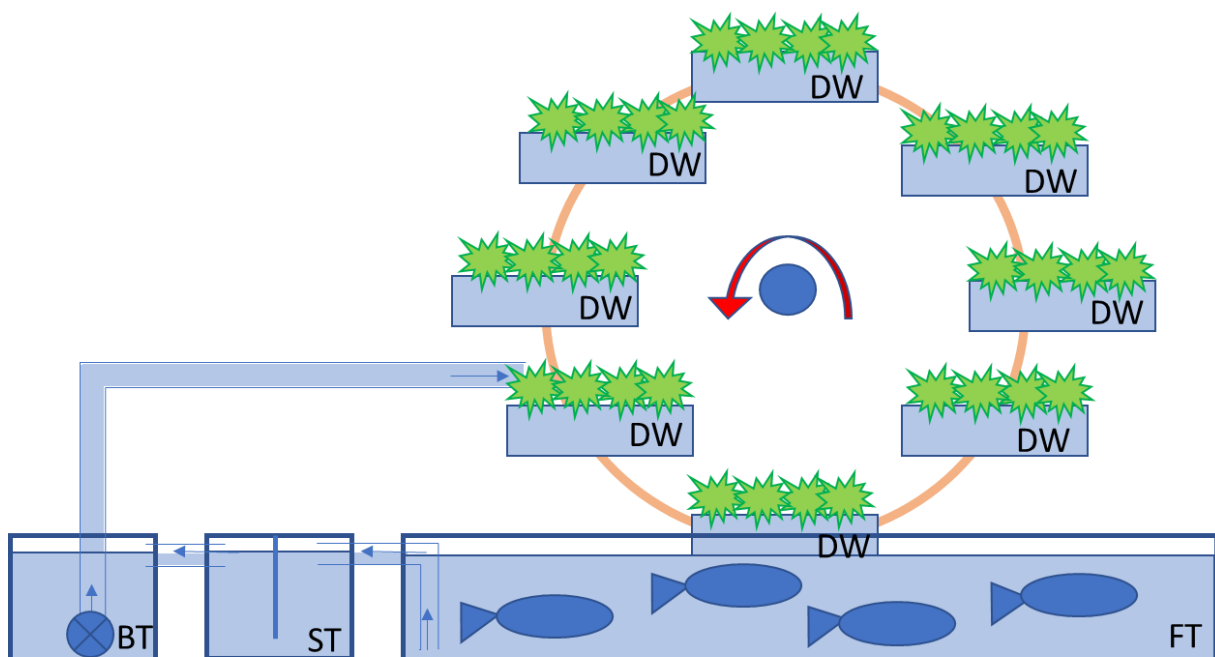

Figure 2.17 Third aquaponic design scheme. (Hygrow Aquaponics, 2020)

2.10.4 Final Design

The final project combines the most effective and appealing ideas from previous drafts. The design of this system has placed an emphasis on its modularity. All the containers are connected by flexible pipes which have valves installed at both ends. The water flow can be stopped in this way and the system element can be conveniently disconnected. Valves for drainage of water or solid waste are additionally placed in the fish tank, biofilter and settling tank. The arrangement of filtering containers connected to DWC at the height of the water surface in the fish tank has reduced the number of water pumps. The water pump must only supply the vertical towers with water. On top of the vertical towers there is a water storage tank from which water is delivered to each tower. DWC system consists of eight containers placed on two stepwise scaffoldings thus all the containers have access to sunlight. The water flows into subsequent plant containers under gravity forces. The design of the shelves makes efficient use of the greenhouse space. Hydroponics and fish tank will be supplied with air pumps and sensors. Moreover, the fish tank, biofilter tank and settling tank will be covered with lids to restrict access of light, thus reducing algae growth and pipe clogging. Finally, the biofilter and settling tank contain the plexiglass sheet to reduce water flow velocity and increase retention time.
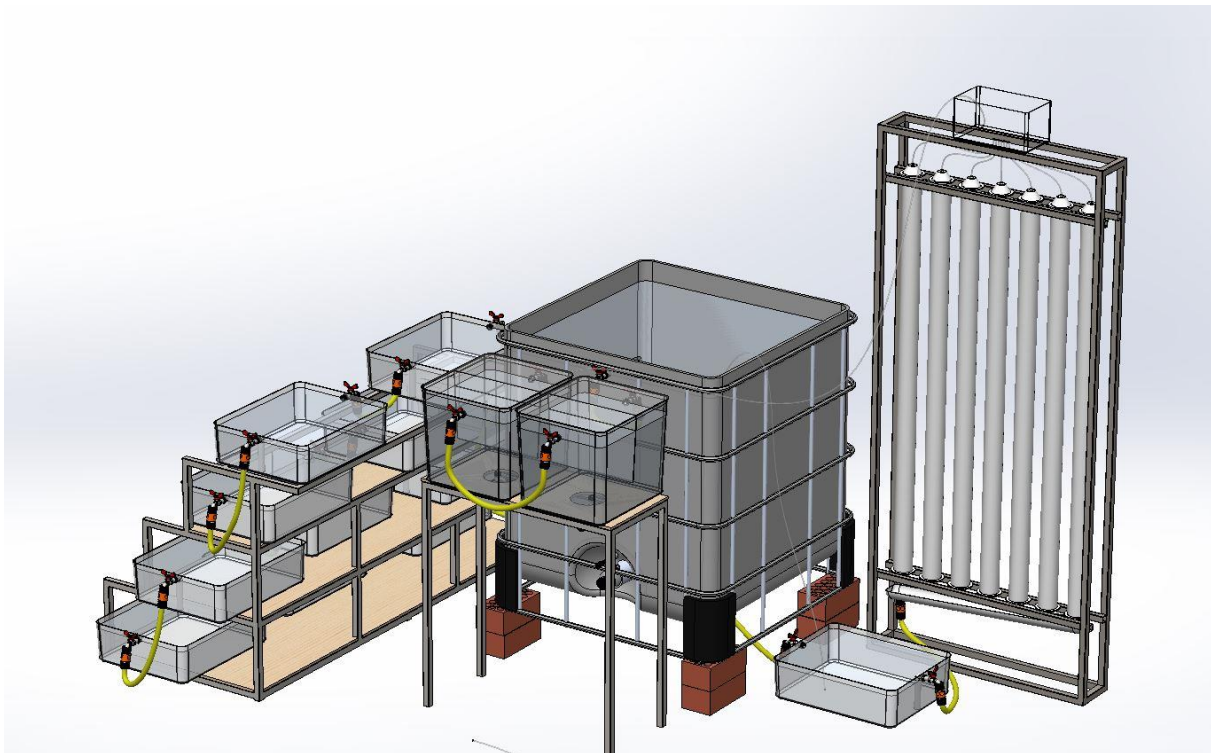
Figure 2.18 Final aquaponic system design (Hygrow Aquaponics, 2020)

The final design was slightly improved during the building process, thus the updated renders present an alternative version of design while maintaining the initial concepts. More renders are available in the Handoff Package.

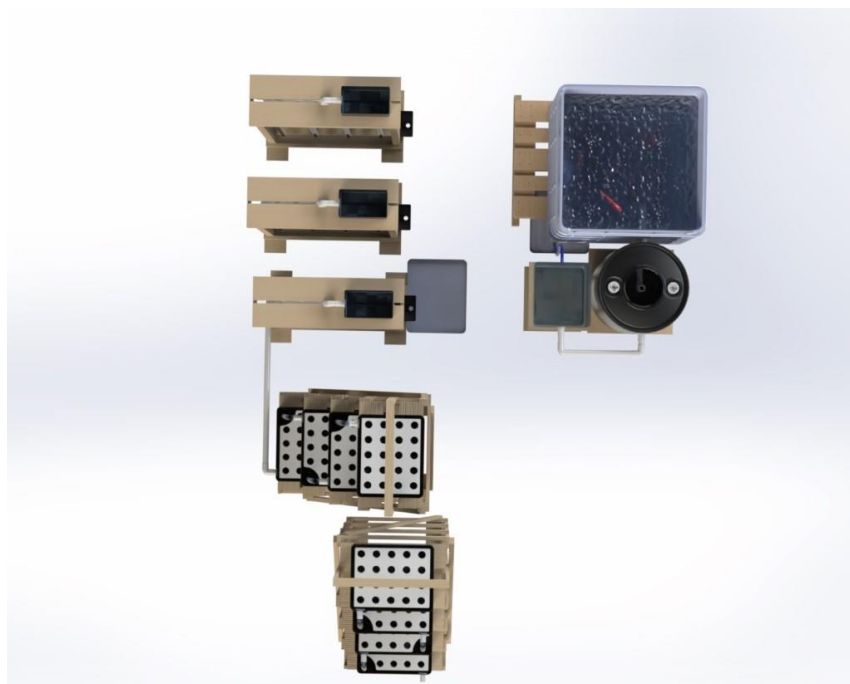*Figure 2.19 Definitive design side view*

Figure 2.20 Definitive design top view

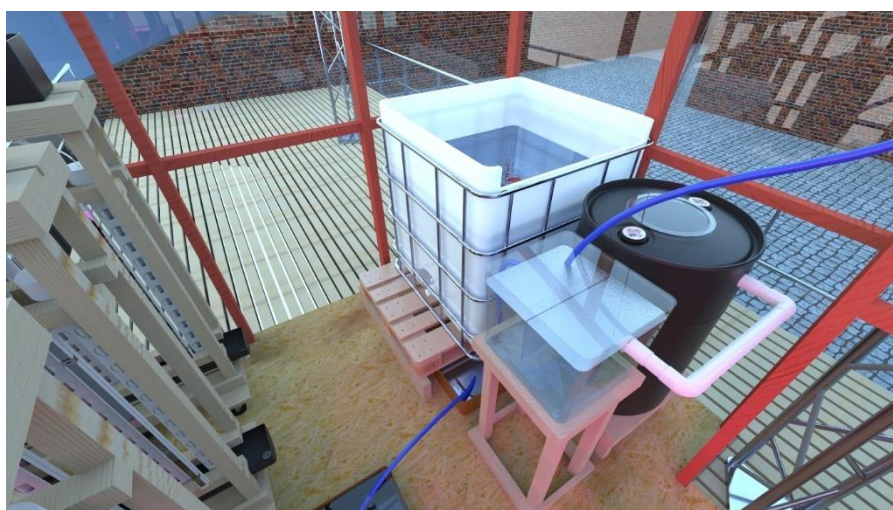*Figure 2.21 DWC Racks*

Figure 2.22 Vertical Towers

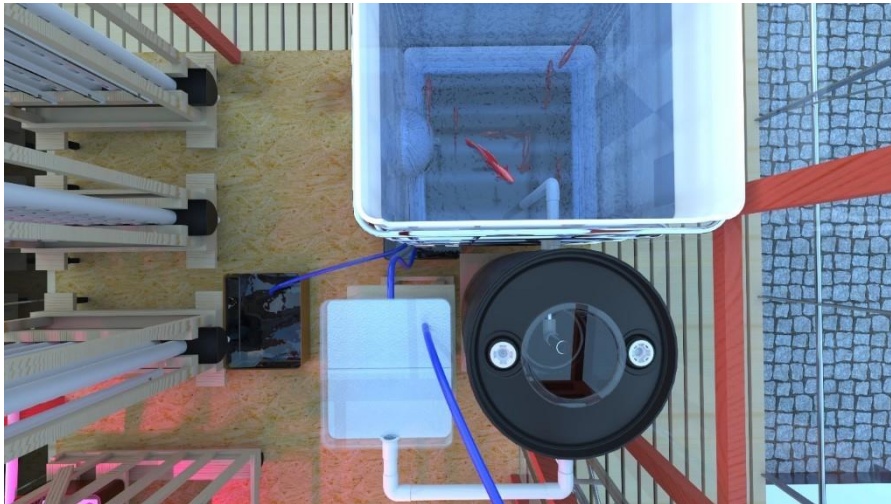*Figure 2.23Rendering fishtank, settling tank (right) and bio filter (left)*

Figure 2.24 Rendering Fish tank, settling tank (right) and bio filter (left)

2.11 System Building

This part focuses on the building process of the aquaponic system. The subsequent stages of construction are explained chronologically. This section describes the successes and reasons for the failure of few project concepts.

2.11.1 Plants

Despite the fish, plants are a crucial component of the aquaponics system. Following the previous group recommendations, the team started sowing plants in February. The team seeded lettuce, swiss chard, rucola, parsley, mint, basil and spinach. Early planting was to provide more time for the growth of strong roots. The seedlings were planted in soil, supplied with 16 hours of light and water with biohumus. After a month several seedlings were transplanted to the Vertical Towers and Deep Water Culture units. The suggestion to purchase already grown plants was rejected on grounds of the risk of disease or parasites. Previously bought plants from the store died of illness.

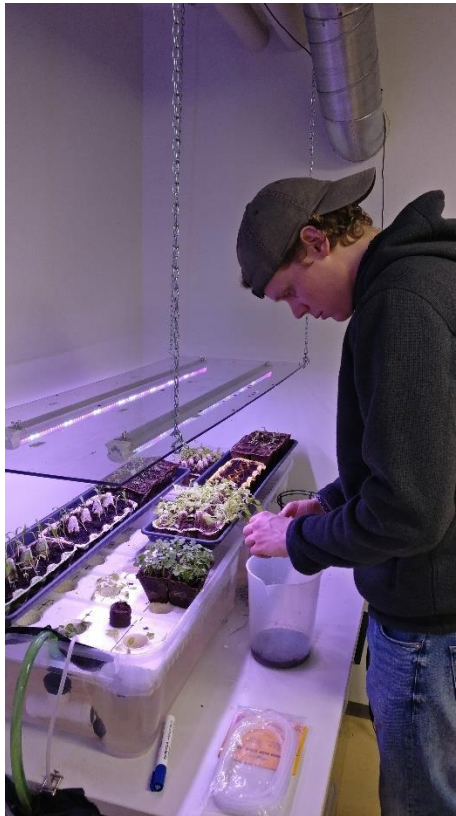*Figure 2.25 First batch of seedlings*

Figure 2.26 First batch of seedlings after three weeks

The seedlings transplanted to the DWC survived, although they did not adapt to the new environment well. The reason for this may have been to weak root system. The plants were removed from the soil and then placed in plastic baskets without any supporting media, which resulted in seedlings underdevelopment.
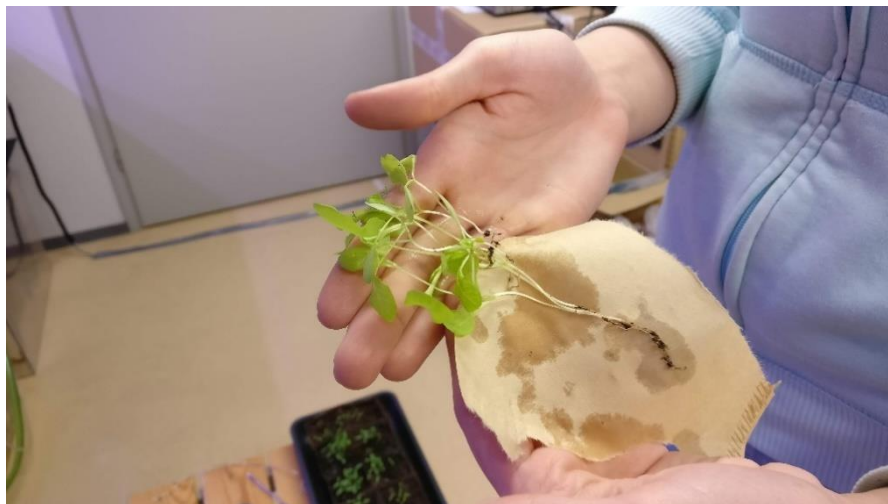

Figure 2.27 Seedlings transplantation

Plants transported to the Vertical Towers were divided into two groups. The team wanted to check if coffee filter wrapped around the root affects the plant adjustment to the VT. After few days the seedlings covered with filter survived and thrived while the plants without the filter withered.

Figure 2.28 Seedlings transplanted into Vertical Tower

In the middle of March, the university was closed. The team did not have access to the plants located in the project basement thus the seedlings were not watered. Additionally, the pump providing water to the VT malfunctioned thereby the plant in this unit also died.

The team decided to sow a second batch outside the university workshop. One of the team members received a small greenhouse from the supervisor and planted at his apartment. The second batch was sown in the soil due to the lack of rockwool as a starting media.

Figure 2.29 Second batch of seedlings in a small greenhouse

Figure 2.30 The lettuce and spinach seedlings

2.11.2 Fish

After the research, the team selected three kinds of fish which are suitable for our aquaponics system. The first choice was carp, although it was not possible to purchase that fish species. The common carp appeared to be unavailable in fish farms. Afterwards, the search for rainbow trout has begun. The team contacted several fish farms. Their respond did not give positive results. The rainbow trout has not been available for commercial purchase during this season.

The last option was for Koi Carp. The team found the aquarium store which sells the Koi at an affordable price. It was planned to buy 10 carps from Akvaario Keidas located in Perttula. However, the epidemic caused the closure of the Helsinki region and delayed the construction of the new system. The old aquaponics system built by previous group was unattended for a certain time. The Malawi Cichlids were donated to a volunteer student. The Koi fish have not yet been bought because the work on the new aquaponics system is ongoing and it will be necessary to cycle the system first.

2.11.3 DWC Racks

DWC containers are designed to be placed on a wooden scaffolding. The racks are constructed from boards which were properly cut and fixed. The final result is a set of two racks with dimensions $1.04 \times 0.7 \times 1.9 \, m$. The shelves are built as steps so that all DWC tanks have access to the light. Each rack can hold 4 aquaponic containers. Mounting of the wheels enabled mobility of the entire structure.

Figure 2.31 DWC Racks Building Process

Figure 2.32 DWC Racks building process

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Aquaponic System
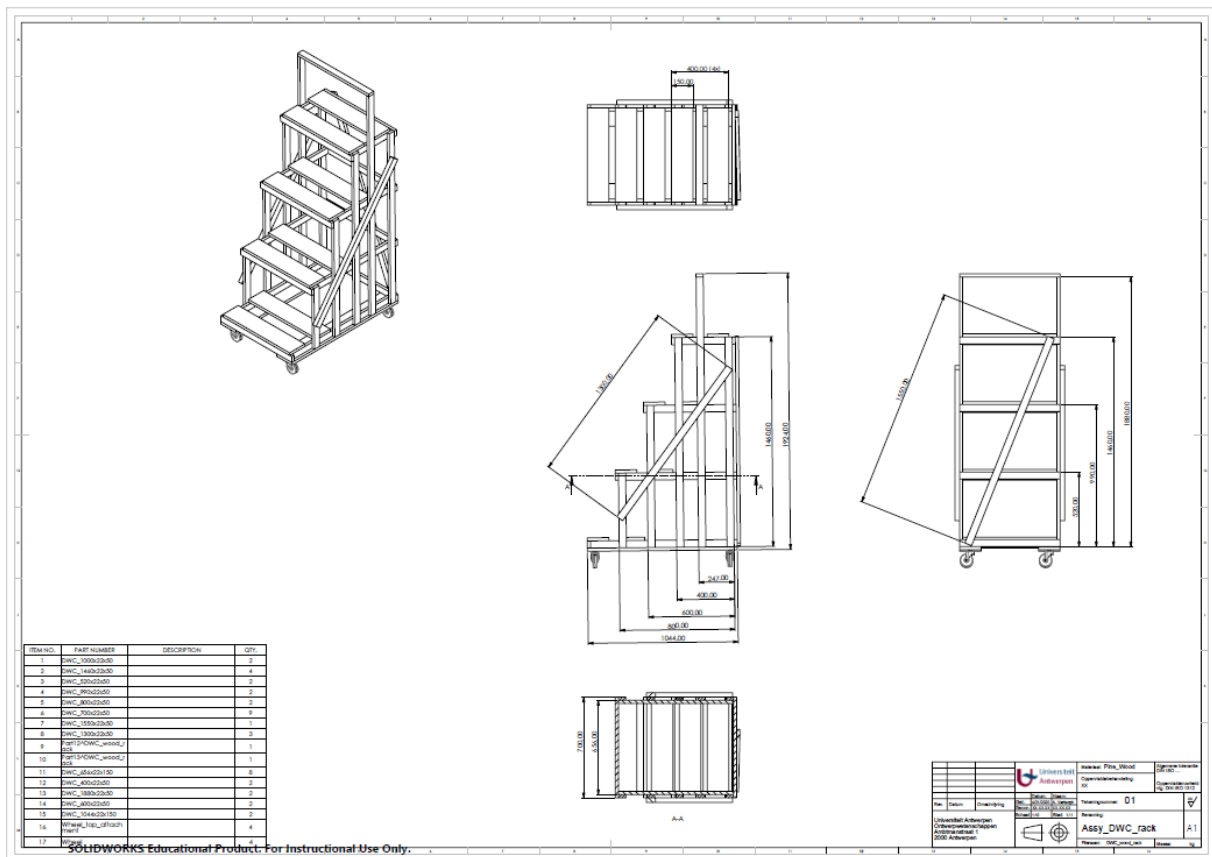
Figure 2.33 DWC Racks and VT Racks

Figure 2.34 The DWC Rack technical drawing

2.11.4 Vertical Towers Racks

The second type of a wooden scaffolding necessary in the project design is Vertical Tower Rack. The construction was made of untreated wood boards. The team aimed to build two racks which accommodate five towers of diameter 110 mm and seven towers of diameter 75 mm. Similar to the DWC Racks, the structure is also equipped with wheels. The height of the racks is adjusted to the greenhouse ceiling and allows easy access to the towers. Additionally, there is a pipe located under the grow towers to drain the water to the fish tank.

Figure 2.35 Vertical Towers Rack
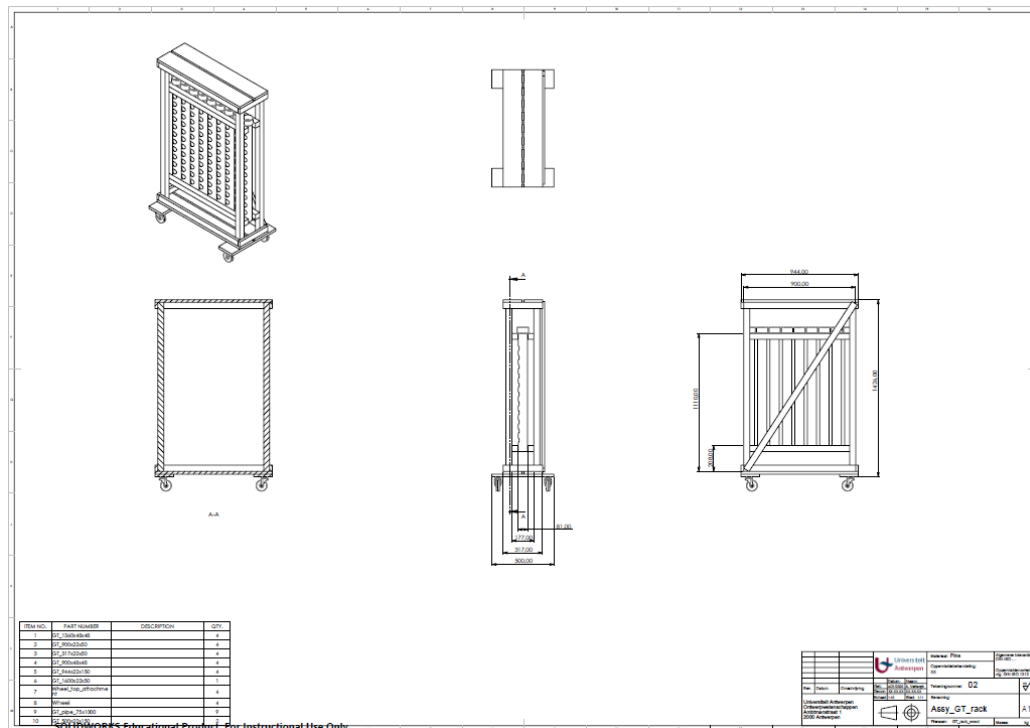
Figure 2.36 Vertical Towers Rack technical drawing

2.11.5 DWC Tanks

The Deep Water Culture unit includes eight containers mantled on two racks. The capacity of one container is 30 L, although it is in fact filled with approximately 25 litres of water to avoid overflowing. The containers were drilled to allow water flow through the system. Firstly, water flowed between the containers on the principle of overflowing like a waterfall. This caused a lot of evaporation. Thereafter, the tanks were connected with plastic pipes. Perpendicular pipe joints were printed on a 3D printer.

Figure 2.37 DWC Tanks building process

2.11.6 Vertical Towers

Team decided to buy two sets of PVC pipes, 5 pieces of large pipes with a diameter 110 mm and 7 pieces of pipes with diameter 75 mm. The pipes were drilled using the table-top drill machine to create a hydroponic area slots for the plants. Each pipe contains 10 slots. Because of a short budget, a new batch of polyurethane filter foam was not purchased. Water will be distributed to the towers through individual tubes, which are connected with a printed nozzle.

Figure 2.38 Drilling slots in vertical tower

Figure 2.39 Vertical Towers module

Figure 2.40 Nozzle distributing water to VT

Figure 2.41 Nozzle printing process

2.11.7 Settling Tank

We found an unused 200 L plastic barrel on the university roof. It became a base of the settling tank. Afterwards, pipe joints were printed by 3D printer to reduce components cost. The barrel was drilled, and pipes were installed. A hole has been cut in the lid of the barrel for a bucket which decelerates the flow of water. Finally, the setup was connected with the fish tank and biofilter tank.

Figure 2.42 Inside the settling tank

Figure 2.43 Settling tank building process

Figure 2.44 Settling tank building process

2.11.8 Fish Tank

We were given the caged IBC Tote tank for free by UPC Print. The top part of the container was cut off. The metal frame was not removed due to a good support of the plastic structure. Then a hole was drilled in the container for a pipe leading to the settling tank. The fish tank is embedded on a wooden platform underneath which the water storage tanks are placed, thus saving space in the greenhouse.
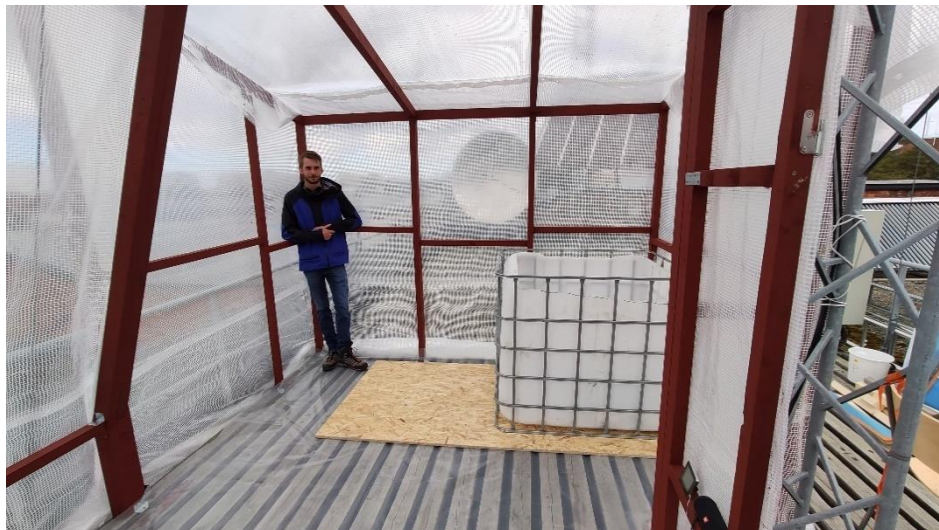
Figure 2.45 Cut Fish Tank

Figure 2.46 Water Storage Tanks

Figure 2.47 Fish Tank connecting process

2.11.9 Pumps

The number of system modules foreseen in the project design had to be reduced due to budget and implementation time constraints. The team decided to construct 1 module of Vertical Towers (VT) and 2 modules of Deep Water Culture (DWC). Decreasing the number of aquaponics units resulted in reducing the number of pumps. We have reused the EHEIM 1002.220 pump purchased by the previous Hygrow Aquaponics group (2019). Two new pumps called BOYU FP-1000 were bought to supply the modules with water. The first BOYU FP-1000 pump will serve the VT and second BOYU FP-1000 pump is designated for the DWC module. Additionally, the large BOYU SPA-2000C pump was purchased to pump the water from the storage tanks back to the fish tank. This pump is oversized for the current system. The advantage of this solution is that the system can be easily enlarged.

Table 2.16 Pump purchase list (Hygrow Aquaponics, 2020)

Pump	Amount	Power	Qmax	Hmax	Exit bore Ø	Price
BOYU SPA-2000C	1	35 W	2000 l/h	2,5 m	13 mm	€ 65,00
BOYU FP-1000	2	16 W	1000 l/h	1,8 m	15 mm	€ 29,50
EHEIM 1002.220	1 (spare)	23 W	1000 l/h	2,0 m	15 mm	/ (prev. group)

Due to the flow losses caused by the influence of the height difference and horizontal pipe losses in the greenhouse, the pumps may deliver a different water flow than the Qmax mentioned in table 16. It is therefore practical that the different types of pumps can deliver an adjustable flow rate, although it can only be adjusted slightly. The adjustment of the water flow rate of all pumps is achieved by a mechanical closure on the pumps themselves. The pumps remain constantly running at full power when switched on, only the mechanical adjuster can be used to modify the water flow rate. In order to obtain a circulation system that is as efficient as possible, the mechanical adjustment on the pumps should therefore not be used and the pumps should be continuously providing their full flow rate.

A second factor to keep in mind is the water level in the tanks. It is important that each water tank remains sufficiently filled at all times to prevent the pumps from running dry. This means that the pumps will definitely have to be adjusted in water flow in order to find a balance in water level. However, some of the pumps can be adjusted further in water flow than the others, which makes it difficult to find a balanced water flow rate. When a compromise is found between these two factors (efficiency vs. water level), overflow is used to compensate any imbalance in the water circulation system.

Figure 2.48 Pumps testing

The pumps need to be tested in order to achieve the optimal water flow, thereby the efficiency of the aquaponics system will improve. When the next group of international students wants to expand the aquaponic system, they will have to find an optimal balance in water flow again.

Reason of testing

Pumps task is to supply the system with constant water flow. It is necessary to deliver both plants and fish with essential nutrients.

Desired result

All the water pumps have the established water flow which circulates 660 litres of water in the system in one hour.

Issues

1. The differences in the height of pipes as well as horizontal water flow losses may cause imbalance in the system circulation

Actual results

We have found that the water flow of the BOYU FP-1000 pumps is difficult to control in practice. Therefore, they will be run at maximum flow rate and depending on the actual flow rate recorder in the VT and DWC modules, the flow rate of the BOYU SPA-2000C will be adjusted to find an ideal balance.

2.12 Conclusions and Recommendations

2.12.1 Conclusions

Our objective was to create a sustainable and flexible aquaponic system. The team aimed to make it modular as well as scaled up in comparison to the first aquaponic system. Among our priorities was also the improvement and development of the control system, which is discussed in the chapter entitled "Control system". While working on the project, many of our intentions and plans have changed. By trial and error, we managed to create an aquaponics system that can be accommodated in the greenhouse. Established system provides 2 m^2 hydroponic surface area and fish tank which can accommodate maximum 10 kg of fish. The flexibility idea is implemented in the form of movable DWC and VT racks together with removable filtration tanks. Although, not all the modular designs could be done. There were plans to implement the flexible piping system equipped with valves, however we had to reject this idea due to budget and time limitations. Moreover, we managed to establish water storage system which helps to maintain the proper water level. Additionally, significant improvements were done such as the water distribution module in vertical towers and protection against algae in the form of dark containers impervious to sunlight. A further innovative concept was to build a radial flow separator that will reduce the amount of solid waste in the system. The biofilter tank did not require any major modifications. On the other hand, we did not manage to cycle and run the system with plants, fish and bacteria. Time constraint did not allow us to gather and analyse the data from thriving system. At this point we cannot claim that our system will be fully functional, although we have made every effort to design it correctly. The team did not achieve all the project goals, nevertheless the next team can continue the development of the aquaponics system and bring it to a new level.

Figure 2.49 Established Aquaponic System in the Greenhouse

2.12.2 Recommendations

This section is devoted to advice on the further development of the aquaponics system. The recommendations are the results of project research, building experience and obtained outcomes. These guidelines are intended to facilitate the work of the future group of students who will take over this project.

2.12.2.1 System cycling

We planned to implement the ecosystem to the aquaponics although it was not possible due to late executed building process. A suitable environment must be prepared before living organisms are introduced into the system. To accomplish this, follow the instructions described in the subchapter 2.9.5 Cycling the system. It is recommended to conduct this process for at least two weeks. Tap water has to be removed of chlorine using UV lamps for 24 hours. Afterwards, ammonia must be added to the system. It can be controlled by adding proper doses of calcium compounds or phosphoric acid, depending on the pH. It is not healthy for fish to use them as a source of primary ammonia. Pure ammonia which can be purchased commercially is a better solution to start cycling the system. Levels of ammonia, nitrites and nitrates need to be adjusted and maintained at the recommended values before implementing nitrifying bacteria. When the stable environment is established bacteria can convert ammonia. The sign of conversion is indicated by the decrease in concentration of ammonia below 1 ppm. Finally, fish and plants can be introduced to the system.

2.12.2.2 Fish

The team had trouble finding a fish farm retailing rainbow trout or carp. However, we managed to locate an aquarium shop where we can purchase Koi Carps. Due to the closure of the Helsinki region, we could not order fish. It is necessary to plan a trip to buy the fish as soon as the system is running. It is a good idea to search for best prices in the aquarium shops. Besides fish, other marine life can be

introduced to the system such as shrimps or small snails. They are usually available in pet shops, though asking in advance is suggested to get enough time for choosing alternatives.

2.12.2.3 Plants

The second essential factor in the aquaponic system are plants. taking to heart the advice of the previous team from the very beginning of the project, we have handled the issue of seedlings. The plants were sown but we did not take into account the starting media. As a result, the young plants did not develop sufficiently strong root systems. The error can be found both in the absence of the medium and in a too short period of growth. The seeds should be sown in rockwool from the very beginning so as not to expose young plants to environmental shock and loss of small roots when the plant is transferred from the soil. It is beneficial to germinate seedlings under the lid. It would help maintaining the humidity and temperature. The second point is plant nutrition. The sustainable aquaponic system should provide most of the micro and macro elements, however the deficiencies may occur. Shortages in iron, potassium and calcium are quite common in aquaponic systems due to their small content in fish feed. Iron can be supplemented in form of chelated iron. Calcium and potassium are added in form of hydroxides or carbonates which serve also as a system buffer. Concentration of inorganic elements should be monitored by the controlling system.

2.12.2.4 Hydroponics

It is suggested to buy a new batch of polyurethane filter foam. Our team did not have sufficient budget to buy plant foam for an enlarged setup. The previous project team purchased the foam from Modulor company located in Germany. Considering the availability of this product in Germany, a longer delivery time should be expected. Therefore, it is good to order the foam as soon as possible. Another system component we were not able to buy is Polystyrene used for rafts in DWC. We used the existing ones, although the aquaponic system is enlarged thus it requires more rafts. The advice is to buy a few more Styrofoam sheets. In connection with the expansion of the DWC unit, also new pots for plants must be created. The previous team used the design from Thingverse which was scaled and printed. It is needed to print additional pots to make full use of hydroponic space.

2.12.2.5 Flexibility

Current aquaponic system can become more modular if implementing flexible piping system with valves will be considered. It has to be estimated if that solution whether this solution will be most beneficial.

2.12.2.6 Lights

As we did not focus on lighting during our project, we suggest that the next team will read the previous aquaponic project report, which explains how the lighting unit works. For the new system, it would be preferable to purchase additional sets of LED lights and program them accordingly.

3   Control System

3.1   Introduction~~Introduction~~

In this chapter the first steps towards a fully controlled and automatized system, that is reliable and failsafe, are shown, as well as ideas and recommendations for future groups to put into practice.

We created a structure that includes options to control the actuators, sensors to keep track of the system, switch cabinets to connect everything and a website to give an overview on the status of the system.

With the help of the sensors, the actuators can be controlled and tested whether they are working correctly or not. This is important to make the system more independent and require less work for the upkeep. It increases the user friendliness and with the decrease of necessary workforce also the economic feasibility.

We designed and built switch cabinets that provide protection for our current electronic set up and space for future additions. To continue with the modular approach to the set-up, there is also an own switch cabinet for each module.

Lastly, the website, similar to the implementation of the sensors, eases the handling of the system and provides the access to the system from far away.

3.2   Technical System

3.2.1   Overview

Just like our entire system, we decided to make our Control System as modular as possible.

This is because, as previously mentioned, we have enlarged the Aquaponic System in size and given it a better design and professional shape and has been positioned in its destined place on the roof of the Technobothnia building and looking at a more long-term view, our greenhouse could be further expanded, moved, and increased, so a modular concept is the one that best suits our needs.

Therefore, also the control part was conceived with a modular approach.

As previously said, our Aquaponic System is made up of different parts. From the controlling point of view, we can identify four different environments, which are the *Fishtank*, the *Vertical Towers*, the *Deep Water Culture* and what we have called *Greenhouse* which is the environment inside the greenhouse in which all the aforementioned parts are contained.
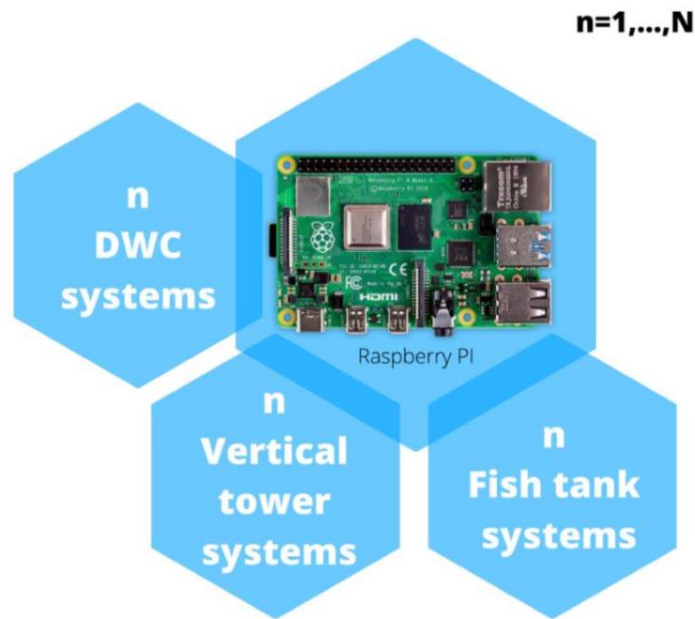
n=1,...,N

Figure 3.1 Modular system concept (Hygrow Aquaponics, 2020)

3.2.2   Central and Decentral Units

In each of these sections, sensors and actuators are implemented to keep the conditions under control and to measure all the necessary values to control the environmental conditions for plants and fish. These sensors are connected to a micro-controller, in our case an Arduino MKR WiFi 1010, used to control the parts of interest. Furthermore, all the electronic components of each section are enclosed in a switch cabinet built by us to make everything even more modular, comfortable to manage, move and give the whole environment a more suitable design. Subsequently, the data collected by Arduino controllers in each section are transmitted via Wi-Fi (since all the components are equipped with this technology) to a Central Unit, constituted in our case by a Raspberry pi 3, which stores and manages them.

Figure 3.2 Arduino MKR WiFi 1010
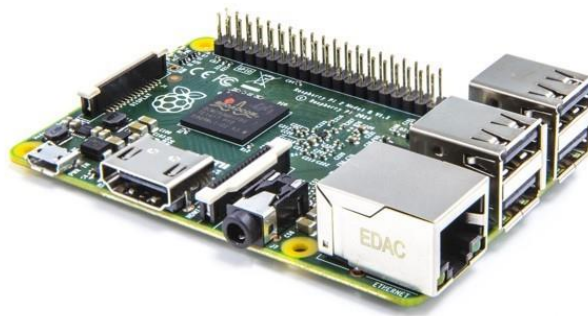
Figure 3.3 Raspberry Pi Model 3B+

3.2.3 Hardware and Software

Initially we had planned an increase in the number of sensors to have a better control of our environment in the different sections. But as the project progressed, multiple problems arose that prevented us from completing everything we had planned. The main problem was the reduction of the budget assigned to this section due to both the change of the main objective during the course of the project, and to the current situation due to Covid-19, making it harder to get shipments of sensors and other elements that we would have like to implement ,to Finland.

To cope with this impossibility of adding new hardware components, we mainly concentrated on the reorganization of the sensors and actuators already in our possession, by reworking the programming code from the beginning in order to create a solid starting point from the point of view of the software for the next group and facilitating the implementation of additional sensors in the system.

The IDE Arduino 1.8.12, that was used to program the microcontrollers responsible for controlling each part of the system, is from the same company as the microcontrollers used by us, which is Arduino.

Our basic idea was to create a single general code, with an equal basis for all sections, which is then adapted to the different modules for which it is used and to the sensors connected to the Arduino.

Figure 3.4 Arduino Logo

3.2.4 General Software Code Analysis

The code is explained in the figure below, by using a flowchart. The full code will be added in the Hand- Off package.

This code begins by identifying the sensors present in the section taken into consideration.

The software operator, in the initialisation phase, must therefore give a value of "1" to the variables corresponding to the components present in that section and a value of "0" to the sensors not present. Once this action is completed and all the hardware part is connected, the microcontroller will carry out the process described below.

The code is running in the *loop* function, meaning that the Arduino, in normal conditions, repeats the code cyclically and indefinitely, and is composed of a series of if-functions, which in practice are used to compare the added parameters ("1" or "0") by the software operator to check if the sensor is available. This process occurs by comparing the variable corresponding to a certain sensor with the value "1". If this equality is true, the code will carry out the process corresponding to this sensor, otherwise it will skip the process related to that sensor and proceed with the verification of the next sensor.

It will therefore be possible to use the same code structure for all sections of the aquaponic system, changing only the previously described parameters, inserting the desired ones for the corresponding section.

Obviously, in addition to setting the parameters as described above, the software operator will have to insert the code all the libraries and setup functions required by each sensor involved.

It should also be noted that the flowchart has a start, corresponding to the moment in which the program is loaded on the microcontroller and the code starts to run, but has no end. This is due to the presence of the loop function mentioned before. So, our microcontroller will continue to execute the code indefinitely, or more realistically until it is manually turned off or hardware damages occur.
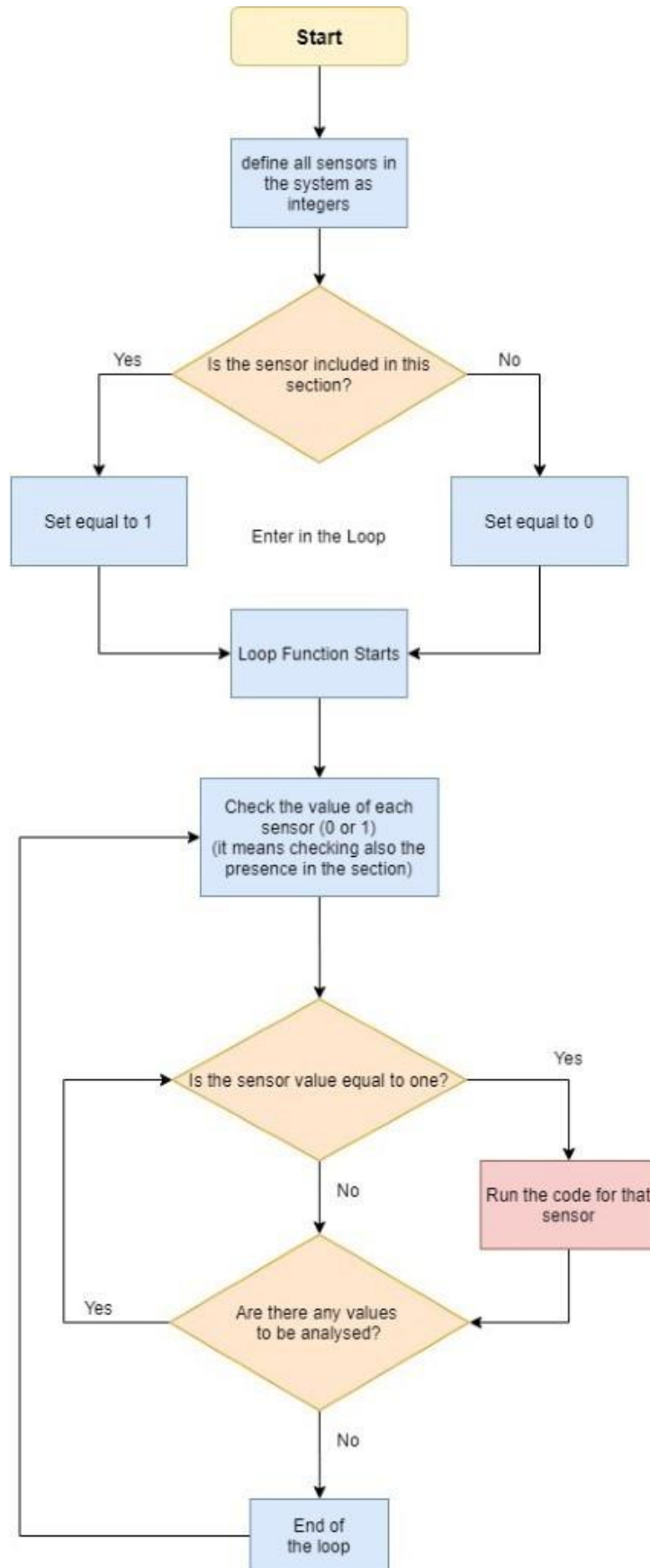
Figure 3.5 General code flowchart

3.2.5 Specific software code analysis

3.2.5.1   Greenhouse

To make it even clearer, as an example, the code used to control the *Greenhouse* will be analysed below. Currently present in the *Greenhouse*, are the temperature and humidity sensor and the light sensor, the code will recognize the presence of these two. Then it will execute the code previously described in figure above, to then execute in correspondence with the red block of the flow chart above, the specific codes that we have designed to use these sensors.

So, to have the complete code for the Greenhouse replace the red block of the general flowchart, once the code relating to the temperature and humidity sensor and once the code relating to the sunlight sensor

This specifics codes will now be examined and described in detail with reference to the following flow chart.

Once the general code has recognized the presence of the temperature and humidity sensor and of the light sensor, Arduino will execute the code corresponding only to these sensors.

Figure 3.6 Temperature and humidity sensor (Groove,2020)
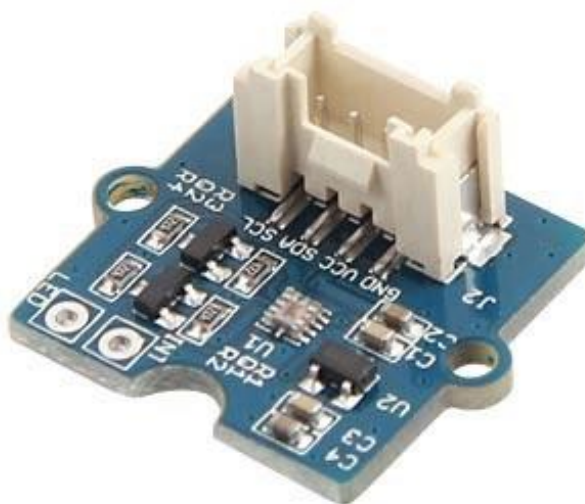
Figure 3.7 Sunlight sensor (Groove, 2020)

The first example is to control the temperature and humidity values inside the greenhouse.

The sensor first measures the temperature and humidity value, then it checks if there has been a problem during the measuring, through an "*isnan*" function (is not a number), and if there are not problems, it communicates the values, otherwise it tries again to measure.

When the code related to this first sensor is finished, the Arduino will run the code for the second sensor in this section, the sunlight sensor.

The light sensor will measure the intensity of light that hits it. In short, the idea is that if this value is greater than the minimum threshold for which the light is sufficient for the light required by the plants, they will remain off, otherwise they will be turned on.

Going more in depth, to make everything more precise and accurate, and also to avoid any temporary problems that prevent light from reaching the sensor (for example clouds, or animals present on the roof of the greenhouse), i.e. problems that obstruct the light for a few seconds, we have edited the code as follows.

Each measurement made by the sensor is stored in an array of the size defined in the software design phase, in our case 10. So after 10 measurements of the light intensity value the program will automatically calculate the arithmetic average of these values, and if that average is lower than the minimum light threshold, then the lights will automatically turn on, otherwise the cycle will be restarted as previously described until the array is filled again. This avoids turning on the lights for short periods of time, and then turning them back off a few seconds later, improving the life of the hardware.
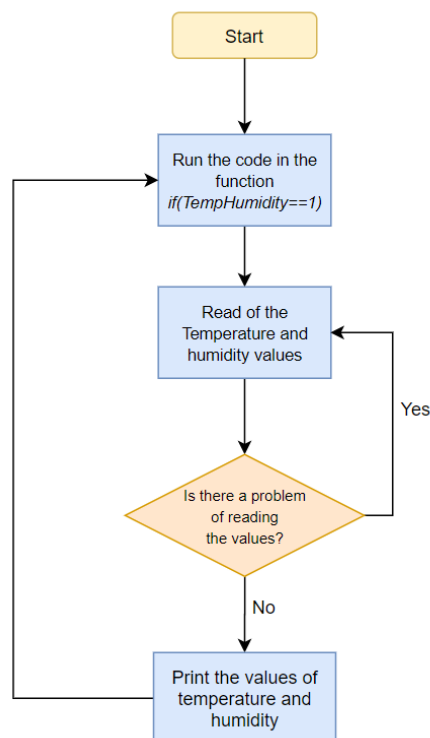

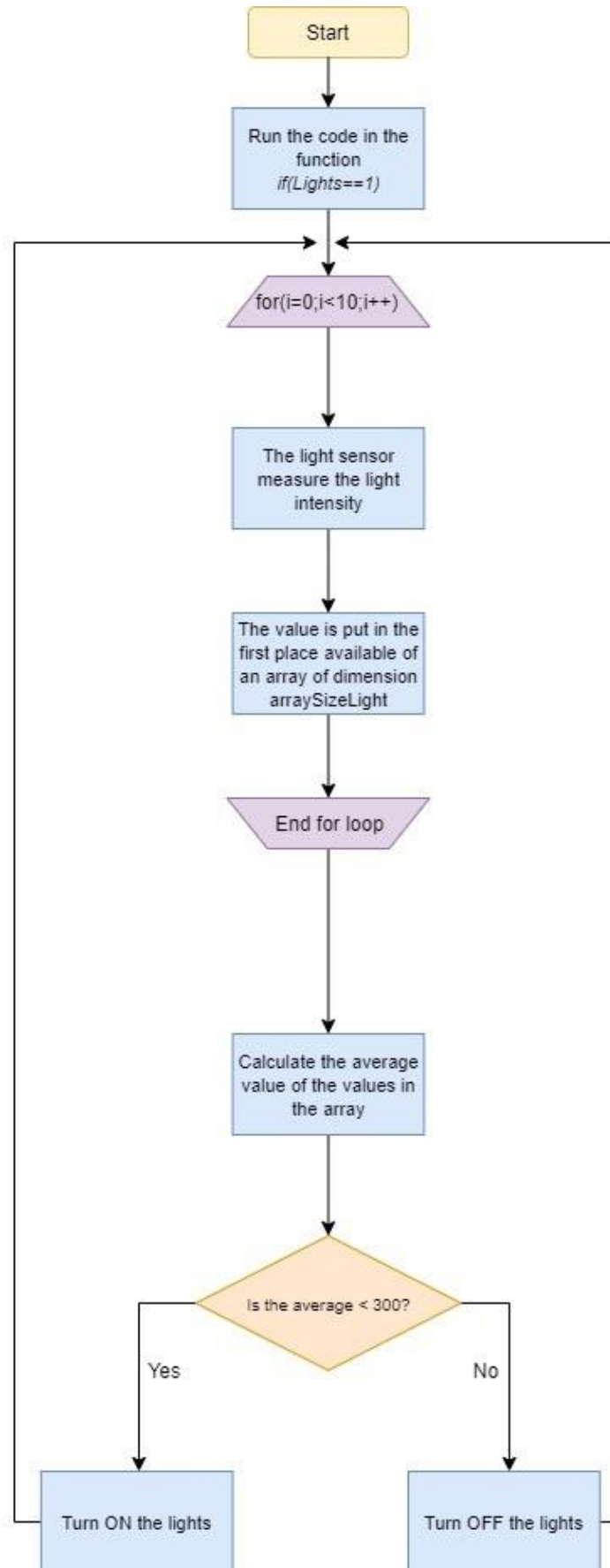*Figure 3.8 Specific code for Temperature and humidity sensor*

Figure 3.9 Specific code for Temperature and humidity sensor

In this section, at the moment, a timed and motorized fish feeder has been implemented by means of a 360° servo. Using an RTC module, that is a Real Time Clock, it is possible during the software design phase to insert one or more specific times at which the correct amount of food is poured multiple times a day for the fish in the fish tank. This quantity can be easily modified during the initialisation phase by changing the time for which the servo will rotate and therefore the fish feeder will be in action. We calculated that in a rotation time of 3 seconds an amount of feed equal to 8 grams is poured. Starting from this, it is therefore possible to calculate the desired quantity of feed, by simply proportioning the time the motors are running to the amount of feed.

In addition, LED strips are also implemented in this section, also programmable and timed by means of the Arduino and the RTC module mentioned above. During the software development phase, it is therefore possible to select the time span for which the lights are on and off. This is to provide the fish with the necessary lights and in this case also provide a simulation of the natural cycle of light and dark during the day.

For this section, we also have a pH sensor that would have been very useful for calculating this value in fish water. However, this sensor needs a calibration for which we would have needed access to the university's chemistry laboratory, and due to the Covid-19 situation, this was not possible. We therefore decided not to implement it, but recommend the next group to do it, since in the future there will be the possibility of accessing the chemistry laboratory.

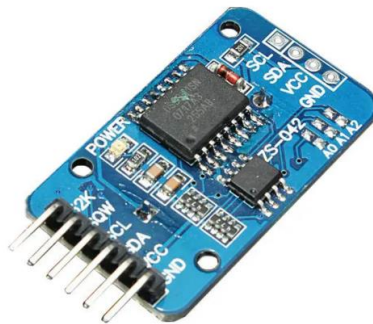The complete code can be found in the Hand-Off Package.
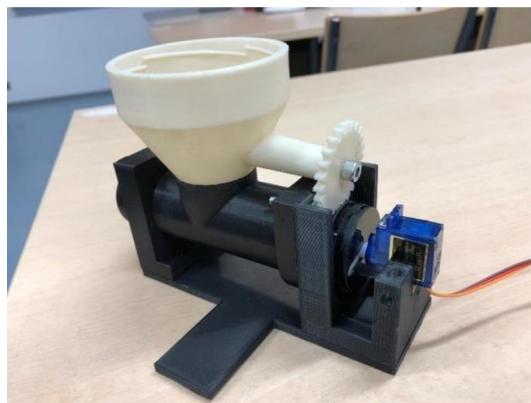

Figure 3.10 RTC Module (Adafruit, 2020)

Figure 3.11 Fish feeder and servo installed (EPS Team, 2019)

3.2.5.3   Deep Water Culture

In this section there are currently only lights are controlled by Arduino through relay modules and a light sensor, which works in the same way as those implemented in the Vertical Towers. But the task of this light sensor is not the same as that mentioned above, it is only to verify whether the lights are working or not. As they are being controlled only by a relay and not directly connected to the microcontroller the Arduino will be able to detect when lights do not work when they should be on. The complete code can be found in the Hand-Off package.

Figure 3.12 Relay module used in the system (Groove,2020)

3.2.5.4   Vertical Towers

In this section, only a light sensor is currently implemented.

The task of this is the same of the one previously mentioned for the Deep Water Culture, i.e. check if the lights are working properly. Also, in this section, in case of malfunction of the lights it will be communicated.

All these values, collected by the Arduinos of the various sections, are transmitted to the Raspberry to be managed and analysed.
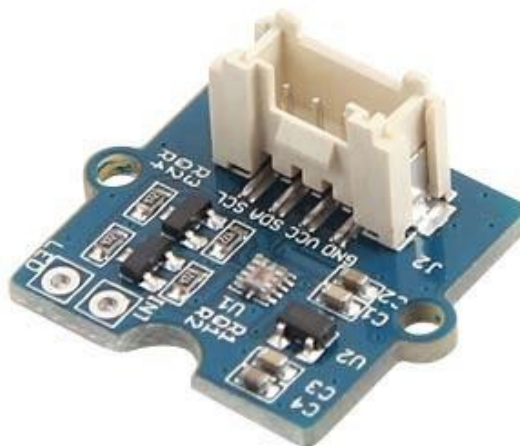
Figure 3.13 Sunlight sensor (Groove,2020)

3.3 Communication Overview

3.3.1 Concept

The system consists of different kinds of communication. As in the picture below illustrates, the individual sensors and actuators are wired to the Arduinos. The communication could be for example a bus protocol like I2C or a normal analogue or digital connection. Between Arduinos and Raspberry a Wi-Fi connection was used to enable data transfer. An Arduino acts as a MQTT client, whereas the MQTT broker is implemented on the Raspberry Pi. To record all data in the system, the MQTT broker is connected to a database on the Raspberry Pi.
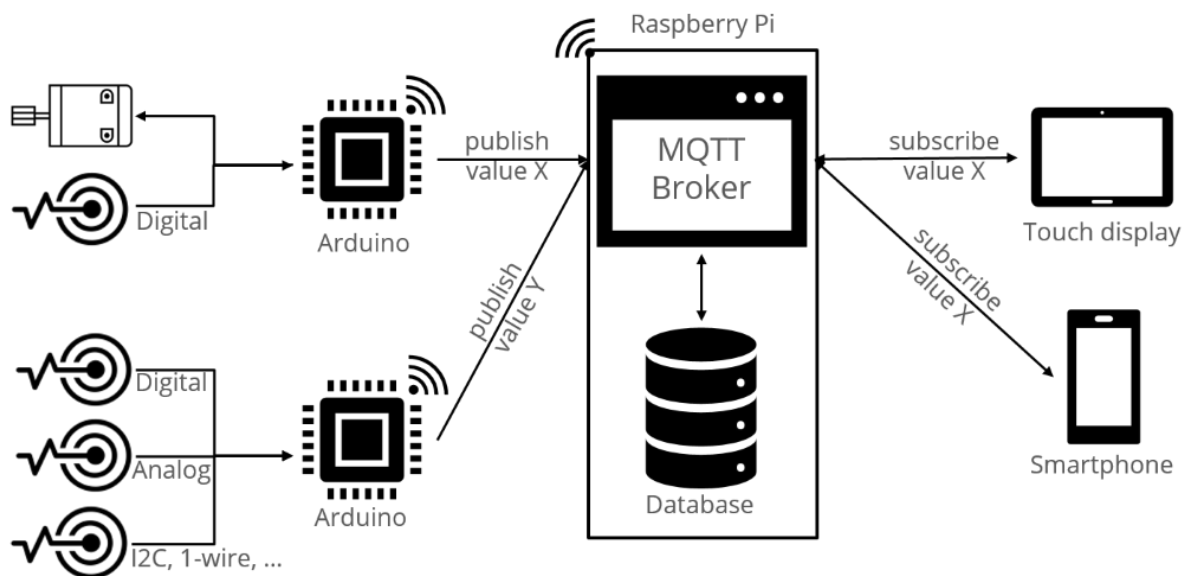
Figure 3.14 Communication overview

3.3.2 MQTT

As mentioned before, we use a wireless data communication between the decentral Arduinos and the central communication unit, the Raspberry Pi. As a communication protocol between the different devices MQTT was chosen. MQTT is an industrial standard designed for machine to machine communication. It was developed for data transfer in situations with unstable connections and where a small footprint was required. (MQTT, 2020)

It is also often used in Internet of Things applications, meaning it is used for communication between devices without human interference such as human-to-human or human-to-computer communication (What is IoT (Internet of Things) and How Does it Work?, 2020).

The difference between MQTT and other communication protocols is that here, there is no constant exchange of data. Basically, with MQTT data is only transmitted if there has been a change and another device is actually interested in it.
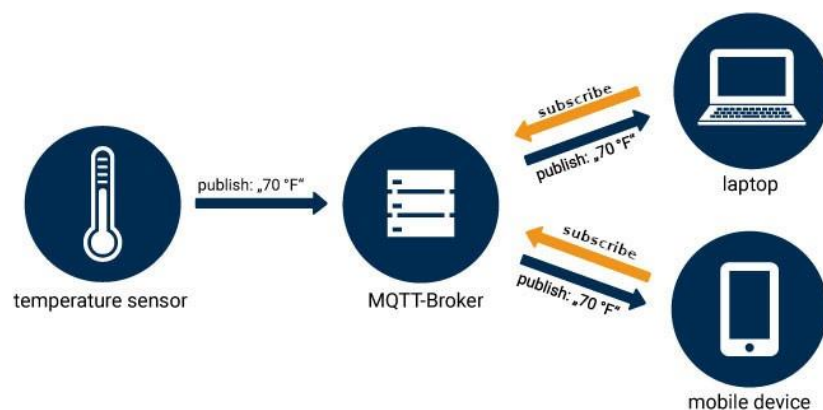
Figure 3.15 MQTT Broker and clients (Gebauer, 2020)

MQTT uses the concept of publish and subscribe. A client, for example a user with a laptop, can subscribe to different topics and each time a message gets published the client receives only the messages he is subscribed to.

For this to work MQTT always requires a broker. In the Aquaponic system case the Raspberry acts as the broker. The broker receives all messages, filters them and then sends them to the corresponding devices (Gebauer, 2020). One advantage is, that even though the broker needs to have a connection with all the clients, the clients their selves do not need to know anything about each other, making it easier to implement the protocol and eliminating the chances of incompatible hardware.

To be able to filter the messages and to determine which client is subscribed MQTT uses topics which consists of different levels. For example, the temperature sensor in the fish tank could be addressed as fish tank/sensor/temperature, with the different levels divided by a backwards slash. Creating new topics is fairly simple, as they do not need to be initialized by the client but all valid topics are directly accepted by the broker (chkr1011/MQTTnet, 2020).

So, each sent message not only includes the content of the message, but also the relevant topic to distribute the message.

For sending a message there are also three different mode, first there is sent "only once" where each message is sent once without regard if it has been received or not. Then there is "at least once" where a message is sent multiple times without waiting for the client to confirm receiving. With this mode it can happen that a message is received multiple times and the action is also performed more often than wanted. And lastly, the most secure way of sending is "exactly once", where a message is sent until the client confirms receiving it (Team, 2020). This is the method with the least confusion and failures, but it is also the mode that requires the most data and has a bigger footprint. The chosen modus for each topic or client should be proportional to their importance and relevance to the system. Sensor values e.g. for the temperature are not as important as orders to the actuators and need to be treated differently.

Another helpful option MQTT provides is the Last Will & Testament (LWT). During the first connection the client establishes a Last Will & Testament message. The broker saves this message and in case of an unplanned disconnection publishes the message. This means it is possible to notice, without actively checking the system, if any clients have lost connection.

3.3.3 Remote Access

The last sections described the technical system and the communication in the greenhouse itself. To increase the usability of the given system, it is necessary to have a remote access to monitor and maintain the system from outside the greenhouse or the Technobothnia building. To provide a remote access, three different types of connection are possible.

A wired connection through an ethernet cable would be the best and most reliable option, but there is no network socket next to the greenhouse on the roof available. The ICT department mentioned that an installation by an electronic company would be too expensive.

Another solution could be a 4G router with a sim card. Therefore, we must buy the router and pay the monthly costs from the sim card, if there is no contract between the university and a telecommunication company, what could provide us the needed equipment.

There is a low Wi-Fi coverage on the roof to connect to the Novia-Guest, Novia or Eduroam network. For the beginning, it is recommended to test the Novia-Guest network, what is the most cost-efficient solution, to get a remote access. If the connection quality is not good enough, the ICT department can install another access point, what can provide a better quality.

The possibilities were discussed with the ICT department and they mentioned that it is not possible to get a direct access to the Raspberry Pi over the Wi-Fi network from the university. A solution therefore is to use the OpenVPN Server from the energy technology laboratory at Technobothnia, which is which is managed by Hans Linden. With this server, it is possible to receive an external access. In addition to that, the ICT department can provide us a subdomain pointing to the Raspberry Pi, like "hygrow.novia.fi" to connect to the website and the maintenance website.
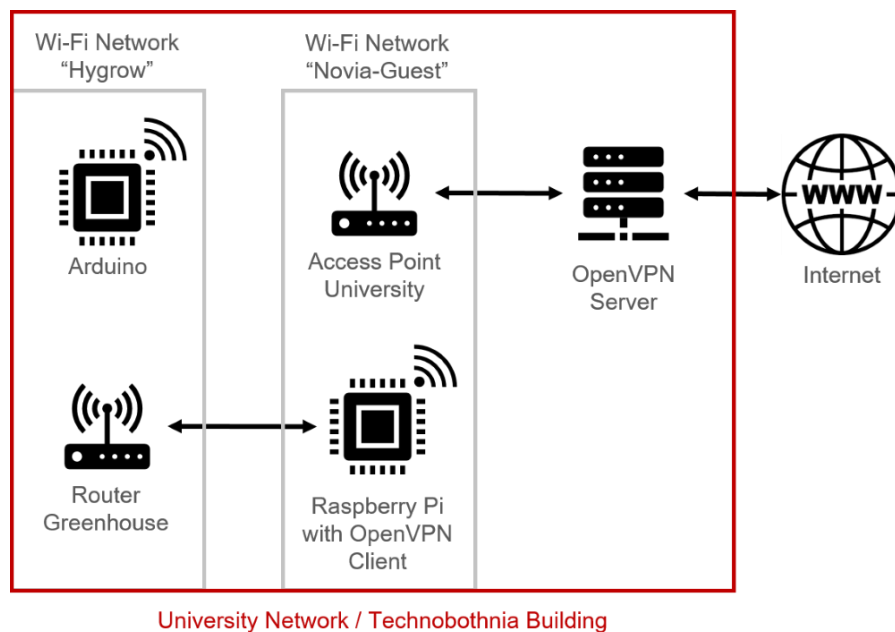

Figure 3.16 Connection setup for remote access

The figure above gave you an overview about the potential system. The decentral Arduinos are connected over an internal Wi-Fi network to the Raspberry Pi. A router with a cable connection to the Raspberry Pi is used as a Wi-Fi access point between the OpenVPN Server in the University and the Raspberry Pi which runs an OpenVPN client. The server itself is connected to the internet. With this setup it is possible to reach the connected devices inside the Novia-Guest network.

3.4   Structure of the Electrical System

3.4.1   Electrical Overview

Besides the software, also the electrical wiring inside the greenhouse and the aquaponic system is as modular as possible. Therefore, different kinds of switch cabinets were built which are mounted directly to the modules in the system. This modular system can be changed and increased efficiently. To run the aquaponic system, different voltage levels are needed. The water pumps, lights for plants and the air pumps need 230 V AC (alternating current) for operation whereas most of the sensors, actuators and microcontrollers like the Arduinos and Raspberry Pi need 5 V DC (direct current) for operation. Some actuators, for example valves, are powered with 12 V DC. All this voltage levels are available in the system.

The following Figure gave an overview about the switch cabinets in the system and what the connection between them is. The hole system has one connection to the power grid of the Technobothnia building. The main switch cabinet has the task to protect the grid connection and the hole system through different types of fuses and convert the 230 V to 12 V and 5 V. Furthermore, the switch cabinet distribute the voltage levels through cables to all other switch cabinets and contains the central communication unit, the Raspberry Pi. This system allows to disconnect each module separately if a failure occurs. In additional to that, it is uncomplicated to include an additional switch cabinet into the system.
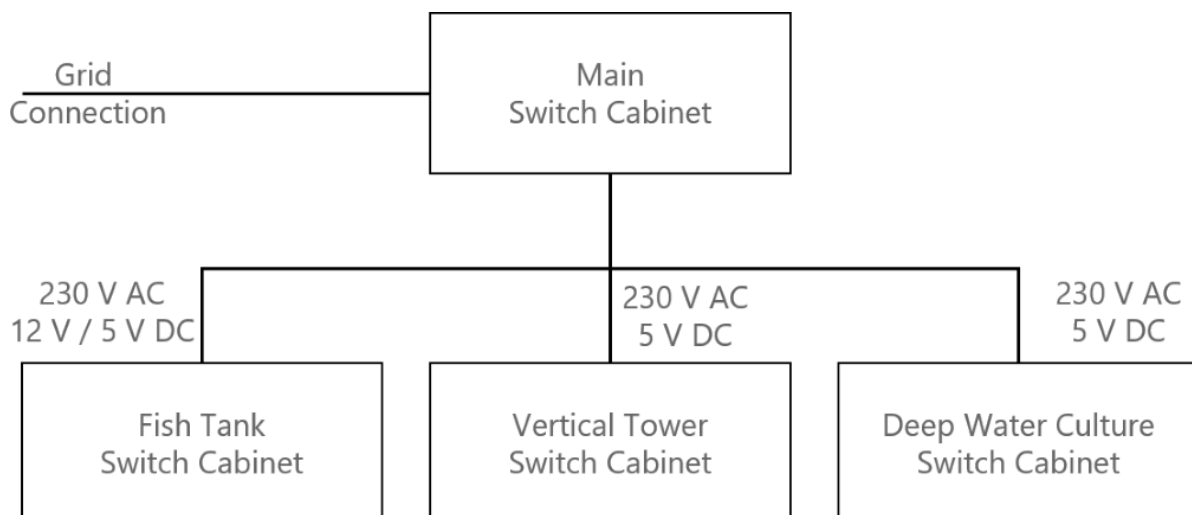

Figure 3.17 Overview wiring connection

3.4.2   Switch Cabinet Building

In addition to modularity, the control cabinets should also be designed for future project groups. To reach this goal, the design phase was highly time-consuming. At the end, the design phase had three main steps, the first of these was to plan the switch cabinet size and the wiring with all our planned material, for example fuses, terminals, sensor, actuators, and microcontrollers. The second step was to assume, which changes in the system can happen and which changes from the switch cabinet can be happen. At least we reduce the planning due to the budget changes, but only for the material inside the switch cabinet. The switch cabinet itself is planned and build for the full system with all possible changes and extensions.

After the design phase, the switch cabinet were built with standard wiring ducts, what you can see in one of the following figures and mounting rails for the components. The switch cabinet itself is built with OSB panels, instead of preferred plywood because of the budget change. All OSB panels were sanded, screwed and then equipped with the wiring ducts and mounting rails.
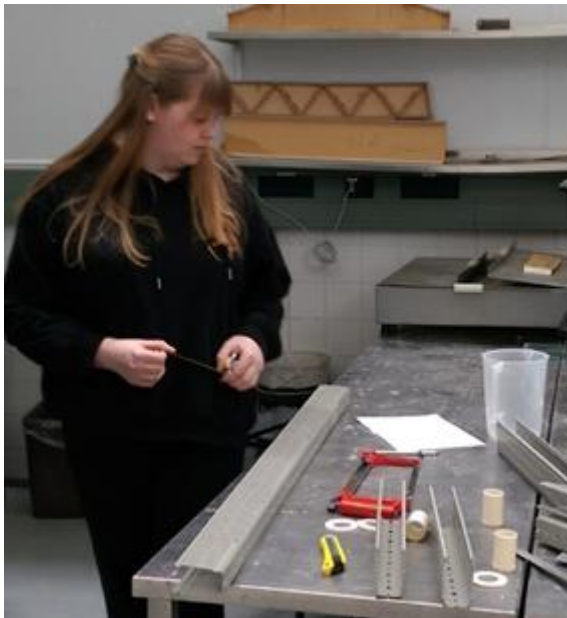

Figure 3.18 Preparing wiring ducts

Figure 3.19 Preparing switch cabinet

Most of the purchased parts can be mounted directly to the mounting rail. They have a high life expectancy and minimise the liability for failures. For other parts, like the Raspberry Pi or circuit boards, we prepared 3D-printed mounting brackets which are shown in the following figure.

Figure 3.20 Mounting brackets for Raspberry Pi and circuit boards

The next step after design and building the switch cabinet was to mount all purchased material in the switch cabinet. Afterwards it was possible to wire all parts in each switch cabinet what is shown in the figure below.
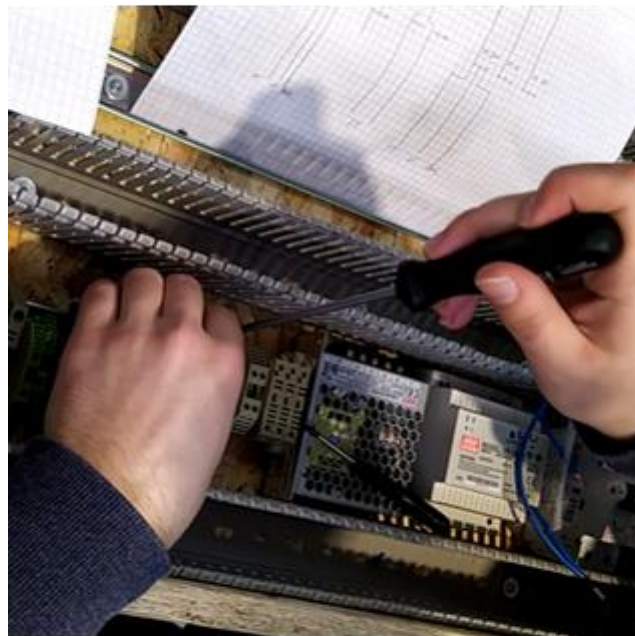

Figure 3.21 Wiring switch cabinet

Finally, in addition to a main switch cabinet there was also one for the fish tank, vertical tower and the Deep Water Culture available. The switch cabinet for the vertical tower and the Deep Water Culture was directly mounted to the modules, while for the main switch cabinet and the one for the fish tank a rack was built. As you can see in the following figures, provide for the moment more space as needed. One reason therefore is long-term planning for the next groups and another reason are the order and delivery problems, which means that not all planned and needed parts are available for the moment. Therefore, it is not possible to test the complete control system with all sensors and actuators. Especially because of the missing microcontrollers for the switch cabinets.

Figure 3.23 DWC switch cabinet

Figure 3.22 Main switch cabinet

3.5   Maintenance Website

3.5.1   Design

To visualize the acquired Data of the system and to access it from remote locations, we created a maintenance website.

The code for the website consists of a html file for each page on the website and a CSS file to set the design parameters. CSS stands for "Cascading Style Sheet", it allows easy changes of colours, fonts, backgrounds and layout of the website as it only requires adjustments in one file as opposed to changing each html page on its own. (What is CSS - javatpoint, 2020)

To achieve a more appealing look and modern design standards, we decided to use a template for the CSS file. We chose the template "concept" by Themewagon (Concept-Free Bootstrap 4 HTML5 admin template for web applications and websites, 2020), that is based on Bootstrap.

```
1688    .sidebar-dark.nav-left-sidebar .nav-link i {
1689        color: ☐#335266;
1690    }
1691
1692    .sidebar-dark.nav-left-sidebar.submenu .nav-item .nav-link:focus
1693    .sidebar-dark.nav-left-sidebar.submenu .nav-item .nav-link:active {
1694        background-color: ☐#335266;
1695    }
1696
1697    .sidebar-dark.nav-left-sidebar .navbar-nav .nav-link:focus,
1698    .sidebar-dark.nav-left-sidebar .navbar-nav .nav-link:hover {
1699        color: ☐#fff;
1700        background-color: ☐#335266;
1701        border-radius: 2px;
1702    }
1703
1704    .sidebar-dark.nav-left-sidebar .navbar-nav .nav-link:focus,
1705    .sidebar-dark.nav-left-sidebar .navbar-nav .nav-link.active {
1706        background-color: ☐#335266;
1707        color: ☐#fff;
1708        border-radius: 2px;
1709    }
```

Figure 3.24 CSS example for navigation Bar

In the figure above you can see an example for the CSS code that applies to all pages. In this except the properties of the navigation bar are described. We chose the dark blue from the Hygrow Logo as a base colour and used a colour picker to get continuous results for the different shades used (HTML Color Picker, 2020). The style of the navigation bar should be the same on every page and therefore it is beneficial to use a CSS file to avoid inconsistent looks. In the next figure it is shown what these properties look like in practice.
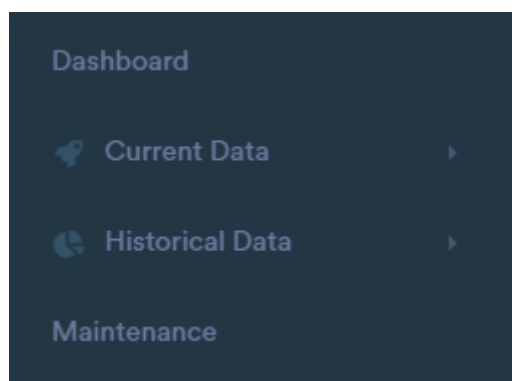

Figure 3.25 Navigation bar Hygrow Website

As mentioned above, this website is using Bootstrap, which is a front-end framework (meaning the result is visible to the user and not only to the programmer) created to aid in the development of responsive websites (What is Bootstrap - JavaTpoint, 2020). A responsive Website changes its Layout depending on the screen it is displayed on. Especially now, when phones are commonly used for internet access this is major factor to increase the user friendliness.

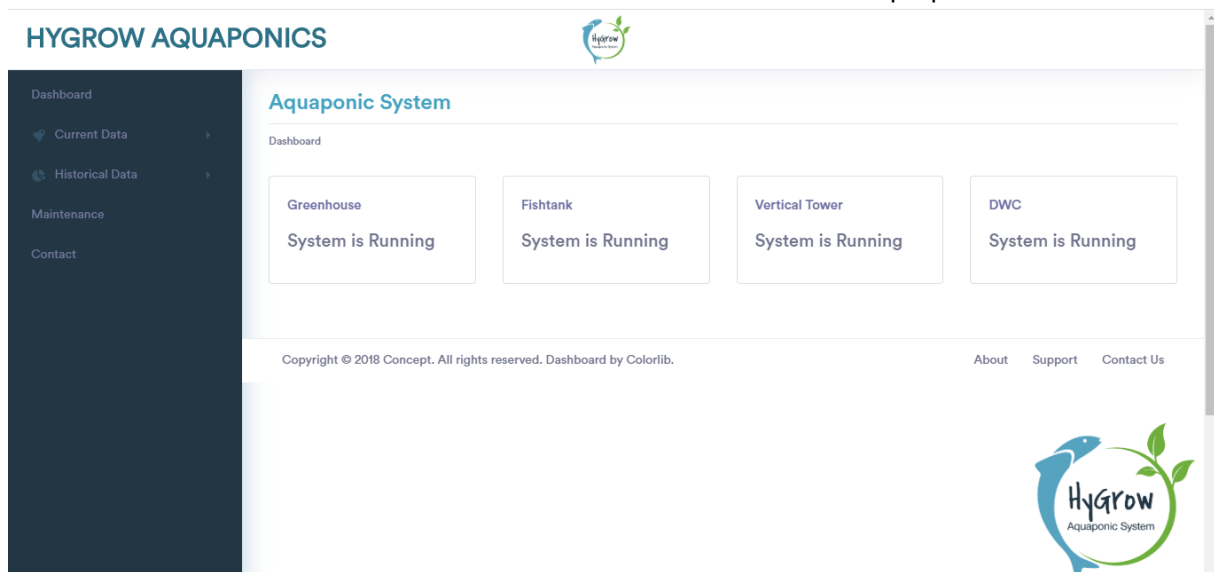This is what the dashboard of the website looks like on a laptop screen.

Figure 3.26 Hygrow Dashboard

And this is what the same page looks like on a smaller screen or with reduced window size.
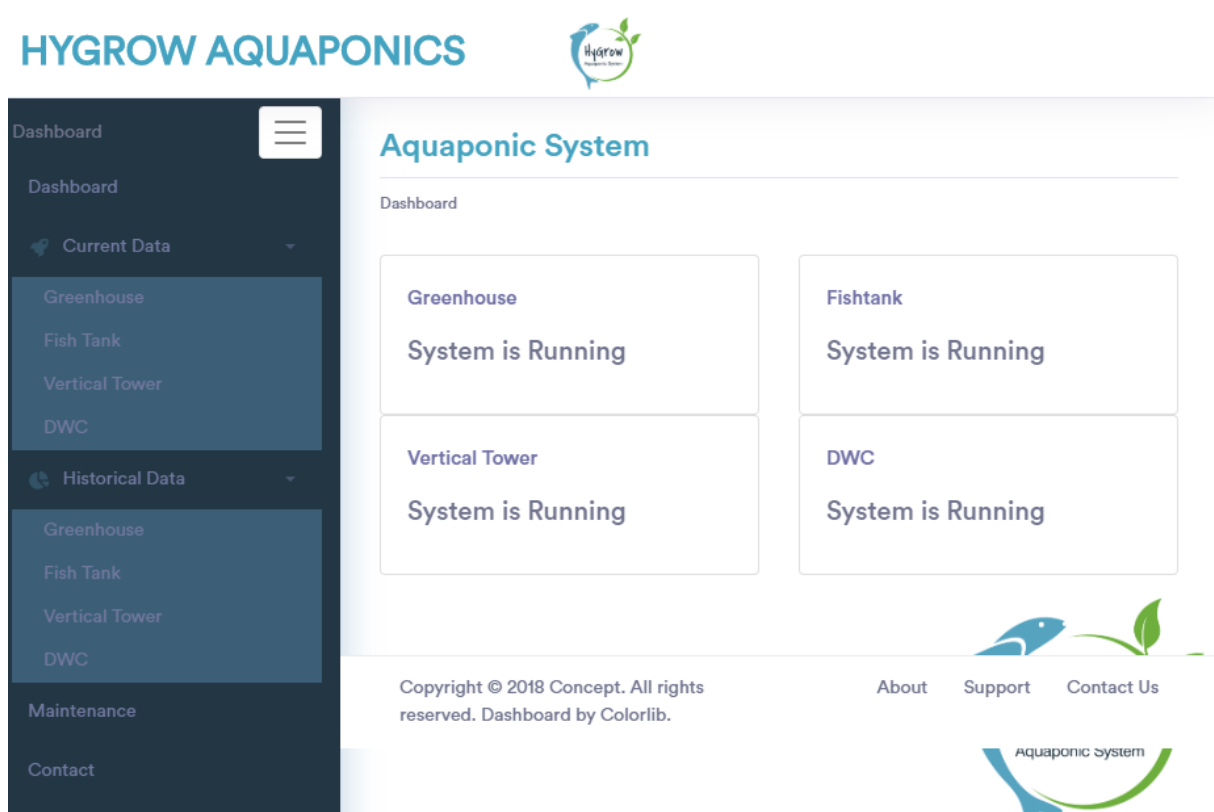

Figure 3.27 Hygrow Dashboard in smaller window

The elements of the layout are now partially stacked instead of next to each other which guarantees the readability of the content, also the navigation bar now offers the option to redact, so that only the three vertical lines stay visible, to optimise the use of the available space.

```
<div class="col-xl-3 col-lg-6 col-md-6 col-sm-12 col-12">
```

Figure 3.28 Responsive Bootstrap Code

In the figure above, the Bootstrap code that is responsible for the responsiveness of a website is shown. In Bootstrap each screen is divided into 12 columns (see "col-12"). With this line of code, the element is assigned a width based on the size of the screen. When the screen is extra-large, such as a big laptop or desktop PC, the described element takes up three columns, meaning that four elements can fit in a row (see: "col-xl-3"). When using a small screen one element takes up all 12 columns and there is only one in each row (see: "col-sm-12").
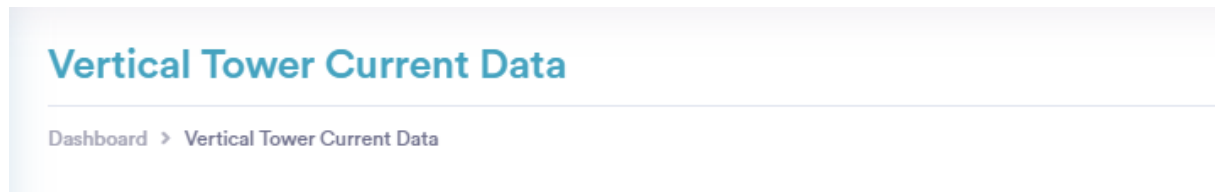

Figure 3.29 Breadcrumb Links on Website

To make the navigation easier, we also implemented breadcrumb links, which allow the user to comfortably get back to previously visited pages.

3.5.2 Content

The website provides a quick and easy overview on the system, visualize the current values of the sensors, as well as the historical data to allow e.g. comparisons, provide maintenance instructions, connect to other online presences of the Hygrow project and include contact information of the supervisors and the project team.

The full code for each page as well as the CSS code and other necessary files can be found in the Handoff Package.
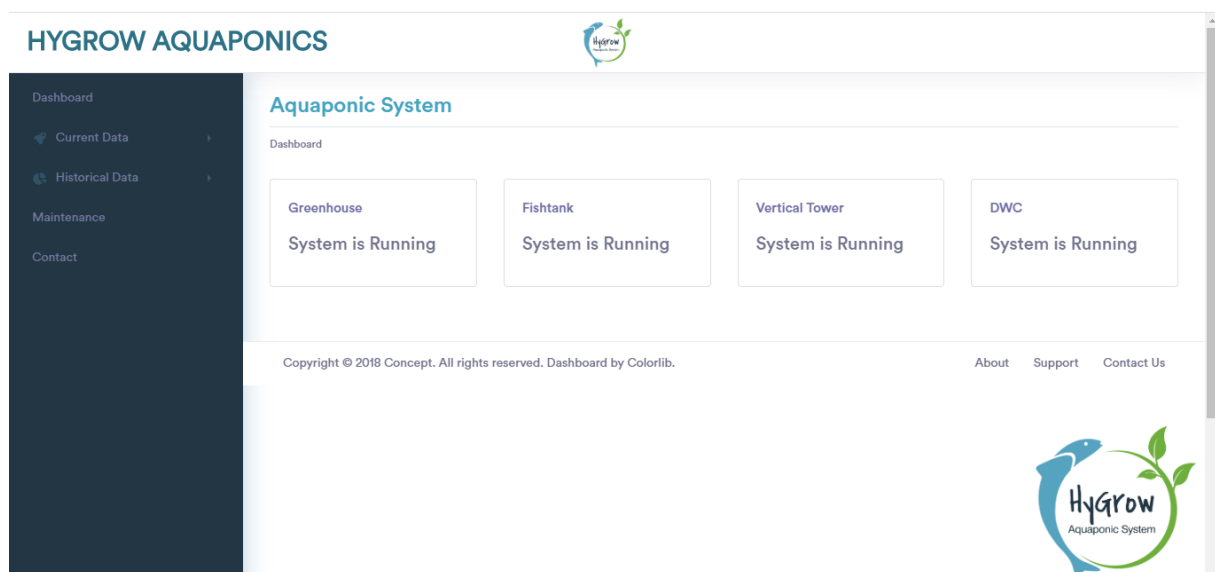

Figure 3.30 Hygrow Dashboard

The Dashboard as seen above consists of the sidebar, the header and the current status of the modules, which links to the current data page of the corresponding module.

To make the left navigation bar clearer and neatly arranged, we used a drop-down menu for the current and historical data, this, as well as the set-up of the code, allows for easy adjustment of the number of modules that are in the system.

Then there is the page with the current data for each module. It includes a list of the values for the sensors as well as the desired range and the actuators and their status and if they are working correctly.
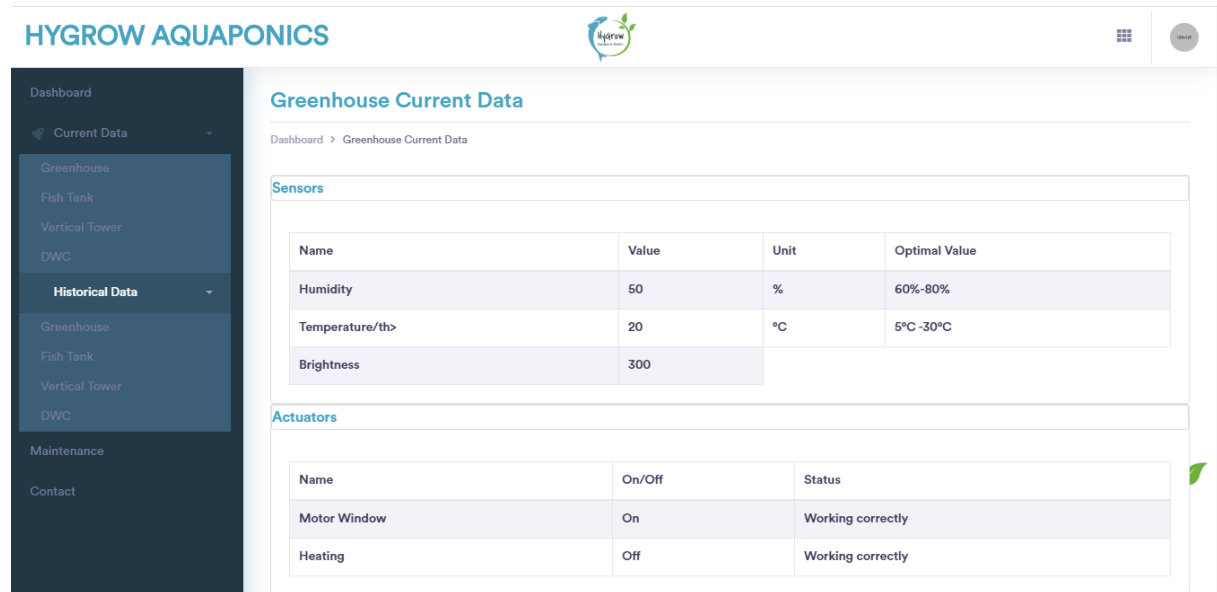

Figure 3.31 Hygrow Current Data Greenhouse

In the figure above, the drop-down menu is active, showing the modules that are currently included. The current data displayed here is not the actual data from the system, as the maintenance site is not yet connected to the database or online.

Figure 3.32 Hygrow Maintenance

On this page we only included the manual maintenance for the moment, for future purposes it could also be possible to use the error handling list that can be found in the appendix to create instructions for failures and to implement the email notifications to inform the responsible person(s).

3.6 Conclusions and recommendations

3.6.1 Conclusions

During the project the Control System encountered more changes and complications than anticipated, which altered the work we were able to do. It led us to consider which parts were necessary and feasible, rather than unrealistic plans and wishes, that exceeded our capacities.

Still, all things considered we were able to put many of our ideas in practice. The electrical system with the switch cabinets is as modular and with as much forethought as we wanted it to be. The switch cabinets include professional material to guarantee a high life expectancy and minimise the liability for failures and thus decrease the maintenance cost. The sensors that are now available are working with the Arduino and can provide the basic controlling for the system. Last of all, we created the maintenance Website, which is modular as well and can be expanded by the next project groups.

For this expansion we discussed various ideas and plans, which can be found in the provided Hand-off Package. We recommend the next group to use the given structure to finish and improve the control system. Invest time and effort for researching and rethinking could be useful to understand the system and what is necessary for it to work properly. But the theoretical part should not be too time consuming as the implementation and building for the whole system takes a significant amount of time, also, of course, because in practical work it is satisfying to see results.

All in all, we built the foundation for a modular, fully controlled system that offers the opportunity to expand.

3.6.2 Recommendations

Due to the fact, that this project will be continued during the next semesters, it is a concern to provide further information and especially recommendations to the next project group. This could be a question where we have not found or get an answer as well as improvements or modifications of the system because of missing time, money or other issues. A more detailed description, compared to this general overview, can be found in the provided hand-off package. The recommendations are divided into three categories: "Electrical System and Switch Cabinets", "Sensors and actuators" and at least "Software and maintenance".

3.6.2.1 Electrical system and switch cabinets

An open question to run the aquaponic system is the energy supply. Next to the greenhouse is a power outlet, but it is not clear, if we are allowed to use this for a continuous operation. This is an important question for the new project group and the supervisors.

For a better regulated system, it is recommended to search for solutions to regulate the water pumps in the system and therefore also the water level.

For regulating the dissolved oxygen in the system, we use normal air pumps which can be regulated by hand. A better solution here is to find a solution for an electronic regulation, perhaps with other pumps.

To use a heating/cooling system as well as windows or a shading system in the greenhouse is useful to extend the usage over spring and autumn. In coordination with the other project parts, the chosen systems should be implemented and regulated over the software.

Depending on the final energy consumption, it could be useful to change the cross section from 1,5 mm² to 2,5 mm² for the power supply cable as well as a few wires in the switch cabinet.

The system is planned as a "plug and play" system. Therefore, it is necessary to add additional cable connectors (230 V, 12 V, 5 V) on the switch cabinets for deep-water culture and vertical tower. With these connectors, it is easier and safer to detach or attach the modules.

The switch cabinets were built with OBC wooden plates. Depending on the water tightness of the roof and the humidity in the greenhouse it could be useful to cover the top with a water repellent cover or rebuild the cabinets with plywood. Additional to that, a door or a touch protection should be added.

3.6.2.2 Sensors and actuators

A DIY weather station, open source weather data from Finland or the weather station next to the greenhouse is useful to monitor the environment conditions to get more information how to act with the sensors and actuators in the greenhouse.

During our research, we found a different DIY sensor, for example for the water level. It could be interesting to compare these sensors with the purchased one to see, which one is better.

Due to various reasons, it was not possible to buy and implement all sensors and actuators. One objective should be the implementation and testing of all sensors / actuators, compare the values with the theoretical one and set the minimum and maximum values of the running system.

For the Energy working part, it is necessary to implement energy meter to get an energy overview about the different modules and the hole system.

3.6.2.3 Software and maintenance

During the continuous operation of the system, the maintenance website can be improved with more live data and a historical overview of stored data. Therefore, the database structure should be implemented and tested. Furthermore, it is recommended to implement a logbook to document problems or changes in the system during maintenance.

In addition to that it is useful to implement a manual for the greenhouse and a maintenance instruction for possible failures in the system. These files should be accessible over the maintenance website.

On important part is the remote connection to monitor if the system is running correct. Therefore, it is necessary to implement a connection to an OpenVPN server, which is running in the university.

For PR purposes and to monitor the system, it is good to implement different webcams in the greenhouse.

4 Greenhouse

4.1 Research

The study of the greenhouse firstly covers weather conditions. Afterwards, the chapter focuses on creating the designs and choosing the final one. Next section describes searching for the relevant components, resulting in finding both affordable and good quality parts. Subsequently, the building process is shown, followed by the project recommendations.

4.1.1 Internal and External Exchange

This chapter investigates methods to improve efficiency of the greenhouse which can be affected by different environmental factors.

Meteorological variables

In Vaasa (Finland), the summers are short, cool, and partly cloudy and the winters are long, freezing, dry, and mostly cloudy. Over the course of the year, the temperature typically varies from -*10°C* to *20°C* and is rarely below *-22°C* or above *25°C*.

Temperature

The warm season lasts for 2.9 months, from June to September, with an average daily high temperature above 15°C. The cold season lasts for 4 months, from November to March, with an average daily high temperature below 1°C.

Clouds

In Vaasa, the average percentage of the sky covered by clouds experiences significant seasonal variation over the course of the year. The clearer part of the year in Vaasa begins around April and lasts for 5.6 months, ending around October.

Precipitation

A wet day is one with at least 1 millimeter of liquid or liquid-equivalent precipitation. The chance of wet days in Vaasa varies throughout the year. The wetter season lasts 7.7 months, from May to January, with a greater than 24% chance of a given day being a wet day. The drier season lasts 4.3 months, from January to May.

Rainfall

The rainy period of the year lasts for 10 months, from March to January, with a sliding 31-day rainfall of at least 13 millimeters.

Snowfall

The snowy period of the year lasts for 6 months, from October to April, with a sliding 31-day liquid-equivalent snowfall of at least 3 millimeters. The most snow falls during the 31 days centered around January, with an average total liquid-equivalent accumulation of 15 millimeters.

Sun

The length of the day in Vaasa varies extremely over the course of the year. In 2020, the shortest day is December 21, with 4 hours, 40 minutes of daylight; the longest day is June 21, with 20 hours, 22 minutes of daylight.

Humidity

We base the humidity comfort level on the dew point, as it determines whether perspiration will evaporate from the skin, thereby cooling the body. Lower dew points feel drier and higher dew points feel more humid. Unlike temperature, which typically varies significantly between night and day, dew point tends to change more slowly, so while the temperature may drop at night, a muggy day is typically followed by a muggy night.

The perceived humidity level in Vaasa, as measured by the percentage of time in which the humidity comfort level is muggy, oppressive, or miserable, does not vary significantly over the course of the year, staying within 1% of 1% throughout.

Wind

This section discusses the wide-area hourly average wind vector (speed and direction) at 10 meters above the ground. The wind experienced at any given location is highly dependent on local topography and other factors, and instantaneous wind speed and direction vary more widely than hourly averages. The average hourly wind speed in Vaasa experiences significant seasonal variation over the course of the year.

Solar energy

The average daily incident shortwave solar energy experiences extreme seasonal variation over the course of the year.

The brighter period of the year lasts for 3.0 months, from May to August, with an average daily incident shortwave energy per square meter above 4.9 kWh. The brightest day of the year is June 21, with an average of 6.2 kWh.

The darker period of the year lasts for 4.6 months, from October to February, with an average daily incident shortwave energy per square meter below 1.3 kWh. The darkest day of the year is December 20, with an average of 0.1 kWh.

(This report illustrates the typical weather in Vaasa, based on a statistical analysis of historical hourly weather reports and model reconstructions from January 1, 1980 to December 31, 2016. Weather Spark, Cedar lake Venture, Inc)

Conclusion of thermal and meteorology researches

We can therefore conclude that after collect of all this information, we can identify several things about the greenhouse design. During winter, thermal exchange between inside and outside of greenhouse will be important. Thermal insulation must be implemented to keep great internal conditions in the housing. Solar energy can be used only between May and September, in the other part of the year, another type of heater and energy generator are necessary. Wind is not strong (average of ≈ 30km/h), the greenhouse structure will not be exposed to a strong wind. The sun lighting must be supported with an artificial light during winter and reduced during summer. The structure needs to be adapted to heavy snow to not collapse under the pressure of snow.

4.2   Design

4.2.1   Encroachment on the roof

To start designing, first step is to know where the greenhouse will be installed.

Figure 4.2 Vaasa localisation (Google Maps, 2020)

The building is situated in Vaasa in Finland. This City is further north than the, it affects meteorological conditions (previously described in the chapter internal and external exchanges). We are looking to optimize its location and its orientation.

The building will be on the roof of the building *Novia Technobothnia* of Vaasa (Figure 4.2).

Housing will be exposed on southern part and can have maximal of sunshine. No building, tree and roof can reduce the sunshine quantity. We will use sun to bring maximum part of thermal energy we need.

Figure 4.1 Encroachment of the greenhouse in Vaasa

The building aera behaves as follows in figure 4.3.

On the roof, we have bodyguard (all around the place of 0.9m high) and one antenna (orange triangle). The antenna is sustaining by three steel cables (orange line) preventing us from build bigger.

Moreover, we need to keep a way for school staff to have access at the other part of the roof.

For it, we have an area of 5.2m² (2.6x2m) for the greenhouse.

Goal is to optimize all the building area to have the maximum floor space for aquaponic system. So, we will create different designs which will be adapted for this provision.
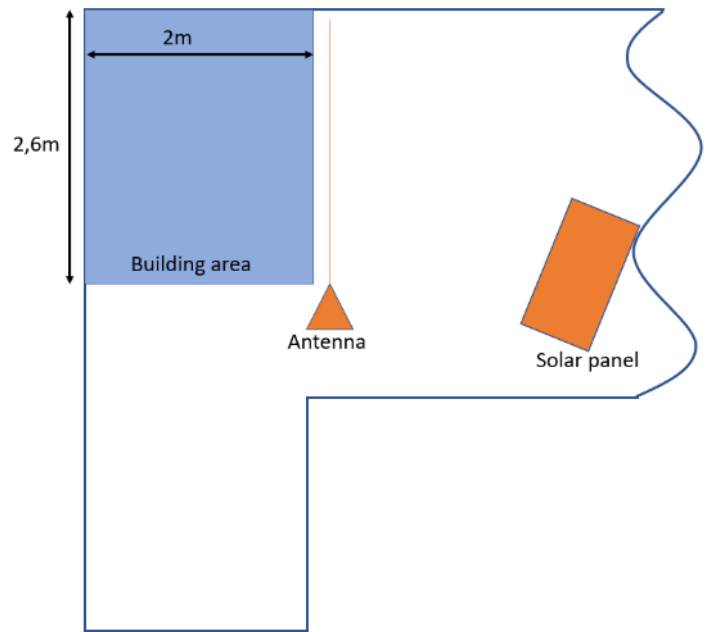

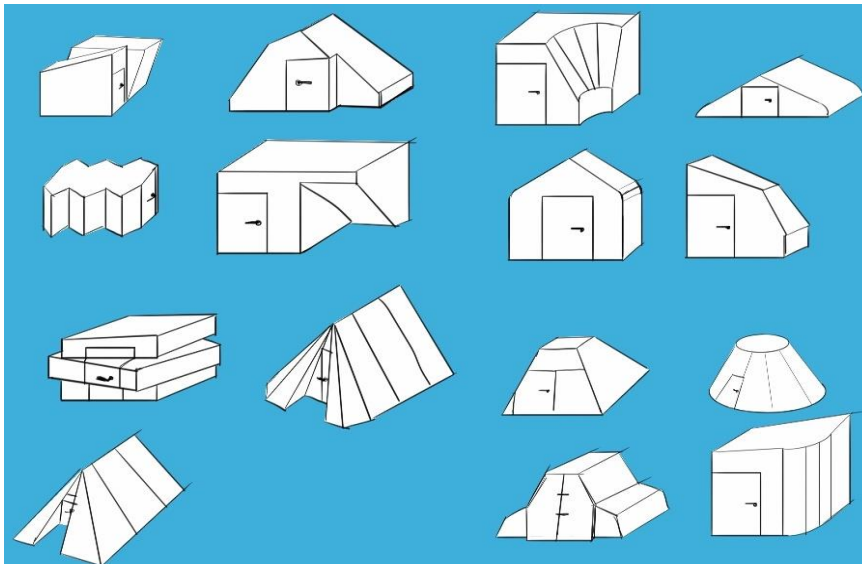*Figure 4.3 Rooftop building area*

4.2.2   View of designs

Figure 4.4 Different designs of greenhouse

Firstly, one goal is to find a design to catch the eye. We start to draw different shell of possible greenhouse.

They are thought to occupy and optimize maximum floor space and volume for the aquaponics system.

Each design has pros and cons, in the next part we will details them.

Table 4.1 Advantages and disadvantages of each idea (Hygrow Aquaponics, 2020)

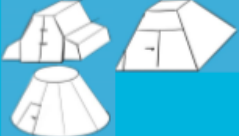| Design number	Advantage	Disadvantage
1	cheap because simple form easy to build because simple form possibility to create windows Robust occupies all available space variable thermal resistance (we can upgrade/downgrade) Possibility to reduce price by 3D printing for support of plexiglass wall Good sunshine into house	Square form (classical) lot of frames not expendable not using space below steel cable
2	cheap because simple form easy to build because simple form possibility to create windows Robust occupies all available space variable thermal resistance (we can upgrade/downgrade) Possibility to reduce price by 3D printing for support of plexiglass wall	Roof not flat to stare material (vertical system) lot of frames not expendable not using space below steel cable
3	Robust occupies big available space variable thermal resistance (we can upgrade/downgrade) Possibility to reduce price by 3D printing for support of plexiglass wall Good sunshine into house	lot of frames not expendable not using space below steel cable not easy to build because simple form no possibility to create windows
4	Robust occupies big available space Possibility to reduce price by 3D printing for support of plexiglass wall Good sunshine into house	lot of frames not expendable not using space below steel cable hard to build because complex form no possibility to create windows
5&6	Robust cheap because simple form easy to build because simple form possibility to create windows Possibility to reduce price by 3D printing for support of plexiglass wall Good sunshine into house	not expendable not using space below steel cable classic aesthetic Small hight under the roof Roof not flat to stare material (vertical system)
7, 8, 9 & 10	Robust cheap because simple form easy to build because simple form possibility to create windows Possibility to reduce price by 3D printing for support of plexiglass wall occupies big available space variable thermal resistance (we can upgrade/downgrade) Good sunshine into house	classic aesthetic not using space below steel cable not expendable
11	Robust cheap because simple form easy to build because simple form possibility to create windows Possibility to reduce price by 3D printing for support of plexiglass wall	classic aesthetic not using space below steel cable waste of space in the triangular expansion not expendable
12, 13 & 14	atypical aesthetic Robust possibility to create windows Possibility to reduce price by 3D printing for support of plexiglass wall variable thermal resistance (we can upgrade/downgrade) Good sunshine into house	not using space below steel cable not expendable waste of space in different roof slopes Small hight under the roof lot of frames
15	Robust Possibility to reduce price by 3D printing for support of plexiglass wall Good sunshine into house cheap because simple form	classic aesthetic not using space below steel cable waste of space in the triangular expansion not expendable Small hight under the roof Roof not flat to stare material (vertical system)

After designing and comparing all our concepts, we determine three best designs (concepts 1 to 3).
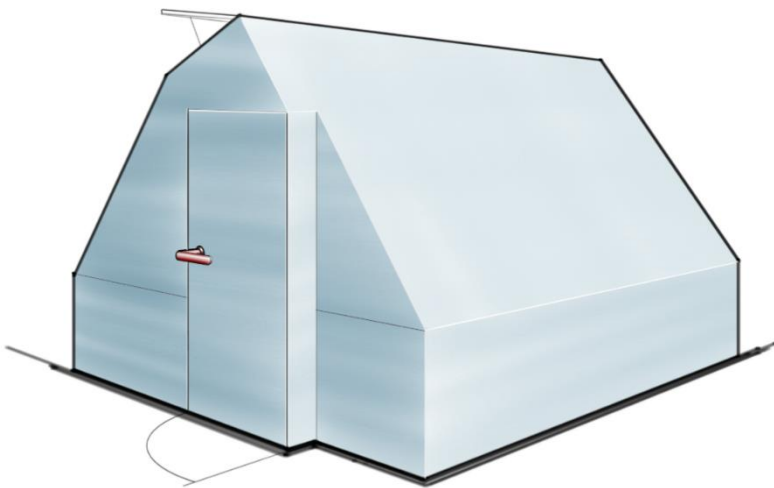
They are originals, they optimize the available volume of the Technobothnia rooftop, they are quickly buildable and not too expensive.

They structures are in big part in wood beams and double sheet plexiglass

CONCEPT 1.
THE AQUAPONIC CRYSTAL HOUSE
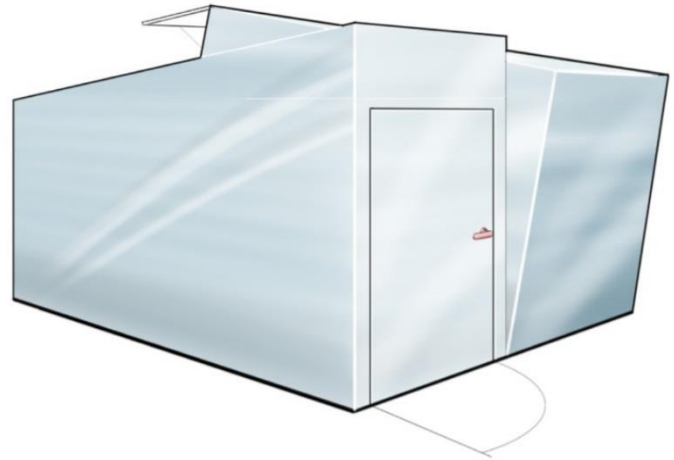
CONCEPT 2.
THE AQUAPONIC RELIGIOUS HOUSE

The concept 1, inspired by a crystal structure possesses two different parts relatively similar shifted by an angle between them giving him the appearance of an amethyst crystal (findable in Finland)

The concept 2 is inspired by the kuokkala church, an atypical Finland church. This design permit to have lot of height under the roof and a good sunshine indoor.

CONCEPT 3.
THE AQUAPONIC SAUNA HOUSE
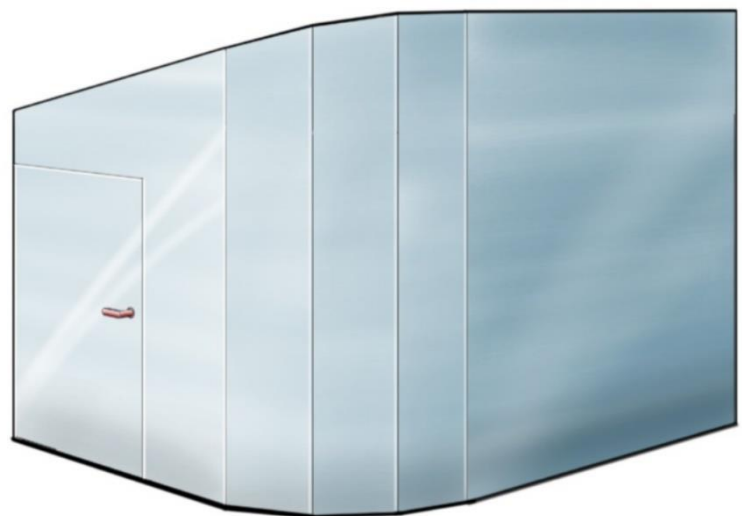
The last concept was inspired by a sauna. This classical form permits to have the biggest available volume for the aquaponic system. It is also the easiest design to size and build with this simple form.
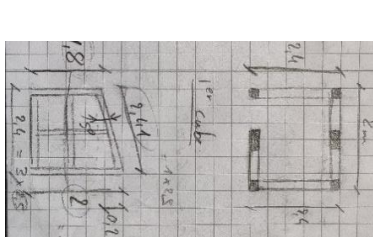
To continue to compare them, we will work on the different price studies of all concepts. They are summarized in the next table.

Figure 4.5 Concepts (Hygrow Aquaponics, 2020)
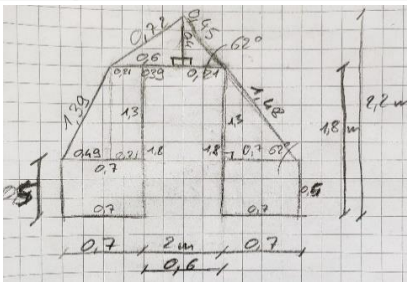
4.3 First price studies

Table 4.2 Price study of the three first greenhouse concepts (Hygrow Aquaponics, 2020)

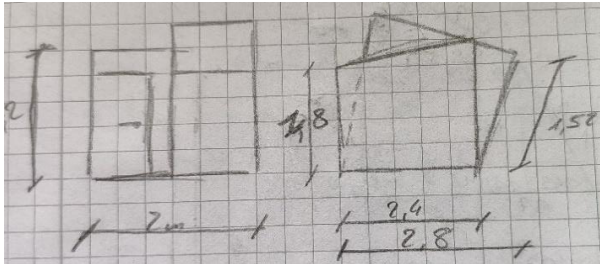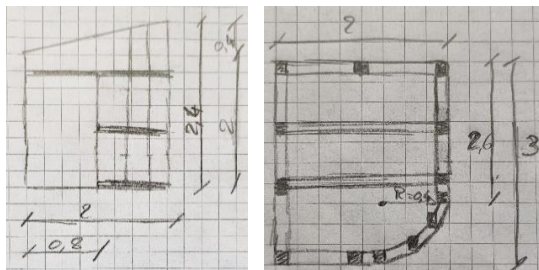| Structure	CONCEPT 1 (Without isolation)			
Matérial	Wood	Plexiglass (2,5m)	Plexiglass (3,9m)	assembly pieces
Unity	m	m²	m²	m
Unitary price	1,51	55	85	8
Quantity	45	8	2	27,8
Price	67,95	440	170	222,4
Total for material	900,35 €	without door and screws		

Structure	CONCEPT 2 (Without isolation)			
Matérial	Wood	Plexiglass (2,5m)	Plexiglass (3,9m)	assembly pieces
Unity	m	m²	m²	m
Unitary price	1,51	55	85	8
Quantity	55	7	3	29,2
Price	83,05	385	255	233,6
Total for material	956,65 €	without door and screws		

Structure	CONCEPT 3 (Without isolation)			
Matérial	Wood	Plexiglass (2,5m)	Plexiglass (3,9m)	assembly pieces
Unity	m	m²	m²	m
Unitary price	1,51	55	85	8
Quantity	76	13	0	32,5
Price	114,76	715	0	260
Total for material	1 089,76 €	without door and screws		

We can see that all these concepts are similar in the quantity of material. The exception is for the concept 3 more expensive than others because we have a bigger wall surface.

The next step is to validate a design with customers and start the 3D conception, the thermal study, material list.

During the designing, we encounter a real problem. The size of the available area is smaller than we need to have for the entire system. After new measures of the rooftop of Technobothnia and with the agreement of supervisors, we found the possibility to enlarge our available area below the steel cable for antenna support and multiply by 200% the building area (to reach approximatively 10 m² of usable surface). We can summarize our new site on the next figure.
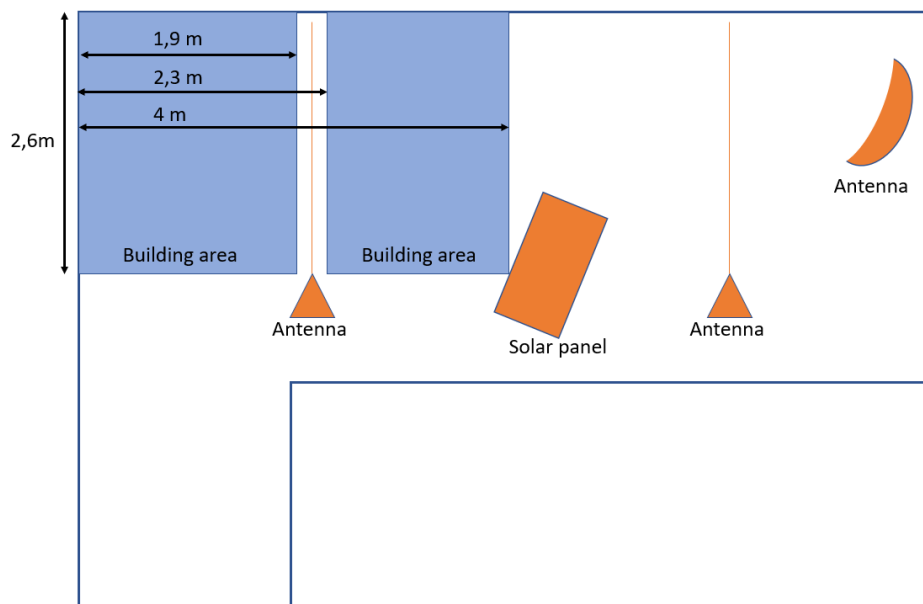
Figure 4.6 new rooftop lay-out (Hygrow Aquaponics, 2020)

4.4   New greenhouse concepts

In addition, we need to create new greenhouse design adapted on the new rooftop area surface. The main difficulty is to think about a design including the steel cable that supports the antenna. The new designs are created to optimize space and volume. We have to take into account the proper height of the greenhouse which affects the heat circulation.
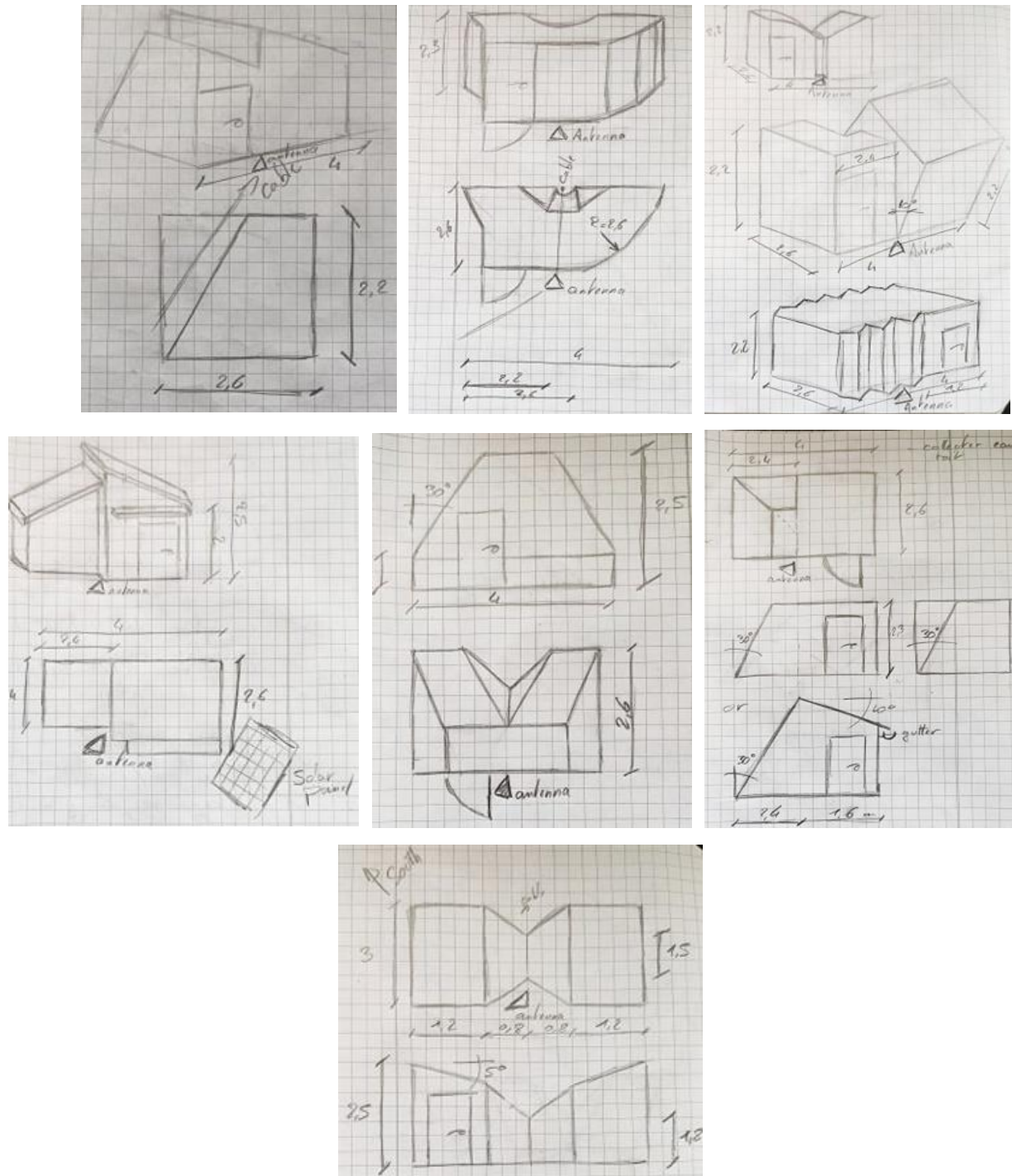
Figure 4.7 The possible greenhouse designs (Hygrow Aquaponics, 2020)

4.5   Final design

4.5.1   3D View

The final design was created around the aquaponics system. In this project, the greenhouse has two distinct parts, one for Deep Water Cultures racks and controlling unit, whereas the second part contains the vertical towers, water treatment system together with the fish tank. The following figure shows the technical drawing of greenhouse shell design.

Figure 4.8 Greenhouse final design (Hygrow Aquaponics, 2020)

Due to the stepwise scaffolding construction of DWC unit we managed to optimize the number of containers and their access to light. The team took the opportunity to make the design of the greenhouse an angular shape which facilitates the entry of light, the passage of the greenhouse under the roof antenna support cable and break with straight lines.

Figure 4.6 Greenhouse final design render

Figure 4.7 Greenhouse final design render

Figure 4.8 Greenhouse final design render

Figure 4.9 Greenhouse final design render

4.5.2   Concept

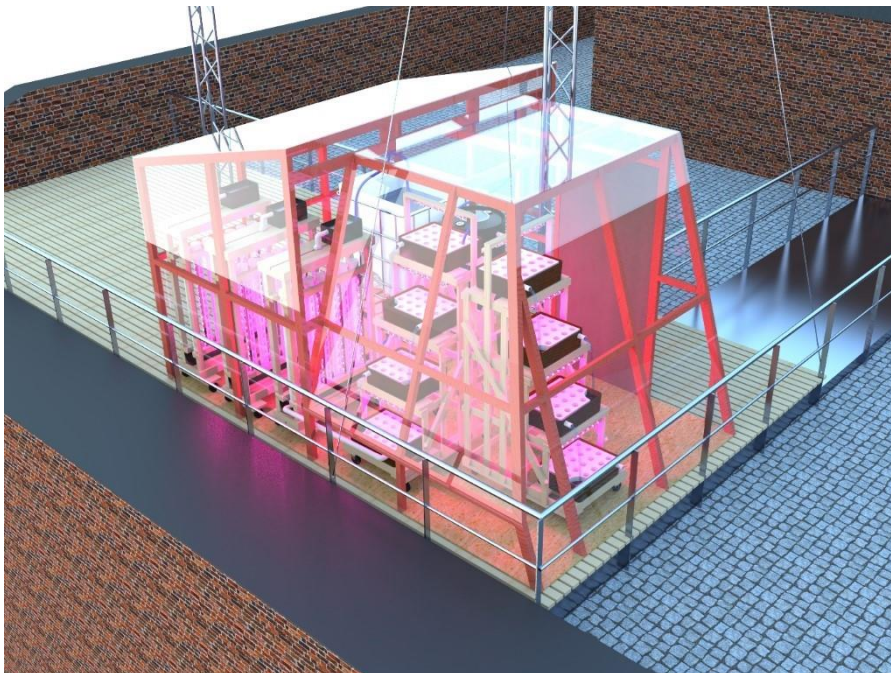After defining the shell design for the greenhouse, we needed to create a detailed plan for the structural part. Before the team address this topic, a strength of materials study for the main beams of the structure must be performed. The beams form both the foundation and the frame of the structure. The study presents calculations of a simple bending on beam on 2 simple supports, it is the beam which will endure unfavourable conditions on the roof e.g. snow during winter. Therefore, it was decided to take hypothetical measures. The rectangular shape of the roof would receive a half of the pressure, while a thickness of snow is 50 cm and wooden beams have a rectangular section of 73x48 mm. To confirm the theoretical strength of materials study, we had to calculate the flitch of the wood with all these factors (snow, plexiglass, proper weight of beams). The result needs to be less than a flitch of 1/200*L (L=length of the beam). The following table summarizes the measures.

Table 4.3 Beams strength measurements

Simple bending on beam on 2 simple supports			
Load case	Calculation	Data		Units
uniformly distributed load	flitch (for x=L/2) f=5/384*(qL⁴)/EI	snow density	300	kg/m3
		snow for 50cm for 3m² of roof (=half of roof surface)	1,5	m3
		Size beam	48 (base) x 73 (height)	mm
	reference do not exceed	f= 1/200*L	0,015	m
		E=	1,20E+10	Pa
		L=	3	m
		q=	150	kg/m
		I=	1,55607E-06	m^4
Calculation		**f=**	**0,009**	**m**

In the table above, the calculation with 50cm thickness of snow yields a result which is approximately in 60% of tolerance. It means that a safety factor is equal 1.67. Additionally, the other part of the structure, the theory states the load-bearing beams are of the same characteristic or more than those which they support. The secondary beams, maintain walls will be cheaper beams in a size of 48x48 mm.

4.5.3   Plan

Knowing the size of beams, the roof area, and the shell design, the next step is to create a detailed plan with all elements necessary for the construction and completion of the greenhouse. Programmes such as Autocad and Autodesk software were used to help us obtaining the perfect measurement and a good 2D render for the building. The plan made it possible to calculate all quantity needed to create a price study for the project.

The plan depicts all elements of the greenhouse. Red colour indicates the door, black the entire wooden structure, purple shows the different measurements and angles of the wooden framework. The location of the greenhouse in relation to the roof surface is also marked on the plan to avoid encroaching on the other components such as the solar panel or an antenna. Finally, the details of the layered plexiglass and water-thickness elements between the plexiglass can be found.

Figure 4.9 AutoCad technical drawing (Hygrow Aquaponics, 2020)

4.5.4   Sustainable system

One of the most important criteria that had to be considered when designing are removability and sustainability. To achieve this goal, a cheap and easy to build system had to be created. We invented six different concepts (in the figure below).

The first one is a system of spacer installed in the wood. This solution permits to attach beams with bolts and nuts instead of wooden screws that can destroy wood due to screwing and unscrewing.

The second idea involves a little part, which can be used to attach the Plexiglas to the beams. It was inspired by the attachment findable in shops. However, in our system it would be different because we need to place a lot of these parts and not a long one.

The third solution is approximately the same as the first one. The only difference is not using a spacer but two metal plates in each part from the wood to avoid breaking it during screwing.

Another solution is to attach beams using the friction. The bolt exerts a pressure on the beam when it is screwed thus it seals metal part and wood together.

The penultimate idea is about attaching two metal brackets on the top of beams and placing an enclosure to attach these parts together. The disadvantage is that the structure can be very movable.

The last system is the simplest one. The goal is to use the gravity to keep beams together set up in a metal hollow square.
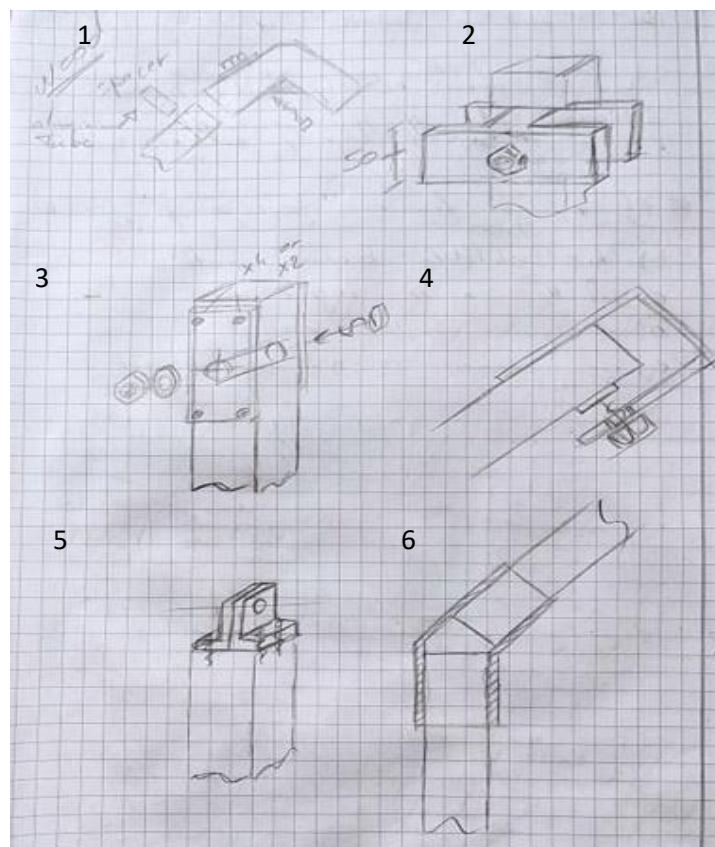

Figure 4.10 Beams attachment ideas (Hygrow Aquaponics, 2020)

The team decided to stay with one choice. The first idea occurred to be the cheapest, easiest, and strongest solution.
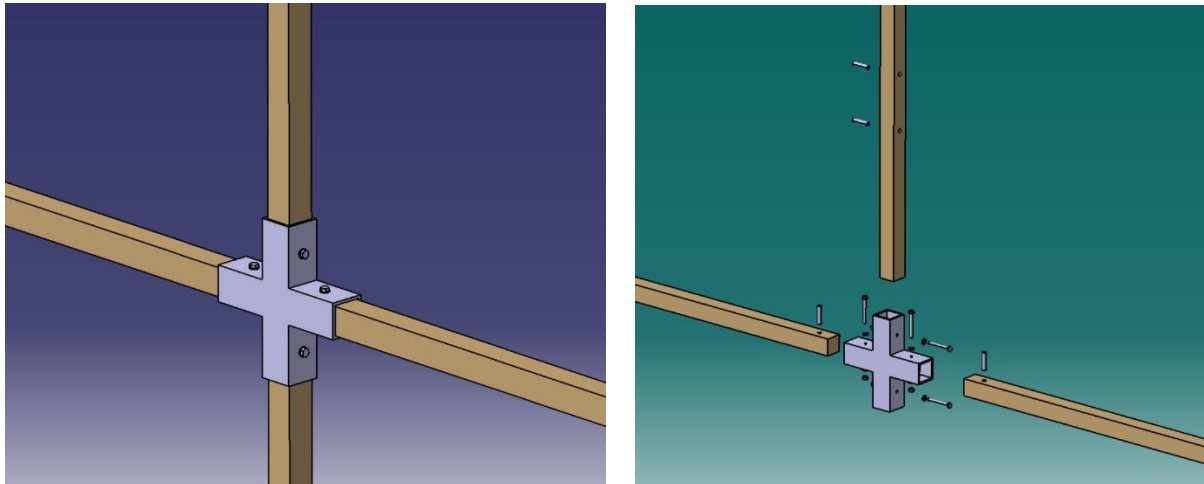

Figure 4.11 3D representation of the modular greenhouse (Hygrow Aquaponics, 2020)

The 3D representation depicts the entire removable module with all elements. It should be noted that for each crossover, 4 bolts and nuts, 4 spacers and a 3D printed cross are used. That solution greatly accelerates the preparation time and reduces the number of items to buy. It is needed to print a link for each crossover which must be adapted for each kind of connection.

4.5.5   Price studies

After receiving all the measurements, the team could start the price study to determine the greenhouse cost and feasibility. The following list presents the components prices which have to be found:

- The wood for the framework
- The plexiglass to cover the roof and walls
- Part for water-thickness for the plexiglass
- Hinges and latches for the door
- Pole holder to attach the greenhouse on the rooftop
- Tubes for spacer of the modular system
- Screws and metal brackets to attach the structure

The table below concludes all the information collected.

Table 4.4 Greenhouse price study

Material	Specification		quantity	unity	Price/u	price	Shop
Wood beams	Front side	48*73mm	17812	mm			
		48*48mm	9224	mm			
	Door	48*73mm	0	mm			
		48*48mm	7056	mm			
	Right side	48*73mm	3000	mm			
		48*48mm	7014	mm			
	Left side	48*73mm	10380	mm			
		48*48mm	8154	mm			
	Back side	48*73mm	13097	mm			
		48*48mm	9718	mm			
	roof	48*73mm	4180	mm			
		48*48mm	3430	mm			
	Total wood	48*73mm	58	m	0,89	51,62 €	Byggmax
		48*48mm	54	m	1,49	80,46 €	
Plexiglass	Front side	2,5m	4	u			
		3,9m	0	u			
	Door	2,5m	1	u			
		3,9m	0	u			
	Right side	2,5m	3	u			
		3,9m	0	u			
	Left side	2,5m	3	u			
		3,9m	1	u			
	Back side	2,5m	4	u			
		3,9m	0	u			
	roof	2,5m	4	u			
		3,9m	0	u			
	Tot plexi	2,5m	19	u	22,24	1 056,40 €	Stark Vaasa
		3,9m	1	u	22,25	86,78 €	
Water tightness (roof)	H		13030	mm	8	104,24 €	
	U		44380	mm	4,57	202,82 €	
hinge			2	u	5,99	11,98 €	Byggmax
latch			2	u	5,99	11,98 €	Byggmax
Wood treatment				L		- €	
Wood screw	5,0 x 70/45 mm		1	200 u	15,1	15,10 €	Stark Vaasa
	5,0 x 35 mm		1	200 u	16,7	16,70 €	Stark Vaasa
Screw for roof			1	50 u	18,2	18,20 €	Stark Vaasa
Pole holder			13	u	4,09	53,17 €	Byggmax
Duct tape			100	m	0,1	10,00 €	Stark Vaasa
Ring			1	100 u	10	10,00 €	Stark Vaasa
Tube	ø8mm inside		2	m	9,8	19,60 €	Stark Vaasa
Metal bracket	50x50x2x35		100	u	2,2	220,00 €	Stark Vaasa

Price =   1 969,04 €

In conclusion, we noticed that the greenhouse budget is towering. Because of budget limitations the team was forced to find alternative solutions to reduce the final cost. To achieve this goal, the design was changed and simplified. We examined the most expensive part of the building thus the Plexiglas accounts for the largest share of the allocated budget. Thereby, the idea of form and beams stays, but the wall materials are changed. We decided to switch the wall plexiglass with a reinforced sail. Moreover, all attach for plexiglass are removed which would drastically reduce the cost of the project.

Additionally, after one meeting with supervisors, we have determined that the greenhouse will probably be removed two or three times maximum. The team concluded that we could remove the modular system. As a result, we created a system which do not break the wood due to screwing and unscrewing. In order to remove the greenhouse few times we could screw directly with wood screws. It allowed us to save all the budget necessary for this modular system and considerably reduces the manufacturing time because we omitted the 3D printing step.

Eventually, the final price study presents in the table below.

Table 4.5 Greenhouse final price study

Greenhouse material quantity (untreated wood)							
Material	Specification		Quantity	Unit	Price/u	Price	Shop
UNTREATED Wood	Tot wood	48*48mm	40	m	0,89 €	35,60 €	Byggmax
		48*73mm	88	m	1,49 €	131,12 €	
Plexiglass	2,5*0,98*0,01m		1	u	22,24 €	22,24 €	Stark Vaasa
	3,9*0,98*0,01m		2	u	22,25 €	44,50 €	
water tightness (roof)	H		6480	mm	8,00 €	51,84 €	Stark Vaasa
	U		9100	mm	4,57 €	41,59 €	
Sail	3,9*10 m		1	u	65,00 €	65,00 €	Internet
	3,9*25 m		1	u	115,00 €	115,00 €	internet
hinge			2	u	5,99 €	11,98 €	Byggmax
latch			2	u	5,99 €	11,98 €	Byggmax
wood treatment	Pot of 9L		1	u	59,00 €	59,00 €	Byggmax
Brush			1	u	6,00 €	6,00 €	
wood screw	4,0x70 mm		4	25 u	3,95 €	15,80 €	Byggmax
	5,0 x 100 mm		1	300 u	35,95 €	35,95 €	Byggmax
Screw for roof			1	50 u	18,20 €	18,20 €	Stark Vaasa
pole holder	73*73 mm		16	u	4,09 €	65,44 €	Byggmax
duct tape			25	m	0,10 €	2,50 €	Stark Vaasa
Ring			1	100 u	10,00 €	10,00 €	Stark Vaasa
(metal bracket)	50x50x2x35		20	u	2,20 €	44,00 €	Byggmax
Price =	787,74 €						

With approximatively 30 % of the total budget instead of previous 70 %, we managed to buy and create the greenhouse.

4.6 Greenhouse Building

During building the greenhouse we could not cut our wood beams on the roof. Therefore, we needed to establish a cut list for each beam to only have to assembly the final structure on the roof. In order to complete this task, we started by creating different groups of beams, subsequently called "side x.y".
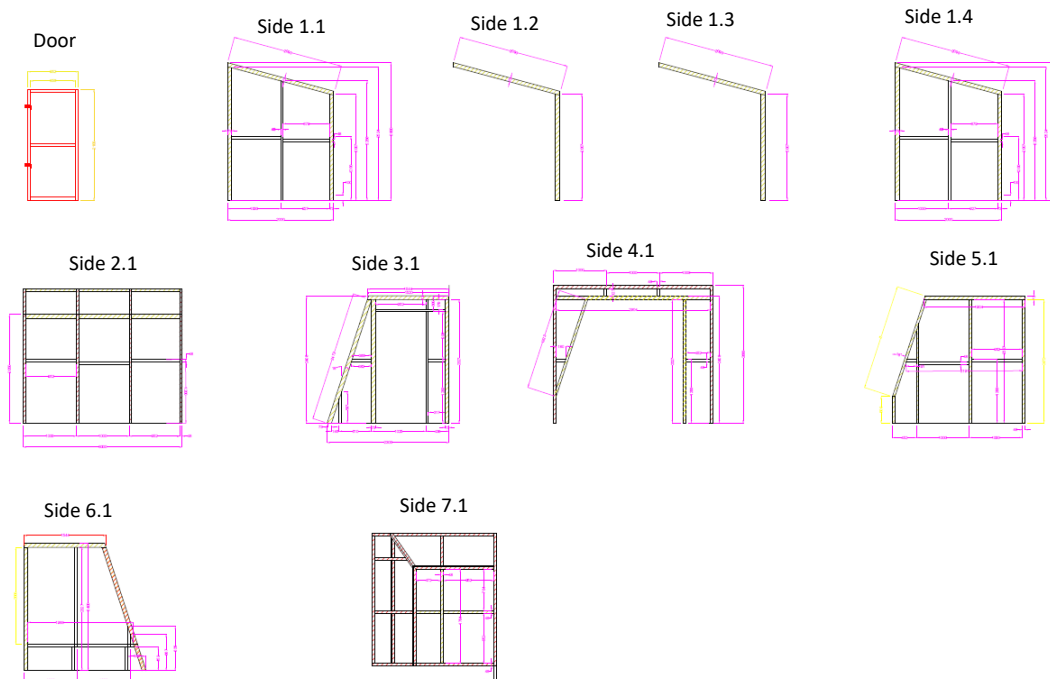

Figure 4.12 All greenhouse sides (Hygrow Aquaponics, 2020)

Organising these compartments were essential for dividing the wood in a material saving manner. The wood was cut in the workshop according to the following figure.
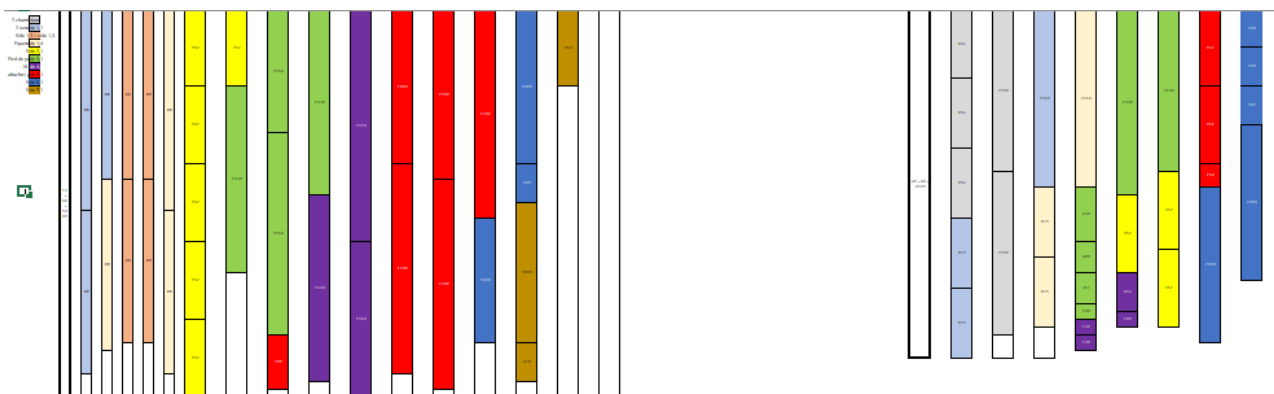

Figure 4.13 Greenhouse wood cutting scheme (Hygrow Aquaponics, 2020)

After cutting, we assembled all the beams in the workshop. We were able to finish cutting all angles of the structure and be sure that all beams are measured properly.
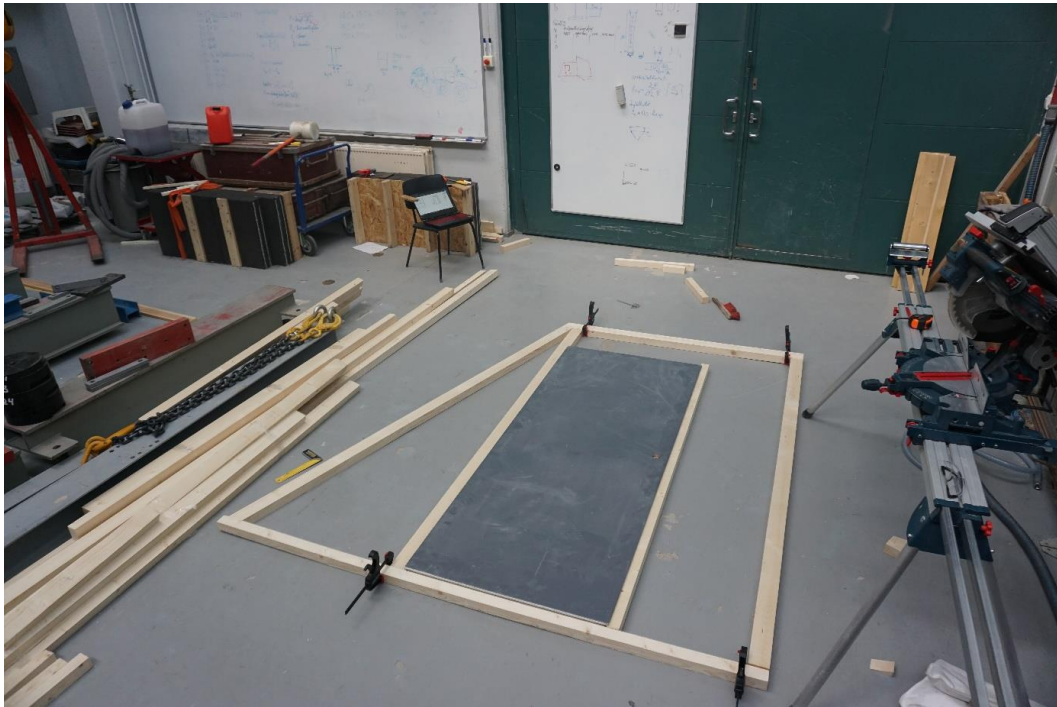
Figure 4.14 The front wall building process

The next step was completing of the assembly and moving the wood boards to the roof. Metal hinges and brackets were drilled into the boards to strengthen the structure. The solar panel had to be moved for the greenhouse to fit on the roof space. The next step was to paint a timber framework.

Figure 4.15 The framework building process

Figure 4.16 The greenhouse framework (Hygrow Aquaponics, 2020)

The wooden skeleton was painted with iron-based paint which is more resistant to rust. In this way, the structure will be better protected from the effects of rainfall. The door was also painted with iron-based paint and the project logo was sprayed on them. Next step involved covering the wooden framework with a reinforced plastic foil. To ensure that the coverage will not be damaged by wind, several wooden boards were screwed to the top.

Figure 4.17 View of the installed sail

The wooden roof terrace was not a suitable greenhouse flooring. On its surface we placed a foil and then a layer of chipboard. These provided a smooth floor surface and thermal insulation.
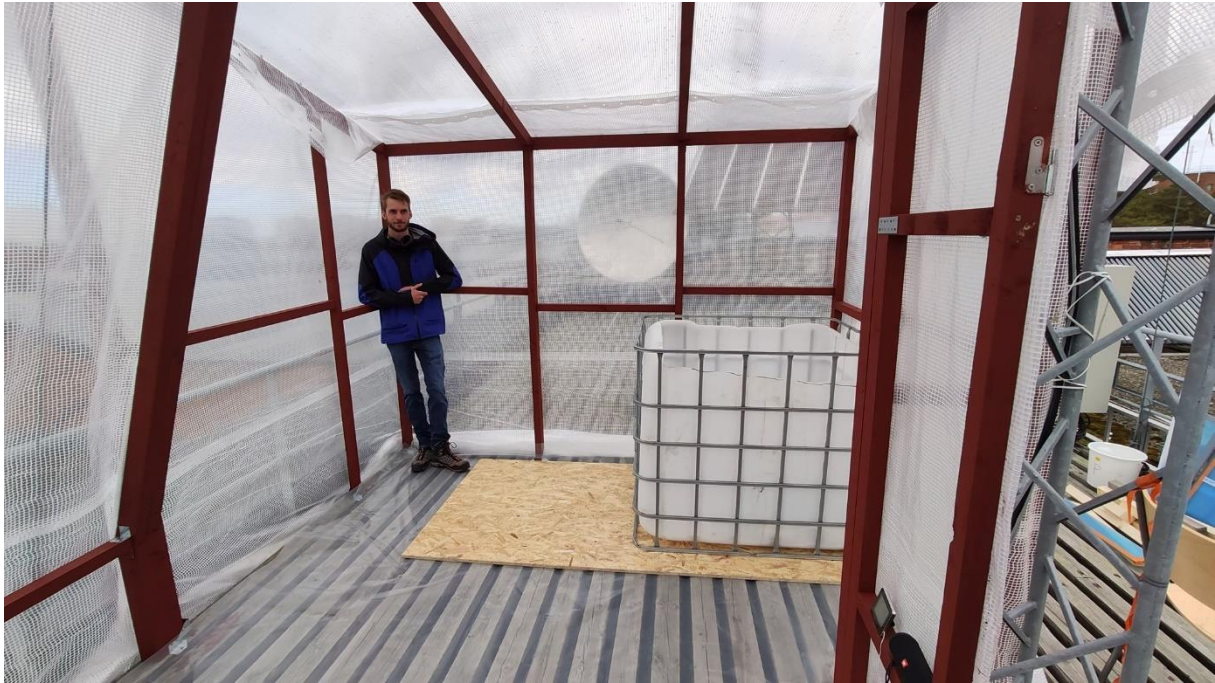

Figure 4.18 Installation of plastic foil

Figure 4.19 Covering the floor with wooden chipboard

The final stage was to move the aquaponics and control system inside the greenhouse. The water transporting hoses were attached to the ceiling beams so that they would not hang freely anywhere and would not hinder a work in the greenhouse.

Figure 4.20 Installation of the aquaponics system in the greenhouse

Figure 4.10 The Greenhouse with complete aquaponic system

Figure 4.11 The Greenhouse with complete aquaponic system

Figure 4.12 The Greenhouse front view

Figure 4.13 The Greenhouse side view

4.7   Conclusions and recommendations

This chapter depicted all the stages of study and realization of the greenhouse construction. To achieve this result, we had to consider a design stage for a good adaptation on the roof of Technobothnia. Afterwards, the team performed the resistance research of the materials in order to find the components necessary for the construction. Finally, we did a price study which allowed us to estimate and choose the proper materials while taking the budget into consideration. Finally, the team did the construction of the building and inserted the aquaponic system inside.

Because not all the objectives of the EPS project have been fulfilled, we have some recommendations for the next group. We did not accomplish the insulation part; thus the greenhouse is not protected from the cold. During winter season, the water is susceptible to temperature drops which may be lower than those recommended for the good maintenance of plants and fishes. A solar water panel was found by the team, which once installed would allow direct heating of the water and therefore better efficiency during cold seasons. Moreover, for a budgetary constraint, we had to install a reinforced sail instead of plexiglass. We have however determined that double layer plexiglass is a better thermal insulator (see the chapter "Energy") and that it makes it possible to be a more easily assembled and dismountable solution than the sail. Finally, one part of the roof has a slight slope, which, in rainy weather, can the water to gather on the roof surface. It would be preferable for the water to drain out more easily afterwards.

5 Energy

5.1 Introduction

A lot of research has been done in the field of energy. This report provides answers to many theoretical questions. However, nothing was purchased for the energy supply, partly because the priorities for the budget during the spring semester were elsewhere.

With the help of the research, the next group is able to make logical decisions on what to buy, depending on the scope of the project. The focus is mainly on sustainability. By using the approach as described in the following paragraphs, these requirements can be met.

5.2 International Organization for Standardization (ISO) Benchmark

The ISO 50001 helps to meet today's energy requirements. It is a standardized way of working that ensures that the desired results are achieved. Furthermore, there are many other ISO standards, for this project the focus was on the basic principles of the ISO 50001.

5.2.1 Basic Principles

To have an overall management tool, the basic principles of the energy management system ISO 50001 were used. This ensures that three pillars are looked at: energy efficiency, consumption and usage. By implementing the basic principles of this international standard, the right decisions can be made scores of times during the development of the energy system.

For example, the components to be purchased will a large majority of the time be considered. These must be chosen as energy efficiently as possible depending on the application. This does not mean that the most efficient components must always be selected, but that alternatives should always be considered before buying a component.

It is important to know the energy consumption of the components. By logging the data, the pattern becomes clear and one can easily expose irregularities. As a result, adjustments can be made to the way, in which they are used. This will increase efficiency and therefore reduce overall energy costs.

As a last pillar, attention is paid to the sensitization of the user of the system. Many operations within the system will still be manual, such as simply turning off the lights or keeping the pumps clean. This user awareness will also result in a reduction in operating costs. In the long term, the aim is to create awareness around energy consumption, which reinforces the general goal of the standard.

As a result, quality decisions can be made from the start and that will contribute to the long term character of the project. The main focus was on sustainability. In the field of energy this resulted in the selection of energy effective components that are used in a smart way where maximum output is strived for with as little as input possible.

5.2.2   Plan Do Check Act (PDCA)

The energy management system, ISO 50001 is based on the Plan-Do-Check-Act (PDCA) continual improvement concept. This ensures quality after repetitive PDCA cycles as illustrated in figure 0.1. In the context of energy management, the PDCA approach can be understood as follows.

Plan: To start with, it is important to understand where the points of interest lie within the project. The scope and the way of control is determined. Therefore an energy policy is created by the energy management team. It consist of a list of components, which are the most important energy consumers and how to manage them so that the overall consumption does not increases, but decreases. This is done by identifying opportunities and risks to which actions are linked. Actions to raise the awareness of the user of the system are also documented.

Do: In this phase, the ideas from the plan part will be implemented. The opportunities will be used and the risks will be eliminated. Opportunities can come from the purchase of systems that have a beneficial effect on the efficiency of the system. Risks can be eliminated by carrying out preventive maintenance and/or installing alarm systems that reveal abnormalities.

Check: During this phase, the previous actions will be monitored, measured, analysed and evaluated. After this, the energy management system and the energy policy can be adjusted if necessary.

Act: Actions will be taken if there are problems that lead to higher energy costs. Because the energy policy is a continuous process, the Plan phase will be restarted after this phase.

Figure 5.1 PDCA cycle according to ISO 50001 (ISO, 2020)

The picture above shows that by repeatedly going through the PDCA cycle coming from the standard (ISO 50001), the quality of the energy management system will increase. It is a continuous process in which locking the progress is perhaps the most important part of all. By securing the results, one can always move forward without having to take a step backwards. This is done by paying attention to the points that turned out to be wrong during the last PDCA cycle. Generally, it is important to eliminate these points, but then again it is equally important to understand why these problems occurred, so lessons can be learned and prevention measures can be developed to secure the progress for the long term development.

5.3   Energy Consumption Aquaponics

In order to determine the energy consumption as clearly as possible, the consumption per module (Vertical Tower vs. Deep Water Culture) will be calculated. Initially, the intention was to monitor the energy consumption per module using energy loggers, but due to the limited budget we had to cancel this.

However, the power consumption per component was manually measured using an AC-logger located in the laboratory. This enabled us to estimate the actual energy consumption per module on the basis of calculations. The image below shows the method of measuring the power consumption per energy consumer.

Figure 5.2: Measuring energy consumption components

All energy consumers are listed below, both those that are in use and those that we keep in stock. The shown power was measured with the energy logger and represents the actually occurring power.

Table 5.1 Measured energy consumption per energy consumer (energy logger)

Water Pumps	
In use	Power
BOYU SPA-2000C	34 W
BOYU FP-1000	13 W
BOYU FP-1000	13 W
Spare	Power
EHEIM 1002.220	16 W
BOYU FP-750	8 W

Air Pumps	
Spare	Power
Sera precision air 550R plus	7 W
Sera precision air 550R plus	7 W

Lights	
In use	Power
LUMERI T8-INTEG100	21 W
LUMERI T8-INTEG100	20 W
LUMERI T8-INTEG80	17 W
LUMERI T8-INTEG80	16 W
To buy	Power
LUMERI T5-INTEG40	10 W
LUMERI T5-INTEG40	10 W
LUMERI T5-INTEG40	10 W
LUMERI T5-INTEG40	10 W

To calculate the energy consumption per module, the energy consumers per module are summed up. For the DWC module, four new LED lights need to be purchased, namely the LUMERI T5-INTEG40. The VT module will be equipped with two LUMERI T8-INTEG100 lights and two LUMERI T8-INTEG80 lights.

Table 5.2 Energy consumption per module (Deep Water Culture vs. Vertical Tower)

Module	Component	Power	Operational hours	Operational factor	Yearly consumption	Consumption
		kW	h	%	kWh	%
DWC	Water pump DWC (IN)	0,013	8 760	100%	114	11,11%
	LED lights DWC (4x)	0,04	8 760	50%	175	17,09%
	Water pump DWC (OUT)	0,017	8 760	100%	149	14,53%
Vertical Tower	Water pump VT (IN)	0,013	8 760	100%	114	11,11%
	LED lights VT (4x)	0,074	8 760	50%	324	31,62%
	Water pump VT (OUT)	0,017	8 760	100%	149	14,53%

The DWC module has an estimated annual consumption of 438kWh while the VT module has an estimated annual consumption of 587kWh.

Table 5.3 Costs per module (Deep Water Culture vs. Vertical Tower)

Module	Component	Yearly consumption	Daytime tariff	Nighttime tariff	Yearly costs	
		kWh	0,0553 €/kWh	0,0467 €/kWh		
DWC	Water pump DWC (IN)	114	50%	50%	€ 5,81	
	LED lights DWC (4x)	175		100%	€ 8,18	€ 21,58
	Water pump DWC (OUT)	149	50%	50%	€ 7,59	
Vertical Tower	Water pump VT (IN)	114	50%	50%	€ 5,81	
	LED lights VT (4x)	324		100%	€ 15,14	€ 28,54
	Water pump VT (OUT)	149	50%	50%	€ 7,59	

In terms of costs, the annual estimated costs are € 21.58 for the DWC module and € 28.54 for the VT module.

5.4   Energy Consumption

For the following team, the estimations of energy consumption per module and the associated costs are interesting to expand the aquaponic system. Based on these estimations, they can work out a future business plan by multiplying the cost per module by the number of modules during the scaling- up process.

5.4.1 Significant Energy Users Aquaponics

A first phase in the implementation of the ISO 50001 standard is to determine the significant energy consumers. The significant energy consumers are the consumers that consume the most energy over a defined period of time. By listing these energy consumers, we obtain a kind of step-by-step plan. Priority should be given to the significant energy consumers and at a later stage to the other consumers.

5.4.2 Identifying the Significant Energy Consumers

The significant energy consumers are determined by comparing the estimated energy consumption of the different components on an annual basis and then ranking them. Only those consumers that are applied and those that still need to be purchased are taken into account.

Table 5.4 Ranking Significant Energy Consumers

Ranking	Component	Yearly Consumption kWh
1	LED lights VT (4x)	324
2	Water pump (OUT)	298
3	LED lights DWC (4x)	175
4	Water pump DWC (IN)	114
5	Water pump VT (IN)	114

The four LED lights of the Vertical Tower are the biggest energy consumers, even though they only operate half the time, namely during the night. These lights are the ones that are being reused from the previous team. The four LED lights are followed by the water pump that pumps the water from the gathering tank back into the fish tank and the third largest consumers are the four LED lights that are implemented in the Deep Water Culture module.

5.5 Significant Energy Consumers

If the next team wants to improve the energy efficiency of the aquaponic system, priority should be given to the significant energy consumers and according to the order above. By following the priority list, the budget for energy will first go to the consumers that can save the most consumption.
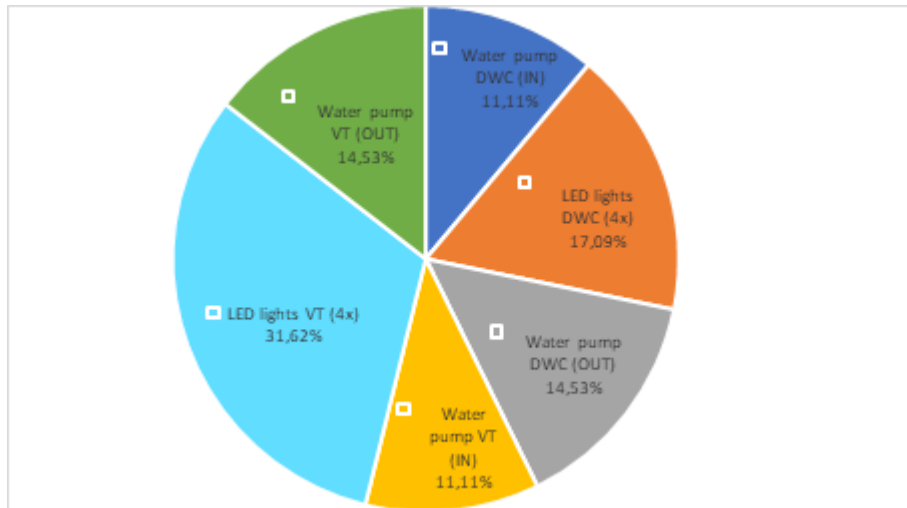
Figure 5.3: Pie chart Energy Consumers

5.6 Energy Consumption Greenhouse

In order to implement the aquaponic system in the greenhouse throughout the whole year, it will have to be heated for most of the time. To determine the heating, we first need to calculate the heat losses to the outside environment.

A comparison will be made between the current structure of the greenhouse on the roof of the Technobothnia laboratory and an improved greenhouse by implementing insulation material.

5.6.1 Current situation

Due to the many changes to the objectives of the project, partly due to the corona crisis the EPS team had to deal with, priority was given to different topics of the aquaponic system. As a result, priority was also given in the budget to parts other than those initially foreseen. It was therefore decided within the team not to provide insulation material in the greenhouse and to save budget for the other parts. The table below shows the construction materials of the different building sections that compose the current greenhouse.

Table 5.5 Building materials

Building part	Now
Walls (south + west)	PE foil
Walls (north + east)	PE foil
Roof	Plexiglass sheets
Floor	PE foil
	OSB wooden boards
Door	Wooden composition

Walls (PE foil)

The walls are covered with a strong PE foil to protect the greenhouse against wind and rain.

Roof (Plexiglass sheets)

The roof should be able to withstand strong gusts of wind, rain and snow and should therefore be stronger than the walls. That is why we use waterproof plexiglass sheets.

Floor (PE foil + OSB wooden boards)

For the floor of the greenhouse, we have to keep the outside environment in mind. Given that the greenhouse will be placed on the roof of the Technobothnia laboratory, it will be exposed to the harshest weather conditions. The floor must be sufficiently water resistant to shield the indoor environment against rainfall. This is because there will be electrical equipment in the greenhouse that cannot tolerate water or moisture. It is also important that the floor is strong enough to support the weight of the aquaponic system. Wood is preferred as construction material because of its attractive purchase price and sustainability.

The floor is constructed from a waterproof PE foil on the outside and on top of that OSB wooden boards for its strength.

Door (Wooden composition)

The door consists of a composition of different wooden materials. A layer of paint which is applied to the outside of the door makes it water resistant.

Heat losses current situation winter – autumn

In order to calculate the heat losses to the outdoor environment, we created an Excel master sheet. In this master sheet all factors that have an influence on the heat loss are highlighted. In the declaration below the master sheet, all factors are described.

For the outdoor environment, we assume the most extreme situation in winter, namely at a temperature of -29°C. The desired indoor temperature is the designer's choice. For two reasons we have chosen an indoor temperature of 15°C. Firstly, as energy managers, we don't want the temperature to be too high. This because for each degree of temperature rise of the indoor temperature, we have to deal with greater heat losses to the outside environment. Secondly, we want the aquaponic system to work in optimal conditions both for the plants, the fish and humans.

Table 5.6 Heat loss calculation: Greenhouse current situation winter - autumn

Quick calculation sheet: heat loss calculation NBN 62 - 003

		Greenhouse current situation: winter - autumn			
Basic outdoor temperature te [°C]	-29				
HEAT TRANSFER COEFFICIENTS					
Structural component (walls, roof, windows and doors). The total surface area must be inserted.	Surface A [m²]	H_v or H_T [W/K.m²]	t_i [°C]	t_i - t_e [K]	Heat losses Φ [W]
Left side wall (south)	8,078	5,823	15	44	2069,78
Right side wall (north)	6,192	5,823	15	44	1586,54
Front side wall (east)	7,448	5,823	15	44	1908,36
Back side wall (west)	9,429	5,823	15	44	2415,94
Door	1,860	2,886	15	44	236,21
Roof	9,069	4,762	15	44	1900,17
Floor	11,750	3,375	15	44	1744,62
TOTAL HEAT LOSS					
Φ$_{total}$ [W]			11861,64		

Declaration:

Surface area A [m²]: the surface area of the face that transfers heat to the outside environment.

H_v or H_t: the total heat loss per degree Kelvin temperature difference per m².

t_i: desired indoor temperature

t_i - t_e: temperature difference between indoor and outdoor environment

In order to determine H_T, the heat transfer factor is calculated in another tab in the Excel master sheet. This factor depends on the materials used in the walls, floor and roof of the greenhouse. The thermal transmittance of the structure in the plane is calculated. This depends on the different materials used in that plane and the thickness of each layer. In the summary below, the example is given of the construction of the floor with the declaration underneath.

Table 5.7 Example: thermal transmittance of the floor

	Description	Current Floor Greenhouse						
	Result:	$H_D = \sum_{i=1}^{n} U_i A_i + \sum_{k=1}^{m} I_k \Psi_k + \sum_{l=1}^{r} \chi_l$	**3,37**	**W/K**	YES	NO	R [m².K/W]	
Heat transfer resistor		Outside air upwards (> 30° compared to horizontal)	☐		0.1			
		Outside air horizontal (< 30° compared to horizontal)	☐		0.13			
		Outside air downwards (> 30° compared to horizontal)	☑		0.17		0.17	
		Ventilated air layer	☐		Ri	0.04	0.04	
Heat resistance	Materials:			thickness [m]	λ [W/(m.K)]	R [m².K/W]	R [m².K/W]	Reference
	PE foil			0.0005	0.290		0.002	
	OSB boards			0.0110	0.130		0.085	

Total R	0,296	m².K/W
U-value	3,375	W/m²K
A (outside dimensions)	1,000	m²
U.A	**3,37**	**W/K**

Declaration:

λ [W/(m.K)]: the heat conductivity of a material

(The lambda values can be found in the Handoff Package 2020 in the part of energy.)

R [m².K/W]: the heat resistance of a material

(The R-values can be found in the Handoff Package 2020 in the part of energy.)

U-value [W/(m².K)]: thermal transmittance

Previous calculations were done for each structure of the walls, roof and floor. However, we do not mention these further in the report.

Heat losses current situation spring - summer

The same calculations were made for the spring and summer periods. However, the coldest outside temperature to be covered is now -5 °C. The desired indoor temperature is again 15 °C to reduce heat losses.

Table 5.8 Heat loss calculation: Greenhouse current situation spring - summer

Quick calculation sheet: heat loss calculation NBN 62 - 003

		Greenhouse current situation: spring - summer			
Basic outdoor temperature te [°C]	-5				
HEAT TRANSFER COEFFICIENTS					
Structural component (walls, roof, windows and doors). The total surface area must be inserted.	Surface A [m²]	H_v of H_T [W/K]	t_i [°C]	$t_i - t_e$ [K]	Heat losses Φ [W]
Left side wall (south)	8,078	5,823	15	20	940,81
Right side wall (north)	6,192	5,823	15	20	721,16
Front side wall (east)	7,448	5,823	15	20	867,44
Back side wall (west)	9,429	5,823	15	20	1098,16
Door	1,860	2,886	15	20	107,37
Roof	9,069	4,762	15	20	863,71
Floor	11,750	3,375	15	20	793,01
	TOTAL HEAT LOSS				
	Φ_{total} [W]		**5391,65**		

During the coldest spring days, the heat losses are approximately half of those in winter (5391,65 W vs. 11861,64 W).

5.7   Implementation XPS Insulation

The next team will be able to add insulation material to the greenhouse with the upcoming budget. With this insulation material the heat losses to the outside environment can be reduced.

Research has shown that XPS boards are the most suitable insulation material for the construction of the floor and the walls. They have the advantage of being easy to disassemble and consist of a hardened structure, which makes them pressure resistant. XPS boards are commonly available in different thicknesses. Based on the next limited budget, the energy team decided to design the structure with XPS boards with a thickness of 5 cm. In addition, the table below shows the properties of XPS boards.

Table 5.9 Properties of XPS boards

XPS boards
Flat sheets: pay attention for seams when mounting
Easily demountable
Hard structure (pressure-resistant)
Water-repellent

The walls can also be built more solidly by using the same plexiglass sheets as on the roof. In this way, we obtain a more water-resistant greenhouse that is able to absorb gusts of wind better. With the following construction of the greenhouse, we want to help the next team on the right track.

Table 5.10 Comparison between the current structure of the greenhouse and the future

Building part	Now	Future
Walls (south + west)	PE foil	Plexiglass sheets
Walls (north + east)	PE foil	Plexiglass sheets
		XPS insulation (5cm)
Roof	Plexiglass sheets	Plexiglass sheets
Floor	PE foil	PE foil
	OSB wooden boards	XPS insulation (5cm)
		Air layer
		OSB wooden boards
Door	Wooden composition	Wooden composition

Walls south and west (Plexiglass sheets)

The walls at the south and west side can be fitted with plexiglass sheets to protect the greenhouse from wind and rain. In these walls we do not provide any insulation material to allow the sunlight to shine in during the day.

Walls north and east (Plexiglass sheets + XPS insulation)

At the north and east side, XPS boards with a thickness of 5cm can be applied to the inside of the plexiglass walls. Along the inside of this XPS insulation, another reflection material can be provided to reflect the incoming sunshine from the south and west side.

Roof (Plexiglass sheets)

The roof remains the same and should be able to withstand strong gusts of wind, rain and snow. It should therefore be stronger than the walls. That is why we use waterproof plexiglass sheets.

Floor (PE foil + XPS insulation + Air layer + OSB wooden boards)

The floor is constructed with a waterproof PE foil on the outside. On top of this, it is recommended to provide a layer of 5cm thick XPS boards to reduce heat losses through the floor. For the next team it would be a good idea to provide a layer of air of a few centimetres to hide cables and if necessary, pipes. The air layer also benefits the insulation quality and for the strength of the floor we provide the inner layer with OSB boards.

Door (wooden composition)

The door remains the same and consists of a composition of different wooden materials. It is made water resistant by a layer of paint which we apply on the outside of the door.

Heat losses XPS insulation winter - autumn

As there are no significant changes in the calculations of heat losses to the outside environment, we only mention the total heat loss that occurs. However, we do know that the structure of the walls, roof and floor has changed due to the use of XPS insulation material. The minimum outdoor temperature is again -29°C and the desired indoor temperature is 15°C.

Table 5.11 Total heat loss: XPS insulation winter – autumn

TOTAL HEAT LOSS	
Φ_{total} [W]	5802,02

Heat losses XPS insulation spring - summer

The same calculation was made for the spring and summer periods. However, we now have to make a repeat the calculation with a minimum outside temperature of -5°C.

Table 5.12 Total heat loss: XPS insulation spring - summer

TOTAL HEAT LOSS	
Φ_{total} [W]	2637,28

5.7.1 Conclusion

A significant reduction in heat loss can be obtained by using XPS insulation material. With a layer of this material with a thickness of only 5 cm, we can reduce the heat loss to the outside environment up to half of the current heat loss. It is therefore important for the next team to include the application of insulation material on their priority list.

5.8 Energy Production Greenhouse

To determine the energy needs of the greenhouse a comparison was made between two scenarios. The first scenario is when the greenhouse has to be operational for the whole year. The other scenario includes the working hours of the spring and summer seasons. Therefore, the energy production for the greenhouse has also a few scenarios.

There are two solutions to meet the energy needs in a responsible way. Namely installing a heat-pump. This system uses electricity to create heat, with COP efficiencies up to 400%. This application is directly

the most expensive but also the most sustainable, individual solution. Another way is by purchasing sustainable energy. The utility company Vaasan Sähkö, owns a number of wind turbines in its energy mix. By paying a small surcharge on the energy costs, the greenhouse can use these through more traditional systems such as electric heating.

The following simulations are based on the values from the consumption part where the greenhouse is fully isolated. This means that first off all, isolation has to be placed before being able to implement the solutions that will be discussed in this topic.

5.8.1 Heat Pump

The isolated greenhouse during the whole year will need maximum 6 kW of thermal energy and for the summer and spring, 3 kW of thermal energy. Via Daikin's Altherma simulation software, heat pumps were selected to cover the entire heat requirement. Both pumps are EDLQ0XCV3 types. The most important features are discussed, the whole document can be found in the Appendix.

Figure 5.4 EDLQ0XCV3 Heat Pump, Daikin

5.8.2 Energy Consumption and Costs per Month in Vaasa

The choice was made for a heat pump that can supply 100% of the required power, for a full year. This means that at the most critical and therefore coldest time of the year, the pump must be able to supply the necessary heat. The maximum indoor temperature chosen was 15°C.

Scenario One: Electric Energy consumption during the whole year

 In this case the month of January and February is the same and also the coldest month(s) in Vaasa, with minimum temperatures down to -29 °C. (Daikin Altherma Selection, 2020) The following table shows the electric power used in time also known as the electric energy consumption.
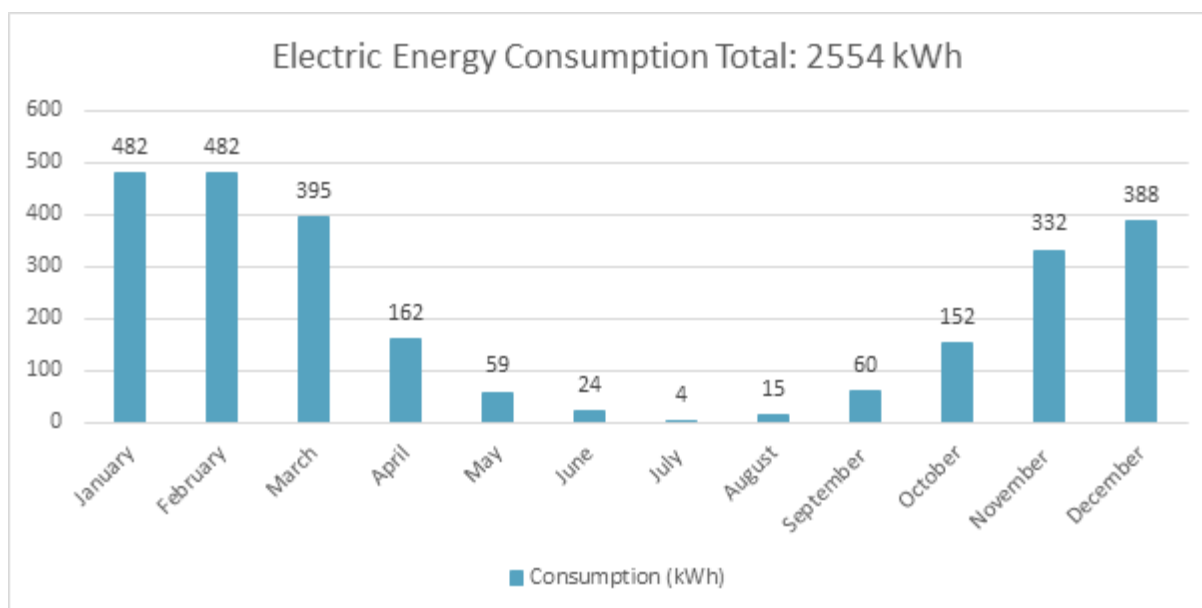
Figure 5.1 Energy consumption during the whole year in Vaasa (Daikin Altherma Selection, 2020)

In total, the system will consume 2554 kWh of electric power on an annual basis. In order to translate this into a better-known figure, namely euros, one has to look at daytime and nighttime tariff. In Vaasa, the daytime tariff applies from Monday to Saturday between 7 a.m. and 10 p.m. The daytime price is €0.0553/kWh and the night-time price is €0.0467/Kwh. (Vaasan Sähkö, 2020) All these parameters were taken into account in the Daikin Altherma simulation program. (Daikin Altherma Selection, 2020)

Table 5.13 Day prices in Vaasa, Finland (Vaasan Sähkö, 2020)

Day	Moment	Hour	Price
Monday-Saturday	Daytime price	7a.m.-10 p.m.	€0.0553/kWh
	Nighttime price	10 p.m.-7a.m.	€0.0467/kWh
Sunday	Nighttime price	all day	€0.0467/kWh
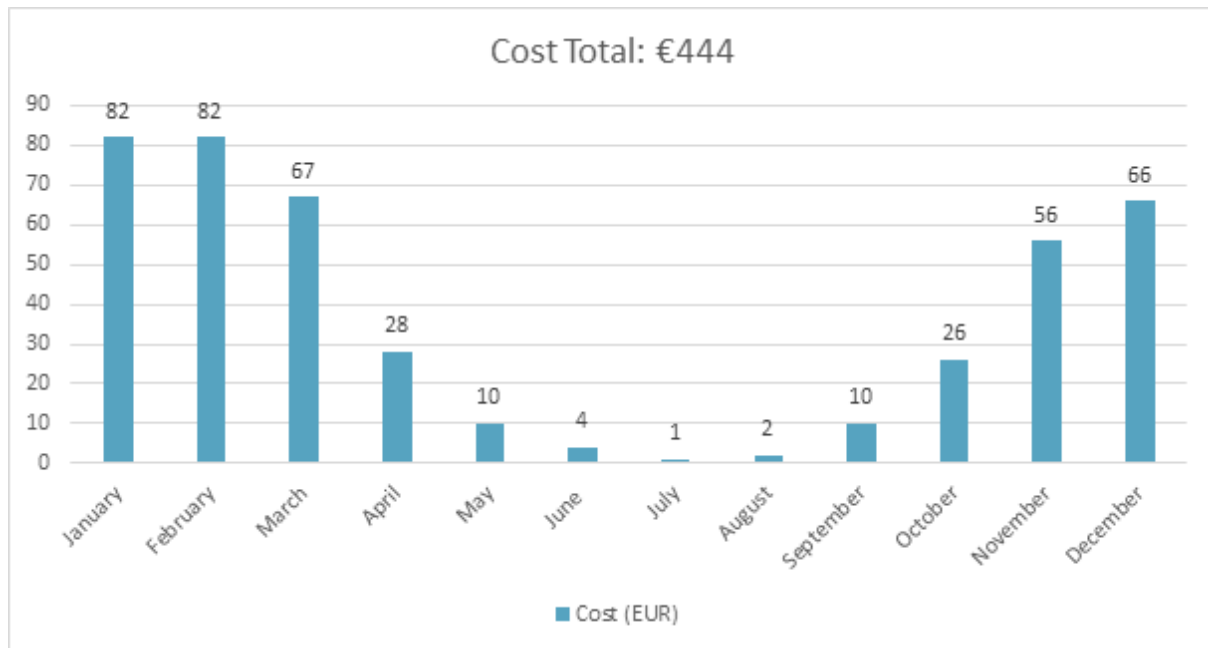
Figure 5.2 Energy Cost during the whole year in Vaasa (Daikin Altherma Selection, 2020)

After setting the electricity profile per day, the simulation calculated the costs per month as shown above in the table. In total, the system will use €440 of electricity. The period between November and March will absorb most of the costs because these months are the coldest. During this period the heat pump will show its greatest value, to keep the temperature for both the plants and the fish at 15°C.

Scenario Two: Energy consumption during spring and summer

Because the costs are the highest during the winter and fall period, as seen in scenario one, the choice could be made to only keep the system running during the Spring and Summer period. Throughout this period, the greenhouse will need 2,7 kW of electric power tops, as calculated in the greenhouse consumption. This change allows to use a smaller heat pump of the EDLQ0XCV3 series from Daikin.

Spring Starts at the end of March and Summer ends at the end of September. The most critical point for the heat pump is now March. The heat loss profile from the greenhouse remains the same but the period that is in use is different. Therefore, the critical point moved from being 6 kW to 2.7 kW maximum.
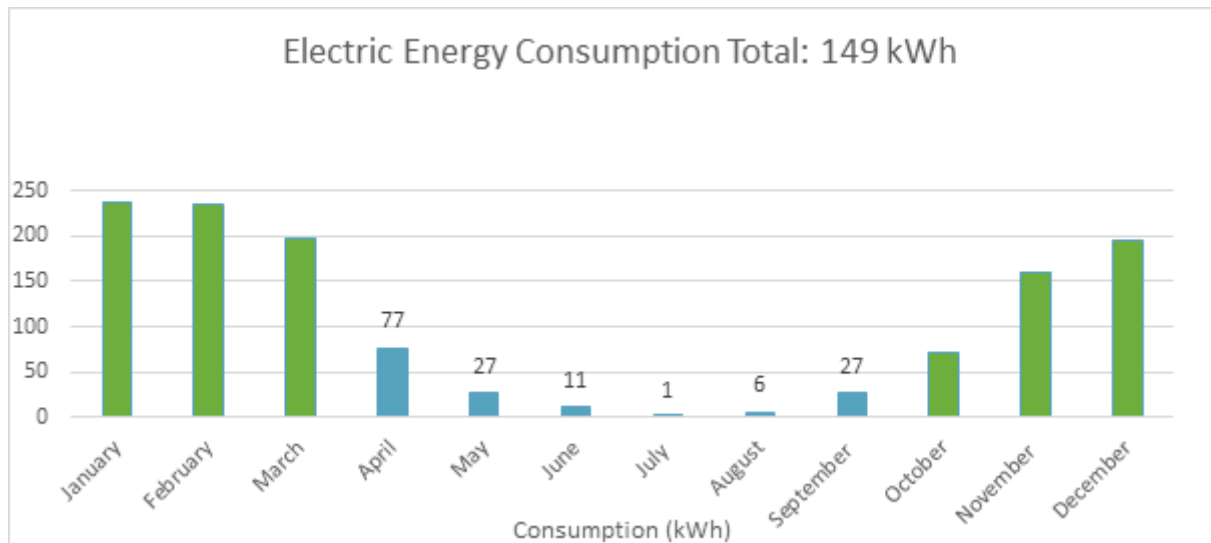
Figure 5.3 Energy consumption during spring and summer in Vaasa (Daikin Altherma Selection, 2020

Remember that a heat pump uses electricity and converts it into heat. The consumptions shown are therefore those electricity consumptions required to heat the room to the desired indoor temperature. The smaller heat pump therefore has a lower efficiency than the pump that can be used for year-round operation.
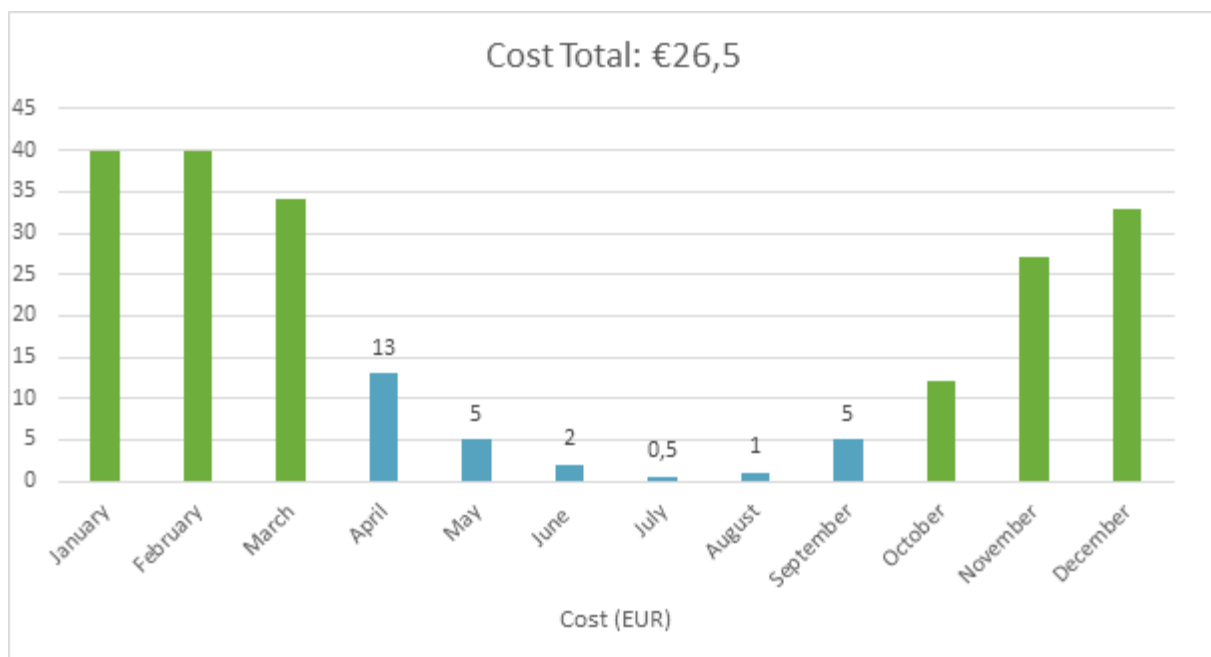
Figure 5.4 Energy Cost during spring and summer in Vaasa (Daikin Altherma Selection, 2020)

What could be concluded from this table is that the energy consumption is really low. Therefore, it is not worth to do the investment. Another option should be looked at if the system only has to be operational during spring and summer.

5.8.3   Buying sustainable energy from Vaasan Sähkö

When the greenhouse does not have to be in use all the time and it turns out that investments have a longer return on investment period, it can be interesting not to make those investments. On the other hand, there are other possibilities that can contribute to the sustainable nature of energy production for the greenhouse.

By buying renewable energy from the local energy supplier, the right decision can be taken both economically and ecologically. Vaasan Sähkö offers energy from the wind turbines they own. This energy is slightly more expensive. However, the additional cost is very limited. it differs €0.0025/ kWh, this is only 4.5% more expensive than the price of the traditionally produced energy.

Table 5.14 Day prices for Windmill energy in Vaasa, Finland (Vaasan Sähkö, 2020)

Day	Moment	Hour	Price
Monday-Saturday	Daytime price	7a.m.-10 p.m.	€0.0578/kWh
	Nighttime price	10 p.m.-7a.m.	€0.0492/kWh
Sunday	Nighttime price	all day	€0.0492/kWh

5.9   Energy Production

A heat pump can be a very energy-efficient solution if the project is supported by the school for a sufficiently long time. In this way, the large investment can be justified. If the project is rather short term, it is best to purchase sustainable energy from the local energy producer.

5.9.1   Implementation Sustainable/Renewable Energy

The aim when building the greenhouse is to build it as profitable and sustainable as possible. It is therefore important for the next group to cover the energy losses, mainly heat losses, that occur with renewable energy sources. In order to use these renewable energy sources as efficiently as possible, larger investments are often required. However, using wind and solar energy will make the system more energy efficient and on the longer-term cost effective.

5.9.2   Wind

In the Technobothnia workshop, a wind turbine has already been created in an earlier project. The blades of the wind turbine were manufactured from plastic using a 3D printer.

However, the report on the wind turbine indicated that it had not yet been tested. The possible energy production is therefore still unclear to us. We would therefore like to refer the following team to the report of the wind turbine to further investigate the possible energy production and the possibility to implement several of these wind turbines within the aquaponic system.

5.9.3 Solar

In the domain of solar energy, detailed research has already been done by the EPS team during the autumn of 2019. Partly due to the limited budget, the corona crisis and other priorities, further research into the production and implementation of solar energy was postponed. We would therefore like to refer the following team to the research already carried out by the EPS team in 2019. The research can be found in the "Handoff Package of 2019" in the folder "07. Energy supply".

5.10 Conclusions and recommendations

5.10.1 Conclusions

For this semester the priorities were to make the Aquaponic system robust. where the necessary data can be obtained by implementing a control system consisting of sensors and processing systems. This allows to compare different systems. Furthermore, the system was housed in a self-designed greenhouse on the roof of the Technobothnia campus.

By calculating the energy consumption per module, it is easy to estimate what the consumption would be if the system were to be increased. When the entire surface of the greenhouse is in optimal use, it is recommended to choose a sustainable way to cover the energy consumption of the system and the greenhouse. In making this choice, account must be taken of the budget and the duration of the project.

5.10.2 Recommendations

It is suggested to measure the energy production and consumption with energy loggers which are compatible with Arduino. After choosing the right component for the modules, such as lights, the team should use them efficiently. For the lights this could mean to have a lux meter that is able to switch the light on or off according to the sunlight in the greenhouse. A useful tool to monitor and adjust the energy consumption of the system is the creation of a visualisation. By having a few energy loggers that communicate with this (online) visualisation, the current energy consumption can be monitored. By means of light sensors, the lights can be controlled when it is dark to reduce energy consumption. In winter, when the sun stays low, the roof can also be fitted with XPS plates to reduce heat losses even further.

6   Public Relations

The goal of the marketing and public relations part is to reach more people and get more people interested in the project and get more sponsors. Furthermore, we also want to create an appealing project that Novia UAS can exhibit on open days and convince more future students that they want to study at Novia UAS.

6.1   Slogan

During the project semester, we collected different proposals to find a good and suitable slogan for our the Hygrow project. Towards the end of the project, a survey was created in which the possible slogans were divided into the two groups "closed loop" and "sustainable / local" in order to find out which slogan and which group was preferred. Besides the current project group, we decided to also invite the last project group to participate in the survey.

In the end we received three possible slogans with the following order:

1.   Your sustainable and local grocery producer

2.   Close the loop, grow local and stay green

3.   Let the fish work for us

We also wanted to know, if we should combine our slogan with the project name "Hygrow" or not and if producer, provider or farmer sounds better in our slogan, if a slogan is chosen which contains one of the terms. The following figure from the response data show the result.

Figure 6.1 Extract of the response data

As a result, two possible version were created, depending in which context the slogan will be used.

- **Your sustainable and local grocery producer.**
  This version should be used fi the project name "Hygrow" is next to the slogan, for example on a poster or flyer.
- **Hygrow. Your sustainable and local grocery producer.**
  The second solution should be used, if the logo or nothing else is next to the slogan. The slogan alone would otherwise not make a connection to our project.

6.2 Analog Advertisement

6.2.1 Poster

We updated the wide poster from the previous group by implementing renders of the new aquaponics setup and from the greenhouse design. The poster should be easy to understand even for people without a scientific background. At the sight of visuals on the poster people should understand it. For a more in-depth understanding text has been added. In order to do so, good documentation and visuals where required. For this we needed infographics, Cad-files and at last renders of those files. We have used a full colour plotter from Technobothnia. The size of posters it can print can vary in length, however the maximal width is 1000 mm. Also, the smaller poster is updated, for this we needed a somehow more attractive image. In order to promote the EPS semester.

Figure 6.2 The EPS Poster
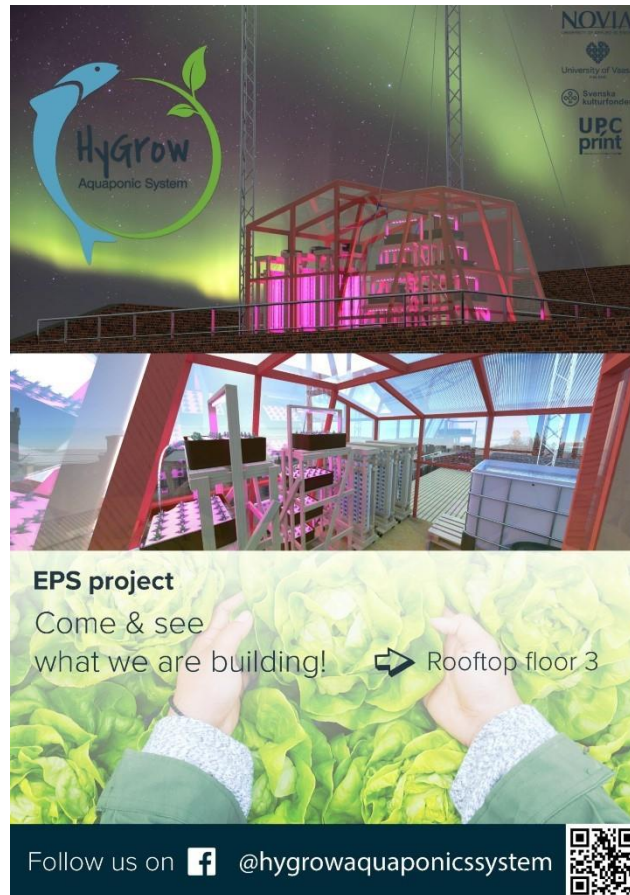
Figure 6.3 EPS Promotionl poster

6.2.2 Keyring

Creating a keyring with the logo could contribute, if the entire EPS group and the supervisors would have one. The benefit would be that in the teachers circles and the exchange students circles the project would draw attention. A prototype has already been created. The CAD-file of the keychain was created with SOLIDWORKS 2018. The Slicer that was used Ultimaker Cura 4.4. The prototype is quite large due to the small font in the logo. If one would leave out the name in the logo, one could create smaller keychains.

Figure 6.4 printed keychain with the support material

6.2.3 Clothes

As this project will be continued in the future, we have decided to design not only a post but also clothes. The focus here was mainly on t-shirts and sweaters. In order to estimate prices and delivery times, four companies in Finland, two of them directly in Vaasa, were contacted. The local suppliers have the advantage that you can establish a personal contact and the delivery times are sometimes shorter.

Because of the three colours in our logo and the difficult choice of a clothing colour, we decided to print the logo completely in white on the clothing. To create as much contrast as possible, we chose a dark blue or royal blue, as the clothing colour. Blue symbolizes the fish and the water in the aquaponic system, which is essential to grow the plants.

The logo is placed as a large print on the back and on the front, there is the possibility to print the name, especially for the project members. For the sweater there is also the possibility to choose a version with pockets and hood or even a zipper.

Figure 6.5 T-shirt design

Figure 6.6 Sweater design

6.3   Social Media

6.3.1   Facebook

There is Facebook account available to reach a variety of different people outside of our project and university. The team has taken over the fan page created by previous aquaponics team. The aim is to show those concerned the progress of our work.

6.3.2   YouTube

The last project group used Youtube to publish a livestream from the aquaponic system in the basement. We will use YouTube also for the livestream and to publish our planned videos over the semester. From time to time it is necessary to check the livestream directly on the computer where the webcams are attached, because it can happen that some failures occur, and you have restarted the programs.

6.4   Digital Advertisement

6.4.1   Pictures and Videos

Due to the closed university it was not possible to create images and videos of the running system during the semester. Advertising measures in general were also not possible. However, during the construction process many pictures were created which can be used for advertising, the final report and presentation.

The initially planned explanatory video could not be implemented due to the short construction and testing time, but it is advantageous for the next group to create such a video. This way it can be explained very clearly how the system works. The initially planned group of visitors also had to cancel their visit, so we could not create a promotional video to show others that we are open for visits and introductions to the project.

6.4.2   Presentation

A good presentation for externals could add value, for explaining the project on exhibitions in the future or to present to old and new sponsors. This presentation should start from explaining what aquaponics is and explain what we already have achieved and what our project scope is. Furthermore, it can show were their logos are advertised.

6.4.3   Website

Due to the longer project time and also the specifications from the EPS manual, we decided to create a website for the project. Our own website gives us more flexibility to show what is our project and what are the benefits. Furthermore, it can be used to present clearly and understandably who is involved in the project and what its purpose is. Our content should be interested, durable and easy to maintain. To maintain the content, we use a Content Management System. WordPress is one of

the most common systems in the world. We are also planning to use WordPress because of the great possibilities of adjustable designs and plugins.

The following figure shows the view that each user sees after calling up the page. The website is accessible for everyone after the EPS project.
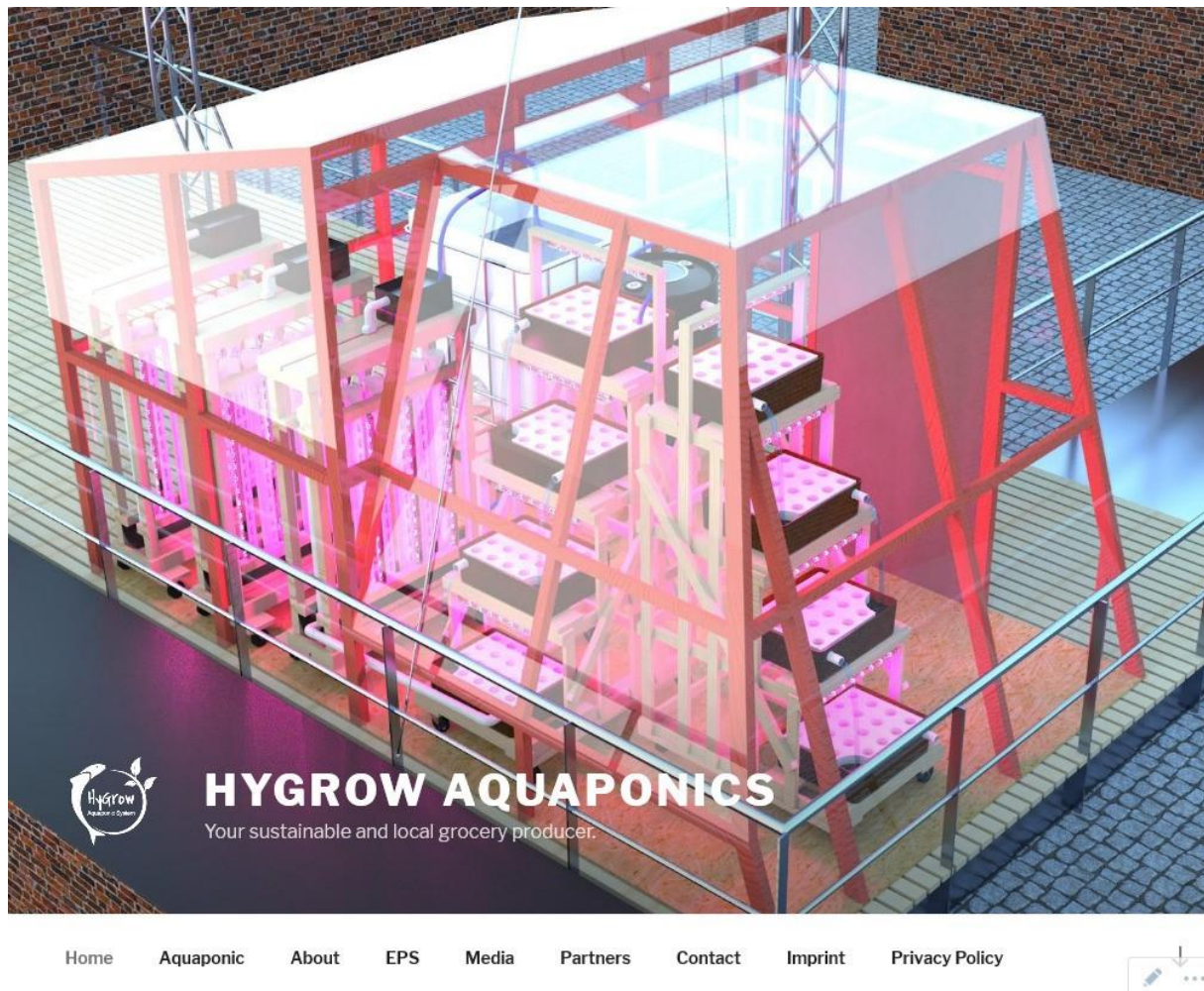

Figure 6.7 Layout of the finished website

The website will be accessible to everyone after the project semester. As you can see in the picture, the content of the website is:

- What is an aquaponic system and how it works
- Progress through different semesters and project groups
- Description what the EPS is
- Renders of the greenhouse and visuals of the system
- Sponsors and project partners
- Contact possibility

At the moment it is provided by Wordpress itself, which has some limitations. However, Wordpress had to be chosen because the original server, the greenhouse operated Raspberry Pi, cannot be

operated permanently at the moment. As soon as this is possible, it should be tested whether the website can be moved to the Raspberry Pi. This has the advantage that the university can provide us with a subdomain, for example hygrow.novia.fi, and by running it on your own server, you are more flexible in the choice of plugins for the website.

6.5 Conclusion

Social media could be updated and have potential. One person should be in charge of PR as his main job instead of a side job. This could result in better updated social media. This person should try to stay focussed even if the project scope changes.

7 Finance

7.1 Introduction

This chapter discusses the use of the budget at our disposal and the documentation thereof, also in hindsight to the budget planning in the beginning of the EPS project.

Furthermore, it provides a look at possible future scenarios and compares the profitability of this greenhouse to other methods of agriculture.

7.2 Budget Changes

At first the budget was assumed to be 3024€ (Hygrow EPS 2019, hand-off package, 05.1 feasibility analysis), but later it appeared that there were contractionary numbers in the hand-off package and the budget was adjusted to 2794€. Due to this change we had to reassess our priorities of the project and cut in the other parts.

After comparing our expenses with the accountant from Novia who manages the invoices for the project, we had to change our budget again, as there were only 2586 € to spend. There was the possibility to exceed that limit and finish the semester with an overrun, which would have had to be settled by next groups budget first, but we were able to stay within the actual budget.

7.3 Documentation

To document the spending for our project and to be able to track all the expenses we had, we decided it would be useful to not only collect all invoices and bills that we have but also to create an excel spread sheet where we can monitor our spending and how much of our budget is still left. This table will hopefully also be helpful for the following groups, as they can check where we already have bought supplies from and how much we spent.

The full list of purchases can be found in the Handoff Package.

Table 7.1 List of purchases

Name	Link/P	Category	Tax	Price Tax exc	Price Tax in	Amo	Cost	Website/ Sto	Date
Liquid level sensor (polypropylene) 200Vac / dc 0.5A Nestepinta-anturi (polypropyleeni)	MLS31Ah	Control System	0,24	8,19 €	10,16 €	2	20,32 €	Starelec	23.03.2020
Terminal strip with cable protection 12-pin. 0,5-2,5mm² Kytkentärima johdonsuojalla	NYL-2.5ht	Control System	0,24	1,09 €	1,35 €	10	13,52 €	Starelec	23.03.2020
Openable cable tie 7.6x125mm black Avattava johdinside 7,6x125mm musta	HV-125htl	Control System	0,24	6,10 €	7,56 €	1	7,56 €	Starelec	23.03.2020
Digital multimeter Cat III 300V / Cat II 500V Digitaalinen yleismittari Cat III 300V / Cat II 500V	DVM853h	Control System	0,24	18,15 €	22,51 €	1	22,51 €	Starelec	23.03.2020
PVC tape 15mm black 10m PVC-teippi 15mm musta 10m	FLX15-ML	Control System	0,24	0,77 €	0,95 €	1	0,95 €	Starelec	23.03.2020
USB-Stick 8Gb (USB 3.0) USB-muisti 8Gb (USB 3.0)	USB3-8GE	Control System	0,24	4,35 €	5,39 €	2	10,79 €	Starelec	23.03.2020
Banana test lead with grip probe, 90cm black Banaanimittajohto tartuntamittapäällä, 90cm musta	3782-MUH	Control System	0,24	7,02 €	8,70 €	1	8,70 €	Starelec	23.03.2020
Banana test lead with gripping probe, 90cm red Banaanimittajohto tartuntamittapäällä, 90cm punainen	3782-PUh	Control System	0,24	7,02 €	8,70 €	1	8,70 €	Starelec	23.03.2020
Automatic peeling pliers 0.2-6mm²		Control System	0,24						23.03.2020

All the purchases add up to 2536,21€ and are divided in the different categories as in the follows.

Table 7.2 Purchases by category

Category	Total:
Greenhouse	830,96 €
Aquaponic System	781,94 €
Control System	916,12 €
Plants	4,60 €
Other	2,60 €
Total	2.536,21 €

The most money was spent on the control system followed by the greenhouse and the aquaponic system.

Another way of monitoring the expenses is the ACWP (actual cost for work performed), it compares the previously made estimations and spending plans with the actual purchases and their times. If there are any deviations, it is either because the previously made estimations were inaccurate, there were significant changes in the planning of the project, or the project work is not following the schedule. For each of these situations it needs to be evaluated if these differences are acceptable or unavoidable, meaning the BCWS or the ACWP needs to be adjusted, or if they are not justified and should not have happened, then the way of working needs to be reassessed.
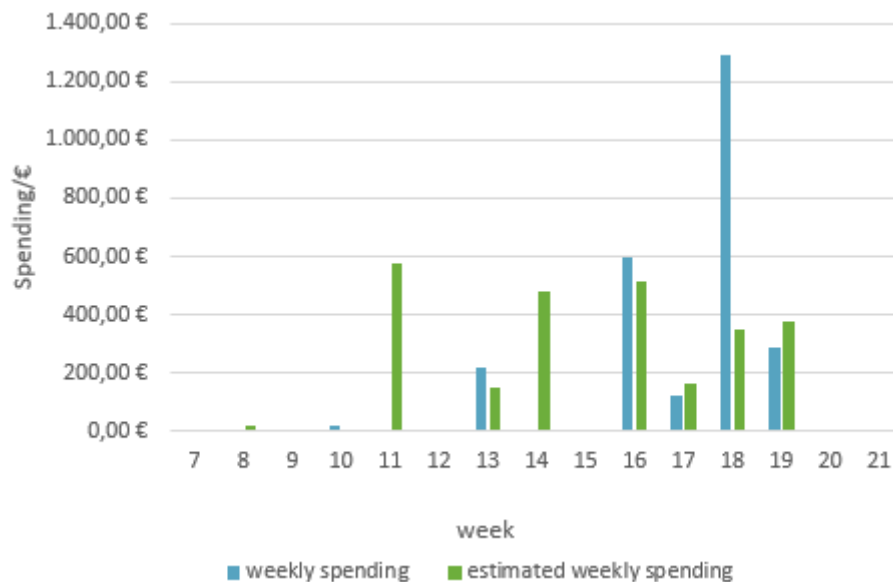
Figure 7.1 Weekly Spending

In this figure the weekly spending is compared to the estimation. It is obvious that there are significant differences in the time the purchases were made. We planned to buy more materials and supplies at an earlier time. The biggest purchases were made in week 18 when the supplies for building the aquaponic system and greenhouse were bought.
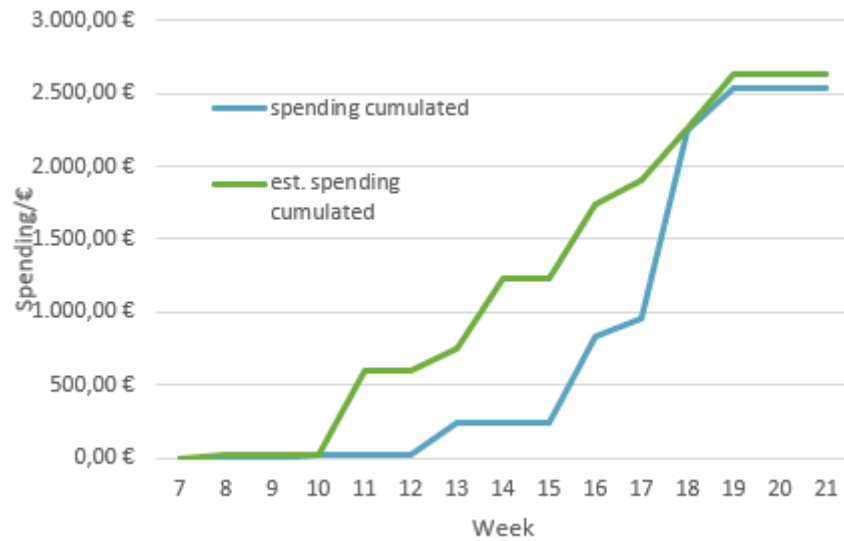
Figure 7.2 Weekly Spending Cumulated

But if the cumulated value of the purchases is taken into consideration, as shown in the figure above, it becomes apparent that while the estimated times were not always adhered to, the overall trend matches.

When we had to change our budget, we implemented another tool to get an overview on future expenses. This was very helpful and is recommended to do at a much earlier point in the project.

We created a file that includes all the materials still needed and their cost and assigned a priority, ranging from high, middle, to low, to each. Adding the buy option with yes, no maybe or already bought, made it possible to calculate different scenarios and see which purchases are reasonable for our budget.

Table 7.3 Planned Purchases

Name	Category	Price	Quantity	Cost	Necessity	Why?/ For What?	Buy ?
Plexiglass	Control System	44,90 €	1	44,90 €	Middle	Lid for switch cabinets	No
Metal Hinge	Control System	2,90 €	6	17,40 €	High	For switch cabinets	Yes
Magnetic locks	Control System	3,80 €	1	3,80 €	High	For switch cabinets	Yes
Handles	Control System	2,90 €	3	8,70 €	Middle	For switch cabinets	No
Cable holder	Control System	0,20 €	20	4,00 €	High	Cable fastening	Bought
Brush for Switch Cabinet	Control System	7,39 €	7	51,73 €	Low	Dust protection	No
Cable Duct	Control System	7,00 €	5	35,00 €	High	For switch cabinets (could be 7 €/m or 7€/2m. Not really sure	Bought
DIN Rail	Control System	1,95 €	5	9,75 €	High	For switch cabinets	Bought
Power outlet	Control System	5,95 €	1	5,95 €	Middle	For main switch cabinet	No

To visualise this concept, we added used two pie charts. These pie charts do not depict our final purchases but are an example of when we were still choosing what to buy.
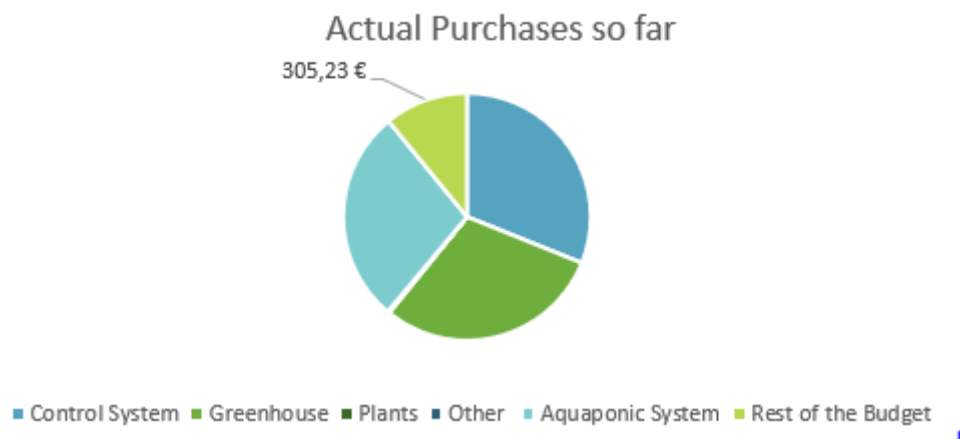
Figure 7.3 Pie Chart of Actual Purchases

This first pie chart shows the purchases already made, sorted by the categories, and the rest of the budget that is still available.
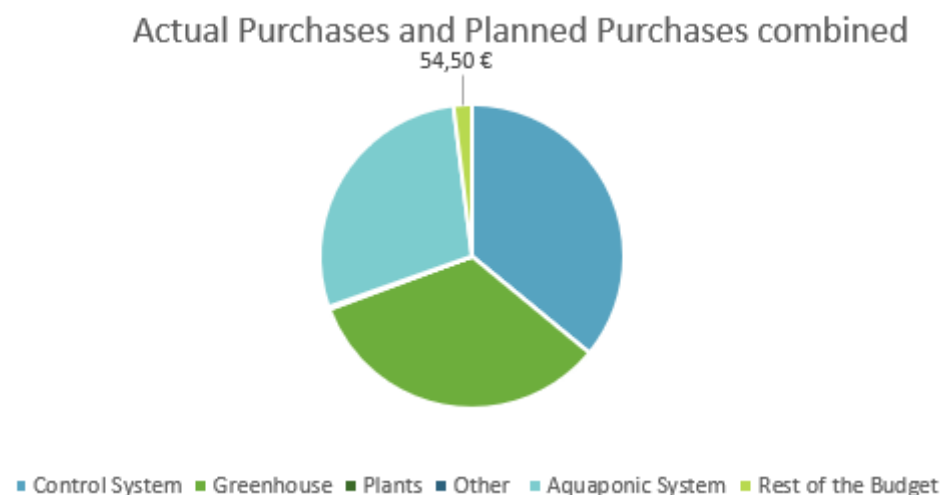
Figure 7.4 Pie Chart of Actual Purchases and Planned Purchases combined

In this second pie chart every planned expense that is marked "yes" in the table is added as if it was already bought, thus decreasing the still available budget. We tried to plan in such a way that we still had at least 50€ left as a buffer, for unexpected expenses or for an emergency, even though we did not need it in the end.

7.4 Greenhouse Scenarios

7.4.1 Greenhouse Yield

To calculate the possible revenue of the aquaponic greenhouse many factors need to be considered. Starting with the plants that are suitable for the system, as previously described in the aquaponic

research. To gather accurate data about their grocery price, multiple prices from Finnish online grocery stores such as k-ruoka.fi and foodie.fi were collected and averaged.

Table 7.4 Average Grocery Prices

Plant	Average Price/kg
Spinach (fresh)	13,20 €
Spinach (frozen)	4,92 €
Lettuce	5,60 €
Basil	81,25 €
Basil (Plant)	1,72 €
Mint (Plant	2,04 €
Rucola	23,92 €
Parsley (Plant)	2,06 €
Parsley	38,16 €

While e.g. lettuce or the whole herb plants do not retail for such a high price, they are less time consuming in harvest and selling preparations and are less wasteful than basil when it is sold in bundles. When choosing how to sell the produce this also needs to be taken into consideration.

Even though this is the price the consumer pays, this is not what the producer gets. In an internal discussion it was decided, that after subtracting 100% gross margin for the retailer, taxes and transport costs, that a quarter of these prices goes to the producer.

Another factor that impact the yield is the time the plants need until they are ready to be harvested. This includes the germination time and the growth time, which can also be found in the aquaponic research. There they are specified as a time span, for calculation purposes only the median is considered. Of course, the times heavily depends on environmental conditions so generalised numbers can be inaccurate.

Furthermore, the available place to grow plants is also important. For the current set-up with two vertical towers and deep-water cultures, the capacity is estimated to be 160 plants at once.

Including all these indicators, this is what a possible yield could look like.

Table 7.5 Aquaponic Yield

Name	size in kg	Plants	kg	Price/kg	Producer Price	Growth Time/	Growth Cycles	Completed Cycles	Yield	Yield/m²	Yield/m² per month
Spinach(fresh)	0,1	20	2	13,20 €	3,30 €	50	3,60	3,00	79,22	6,60 €	0,04 €
Spinach (frozen)	0,1		0	4,92 €	1,23 €	50	3,60	3,00	0,00	0,00 €	0,00 €
Lettuce	0,6	50	30	5,60 €	1,40 €	33	5,45	5,00	839,50	69,96 €	11,66 €
Basil	0,5		0	81,25 €	20,31 €	46	3,91	3,00	0,00	0,00 €	0,00 €
Basil (Plant)	1	20	20	1,72 €	0,43 €	46	3,91	3,00	103,40	8,62 €	1,44 €
Mint (Plant	1	20	20	2,04 €	0,51 €	92	1,96	1,00	40,80	3,40 €	0,57 €
Rucola	0,3	30	9	23,92 €	5,98 €	41	4,39	4,00	861,12	71,76 €	11,96 €
Parsley (Plant)	1	20	20	2,06 €	0,51 €	34	5,29	5,00	205,67	17,14 €	2,86 €
Parsley	0,6		0	38,16 €	9,54 €	34	5,29	5,00	0,00	0,00 €	0,00 €
Total		101							2129,71	177,48 €	28,52 €

The table above is generated for six month running time of the greenhouse. To make it more comparable the categories yield/m² and yield/m² per month were added, they are based on the current greenhouse size of 12m².

By changing any of these parameters vastly different results can occur. In this chapter only a few possibilities will be discussed, more can be found in the hand-off package.

For example, by increasing the running time of the system to a whole year, the yield/m² per month increases as seen in the figure below. This is mostly due to the fact that only completed growth cycles are taken into account and by changing the number of days, the difference caused by the downward adjustment is smaller.

Table 7.6 Aquaponic Yield- whole Year

Name	size in kg	Plants	kg	Price/kg	Producer Price	Growth Time	Growth Cycles	Completed Cycles	Yield	Yield/m²	Yield/m² per month
Spinach(fresh)	0,1	20	2	13,20 €	3,30 €	50	7,30	7,00	184,85	15,40 €	0,04 €
Spinach (frozen)	0,1		0	4,92 €	1,23 €	50	7,30	7,00	0,00	0,00 €	0,00 €
Lettuce	0,6	50	30	5,60 €	1,40 €	33	11,06	11,00	1846,90	153,91 €	12,83 €
Basil	0,5		0	81,25 €	20,31 €	46	7,93	7,00	0,00	0,00 €	0,00 €
Basil (Plant)	1	20	20	1,72 €	0,43 €	46	7,93	7,00	241,27	20,11 €	1,68 €
Mint (Plant	1	20	20	2,04 €	0,51 €	92	3,97	3,00	122,40	10,20 €	0,85 €
Rucola	0,3	30	9	23,92 €	5,98 €	41	8,90	8,00	1722,24	143,52 €	11,96 €
Parsley (Plant)	1	20	20	2,06 €	0,51 €	34	10,74	10,00	411,33	34,28 €	2,86 €
Parsley	0,6		0	38,16 €	9,54 €	34	10,74	10,00	0,00	0,00 €	0,00 €
Total			101						4528,99	377,42 €	30,21 €

For this option the increased running cost of the system, e.g. for heating and additional lights will have a negative impact on the gross margin.

Another possible scenario is that the germination of the plants happens separately, and therefore do not take up space in the designated growing spots.

Table 7.7 Aquaponic Yield- Without Germination

Name	size in kg	Plants	kg	Price/kg	Producer	Growth Ti	Completed Growth Cycles	Yield	Yield/m²	Yield/m² per month
Spinach(fresh)	0,1	20	2	13,20 €	3,30 €	43	4,00	105,63 €	8,80 €	0,05 €
Spinach (frozen)	0,1		0	4,92 €	1,23 €	43	4,00	0,00 €	0,00 €	0,00 €
Lettuce	0,6	50	30	5,60 €	1,40 €	28	6,00	1.007,40 €	83,95 €	13,99 €
Basil	0,5		0	81,25 €	20,31 €	39	4,00	0,00 €	0,00 €	0,00 €
Basil (Plant)	1	20	20	1,72 €	0,43 €	39	4,00	137,87 €	11,49 €	1,91 €
Mint (Plant	1	20	20	2,04 €	0,51 €	85	2,00	81,60 €	6,80 €	1,13 €
Rucola	0,3	30	9	23,92 €	5,98 €	35	5,00	1.076,40 €	89,70 €	14,95 €
Parsley (Plant)	1	20	20	2,06 €	0,51 €	25	7,00	287,93 €	23,99 €	4,00 €
Parsley	0,6		0	38,16 €	9,54 €	25	7,00	0,00 €	0,00 €	0,00 €
Total			101					2.696,83 €	224,74 €	36,04 €

This was calculated for six months again, and with the decreased growth time. In comparison to the first scenario, with 32 significant growth cycles completed, there is a 52% increase. Leading to a 26% increase of the yield/m² per month.

Lastly, a singular choice of plant can also give vastly different results.

Table 7.8 Aquaponic Yield- Singular Plant

Plant	yield/m² per month
Spinach (fresh)	0,29€
Spinach (frozen)	3,28€
Lettuce	37,31 €
Basil	270,83€
Basil (Plant)	11,49€
Mint (Plant	4,53€
Rucola	53,16€
Parsley (Plant)	22,85€
Parsley	254,38€

While choosing an herb may seem tempting, as they appear significantly more profitable, a mixture of multiple plants still seems to be the best choice. Monocultures are often not very sustainable as they do not require a wide range of nutrients, that can quickly become depleted as well as be more susceptible to diseases, which can be fatal in such a closed environment.

7.4.2   Comparison

To evaluate the profitability of the system it is necessary to compare it to already existing greenhouses. As the aquaponic system is not yet very common and additionally operates under partially extreme weather conditions in Finland, it was not possible to find data that is inherently comparable to all aspects. Thus, different aspects are compared to different studies to garner further insights.

The first study analyses commercial greenhouses in Alberta, Canada producing cucumber, tomato, pepper, flowers and tree seedlings. The climate is, to a certain degree comparable to Finland. Focusing on the cucumbers, the surveyed greenhouses report crop sales of 93,92 $/m² (61,89€) per year, which is a significantly lower yield than in the scenarios. But it is important to note that cucumber plants have different growth cycles and not the whole plant can be harvested. These greenhouses spend 25,17 $7/m² (16,59€) on average on hired labour to care for their systems. This amounts to 32% of their annual budget. The more automated the aquaponics system will become the less work will be required and reducing running cost even further. (open.alberta, 2020)

This next study was conducted in Arizona comparing conventional agriculture and hydroponics with salad. Its shown that hydroponic can yield approximately 10 times as much as the conventional agriculture with 41kg/m²/year and 3,9 kg/m²/year respectively. (Barbosa et al., 2015) The hydroponic yield seems to be not as efficient as the aquaponic yield of 80 kg/m²/year, by examining the different parameters used for the calculation the difference becomes apparent. While the study calculates with 24 plants/m² and a growth cycle of 30 days, as opposed to 13 plants/m² and 33 days, it also uses 144g as weight for one plant, (Barbosa et al., 2015) where for this calculation 600g were used. (Weight Equivalents: Lettuce - Hannaone.com, 2020)

If that difference is adjusted, the hydroponic system produces 172,8 kg/m²/year and is therefor twice as profitable as the aquaponics.

Smaller scale horticultural experiences report for example an average harvest of parsley of 2,44kg/m² or 1,5kg/m² of spinach. (sustainable-farming.rutgers, 2020) and one article about aquaponic system

talks about salad revenue of 14,34 €/m² per season and 13,96 €/m² per season for romaine lettuce. (Bailey and Ferrarezi, 2017)

By and large this number show, that, while the system still has room to improve and the true number of plants will only be verified when the system has been running for a few growth cycles and it will become apparent how many plants survive each time, it is already exceeding the traditional agriculture by far.

7.4.3 Break-Even Point

The break-even point is calculated by determining the point of intersection between the revenue and the cost in dependence of the produced quantity. As the number of units that can be produced is fixed by the built aquaponic elements, the calculation is focuses on the time it takes for the system to be profitable.

to calculate this, different values are needed. There are variable costs, which, opposed to fixed cost, can be directly assigned to a specific product, e.g. material cost or wages for working hours. The variable costs per piece will be referred as c_{var} , whereas the variable cost in total will be C_{var}.

The link between the variable cost is:
$C_{var} = c_{var} * quantity$.

The cost for c_{var} is in this case rather low, as it only includes the price for each seed which is estimated to be about 0,03€

The fixed costs (C_{fix}) for example, can consist of insurance, rent or heating expenses.

Table 7.9 Estimated Fixed Cost per Month

Name	Cost per month/ €	Description
Fish feed	13,8	Based on the last group's work
Energy, Heating/cooling, water	19	Source is for 85 m², sized down to 10m² (Living, 2020)
Rent	45	For a one-bedroom flat, sized down 10 times, industrial spaces will be cheaper (Living, 2020)
Working hours	225	15h/months with an hourly wage of 15€ to keep the system running and to harvest
Total	302,8	

The break-even period can be calculated as follows:

$$cost = revenue$$

$$yield\ per\ month * x = C_{var} * x + initial\ cost + C_{fix}$$

With x being the time measured in months.

To create realistic results, it needs to be acknowledged that during the first two months the greenhouse will not produce the calculated yield/m² per month. It was therefor decided to add these two months to the break-even period, so that the system has a starting phase.

Table 7.10 Break-Even Period

Scenario	Break-Even Period in Months	Break-Even Period with Starting Phase
1 Aquaponic Yield	6,35	8,35
2 Whole Year	5,99	7,99
3 Without Germination	5,02	7,02

It is no surprise that Scenario has the shortest break-even period, meaning that this would bring profit before the other scenarios. In the calculations above the initial cost consist only out of the spent budget, even though the cost for the working hours, approximately 76.000€, could also be considered part of the acquisition cost. In that case, the greenhouse would need 171 months of running system to gain the money back.

7.4.4 Depreciation

The Depreciation describes the loss of value over time. In accounting it is booked as an expense and therefore decreasing the profit. While a decreased profit does not necessarily seem desirable, it adds the benefit of decreasing the taxes that need to be paid.

In general, all expenses reduce the taxes, but with the depreciation there was not actual money paid, just the subtraction of the value in the balance of accounts.

In this calculation linear depreciation will be used.

$$Amount\ of\ depreciation = \frac{acquisition\ cost}{average\ useful\ life}$$

$$Depreciation\ rate = \frac{100\%}{average\ useful\ life}$$

To find the correct average useful life to calculate the amount depreciation a depreciation rate finder was used (Depreciation rate finder, 2020).

Table 7.11 Linear Depreciation

Name	Cost	Date of Purchase	Life Exp.	Residual Value	Depreciation year	Depreciation Month
Greenhouse	830,96 €	18.05.2020	10	100,00 €	73,10 €	6,09 €
Aquaponics	781,94 €	18.05.2020	5	100,00 €	136,39 €	11,37 €
Control System	916,12 €	18.05.2020	5	0,00 €	183,22 €	15,27 €
	2.529,01 €		6,67	200,00 €	392,71 €	32,73 €

7.5　Recommendation

For the next group the recommendation is to start as early as possible with the planned purchases, with specific amounts and concrete products. I will be hard to know what to buy, but even if something changes, it is very helpful not to be surprised by any expenses.

To avoid further surprises it is advised to get into contact with the Novia accountant to check in detail how much money there is, to have a reliable base to plan on.

For the greenhouse scenarios it would be good to have more specific running costs, for example from energy loggers or a better estimation of the workforce needed to keep the system running.

7.6　Conclusion

To summarise the two aspects of the finance part are the documentation and keeping track of the budget and the greenhouse scenarios.

The budget and purchase files are rather comprehensive and can be used as is by the next group as well, to ease the start into the accounting part of the project.

As for the greenhouse scenarios, there are still many more combinations that can be tested in excel and also possibly in real life, to try out how accurate these calculations are.

8 General Recommendations

We managed to build an aquaponics system adapted to the greenhouse, equipped with a control system placed in the switch cabinets. However, our work requires several improvements. The next aquaponics team can use our knowledge and work to improve project results. For this purpose, we have prepared recommendations that can be found in each chapter. All the necessary documentation can be found in the Handoff Package.

It is proposed to test the running system and cycle it before introducing living organisms. The next priority is to improve the modularity and introduce better light system. When it comes to the greenhouse, insulation is needed as well as change in coverage. The reinforced sail should be changed to plexiglass. It would be profitable to use the solar panel as an energy source together with a purchase of energy loggers. To improve the controlling system all the purchased sensors should be tested and controlled by the maintenance website. Additionally, the sensors we could not buy because of budget limitation may be considered.

In addition to technical matters, we also have advice on teamwork. The aquaponics project, due to its size, requires division into task groups, which may hinder effective communication. Each group, not just the one responsible for the task, should be consulted in order to avoid misunderstandings. A good way to check the progress of teamwork is to establish and check the milestones of the task force.

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9.2   Tables

9.3   Figures

10 Appendix

10.1 Project Management

10.1.1 Earned Value Analysis

The earned value analysis is a tool to keep track of the progress made in a project. It includes the actual cost, the planned value and the earned value.

For the actual cost we included the purchases we made as well as the working hours. On average each person worked 355 hours during the EPS and the weekly average of the group is 196 hours.
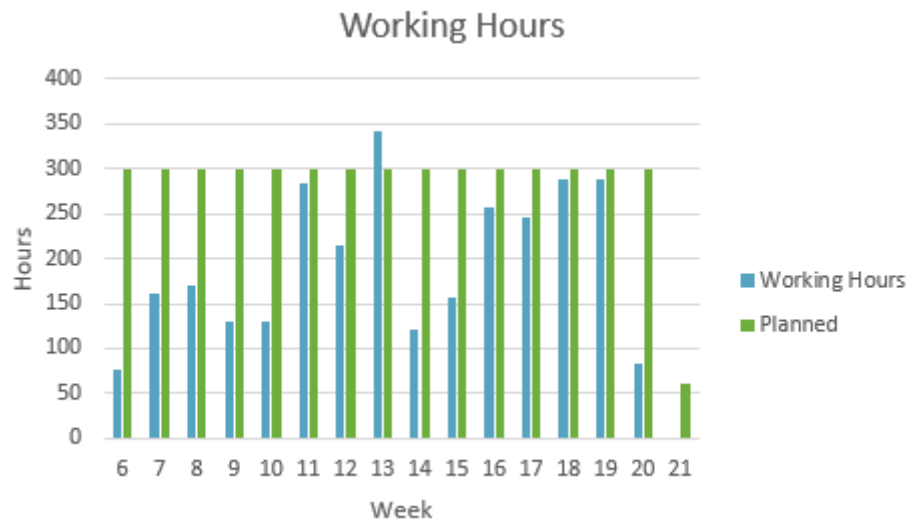
Figure 10.1 Working Hours per Week

The planned working hours are based on the 37,5 hours per week of the EPS project multiplied with eight, as we are eight team members. Because the project ends on a Monday, week 21 only has one day of work planned and is therefore the shortest week.

In the figure above it is clearly noticeable that our working hours increased when a report was due and that we worked significantly less in the beginning than compared to the last four weeks. This is partly caused by the report deadline, but mostly because we were allowed to start building in the university in week 17 and have been busy with practical work.

Based on internal discussion we decided to use an hourly wage of 25€, as this is a realistic amount for engineers.
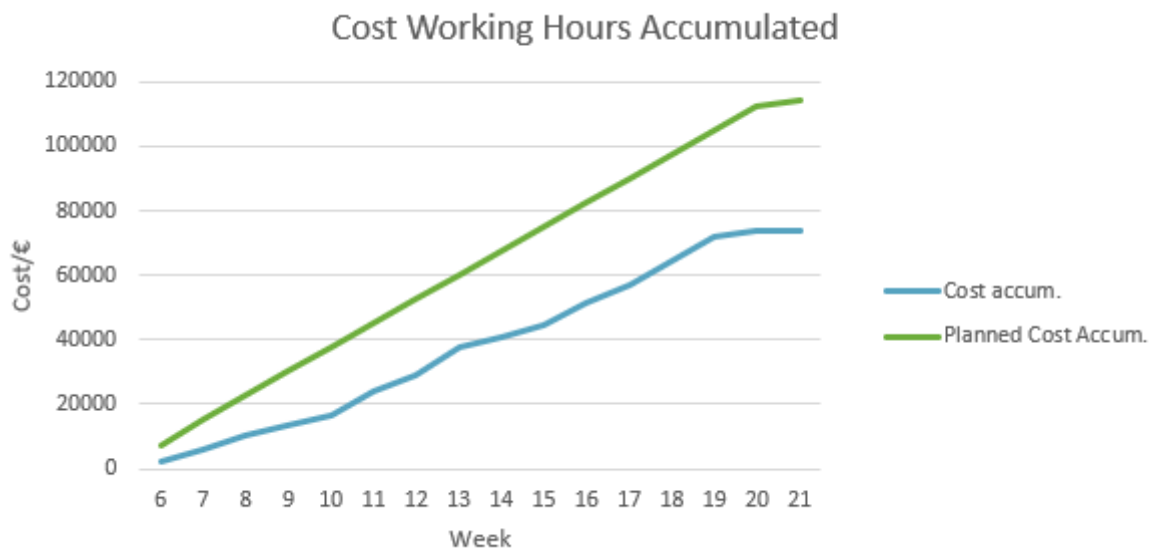
Figure 10.2 Accumulated Cost for Working Hours

The figure above shows the cost of our work based on the time we invested. The total cost for the planned working hours would be 114.000€ and is now at 73.756,5€, which is still very expensive compared to our actual budget of 2586€.

The planned and earned value are based on the percentage of work already completed for the project. To calculate these percentages as accurately as possible, we took the time it took to finish the task into consideration and then weighted it with a subjective factor from zero to one. From these weighted days we calculated the percentage of each task.

Table 10.1 Example for EV Calculations

Name	weight	est. Days	weighted	est. Perc	days	weighed	percenta
First meeting with coordinators, team brainstorm	0,2	1	0,2	0,05	1	0,2	0,05
Reading final report and handoff package	0,5	2	1	0,27	1	0,5	0,13
Defining stakeholders, mission and vision	0,8	1	0,8	0,21	1	0,8	0,20

To get the monetary values, these percentages were sorted by week and then multiplied by our budget of 2586€, as shown in the figure below.

Table 10.2 Earned value by week

week	planned value	Planned Value acc.	Monetary Value	Earned value	Earned Value acc.	Monetary Value
6	0,318809777	0,318809777	8,25 €	0,178207739	0,178207739	4,61 €
7	0,531349628	0,850159405	21,99 €	0,381873727	0,560081466	14,49 €
8	0	0,850159405	21,99 €	0	0,560081466	14,49 €
9	22,74176408	23,59192349	610,17 €	6,00814664	6,568228106	169,88 €
10	0,850159405	24,44208289	632,16 €	21,84317719	28,4114053	734,82 €
11	5,286928799	29,72901169	768,90 €	6,288187373	34,69959267	897,46 €
12	11,18490967	40,91392136	1.058,18 €	0,356415479	35,05600815	906,67 €
13	2,178533475	43,09245484	1.114,53 €	14,2311609	49,28716904	1.274,74 €
14	5,021253985	48,11370882	1.244,39 €	2,036659878	51,32382892	1.327,42 €
15	13,54941552	61,66312434	1.594,83 €	16,26782077	67,59164969	1.748,16 €
16	0	61,66312434	1.594,83 €	0	67,59164969	1.748,16 €
17	14,55897981	76,22210414	1.971,38 €	6,568228106	74,1598778	1.918,04 €
18	0	76,22210414	1.971,38 €	0	74,1598778	1.918,04 €
19	2,391073326	78,61317747	2.033,22 €	3,309572301	77,4694501	2.003,64 €
20	12,08820404	90,70138151	2.345,86 €	17,28615071	94,75560081	2.450,72 €
21	9,298618491	100	2.586,36 €	5,244399185	100	2.586,36 €
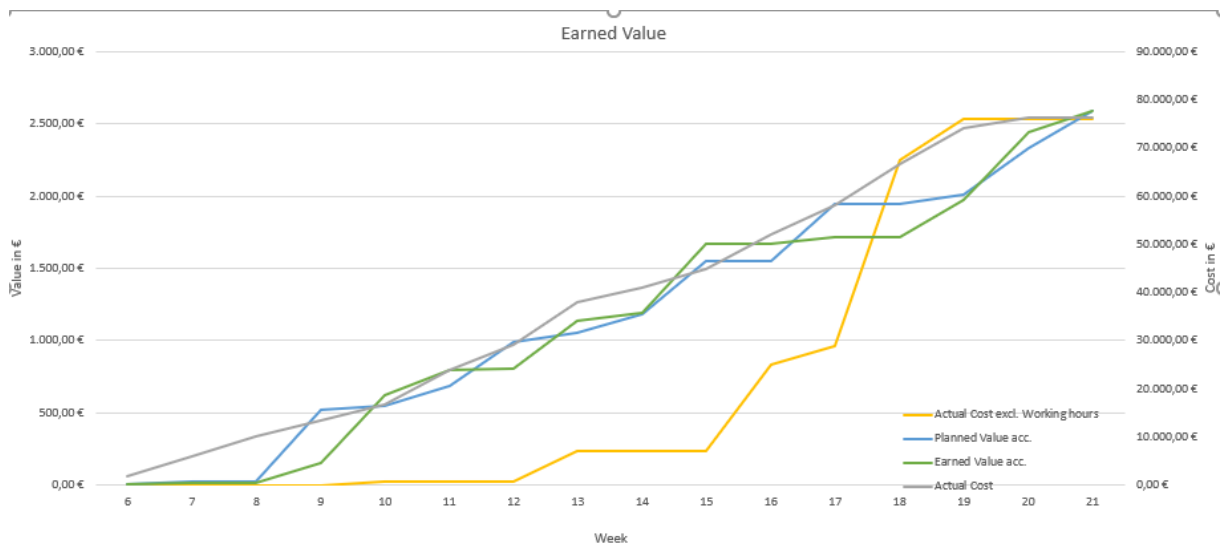
Figure 10.3 Earned Value Analysis

As mentioned before, the cost for the working hours are significantly higher than the budget we had. To make our purchases still visible in the earned value analysis, we added a graph that does not include the working hours.

In this figure the actual cost excluding working hours, the planned value and the earned value are corresponding to the primary vertical axes, while the actual cost is scaled by the secondary.

Certain events are clearly recognisable in this analysis. For example, in week 12, when the midterm report should have been, there were no tasks completed and the earned value fell under the planned.

Another milestone was when we finished planning the greenhouse and bought material, which is visible in the actual cost from week 17 and 18, and after which we made great progress in our practical work, even surpassing the planned value.

10.1.2 Change Management Log

| OWNER NAME	ESTIMATED COMPLETION DATE	ACTUAL COMPLETION DATE	DESCRIPTION OF REQUESTED CHANGE	STEPS REQUIRED	IMPACT SUMMARY	CHANGE REQUESTED BY	DATE OF REQUEST	CHANGE TYPE	CURRENT STATUS	PRIORITY
Arthur	06.03.2020	06.03.2020	WBS should be changed	redesign the layout of WBS	High impact	Rayko and Mikael	21.02.2020	change in structure	CLOSED	HIGH
All	20.05.2020	IN PROGRESS	Build for the future	scope has to be changed	High impact	Rayko and Mikael	21.02.2020	Chhange in mission	IN-PROGRESS	HIGH
Stefan	06.03.2020	06.03.2020	adjust the controlling build-up	visualize the structure	Medium impact	Rayko and Mikael	28.02.2020	change in structure	CLOSED	MEDIUM
Sascha	16.03.2020	16.03.2020	change team contract	update to the situation (corona)	Medium impact	All	13.03.2020	change in structure	CLOSED	MEDIUM
Stefan	17.03.2020	17.03.2020	Test of pH sensor	No access to the chemistry laboratory and lockdown due to corona crisis to calibrate the sensor	Medium impact	Stefan, Karina, Filippo	16.03.2020	change in control system	CLOSED	LOW
Arthur	27.03.2020	29-03-2020	change layout	new template for doc	Medium impact	Arthur	02.03.2020	change in structure	CLOSED	MEDIUM
Natalia	15.05.2020	15.05.2020	the new batch of plants	plant a new batch of seeds under the seeding tray cover	Medium impact	Natalia	06.04.2020	change in aquaponic system	CLOSED	MEDIUM
Karina	01.05.2020	01.05.2020	change in budget	the actual budget is 2586 instaed of 3024	High impact	Rayko and Mikael	01.04.2020	change in project goals	CLOSED	HIGH
Stefan	23.04.2020	23.04.2020	No access to data over Touchdisplay	change in budget	Medium impact	All	23.04.2020	change in control system	CLOSED	HIGH
Stefan	23.04.2020	23.04.2020	Stroke most expensive sensors	change in budget	Medium impact	All	23.04.2020	change in control system	CLOSED	HIGH
Maxime	5-05-2020	5-05-2020	Plexiglass coverage has to be changed for the foil due to budget cuts	New coverage material was ordered	Medium impact	All	25-04-2020	change in greenhouse construction	CLOSED	HIGH
Stefan	23.04.2020	23.04.2020	budget distribution change	part of the controlling unit budget was distributed to other units	High impact	All	23.04.2020	change in budget allocation	CLOSED	HIGH
Stefan	18.05.2020	18.05.2020	No remote access to maintenance website	no network cable available, test of Wi-Fi connection	High impact	ICT Departement	27.04.2020	change in control system	IN-PROGRESS	MEDIUM
Stefan	08.05.2020	08.05.2020	Change wood of switch cabinets	Used OSB insted of plywood because of budget change	Low impact	Stefan, Karina, Filippo	29.04.2020	change in control system	CLOSED	MEDIUM
Sascha	01.05.2020	01.05.2020	Lack of energy loggers	Energy loggers could not be bought because of budget limitations	Low impact	Sascha, Felix	01.05.2020	change in energy part	CLOSED	LOW
Felix	10.05.2020	10.05.2020	changes in piping system	plastic pipes with printed joints replaced flexible pipes and valves	Medium impact	Felix, Arthur and Sascha	07.05.2020	change in aquaponic system	CLOSED	LOW
Natalia	18.05.2020	18.05.2020	remote work	writing the final report and preparing documentation	Low impact	Natalia	01.04.2020	change in team work	CLOSED	MEDIUM
Arthur	14.05.2020	14.05.2020	improving the operation of the water storage tanks	water storage tanks were moved from under the fish tank to the space behind grow towers	Medium impact	Felix, Arthur and Sascha	12.05.2020	change in aquaponic system	IN-PROGRESS	HIGH
All	14.05.2020	14.05.2020	change in building priority	focusing on building the greenhouse together with aquaponic system more than control system improvement	High impact	All	20.04.2020	change in project goals	IN-PROGRESS	HIGH
Maxime	12.05.2020	12.05.2020	greenhouse framwork connection	connecting beams with brackets instead of 3D printed parts	Medium impact	All	04.05.2020	change in greenhouse construction	CLOSED	MEDIUM
Stefan	11.05.2020	18.05.2020	Delivery / order problems	change control system / decrease system	High impact	Stefan	30.04.2020	change in control system	IN-PROGRESS	HIGH

10.2 General Planning

#	Status	Consulted 1	Consulted 2	Checked by	Finished	Person responsible	Phase	Description	Est. Start	Est. End	Est. Days	Act. Start	Act. End	Act. Days	Schedule
1	Finished	-	-	-	✓	All	Orientation	First meeting with coordinators, team brainstorm	07.02.2020	07.02.2020	1	07.02.2020	07.02.2020	1	0
2	Finished	-	-	-	✓	All	Orientation	Reading final report and handoff package	08.02.2020	09.02.2020	2	09.02.2020	09.02.2020	1	-1
3	Finished	-	-	-	✓	All	Orientation	Defining stakeholders, mission and vision	10.02.2020	10.02.2020	1	10.02.2020	10.02.2020	1	-1
4	Finished	-	-	-	✓	All	Orientation	Internal meeting, teamcontract applying 2 PM tasks in powerpoint	11.02.2020	12.02.2020	2	12.02.2020	12.02.2020	1	-2
5	Finished	-	-	-	✓	All	Orientation	Meeting with coordinators	14.02.2020	14.02.2020	1	14.02.2020	14.02.2020	1	-2
6	Finished	All	-	-	✓	All	Definition	**Project Management**	10.02.2020	23.03.2020	43			0	-45
7	Finished	All	-	Sascha	✓	Natalia	Definition	Team Contract	10.02.2020	27.02.2020	18	10.02.2020	27.02.2020	18	-45
8	Finished	All	Natalia	Sascha	✓	All	Definition	WBS General planning	10.02.2020	11.03.2020	31	10.02.2020	11.03.2020	31	-45
9	Finished	-	Sascha	Natalia	✓	All	Definition	WBS Detailed planning	04.03.2020	08.03.2020	5	04.03.2020	10.03.2020	7	-43
10	Finished	-	-	-	✓	All	Definition	Meeting with coordinators	06.03.2020	06.03.2020	1	06.03.2020	06.03.2020	1	-43
11	Finished	Sascha	-	-	✓	Sascha	Definition	Quality management	13.03.2020	18.03.2020	6	18.03.2020	18.03.2020	1	-48
12	Finished	All	-	-	✓	All	Definition	Risk management	09.03.2020	18.03.2020	10	18.03.2020	18.03.2020	1	-57
13	Finished	All	-	-	✓	All	Definition	**Research**	10.02.2020	29.02.2020	20			0	-77
14	Finished	Felix	-	-	✓	Natalia	Definition	Aquaponic system	10.02.2020	29.02.2020	20	10.02.2020	08.03.2020	28	-69
15	Finished	Filippo	Karina	-	✓	Stefan	Definition	Control system	10.02.2020	29.02.2020	20	10.02.2020	08.03.2020	28	-61
16	Finished	Stefan	Natalia	-	✓	Arthur	Definition	Marketing and PR	10.02.2020	29.02.2020	20	10.02.2020	29.02.2020	20	-61
17	Finished	Sascha	Maxime	-	✓	Felix	Definition	Energy Management system	10.02.2020	29.02.2020	20	10.02.2020	29.02.2020	20	-61
18	Finished	Sascha	-	-	✓	Karina	Definition	Cost analysis	10.02.2020	29.02.2020	20	10.02.2020	08.03.2020	28	-53
19	Finished	Arthur	Felix	Filippo	✓	Maxime	Definition	Greenhouse	10.02.2020	29.02.2020	20	10.02.2020	06.03.2020	26	-47
20	Finished	Karina	-	-	✓	Sascha	Definition	Project Management	10.02.2020	29.02.2020	20	10.02.2020	08.03.2020	28	-39
21	Finished	-	-	-	✓	All	Definition	Meeting with coordinators	12.03.2020	12.03.2020	1	12.03.2020	12.03.2020	1	-39
22	Finished	All	-	-	✓	All	Analyse	**Mid-term**	04.03.2020	23.03.2020	20			0	-59
23	Finished	All	-	-	✓	All	Analyse	Writing mid-term report	04.03.2020	18.03.2020	15	04.03.2020	28.03.2020	25	-49
24	Finished	Sascha	-	-	✓	All	Analyse	Making mid-term presentation	16.03.2020	20.03.2020	5	16.03.2020	29.03.2020	14	-40
25	Finished	All	-	-	✓	All	Analyse	Presenting mid-term presentation	23.03.2020	23.03.2020	1	23.03.2020	30.03.2020	8	-33
26	Finished	Natalia	-	-	✓	Sascha	Analyse	Delivering Project Management documents	04.03.2020	20.03.2020	17	04.03.2020	28.03.2020	25	-25
27	Finished	-	-	-	✓		Design	**Design**	17.02.2020	31.03.2020	44			0	-69
28	Finished	Arthur	Stefan	Felix	✓	Maxime	Design	Greenhouse design	17.02.2020	06.04.2020	50	17.02.2020	09.04.2020	53	-66
29	Finished	Felix	Maxime	Arthur	✓	Natalia	Design	Aquaponic system redesign	29.02.2020	12.03.2020	13	29.02.2020	12.03.2020	13	-66
30	Finished	Stefan	Natalia	-	✓	Arthur	Design	Digital advertisement	10.02.2020	20.05.2020	101	10.02.2020	10.04.2020	99	-68
31	Open	Filippo	Karina	-		Arthur	Design	Analog advertisemeny	11.02.2020	21.05.2020	101	11.02.2020	18.05.2020	98	-71
32	Finished	Sascha	Karina	-	✓	Stefan	Design	Hardware redesign	05.03.2020	26.04.2020	53	05.03.2020	05.05.2020	62	-57
33	Finished	Sascha	-	-	✓	Karina	Design	Creating BCWS, ACWP and PCTS	05.03.2020	28.03.2020	24	20.03.2020	06.04.2020	18	-63
34	Finished	-	-	-	✓	All	Development	**DIY**	01.03.2020	30.04.2020	61			0	-124
35	Finished	Sascha	Maxime	-	✓	Felix	Development	Calculating thermal energy usage	06.04.2020	09.04.2020	4	06.04.2020	11.04.2020	6	-122
36	Finished	Natalia	Stefan	-	✓	Arthur	Development	Establishing social media	05.03.2020	31.03.2020	27	05.03.2020	10.04.2020	37	-112
37	Finished	Filippo	Natalia	-	✓	Stefan	Development	Implementing sensors in the aquaponics	06.04.2020	15.05.2020	40	14.05.2020	15.05.2020	2	-150
38	Finished	Filippo	Karina	-	✓	Stefan	Development	Error handling in the control system	01.04.2020	18.05.2020	48	01.04.2020	20.04.2020	20	-178
39	Finished	Sascha	-	-	✓	Karina	Development	Long term cost analysis	13.04.2020	20.04.2020	8	17.04.2020	11.05.2020	25	-161
40	Finished	Felix	Maxime	-	✓	Natalia	Finishing	Aquaponics upscaling	23.03.2020	23.04.2020	32	21.04.2020	15.05.2020	25	-168
41	Finished	Sascha	Maxime	-	✓	Felix	Development	Energy supply	23.03.2020	06.04.2020	15	20.04.2020	20.04.2020	1	-182
42	Finished	All	-	-	✓	Maxime	Development	Greenhouse building	04.05.2020	18.05.2020	15	28.04.2020	10.05.2020	13	-184
43	Finished	All	-	-	✓	Felix	Development	Preparing manual for operating the system	16.03.2020	20.03.2020	5	10.03.2020	10.03.2020	1	-188
44	Finished	Stefan	-	-	✓	Arthur	Finishing	Advertisement and future sponsors	14.03.2020	31.03.2020	18	14.03.2020	15.05.2020	63	-143
45	Finished	All	-	-	✓	All	Finishing	**Final report**	01.05.2020	20.05.2020	20			0	-163
46	Check	All	-	-		All	Finishing	Tests and data analysis	01.05.2020	10.05.2020	10	14.05.2020	15.05.2020	2	-171
47	Check	All	-	-		All	Finishing	Preparing final report	01.05.2020	20.05.2020	20	28.04.2020	15.05.2020	18	-173
48	Check	All	-	-		All	Finishing	Final presentation	20.05.2020	20.05.2020	1	18.05.2020	18.05.2020	1	-173

10.3 Individual time-follow-up

Week	Arthur	Felix	Filippo	Karina	Maxim	Natalia	Sascha	Stefan	Total
Week 6	9,5	6,5	10,5	8	8	9,5	9,5	16	77,5
Week 7	25	19,5	20	15	21,5	16,5	19,5	23,5	160,5
Week 8	24,91	18,5	18	18,5	33	20	17	19,75	169,66
Week 9	9,5	14,5	11	16,5	18	20,5	19	20	129
Week 10	12	11,5	18	15,5	9	24	18,5	22,5	131
Week 11	36,5	26,25	41,5	37	33,5	42,5	26	41	284,25
Week 12	31	31	26	28	22	29,5	27	20	214,5
Week 13	55,5	50,5	35,5	40,75	28	39	42,5	50,5	342,25
Week 14	12,5	10,5	24	14,5	13	9	11,5	27	122
Week 15	26	10	18,5	21,75	10,5	28,5	18,5	24,5	158,25
Week 16	42	26,5	31,75	22,5	31,5	22,5	31,25	48,75	256,75
Week 17	35,5	35,5	26	26	30,5	20,3	29,5	42	245,3
Week 18	58,5	40	33,75	35	29,15	18	30,65	45,5	290,55
Week 19	50,5	44	42,75	47	38	19,5	43,25	55,75	340,75
Week 20	50,5	34,5	28,5	46,5	29	36	28	49	302
Week 21	4	4	4	4	4	4	4	4	32

Figure 10.4 Weekly hours
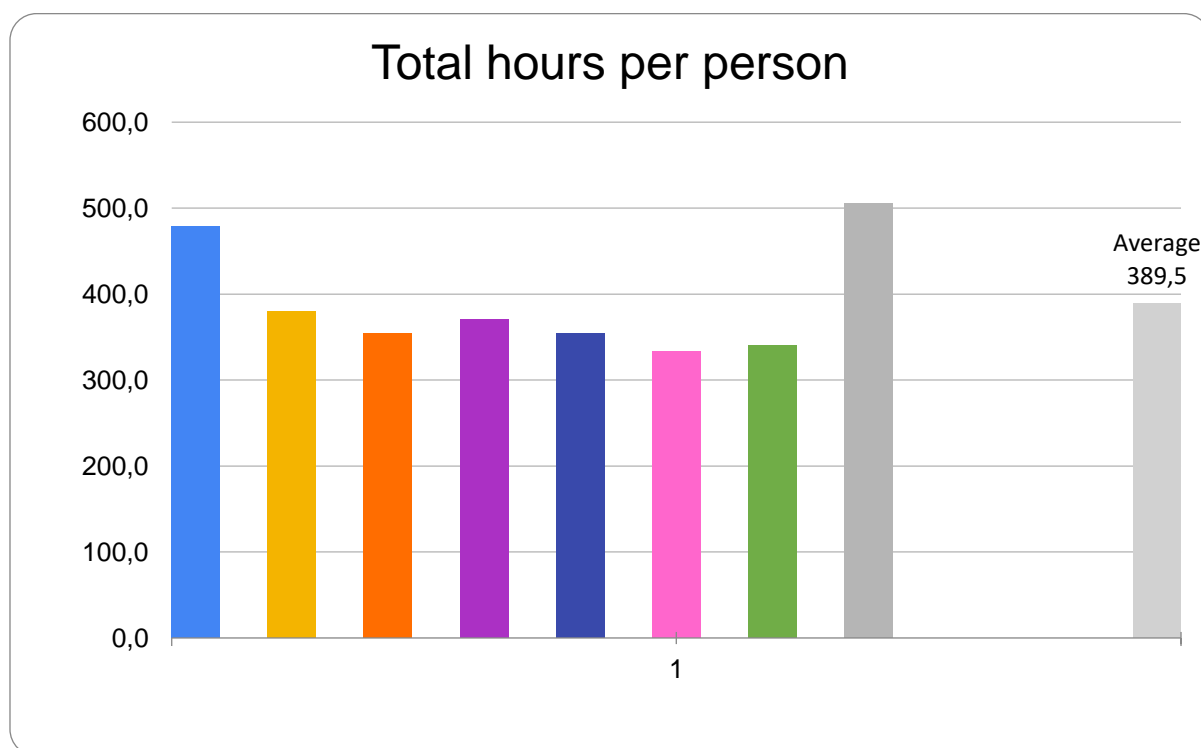
Arthur Verburgh	AR	Felix van de Looverbosch	FVdL	Filippo Lorenzoni	FL	Karina Dwenger	KD	Maxime Bourras	MB
Total hours	479,4	Total hours	379,3	Total hours	354,0	Total hours	370,0	Total hours	354,7
Average	34,2	Average	27,1	Average	25,3	Average	26,4	Average	25,3

Natalia Grabarczyk	NG	Sascha Diels	SD	Stefan Stiegler	SS				
Total hours	332,8	Total hours	340,4	Total hours	505,8	Total hours		Total hours	
Average	23,8	Average	24,3	Average	36,1				

Total Average			389,5
First Calendar/Project Week			6
Last Calendar/Project Week			20
This Calendar Week			20
Total Project Weeks			14
This Project Week			14
Hours per Week			37,5
Working hours till end of this week			525
Total Working Hours			525

Figure 10.5 Overall Hours Plan