



Hydroponic system

Design and verification of a solar powered automatic rooftop hydroponic system with real time individual measuring of potassium and calcium.

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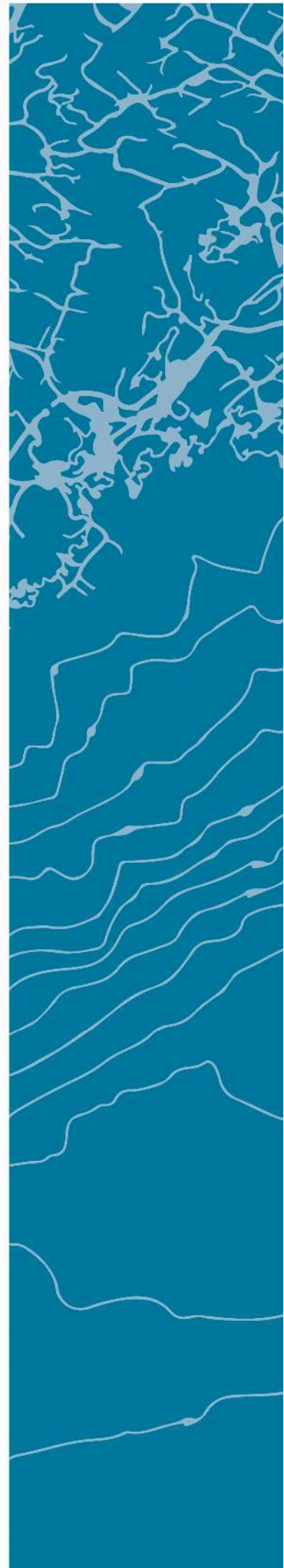
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# Abstract

This report covers development and implementation of two hydroponic systems. One at a lab inside the University of Agder, and one at the roof on the J-Building at the University. This report tries to answer the following main research question: How can an automated system for control of nutrient concentration and pH in a solar powered hydroponic system be developed, implemented and verified?

The focus of the report has been to create a fully functional system for the lab, generating data for electronic conductivity for measuring a specter of nutrients, pH value, individual nutrients and temperature for comparison. The work has been divided into the two systems, where the rooftop system is a much bigger and complex system than the one built in the lab.

The approach has been to measure the parameters mentioned above while growing several crops inside the lab through the period. Knowledge has also been gathered through reviewing already published articles along with conferencing with the supervisors. The results have shown two fully functional hydroponic system, where the roof top system is powered by solar power. The results have also provided more data which can be used regards optimization of lettuce and maybe other plants.

# Preface

The report is written by Jarle Espeland, and is the master's thesis of the Renewable Energy master program. The master's thesis has the subject code ENE500-G 19V. The choice of task is: Design and verification of a solar powered automatic rooftop hydroponic system with real time individual measuring of potassium and calcium. The writers background regards education is certificate of apprenticeship in service electronics, bachelor degree in mechatronics, and master in industrial economics and technical management(Indøk). The motivation for the task was to continue the research done in the fall 2018 in subject ENE503 Energy Research Project, and to learn more in depth how a hydroponic system could be optimized. I would like to use this opportunity to thank my supervisors Helge Liltved, Jonas Høgli Major and Johan Olav Brakestad for all help along the way. I would also thank Thomas Larsen for help with both the Labview code and with assembling the rooftop hydroponic system.

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# Notation

$c$	Concentration of ion to be measured
$C_0$	Detection limit
$E$	Measured potential ( $mV$ )
$E_0$	Reference potential ( $mV$ )
$F$	Faraday constant ( $96485 \text{ C mol}^{-1}$ )
$n$	Valence of the ion
$R$	Universal gas constant ( $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ )
$T$	Temperature in $K$ (Kelvin), with $T (K) = 273.15 + t \text{ } ^\circ\text{C}$ where $t$ is the temperature of the measured solution in $^\circ\text{C}$ .

# Abbreviations

AI	Analog input
AO	Analog output
cF	Conductivity Factor
cm	Centimeter
DIO	Digital input and output
EC	Electronic conductivity
FIA	Flow injection analysis
GB	Gigabyte
IC	Integrated Circuits
ICE	Ion-selective electrodes
IOT	Internet of things
IP	Internet Protocol
LCA	Life Cycle Assessment
mS/cm	Millisiemens per centimeter
OS	Operating system
PPM	Parts Per Million
PV	Photovoltaics
PVC	Polyvinyl chloride
REST	Representational State Transfer
RFID	Radio-frequency identification
SBC	Single board computer
STC	Standard Test Conditions
TCP	Transmission Control Protocol
TDS	Total Dissolved Solids
UART	Universal Asynchronous Receiver/Transmitter
UiA	University of Agder
$\mu S/cm$	Microsiemens per centimeter



# Chapter 1

## Introduction

### 1.1 Background

This report is the Master Thesis of the Renewable Energy master program. The subject has the subject code ENE500-G 19V, and is written by Jarle Espeland. The choice of task is: Design and verification of a solar powered automatic rooftop hydroponic system with real time individual measuring of potassium and calcium. The background for the choice of task is continuing the research from ENE503 Energy Research Project which is also part of the renewable energy master program, and to learn more in depth how a hydroponic system could be optimized. The Energy Research Project was meant as a start for the Master Thesis.

Through the energy research project there was made a basic code in Labview, working together with the myRio micro controller for controlling probes for measuring, and relays for activating pumps [15]. The system was measuring pH value, electronic conductivity(EC) as a sum parameter for nutrient concentration and temperature. The system was also measuring potassium as one individual nutrient. This system was only tested with the electronics on breadboards, without plants, and with a small volume box containing fluid. The master thesis is in the first part focusing on implementing the system at the lab inside the university. During spring, the system will also be implemented and tested on the rooftop of the J-building at the University as the second part of the thesis. The rooftop system will be powered by solar power. The system will also be assembled with enclosure boxes for the electronics. In the lab the Labview code will be improved, and the system will be tested with plants. This will generate real time results for pH, EC and temperature from the crops production. Potassium will also be measured, and calcium will be added as one more individual nutrient that will be measured and studied. The target is to establish a fully automated hydroponic system with pH- and EC control, and monitoring of potassium and calcium, and analyse if there are changes in the values over time.

The term hydroponics is a fairly recent term used for growing plants without soil, but the method is not new[16, page. 1]. The method dates back to when the Theophrastus (372-287) experimented with crop nutrition, but the earliest recorded scientific approach was in 1600 when Jan van Helmont from Belgium showed that plants obtain substances from water. Further research until today have shown that plants could be grown in an inert medium like rock wool moistened with water containing minerals. Research has also led to knowledge about what nutrients that are most and least important, and also how they are obtained[15, 17]. With newer technology in plastic materials, computers and electronics, there have been more focus and research on automatic hydroponic systems. This may be due to reduce operational cost and to contribute to

food production, and to reduce ( $CO_2$ ) emission. Research regards to hydroponic systems used for growing food in space, may also have increased the interest. Even with increased interest and use there is still a need for further research, especially with focus on the individual nutrients. Without proper measuring, imbalance in the individual nutrients in the nutrient composition can only be seen by symptoms of nutrient deficiency or excess in plants. This is not an accurate analysis method and cannot provide quantitative information about the necessary nutrient control. Correct composition of the nutrient solution added to the system is crucial for optimum growth and healthy plants. With more research on individual nutrients the content of this mixture could be optimized.

To optimize growth and the content of nutrition are important aspects of hydroponic research[18, page. 1-2]. Hydroponic crops could also contribute to the common good in a bigger aspect by reusing heat, water and nutrition. Most people are aware of that the climate is changing, and in several places in the world people are starving, and others are struggling because they are undernourished by eating improper food. In other places people struggle with obese. Due to this it is important to secure food production, improve nutrition content, and to end world hunger. To satisfy the future increase in population and the need for change in diet, the food production needs to increase by over 60 percent in the next decades[18, page. 1].

To grow crops inside buildings instead of outside gives the possibility to grow food in healthy environments with stable temperature, and minimal interference of bugs and animals[19]. Growing crops inside makes it also easier to avoid pest and deceases. The focus on reducing  $CO_2$  emission can be an important matter to reduce pollution. More than 68-70 percent of the worlds population lives in cities, and by growing crops outside on for example rooftops or down in a basement, the transport cost could be lowered [19, 20]. Another advantage is that the plants will absorb  $CO_2$  from the air which may improve the air quality. Also local florists and small food shops could benefit from hydroponic crops. Having the production of groceries in the same building may save transport cost, and because more than half of the earths population lives in cities, this can also greatly reduce the need for packing materials used for transport. When cities today consume more than two-third of the worlds energy, solar powered hydroponic crops could both benefit to reduce energy demand in food production and reduce wast. Use of rainwater with recycling system for nutrient solution could also benefit the environment by lowering the total amount of water needed for crop to grow.

## 1.2 Problem definition and limitation

The report will focus on lettuce production, and implementing the system in a lab inside the university, and at the rooftop of the J-building as shown in figure 1.1. With implementing and testing a system like this there might be revealed some errors and challenges along the way. Due to this, the report will also focus on improving the Labview code for controlling and regulating the nutrients in the hydroponic systems, and it will describe the full code made in Labview for controlling myRio, sensors, relays and pumps. One of the biggest challenges with the outdoor system is variable weather conditions. The code will also be tested in the lab with stable temperature and humidity. Regard the results the comparison of potassium, calcium and EC will also be important. The outdoor system will be powered with solar power, and simulations for the solar power system will also be carried out. Connection sheets, all relevant drawings, simulation and calculations of the solar power system will be covered. A theoretical study looking into how a hydroponic system can contribute to benefit the local community will also be included. The report will not include a full Life Cycle Assessment(LCA) analysis. This report will also not cover regulation of water inlet and control

of light exposure. The part of the system in the lab regard lights are controlled by simple time relays with sequences with off time for the light between midnight and 4AM. The rooftop system benefit from natural light, and the frame of the rooftop hydroponic system is shown in figure 1.1. Refill of water is done manually.



Figure 1.1: Frame for hydroponic rooftop system

Browsing the literature, there is not done much research on measuring individual nutrients. There is an article that is focusing on phosphate measuring, and there is also an article which focus on the different ion-selective membranes measuring nutrients in a lab based environment [21, 22]. There are also a similar article which has focus on tomato production [23]. These and other articles will be reviewed and explained more in chapter 2.7.

The title chosen for this report is: *Design and verification of a solar powered automatic rooftop hydroponic system with real time individual measuring of potassium and calcium.*, and the report will try to answer the following question: How can an automated system for control of nutrient concentration and pH in a solar powered hydroponic system be developed, implemented and verified? The report will also try to answer the sub-questions:

- How can an operational hydroponic control and monitoring system be designed and implemented?
- How can a functional solutions for automatization and off-grid operation of an outdoor hydroponic system be designed and implemented?
- What is the benefit of measuring individual nutrients, and how can this contribute to optimization of a hydroponic system?
- Which improvement, beyond current practice, can be implemented in the future?

### 1.3 Method

The literature study showed that there are limited new research regard monitoring and control of hydroponic systems, but regard the biology part there was plenty. Research articles, books and other theory with focus on real time monitoring of individually nutrients were hard to find. Still, there are some available. Based on this, the method chosen for the task is empirical study using mostly quantitative research method to collect some of the results, like values measured by probes. The thesis also uses qualitative method to present the solutions for the Labview code and the connection sheets for the electronics with pictures and text. All these data is generated by the researcher, and the main target is to use this information to answer the research question listed in chapter 3.1. The thesis is interdisciplinary research and therefor consulting the supervisors have also been done to get advice and expertise along the way. The thesis also uses qualitative method to present the solutions for the Labview code and the connection sheets for the electronics with pictures and text.

### 1.4 Report structure

The report is structured in six chapters starting with the introduction. The introduction contains short about the background and what is briefly done in the research project. The introduction also contains the problem definition, short about the method used, and how the report is structured. The theory chapter is the theoretical part of the report. It is here theory from the literature have been listed to support and build up a foundation the research can focusing on. The theory chapter starts with literature regard plants and hydroponic, and then moving the focus to the more technical part of the system. Here theory relevant from the literature is described. The chapter also includes a brief review of some of the state of the art technology relevant for use in the task. The third chapter describes the research questions and how they were decided. The method chapter, which is the fourth chapter, includes some theory regard research methods, data collection, reliability and validity. The chapter also describes the approach for building, developing and implementing the system, and how the Labview code has been created and tested. This also include how the results have been generated. The fifth chapter describes the complete system and the results that have been generated. Here the results are also discussed. In the two last chapters, a conclusion is made and the recommendations based on conclusion and discussion are listed.

# Chapter 2

## Theory

### 2.1 History

Hydroponic is a modern term of growing plants, vegetables, berries etc. without soil where the plants get the nutrients from the water. The word "Hydroponics" is Greek [24, page. 12]. "Hydro" means water, and "Ponos" means labor. In the literature there are mentioned several examples of cultures that have been using the method from before B.C. [16, page. 1]. The floating garden of Aztecs of Mexico, the hanging garden of Babylon, and also the Chinese used a form of hydroponic method. One of the oldest culture that is recorded growing plants in water is the Egyptians. There are found hieroglyphs several hundred years B.C. documenting this. Also the Greek philosopher Theophrastus (372-287) B.C. did experiments growing crops in water containing nutrients. In the 1600 Belgian Jan Van Helmont demonstrated that plants obtained substances from water. In the following years there were a lot of research on hydroponics, and the largest step was made with the development of plastics [16, page. 2]. The benefit with plastic is that it replaced the concrete beds and tanks that were used and made the system easier to construct. With also improved pumps, timer clocks, plumbing made from plastics, valves and more, the system can be easier automated.

Hydroponic systems can be used in most climates, and it is already used around the world for growing both flowers and vegetables [16, page. 3]. In the United States, Canada and Mexico there are several production greenhouses that are over 20 *ha*. The largest Mexican hydroponic greenhouse operates on 80 *ha* and is employing 1000 people. This is named Bionatur Invernaderos Biologicos de Mexico, and has both measuring for pH and EC value. It also has a system for recycling nutrient [16, page. 71-73]. Gary W. Hickman claims in a publication that the total world hydroponic vegetable production is about 35 000 *ha* [16, page. 3]. Gary also claim that it is hard to point out an exactly number because of the unspecific definition. This is because greenhouse hydroponic production is often confused with the system that is covering soil with plastic tunnels and applying water and nutrient with a drip system.

As mentioned, today hydroponic systems are a potential food source which can be grown in several places both inside and outside. There have also been some attempts for growing food in limited areas, which can benefit countries from the third world for producing food [16, page. 4]. Also some research regard space science have been made. Usually outside the restraints are nutrients and water, but inside it also needs to be sufficient of light and correct temperature.

## 2.2 Production

An indoor automatic hydroponic system may consist of plastic tubes with holes for each plant, support material to give the plant something to grow in, nutrients, a mixing tank for water, hoses from the mixing tank to the tubes, acid to reduce the pH value, artificial lights, pumps and the control system[16, page. 245].

### 2.2.1 Support medium

For supporting plants there are several options, and one of the most used medium the past years is rockwool as shown in figure 2.1 [16, page. 245].



Figure 2.1: Rockwool in a net pot

Rockwool is made from solidified lava that is molten in a furnaces. The temperature in the furnaces is between 1500 °C and 2000 °C degrees[16, page. 245]. Rockwool consists of silica dioxide (45%), aluminium oxide (15%), calcium oxide (15%), magnesium oxide (10%), iron oxide (10%) and other oxides (5%), but this may vary between the manufactures. It was in 1937 the commercial stone wool production started in Denmark with the Rockwool group, and in 1949 they started manufacturing rockwool in Nederland. Grodan was founded in 1969 as a subsidiary of the Rockwool group and is now established in more that 60 countries. Rockwool culture is now the most used form of hydroponics in the world. Rockwool has been one of the most popular substances used in the industry for the last 15 years, but because it is hard to disposal and does not break down in landfills coco coir has been a potential alternative. Based on this Grodan has created a recycling program for rock wool, making it possible to create new rock wool from the used wool.

The abilities for rockwool are (95%) pore space, and it does not contribute with nutrient[16, page. 264]. All nutrient needs to be added water for the plants. Rockwool also has a water-holding capacity of (80%), and a pH value between 7 and 8,5. Rockwool has no buffer, so it is easy to reduce the pH value to the

optimal value for the plants and vegetables. A perfect medium to support the plants or vegetables should have these abilities [24, page. 16]:

1. To hold an even ratio of air to water.
2. Help to buffer pH changes over time.
3. Is easily flushed and re-wets after being completely dehydrated as would be the case during storage.
4. Is reusable or biodegradable to insure safe disposal.
5. Is inexpensive and easy to obtain.
6. Should be lightweight and easy to work with both indoors and out.

### 2.2.2 Nutrient requirements

The function of the support or growth medium like rockwool is to replace the function soil gives to the plants[16, page. 12]. The plants normally obtain water, oxygen and minerals from the soil in addition to support for the roots. The ability of the medium or soil is to provide nutrient dependent of the amount of different nutrient presented, their form and combination, how they are available for the plants and pH value. In hydroponics, all minerals are supplied to plants by dissolving fertilizer salts in water. The minerals are divided into macro and micro nutrients[16, page. 10][24, page.27]. Macro nutrients are obtained in high concentrations and include carbon(*C*), hydrogen(*H*), oxygen(*O*), nitrogen(*N*), phosphorus(*P*), potassium(*K*), calcium(*Ca*), sulfur(*S*) and magnesium (*Mg*). Examples for micro nutrients are calcium(*Ca*), sulfur(*S*), iron(*Fe*), magnesium(*Mg*), boron(*B*), manganese(*Mn*), zinc(*Zn*) molybdenum(*Mo*), copper(*Cu*) and cobalt(*Co*). Most of these minerals are obtained by water, but carbon and oxygen are obtained through the atmosphere. A more detailed overview of the functions some of the essential elements have within the plants are listed bellow.

1. Nitrogen: Part of a larger number of necessary organic compounds, including amino acids, proteins, coenzymes, nucleic acids and chlorophyll.
2. Phosphorus: Part of many important organic compounds, including sugar phosphates, ATP, nucleic acids, phospholipids and certain coenzymes.
3. Potassium: Acts as a coenzyme or activator for many enzymes. Protein synthesis requires high potassium levels. Potassium does not form a stable structural part of any molecules inside plant cells.
4. Sulfur: Incorporated into several organic compounds including amino acids and proteins. Coenzyme A and the vitamins thiamine and biotin contain sulfure.
5. Magnesium: An essential part of the chlorophyll molecule and required for activation of many enzymes, including those involved in ATP bond breakage. Essential to maintain ribosome structure.
6. Calcium: Often precipitated as crystals of calcium oxalate in vacuoles. Found in cell walls as calcium pectate, which cements together primary walls of adjacent cells. Required to maintain membrane integrity and is part of the enzyme  $\alpha$ -amylase. Sometimes interferes with the ability of magnesium to activate enzymes.

7. Iron: Required for chlorophyll synthesis and is an essential part of the cytochromes, which act as electron carriers in photosynthesis and respiration. Is an essential part of ferredoxin and possibly nitrate reductase. Activates certain other enzymes.
8. Chlorine: Required for photosynthesis, where it acts as an enzyme activator during the production of oxygen from water. Additional functions are suggested by effects of deficiency on roots.
9. Manganese: Activates one or more enzymes in fatty acid synthesis, the enzymes responsible for DNA and RNA formation, and the enzyme isocitrate dehydrogenase in the Krebs cycle. Participates directly in the photosynthetic production of  $O_2$  from  $H_2O$  and may be involved in chlorophyll formation.
10. Boron: The role in plants is not well understood by now, but boron may be required for carbohydrate transport in the phloem
11. Zinc: Required for the formation of the hormone indoleacetic acid. Activates the enzymes alcohol dehydrogenase, lactic acid dehydrogenase, glutamic acid dehydrogenase, and carboxypeptidase.
12. Copper: Acts as an electron carrier and as part of certain enzymes. Part of plastocyanin, which is involved in photosynthesis, and also of polyphenol oxidase and possible nitrate reductase. May be involved in  $N_2$  fixation.
13. Molybdenum: Acts as an electron carrier in the conversion of nitrate to ammonium and is also essential for  $N_2$  fixation.
14. Carbon: Constituent of all organic compounds found in plants.
15. Hydrogen: Constituent of all organic compounds of which carbon is a constituent. Important in cation exchange in plant-soil relations.
16. Oxygen: Constituent of all organic compounds found in plants. Only a few organic compounds, such as carotene, do not contain oxygen. Also involved in anion exchange between roots and the external medium. It is a terminal acceptor of  $H^+$  in aerobic respiration.

For the plants to benefit of the nutrient they are dependent of the availability, and the amounts of the elements in the nutrients depend on the form [16, page. 13]. There exist three forms; complex, insoluble compounds and as simple forms. The simple forms on ionic form are usually available to plants directly, but the complex forms must be broken down to a simpler and more available form for the plants. This is done by a reaction in the solution, and is dependent of the *pH value*. *pH* is a value for measuring acidity or alkalinity. If the *pH* value for the solution is less than 7 the solution is acidic. If it is 7 the solution is neutral, and if it is above 7 it is alkaline. Most plants prefer a *pH* value around 6,5. Potassium ( $K$ ) is absorbed by the plants at the maximum from a *pH* value of 6. This absorption rate is maintained with increased *pH* values. For calcium ( $Ca$ ) the absorption rate is at the highest when the *pH* value is 7. The value decreases both above and below 7 which is neutral. The available form for potassium is  $K^+$  and for calcium  $Ca^{2+}$ . Potassium and calcium are positively charged ions [16, page. 14]. An example for anions are chloride ( $Cl^-$ ) or sulfate ( $SO_4^{2-}$ ).



### 2.2.3 Impacts of nutrient deficiencies

One of the advantages with hydroponic systems is the possibility to maintain optimal growth with the correct amount of nutrients. If the nutrient level is too low or high over time it could result in abnormal growth[16, page. 20]. The disorder is expressed by the plant externally and/or internally in the form of symptoms. With abnormal growth the plant can with accurate description and identification of the disorder be diagnosed. Elements are sorted and grouped in mobile elements, immobile elements and those who are gradations mobile. The difference between mobile and immobile elements with a deficiency of elements are that the mobile elements are retranslocated, which means that the element will change from one place or position to another. Because of this the element will move from the older leaves to the active growing part of the plant, which is the younger leaves. This will generate symptoms on the the older leaves. The immobile elements are the elements that do not retranslocate to the growing area of the plant, but remain in the old leaves where they were originally deposit. This generates symptoms in the older leaves. The mobile elements are magnesium, phosphorus, potassium, zinc and nitrogen, while the immobile elements are calcium, iron, sulfur, boron, copper and manganese. Some of the regular symptoms with depletion of nutrients are yellow or brown areas on the leaves. It is important to discover the symptoms at an early stage due to the rapid increase of the symptoms. The deficiency symptoms for potassium are that they are first visible on older leaves were dead areas are developed, and it is often the tip and margins of the leaf that dies first[16, page. 24]. Toxicity symptoms may come from to high levels of potassium, which may lead to magnesium deficiency, and possible manganese, zinc or iron deficiency. Deficiency symptoms are usually visible in young leaves first, and they become distorted and small with irregular margins and spotted areas. Several symptoms can occur with deficiency and accumulation of the different nutrients. Deficiency symptoms for calcium is that the plant become undeveloped and the root tips often dies. With deficiency of calcium the young leaves often dies before the old leaves. Other symptoms example on deficiency are reduced growth and pigments may accumulate. This may be because of depletion of phosphorus. Higher concentrations of phosphorus may lead to iron deficiency in the plants[21].

### 2.2.4 Light requirements

To have photosynthesis the plants are dependent of light [24, page. 40]. Photosynthesis convert  $CO_2$  into sugar which is used as fuel for the plants, and the sun is the best energy source for this process. If the plants are going to grow indoors there will be a need for extra light, and there exist different types. Fluorescent lights can be used for low-light plants, but to benefit from the full growth potential high intensity discharge lightning is needed. The maximum output from the light is measured in photosynthetically active radiation(*PAR*). The *PAR* spectrum is covering the photosynthetically active radiation, which are red(600-680nm in wavelengths) and blue(380-480nm wavelengths of light). Blue light is most present in spring and summer days because then the sun is at the highest in the sky, while red light are most present in the autumn. The recommended amount of light exposure is between 16-18 hours per day.

## 2.3 Hydroponic systems

There exist several hydroponic techniques, and common for them all are some requirements[16, page. 97]. One of the requirement is that the roots need to have access to a balanced supply of water and nutrients. This could be done in several ways. Regards to air this can be done by pumping air into the water that are

surrounding the roots. It can also be done by circulating the water by a pump through the system, which will aerate the water when it is stirred in the process. Another requirement is to keep the roots dark. If the roots are not kept dark, it will promote growth of algae which again will compete with the plants for nutrient, and oxygen at night. The algae may also produce some toxic products that can interfere with the growth of the plants. Hydroponic systems can be either passive or active[24, page. 20]. The difference between the passive and active system, is that for a passive system it is dependent of gravity or absorption for the roots to have access to nutrition. While in an active system the nutrients can be pumped by mechanics to be re-circulated. There are several passive and active systems. Some of them are:

- The Dutch Bucket Method is a technique that was introduced in Holland and works well for long term crops, for example tomatoes, cucumbers and roses [24, page. 22]. The technique uses a drip system that feed the plants with nutrient solution. Most growing mediums are suitable, for example gravel. The nutrient solution that is not absorbed by the plant is accumulated as a reserve in the bottom of the bucket. At the bottom of the bucket there is a tube. This tube is mounted slightly above the nutrient solution, and is connecting the buckets together. When the nutrient solution are above the level of the entrance of the tube, gravity makes sure the nutrients is led to a reservoir were the nutrient solution is recycled.
- The Raft System is a suitable technique for lettuce production, and other short stature crops[24, page. 22]. The system consists of beds with water mixed with nutrition, and the plants are supported by sheets made of styrofoam. The circulation is  $2-3L/min$  if the beds are  $60cm$  wide,  $20cm$  deep and  $20m$  long. The nutrient ends up in a tank were it is recycled and pumped back into the beds. The solution is mixed with air in the tank. Some systems also have temperature regulation and ultraviolet sterilizers. A sterilizer is effective against for example bacteria, fungi and viruses.
- Ein Gedi System was developed by Ein Gedi from Israel, and consists of a vortex sprayer on top of a self contained reservoir[24, page. 24]. As it spins, water is pulled up the tube and sprayed by the spinning disk. This technique makes sure the nutrient solution are constantly aerated, which improve growth.
- Aeroponics is growing of plants in an supporting container[16, page. 119]. In the container the roots are sprayed with nutrient solutions. This method is mostly used in laboratory studies and not so much in commercial scale. An advantage with aeroponics are that they get maximum amount of air, since the roots are hanging down and are sprayed with nutrients[24, page. 24]. The nutrients that are not absorbed is drained back into the reservoir and recycled. The disadvantage is that the plants are vulnerable if the pump and spray stops. If the system fail the roots may dry out.
- Vertical Gardening was invented by Vertigro and is a technique that function in almost the same way as aeroponics[24, page. 25]. The growing cylinders are hung vertically to save space and they share the same drain pipe.
- Rotary hydroponic systems are a technique that uses rotation to cycle how often the plants are added nutrients[16, page. 23]. The plants are mounted in a big cylinder that circles around a light source. Bellow this cylinder there is a bed filled with nutrients, and the cylinder is circling with the growth medium and the roots in this bed. This system is suited for grass-growing.

- The Nutrient Film Technique (NFT) was developed and used for the first time by Allen Cooper at the Glasshouse Crop Research Institute in 1965 [24, page. 23]. But the system has been continued modified and developed through the time. The reason for that some people use the term nutrient film technique regard the NFT system compared to nutrient flow technique, is that with nutrient film technique the focus is on depth of the liquid flowing past the roots. With nutrient flow technique the focus is on the constantly circulating.

Early in 1990 there were made several attempts by commercial operations to grow tomatoes, but it was hard to get sufficient oxygen in the nutrient solution[16, page. 145]. The system works when a pump is adding nutrient solution from a tank, through hoses into pipes where the plants are placed in line after each other. Due to the gravity the nutrient is discharged at the end of the pipes and lead back to the tank. After rockwool was introduced in the 1990s this became the most used method. The NFT method is suited for lettuce and herbs, and one advantage with the system is that the nutrient solution almost not evaporate as long as the pipes are closed with plants.



Figure 2.2: NFT System with lettuce

## 2.4 Probes and electrodes

The minerals obtained by the plants are depending on various variables like pH value, EC value, temperature and the light [15, 17]. The sum of minerals or ions in a solution is determined by the combination of these minerals, and is measured in electrical conductivity. Temperature and pH among others are two of several parameters that determine the availability of nutrients. Depending on pH-value the plants ability of absorbing nutrition can be manipulated. Measuring of both pH and EC are dependent of temperature [2, 9]. If the temperature has major changes, probes for measuring pH and EC should be temperature compensated. Mentioned in chapter 2.2, this report is focusing on lettuce production which has the growing factors as shown in table 2.1[12]. Electro-Conductivity (EC) or Conductivity Factor (cF) can be expressed as either milliSiemens ( $mS$ ), cF, or parts per million (PPM)  $1 mS = 10cF = 700PPM$ .

Table 2.1: pH and electro-conductivity values specified for lettuce [12]

<i>Plant</i>	<i>pH</i>	Conductivity Factor ( <i>cF</i> )	Electro-Conductivity ( <i>EC</i> )	Parts Per Million ( <i>PPM</i> )
<i>Lettuce</i>	5.5 – 6.5	8 – 12( <i>cF</i> )	0.8 – 1.2( <i>mS</i> )	560 – 840( <i>PPM</i> )

### 2.4.1 pH

The temperature and pH value are important parameters to measure. The pH probe is measuring the hydrogen ion activity in the liquid [9, 15]. In a system that is inside a lab with room temperature, there will almost be no changes in temperature compared to an outdoor system. But refilling water and chemicals may still increase or decrease the temperature. This way, it is still important to measure temperature.

The pH probe consists of several layers of glass[9, 15]. The outer tip layer lets small hydrogen ions through, and the difference in concentration create a small current that the probe measures. When measuring hydrogen ions at 25 °C (298K) the probe outputs a value of 59.16 *mV* [25]. For a unit change in pH, an ideal measuring system will sense a *mV* change of 59.16 *mV*. The voltage and current are proportional with the concentration of hydrogen ions and a large concentration outside the glass means an acid solution with a pH value below 7[9, 15]. An neutral concentration means the pH value is 7, and a base solution has concentration over 7. The total potential difference  $E$  for pH can be calculated by equation 2.1.

$$E = E_o - 2,303 \times \frac{RT}{F} pH \quad (2.1)$$

Table 2.2: Constants and variables for equation 2.1 [9]

E:	Measured potential or total potential difference ( <i>mV</i> )
$E_o$ :	Reference potential ( <i>mV</i> )
F:	Faraday constant (96485 C mol <sup>-1</sup> )
R:	Universal gas constant ( $R = 8.314 J mol^{-1} K^{-1}$ )
T:	Temperature in K (Kelvin)

### 2.4.2 Temperature

To measure temperature could be important depending if the hydroponic system is an in- or outside system. Temperature measuring could be done by using a NTC connected in series with a 10KΩ resistor as shown in

figure 2.3, and calibrated due to the Steinhart Hart thermistor equation. The formula is shown in equation 2.2. The Steinhart Hart equation is an empirical expression that has been determined to be the best mathematical expression for the resistance - temperature relationship of a negative temperature coefficient thermistor. The equation are usually solved for  $T$  where  $T$  are expressed in degrees, and “ $A$ ”, “ $B$ ” and “ $C$ ” are coefficients derived by measuring the resistance at three different temperatures. With three different temperatures the equation needs to be solve with three simultaneous equations. One equation for  $T_1$  and  $R_1$ , one for  $T_2$  and  $R_2$  and one for  $T_3$  and  $R_3$ .

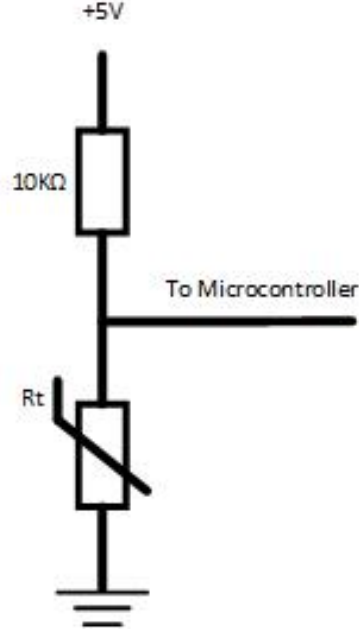


Figure 2.3: NTC [1]

$$\frac{1}{T} = A + B(\ln(R)) + C(\ln(R))^3 \quad (2.2)$$

The coefficients “ $A$ ”, “ $B$ ” and “ $C$ ” can be derived from equation 2.6, 2.7 and 2.8 [26]. The equations 2.3, 2.4 and 2.5 are used for deriving equations 2.6, 2.7 and 2.8.

$$L_1 = \ln(R_1) \quad L_2 = \ln(R_2) \quad L_3 = \ln(R_3) \quad (2.3)$$

$$Y_1 = \frac{1}{T_1} \quad Y_2 = \frac{1}{T_2} \quad Y_3 = \frac{1}{T_3} \quad (2.4)$$

$$\gamma_2 = \frac{(Y_2 - Y_1)}{(L_2 - L_1)} \quad \gamma_3 = \frac{(Y_3 - Y_1)}{(L_3 - L_1)} \quad (2.5)$$

$$C = \frac{(\gamma_3 - \gamma_2)}{(L_3 - L_2)} \times (L_1 + L_2 + L_3)^{-1} \quad (2.6)$$

$$B = \gamma_2 - C(L_1^2 + L_1 \times L_2 + L_2^2) \quad (2.7)$$

$$A = Y_1 - L_1(B + C \times L_1^2) \quad (2.8)$$

### 2.4.3 EC

The table 2.1 also presents the recommended values for Electro-Conductivity (EC) and pH. The Conductivity Factor (cF) is also a measurement for conductivity, and can be expressed as either milliSiemens (mS), cF, or parts per million (PPM).  $1mS = 10cF = 700ppm$ [12, 15]. The EC probe measure conductivity by using two electrodes that are positioned opposite from each other as shown in figure 2.4. When AC voltage is applied, the cations which are positive charged will go to the negative charged electrode and opposite for the anions which are negative charged. The electrical conductivity is decided by how many free electrolytes the fluid consist of. The more free electrolyte the higher EC.

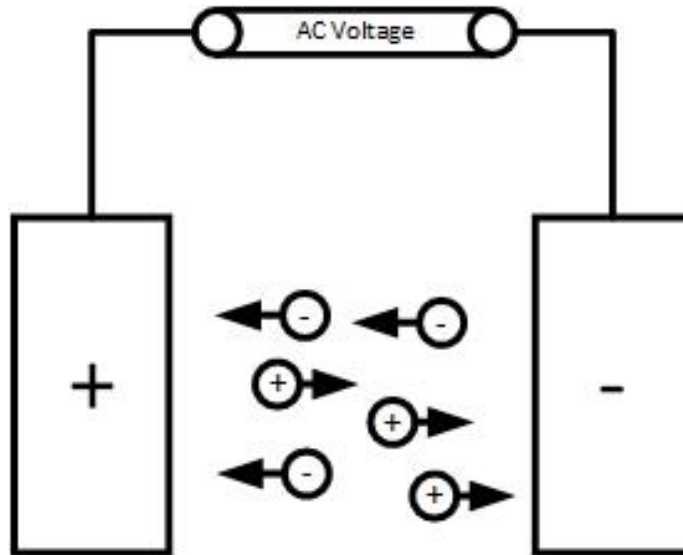


Figure 2.4: Principle of free electrolytes in liquid and electrical conductivity [2]

### 2.4.4 Potassium and calcium

Measuring potassium and calcium can be done by using electrodes designed for this purpose[15, 10]. The key component of an ISE is the ion-selective membrane that responds selectively to one analyte in the presence of other ions in a solution[22]. The potassium electrode is used to measure the concentration of potassium ( $K^+$ ) ions(ion-concentration) [13]. The way the potassium probe works is comparing measurements from ion-specific half-cell with a reference half-cell. The ion-specific half-cell is the sensing cell, and it produces a potential depending on the activity of the target ion. This is measured and compared against the reference. This relation is described by the Nernst equation as shown in equation 2.9.

$$E = E_o - 2,303 \times \frac{RT}{nF} \log(C + C_o) \quad (2.9)$$

Table 2.3: Constants and variables for equation 2.9 [13].

C:	Concentration of ion to be measured
$C_o$ :	Detection limit
E:	Measured potential ( $mV$ ) between the ion-selective and the reference electrode
$E_o$ :	Standard potential ( $mV$ ) between the ion-selective and reference electrodes
F:	Faraday constant (96485 C mol <sup>-1</sup> )
n:	Valence of the ion
R:	Universal gas constant ( $R = 8.314 J mol^{-1} K^{-1}$ )
T:	Temperature in K (Kelvin), with $T (K) = 273.15 + t \text{ } ^\circ C$ where t is the temperature of the measured solution in $^\circ C$ .

## 2.5 Microprocessors

Developing systems with the purpose of monitoring parameters and controlling different electronic components, generates a need for a control unit that is functioning as the brain for the system. There are several options in the category microprocessor/embedded systems and single board computers. A microprocessor is a chip that is built in inside of a integrated circuit, like the 8 bit ATmega328 [27, page. 10]. This together with memory and in and output channels are called a microcontroller or an embedded microprocessor. Arduino which can be seen to the right in figure 2.5 and which are made for experimenting, is an example for a micro controller. This can be used for education and hobby projects, and it can also be called a development board. A microcontroller like Arduino is a low power and low level device that is programmed by  $C$  and  $C++$ . It is also open hardware and open source, so everyone can contribute to the development of the microcontroller, and it supports UART, which stands for Universal Asynchronous Reception and Transmission [28]. UART is a simple communication protocol that allows the Arduino to communicate with serial devices and computers through digital pins and an USB port.[27, 29].

An example for single board computer(SBC) could be the Raspberry Pi which can be seen in the middle of figure 2.5 [30, 31]. Raspberry pi is a computer sized as a credit card, including everything needed to use it like a real size computer. The Raspberry Pi is a higher level device that can run an operating system like Linux, and supports HDMI display output, computer mouse and keyboard. Raspberry Pi also supports several in and output channels, and have support for Transmission Control Protocol/Internet Protocol(TCP/IP), which makes it easier to integrate into a IOT system. With support for several languages like Python,  $C$ ,  $C++$ , HTML and Java to mention some, and also TCP/IP makes it easier to connect to internet and work towards cloud solutions as part of Internet of Things (IOT). An important difference from micro controller is that a SOC can not sleep when a system has no activity.

Another example for a single board computer or system on a chip (SOC) is the myRio from National Instruments [32]. This is shown to the left in figure 2.5. This SBC is a portable reconfigurable device that students can use to design and control robotics and mechatronics systems. The myRio also runs with Linux and supports TCP/IP, but can not be controlled directly by a computer mouse or keyboard. The program-



ming language used for the myRio are National Instruments own graphical programming language created in Labview.

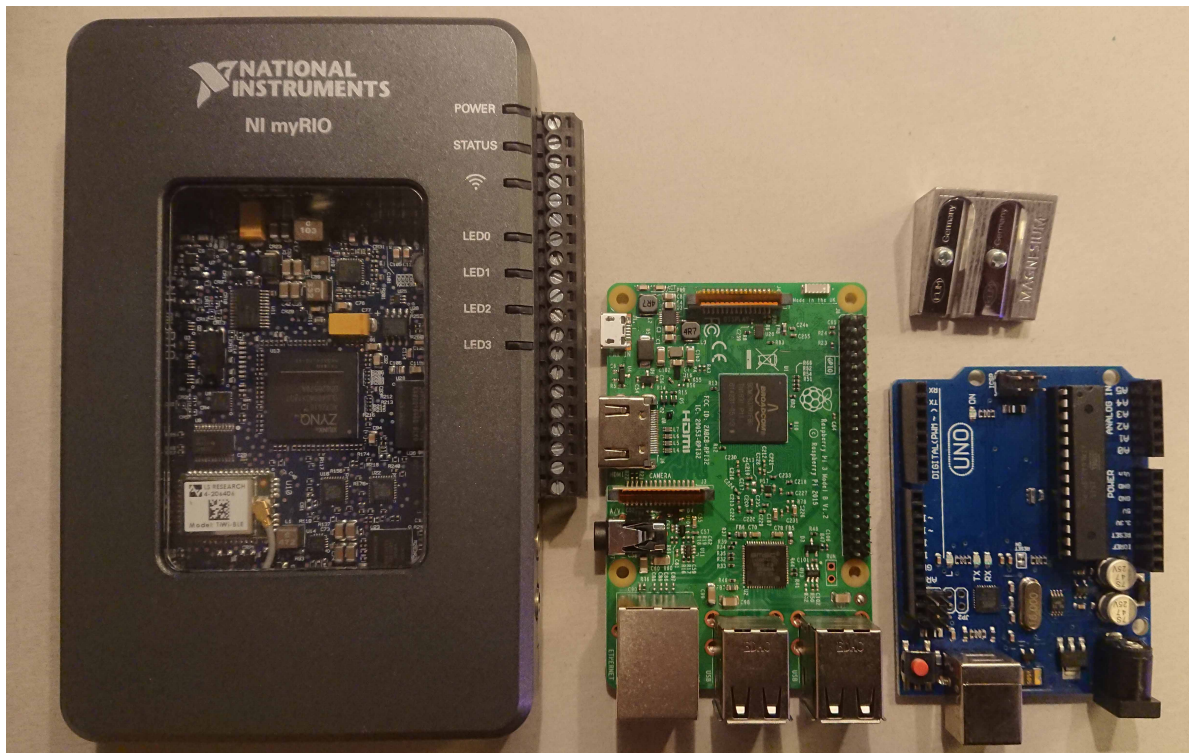


Figure 2.5: Pencil sharpener for illustration of size. Showing from the left: myRio, Raspberry Pi, Arduino

### 2.5.1 Internet of things

In the recent years it has been more and more common to implement sensors across many areas, which offers the ability to measure, monitor and understand environmental indicators [33]. With high speed internet it will also be possible to implement this online, called Internet of things(IoT). Kevin Ashton was in 1999 the first to use this term. IoT consists mainly of sensors and actuating units like motors, sensors and other devices that execute tasks, and the data is available for the users online. Use of Radio-frequency identification (RFID) tags are also an example for units that could be used for data generation where for example logging and tracking of attached units on packages under transportation is made possible. This makes monitoring and control possible from other locations where the sensors and actuators are located. As internet is developing, changing from static web pages to dynamic pages with social networking and cloud integration implementation of embedded microprocessors in a hydroponic system would be beneficial. Including an also wider range of applications like healthcare, utilities, transport and more, the term is also developing. However the human interaction remains the same. With online monitoring and control, the need for daily interaction can be reduced and replaced by automatizing and alarm sensors.

There are several IoT protocols like LoRa, Sigfox, 4g NB-IOT and Wi-Fi, and an IoT system can be built with many different applications[34]. One way can be to bundle up http Representational State Transfer(REST), InfluxDB and Grafana. http REST creates the ability to exchange and make use of information between the computer and the internet [35]. The Influx DB is a cloud solution that store and sort the information. Influx DB also has the ability to timestamp any incoming data [36]. The ability to send



queries, analysing data, setting up alerts and sending notifications are also present. Grafana is an open source monitoring and time series analysing tool. It allows the user to query, visualize, create alerts and graphical visualise the data. It is also possible to have shared desktops [37]. This bundle makes it possible for the computer, micro controller or SOC in an embedded system to send data with http REST to InfluxDB that store and process the data. Grafana makes this data viable to the user through a graphical interface.

## 2.6 Solar power

Solar power is power converted from the radiation created by the nuclear fusion process at the sun[38, page. 2]. This can be done by using Photovoltaics(PV) which are the process of converting sunlight into electricity using solar cells[38, page. 2]. The orientation of the solar panels are important due to the efficiency of the panels [39]. Two parameters that need to be taken into account are the azimuth angle and the elevation angle at solar noon. These angles are used to orientate the solar panels.

Regards to electricity, Ohms law describes the relation between voltage, current and resistance [40, page. 25]. The formulas for Ohms law are shown in equations numbered 2.10. Voltage is measured in volt, current in ampere and resistance in ohm. To calculate the effect the formula shown in equation 2.11 is used [40, page. 36]. Power is measured in watt.

$$I = \frac{U}{R} \qquad U = U \times R \qquad R = \frac{U}{I} \qquad (2.10)$$

$$P = U \times I \qquad (2.11)$$

Watt hour(*Wh*) are calculated by multiplying watt total with T as shown in equation 2.12 [40, page. 89]. If T is in seconds the value needs to be converted to seconds as shown in equation 2.13. The same goes for minutes as shown in equation 2.14

$$Watt\ hour = P_{total} \times T \qquad (2.12)$$

$$Watt\ hour(Peristaltic\ liquid\ pump) = P_{total} \times \frac{Seconds\ used\ each\ day}{24\ hours \times 60\ minutes \times 60\ sec} \qquad (2.13)$$

$$Watt\ hour(Peristaltic\ liquid\ pump) = P_{total} \times \frac{minutes\ used\ each\ day}{24\ hours \times 60\ Minutes} \qquad (2.14)$$

Kirchhoff's law for serial connections in a circuit means that the voltage drop for each load is equal to the total voltage, as shown in equation 2.15 [40, page. 51]. Here the current are the same in all the resistors. Kirchhoff's law for parallel connection in a circuit means that the sum of all currents entering a node will be zero [40, page. 155]. By knowing this total current can be calculated as shown in equation 2.16, and the sum of voltage over these resistors would be the same.

$$U_{Total} = U_{R1} + U_{R2} + U_{R3} + \dots + U_{Rn} \quad (2.15)$$

$$I_{Total} = I_{R1} + I_{R2} + I_{R3} + \dots + I_{Rn} \quad (2.16)$$

AM1.5G is the standard spectrum at the Earth's surface and includes both direct and diffuse radiation. Usually PV modules are tested under standard test conditions (STC) which has the conditions 1000 W/m<sup>2</sup> of sunlight, 25 °C and spectrum of Airmass 1.5 (AM 1.5)[41]. Figure 2.6 shows an example for a solar module with 36 solar cells connected in series, and it is the number of solar cells that determine the voltage [3]. The voltage of a PV module is often chosen based on compatibility with the battery, usually 12V. The most common for PV modules are 36 solar cells in series, as shown in figure 2.6. The reason for this is that PV module has to be able to charge batteries that may need voltage as high as 15V or more. A module with 36 solar cells in series, with each producing about 0,5V under STC, the open-circuit voltage would be about 21V. The open-circuit voltage is the voltage produced from the solar module with no current. The operating voltage at maximum power and operating temperature would be about 17 or 18V.

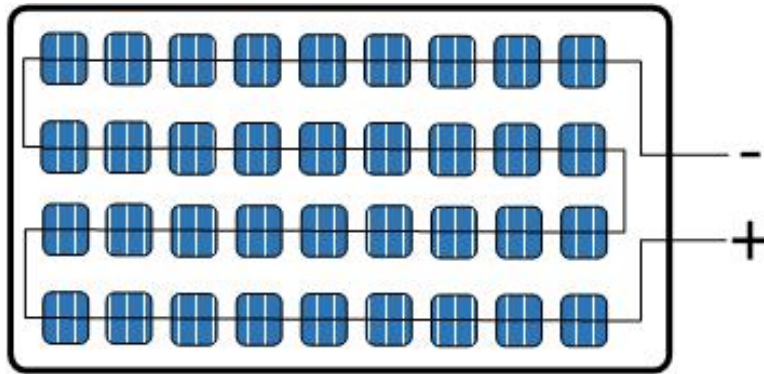


Figure 2.6: Solar module [3]

The challenge with solar power is that power is produced when the sun is present. This means storing the power for use at night or days when the solar modules are not producing at full effect, it is important to have storage [42]. To have power for a longer period of time that are reliable, and when the power comes from batteries, the relation between depth of discharge and the battery capacity are factors that are important. The energy that can be extracted can be found by multiplying the battery capacity with the depth of discharge. Temperature and charging regime will also affect capacity and lifetime. Batteries are usually marked with (Ah), and if the battery has 40(Ah) it means in theory that the battery can deliver 40A for one hour, 20A for two hours etc [40, page. 81].

## 2.7 State of the art technology

There have been some research on the field of automatizing hydroponics before but not too much on individual nutrient. Much of the research is not from a newer date. There is however an article from 2017 focusing on using a low cost AVR microcontroller board together with Labview for measuring humidity,

temperature, pH and light [43]. The article also include controlling elements like fans, blowers, halogen light bulbs, pumps and motors. No electrical conductivity(*EC*) or individual nutrients are measured or controlled. Another article from 2012 describes a solar powered system with nutrient solution level measuring, *EC* and pH monitoring and regulation [44]. This system is used for growing rock-melon, and the system used consists of two tanks of nutrients A and B(30*L*), pumps to pump it into the mixing tank(60*L*), a valve and filter connected to the water inlet, a developed control board, irrigation pump and valves to control nutrients to the dripper supplying the pots with melons. pH and *EC* are also monitored and regulated, and the system is powered by solar power. Another article from 2014 is also focusing on measuring, and regulating *EC* and pH value during production of tomatoes[23]. This system uses a developed software programmed in C++ specifically written to minimize the hardware requirements. This system uses three 100*L* reservoirs to store the stock solution A and B plus the water, and a 30*L* reservoirs to store nutrient solution. A similar system with measuring temperature, pH and *EC*, is also described in an article from 2012[45]. This article contains automation of lettuce production, and have also included a webcam. The webcam is used for monitoring of the production, and to follow the development of the hydroponic lettuce. The webcam also makes it possible to diagnose diseases by the appearance of the leaves, as well as it is functioning as a security camera.

Another article from 2018 focus also in addition to sensors access to the web for control and monitoring[46]. This is often referred to as Internet of things(IoT). This gives *EC*, pH, temperature, humidity, pictures and video through video camera available online. This gives more or less no need for physical involvement from humans to maintain the system. In addition to measuring *EC*, the ideal situation would be to have real time information for all individual nutrients at all times, but for most this would be a too expensive solution, and the technology is maybe not commercially present. There have not been much research on individual nutrients, but there are still some. One article is focusing on measuring phosphate( $\text{PO}_4^{3-}$ )[21]. The system allows real-time monitoring of phosphate concentration in a continuously flowing nutrient solution. The article is using molybdenum blue method and UV-visible spectrophotometry to determine the phosphate-ion concentration in the nutrient solution, together with the flow injection analysis(FIA) method. FIA is an automated method of chemical analysis, were a sample is injected into a flowing carrier solution. This solution then mixes with reagents before reaching a detector. The effects of reagent flow rate, injection volume and flow path length on FIA response are investigated, and here the result are presented as absorbent versus time during analysis. This system consists of pumps, valves, degassing unit and a UV-visible detector, and the software used is also here Labview. This system is capable to measure 100 samples per hour.

One article from 2013 has looked into measuring several macronutrients ( $\text{NO}_3\text{-N}$ , *K*, *Ca*). This is done for testing the sensitivity of different electrodes in a lab environment[22]. The tested *Ca* electrode did not provide satisfactory results, and the article conclude that this is due to reduced sensitivity, and poor selectivity in the hydroponic solution. The tests were done with data acquisition and control system that allowed automatic measurement of the Ion-selective electrodes(ISE) voltages. The tests include eight ISE electrodes to look into which one is best suited or for measuring typical concentration ranges of macronutrients.

### 2.7.1 Probes, electrodes, sensors and microprocessors

There are many different electrodes and microprocessors on the marked, and new technology are being presented continuously. Solar power systems as power source and microprocessor technology have also been improved through the years. There are several probes on the marked to measure pH, *EC* and individual nutrients. Vernier, Atlas Scientific, Hanna Instruments, OxyGuard, Mettler and Jumbo are some examples

of manufacturers and suppliers of different electrodes[13, 9, 2, 47, 48, 49]. National Instruments, Raspberry pi, Arduino, Lattepanda, Asus are examples of platforms or producers of embedded microprocessors and single board computers that could be used for reading and controlling electronics [32, 30, 29, 7, 50].

### 2.7.2 pH probes

There are several producers and manufacturers that offer probes for measure pH. The terms probe and electrodes are by the vendors used interchangeably. Vernier, Atlas Scientific, Omega and Jumo are some of them [9, 51, 49, 47]. Vernier provides several types, both for industrial and educational use. The pH Electrode BNC is designed for educational use from middle school to university level [52]. The probe is sealed so the gel does not need to be refilled, and the probe can measure pH values in the range 0 to 14. For the pH electrode to not dry out, it needs to be stored in a pH storage solution from Vernier at all times when it is not in use. This probe can not be connected directly to a computer, but need to be connected through an interface to be functional. Vernier also has more professional electrodes, like the Glass-Body pH Electrode BNC, PH-BTA pH sensor and the Flat pH Electrode BNC [53]. The difference between industrial and educational probes may be that the industrial are more robust or different shaped. These probes also need to be connected through an interface to be functional. Vernier also has a probe that can be connected directly through the USB connection or Bluetooth [54]. This is designed for educational, lab and field activities. It can provide live readings and captures data in real-time both during Verniers software or third party software.

Atlas Scientific also has a broad range of pH probes, both educational and industrial [55]. All the probes measure in the pH range of 0 to 14. The different types of probes they have are a mini pH probe, one with a spear tip which is good for measuring directly in the soil and one industrial probe that is more robust. Atlas Scientific also provide a regular pH probe and the accuracy of this is  $\pm 0.002$  with a response time of 95% in 1s[9]. The resolution for the probe is  $\pm 0.0001$ . There are also several other manufacturers and producers that can supply pH probes. Most of them like Hach, Mettler, Hanna Instruments, Omega and Jumo provide similar probes to the ones from Vernier and Atlas Scientific[51, 49, 56, 57, 58, 59]. But there are also some pH probe solutions that provide additional data, like OxyGuards pH/Redox Probe[60].

### 2.7.3 EC probes

Some of the producers and manufacturers that are producing pH probes are also producing EC probes, like Vernier and AtlasScientific [2, 48]. Vernier has different probes with different abilities like built in battery, built-in temperature compensation or the possibility to use the Go direct amplifier, which makes it possible to connect directly to a computer without an interface through USB or Bluetooth. The range for Verniers conductivity probe with the Go direct amplifier is 0 to 20,000  $\mu S/cm$  or 0 to 10,000  $mg/L$  TDS, and the resolution for this probe is 0.01  $/cm$ . The Platinum-Cell Conductivity Probe from Vernier has a lower range 0 to 2,000  $\mu S/cm$  but higher accuracy. This probe is also a plug and play device designed to be easy to use for students. The probe does not need to be calibrated. The third probe from Vernier is a probe that has three settings for measuring. All three settings have different resolution and accuracy. The low range is from 0 to 200  $\mu S/cm$  or 0 to 100  $mg/L$  TDS. The mid range is from 0 to 2000  $\mu S/cm$  or 0 to 1000  $mg/L$  TDS, and the high range is from 0 to 20,000  $\mu S/cm$  or 0 to 10,000  $mg/L$  TDS. The probe also has high response time with 98% of full-scale reading in 5 seconds, 100% of full-scale in 15 seconds.

AtlasScientific also offer a broad range of EC probes designed for industrial and educational use[48]. All probes can be connected to interfaces with a screen to display information, or directly to a computer through an electric circuit and a microprocessor or single board computer that are able to read *UART* or *I<sup>2</sup>C*. The range of the K 0.1 probe is  $0,07 \mu S/cm$  to  $50,000 \mu S/cm$ , for the K 1.0  $5 \mu S/cm$  to  $200,000 \mu S/cm$  and for the 10  $\mu S/cm$  to 1 S. The industrial probe from AtlasScientific is a more robust version of the k 1.0 probe, and it comes with a container designed as a T-piece pipe that can be connected in an existing piping system. This way the probe is fully protected and stay in the same position at all time. Hach, Mettler, Hanna Instruments can also supply different EC probes for measuring conductivity [61, 62]. Hatch also supply portable reading devices including probes for pH, EC, Oxygen etc., like the HQ40D [63].

#### 2.7.4 Ion-selective electrodes

Ion-selective electrodes have a more narrow selection of producers and manufacturers than pH and EC probes, but there are still some options for some of the ions that may be relevant to measure in a hydroponic system. Some of the electrodes available on the market are from Mettler, Vernier, Orion and Hanna Instruments [10, 64, 65, 66]. Mettler has electrodes for Calcium, Chlorine, Copper, Potassium, Nitrate and Sulfur [64]. Hanna Instruments has electrodes for Calcium, Chlorine, Nitrate and Potassium [65]. Vernier has electrodes for Calcium, Chloride, Potassium, Nitrate and Oxygen which can be connected wireless directly to a computer [10]. Orion has also several types of ion selective electrodes [66].

#### 2.7.5 Other sensors

Special sensors for measuring water levels in live plants can be done by the leaf sensor from Agrihouse as shown in picture 2.7 [4]. The sensor can be used to measure moisture levels, leaf thickness and sap flow in real time. The sensor is for both in and outdoor use, is self-calibrating, and has a 16-bit signal resolution at  $0.00001VDC$ . The leaf sensor can be used in a temperature between  $0^{\circ}C$  and  $49^{\circ}C$  degrees, and is also compatible with the wireless data harvesting through XBee using the ZigBee protocol. There are also available a solar power module with battery pack to powering the system.



Figure 2.7: Leaf sensor from Agrihouse [4]

The distance sensor shown in figure 2.8 from Sharp can be used for measuring distance between  $10cm$

and 80cm [5]. The sensors are good for short-range detection. The sensor sends infrared light towards an object and detects the reflection to determine how far away it is. It returns an analog voltage that can be used to determine how close the nearest object is.

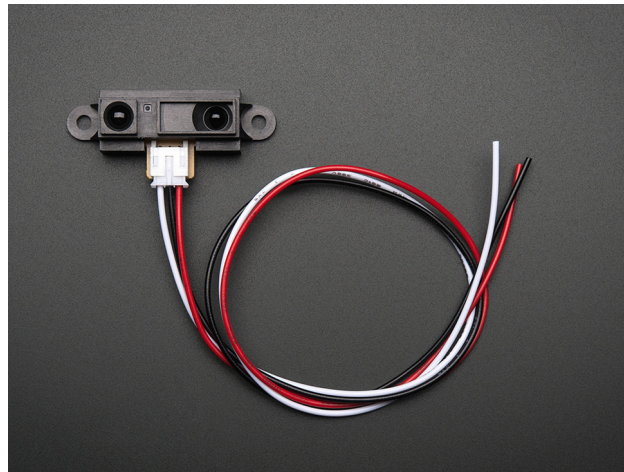


Figure 2.8: Sharp IR Sensor for distance measuring between 10cm and 80cm [5]

### 2.7.6 Microprocessors

Probably the most used single microcontroller is Arduino, but there are several alternatives. Since Arduino is open hardware there are also other microcontrollers built on the Arduino, which gives more functions and are made for making the Arduino dedicated certain purposes. An example of this is the Industrino as shown in picture 2.9[6]. The Industrino is a fully featured Arduino compatible board. It is housed in a DIN-rail mountable case making it easy to attach, and it also has prototyping area, onboard LCD screen and buttons. There are also several modules that can be attached to the Industrino to expand the possibilities. Some of the modules give wired or wireless network which makes it easy to implement with IoT, GSM/GPRS expansion module, which gives the opportunity to connect to the internet via GPRS and Send/Receive SMS messages.



Figure 2.9: Industrino, a fully featured Arduino compatible board [6]

Regard examples of state of the art in size and low power consuming microprocessors or integrated circuits (IC), the ESP32 and ATSAMR34J18 are worth mentioning[67][68]. The ESP32 is a low power chip with Bluetooth and Wi-Fi integration, and it can function reliably in industrial environments. The microprocessor has an operating temperature ranging from  $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ . The ATSAMR34J18 supports Lora instead of Wi-Fi which has less power consumption[68]. The ESP32 used in an embedded microcontroller, the Adafruit HUZZAH32 – ESP32 Feather Board would be worth mentioning. The feather board supports USB, Wi-Fi, Bluetooth, and has a chargeable battery [69]. Even due to the small size, this microcontroller has several in and outputs, and the size of the controller is as small as  $51.0\text{mm} \times 22.7\text{mm} \times 7.3\text{mm}$ . The weight is as low as  $6,8\text{g}$ . An alternative to the feather board are the Pycome series containing WiPy 3.0, SiPy, LoPy4, GPy and FiPy [70]. These micro controllers are available with WiFi and Bluetooth, LoRa, Sigfox and dual LTE-M (CAT M1 and NBIoT) or all in one controller[71]. The controllers are as small as  $55.0\text{mm} \times 20.0\text{mm} \times 3.5\text{mm}$ , and the weight is as low as  $31\text{g}$ .

The Orange Pi, Banana Pi, Thinker Board and Late Panda would be some state of the art alternatives for SBC like Raspberry Pi and myRio [72, 73, 50, 7]. Orange Pi and Banana Pi are more or less similar to the Raspberry Pi described in chapter 2.5, and they are both Android and Linux compatible. But they can also be used with other operating systems. Both are also open hardware. The area of use can be prototyping, testing, creating games, programming and communication both through wired or wireless network depending on the model chosen. Both have several models designed for either to have low power consumption or high performance. The Banana Pi also has custom accessories like cameras, sensors, motors and valves, to mention some. These components could be useful in an embedded system together with an IoT solutions. The Orange Pi 3 has a H6 Quad-core 64-bit 1.8GHZ ARM Cortex<sup>TM</sup>-A53 CPU compared to 1.2 Ghz Quad-Core ARM Cortex A53 64-Bit Processor-A64, which are used in the Banana Pi M64. The processors can vary depending on the model chosen. The Raspberry Pi uses a Broadcom BCM2837B0, Cortex-A53 (ARMv8) 64-bit SoC @ 1.4GHz processor. The Orange Pi comes with both 1 and 2 GB of ram, the Banana Pi comes with 2GB and the Raspberry Pi comes with 1 GB.

The Thinker board made by ASUS is worth mentioning regards to state of the art[50]. This SBC runs on Tinker operating system(OS) which is based on Debian, and it can also run on Android. Thinker board runs with a Rockchip Quad-Core RK3288 processor 1.8GHz CPU, and 2GB Dual Channel DDR3 ram. The Tinker Board's ARM<sup>®</sup> Mali<sup>TM</sup>-T764 GPU and fixed-function processors are designed for improve high-quality media playback, computer vision, gesture recognition, image stabilization and processing, as well as computational photography and more. There are also H.264 and H.265 playback support, including playback of HD and UHD video. The Tinker Board is also equipped with an HD codec that supports up to 24-bit/192kHz audio. The Lattepanda is a SBC that runs with a 1.1-3.4GHz Dual-Core Intel 8th m3-8100y processor and 8G LPDDR3 ram [7]. It also has built in 64GB memory, a Intel HD Graphics 615, 300-900MHz graphics processor and a built in Arduino. The Lattepanda also due to its Intel processor manage to run Windows 10. This makes it possible to run applications and software made for Windows. It can also be expanded with a IO card. Most of these SBC including Lattepanda is capable of be connected to a touch sensitive monitor, making it able to work as an tablet or cellphone as shown in figure 2.10. This may be especially beneficially if Android is chosen as OS.





Figure 2.10: LattePanda connected to 7 1024 x 600 IPS display, showing Windows [7]



# Chapter 3

## Research Questions

### 3.1 Research Questions

The background for this task is as mentioned in chapter 1.1 to continue the research from ENE503 Energy Research Project which is also part of the renewable energy master program. The foundation for the Energy Research Project was the need for automatizing the EC and pH, temperature in a hydroponic system. This became the focus of this task and a test system for control of EC, pH and temperature and pumps were built. This system was only tested in a bucket of water to demonstrate the functionality. The research project also demonstrated real time monitoring of individual monitoring of potassium. Through further discussing of the topic regard individual nutrients with the main supervisor Helge Liltved of this master thesis, there was revealed a hypotheses from previously research at the University of Agder. Over time in a closed hydroponic system, circulating the same water with the same nutrients, potassium will decrease to 0% and calcium would accumulate to possibly unhealthy values for the plants.

As mentioned in chapter 1.2 there is built an experimental roof-top hydroponic system on top of the J-building of the University of Agder. This is used as a test facility, alongside a lab inside the university for implementing and verifying that the control system works. To power the system there are several options, but with regard to space, maintenance, economy and location, only solar power has been considered. To implement the hypothesis regards to potassium and calcium, solar power, hydroponic rooftop system and control system, the following title is chosen for this report: *Design and verification of a solar powered automatic rooftop hydroponic system with real time individual measuring of potassium and calcium*. The report will try to answer the following question: How can an automated system for control of nutrient concentration and pH in a solar powered hydroponic system be developed, implemented and verified? The report will also try to answer the sub-questions:

- How can an operational hydroponic control and monitoring system be designed and implemented?
- How can a functional solutions for automatization and off-grid operation of an outdoor hydroponic system be designed and implemented?
- What is the benefit of measuring individual nutrients, and how can this contribute to optimization of a hydroponic system?
- Which improvement, beyond current practice, can be implemented in the future?

# Chapter 4

## Method

### 4.1 Method

The purpose of a method is to give insights of how a scientist collects, treats, analysis data and conducts the experiment [74, page. 12]. There are two different studies, empirical and normative studies[14, page. 14]. Normative studies are focusing on values and discuss questions regard this, and empirical studies are focusing on questions about facts. Empire are information that builds on our experience, and scientifically studies are characterized by structuring the empirical information on a systematical way [14, page. 33]. The focus is on collecting as much empirical information as possible that is relevant for the research question. The data or information which are quantitative are often presented as numbers and qualitative data would be presented as text and pictures.

A method is a process for collect and process information. When this is done the purpose is that the result will consist of new knowledge. There are several methods for research like quantitative research method and qualitative method[74, page. 13]. Quantitative research is used for gathering numerical data to quantifying empiricism to get the data on a more structured format. An example can be to create a matrix to organize the data. This method follow the scientific method closely. One way of using quantitative methods is to try investigating a hypothesis conducting experiments. Hypothesis are predictions about phenomenons, which state how two tings are related. This are often referred to as both dependent and independent variables. The goal of the experiment can be to discover the cause of the phenomena based on the two variables.

Non numerical data like meanings or opinions are gathered and investigated in qualitative research[74, page. 13]. It can also be used to find the underlying reason from its subjects. An example of how to gain data could be to do interviews with groups or people person to person. The structure of the qualitative research method is less structured than quantitative research method, and the sample sizes are often small. Both quantitative and qualitative method have their own sub group of research methods.

There are two types how to collecting data[74, page. 100-101]. The first type is data that are produced through an experiment that is considered the researchers own data, and the second type is data that are already present from other experiments and research. Data that is considered the researchers own data are unique and would not exist if it was not for the experiment done by the researcher. Examples of data that are produced by the researcher can be data collected by interviews, through mail, or meeting people and asking for information. Numerical data can also be gathered through experiments and scenarios the researcher

creates. Already made data that are present from other experiments and research can be gathered through published articles, books, private letters and diaries. Data can be sorted in quantitative and qualitative data as shown in table 4.1 where A and B are the extremes [14, page. 124]. In practice these extremes are not absolute, but may also blend together in some degree. The data that are most quantitative are the metrical data and can be variables like intervals or ratio levels. The data that are non metrical data but are still presented as numbers are less quantitative but still more qualitative than metric data. These data can still be variables but are not linked or assigned to something. These are named nominal data. Some of these data can still be in some order. These data are called ordinal data. The next category in the table is data expressed by other quantity terms. To the extreme at the right side (B) in the table data expressed by pure text are placed. It is important to remember that these data are not competing with each other, but it is rather an advantage if the data types can complement each other.

Table 4.1: Different types of data [14, page. 124]

Quantitative data (A)		Qualitative data (B)	
Metric data	Non metric data, expressed by numbers	Data expressed by other quantity terms	Data expressed by text

Regards to data quality, reliability and validity are important to consider [14, page. 220-221]. A researcher needs to consider what sources that are suited and appropriate to use regard the experiment that are going to be performed. At one side, the validity or relevance of the data are important, but also as reliable as possible. The main reason for this is to avoid mistakes, misunderstandings and minimize the change of errors. The validity depends on if the information collected are good for the problems that are going to be solved. Data with high quality for one problem can have low quality for another problem. High validity depend on how the research question are being formed and presented. The validity is considered good and satisfactory if the data collected are meeting the intention of the study.

This master thesis is an empirical study using mostly quantitative research method to collect some of the results, like values measured by probes. The thesis also uses qualitative method to present the solutions for the Labview code and the connection sheets for the electronics with pictures and text. All these data are the researchers own data. As shown in table 4.1 with different types of data, this thesis will be somewhere in the middle. This thesis consists of several science fields like biology, computer programming, electronics consisting of small circuits and solar power. This makes the thesis interdisciplinary research, and considering the researcher is a student, the validity could be lowered compared to an expert of each field. This in spite of that the reliability is high. The article also uses theory from already published articles and books to make a foundation that can build up under the results and data collected. Consulting the supervisors have also been done to get advice and expertise along the way. This information is also considered qualitative data, and the validity and reliability regard these data are considered high.

## 4.2 Preparations

As this master thesis was a continuing of the energy research project a small amount of the parts were already bought and reused throughout the master thesis. However, the research project was a small part of a full monitor and control system, only demonstrating the principle of how it could be solved, not a full system for in and outdoor use. This means that a lot of parts had to be planned and ordered, for both the system used for testing at the lab, and the rooftop system. The most parts need to be ordered, except the few components that could be reused from the research project. This process was very time consuming because the parts needed to be put to order while the functionality of the system also was decided. So it was hard to decide what to order and buy when the functionality was not fully decided. An example is the one of the electrodes was ordered in February and received in the end of March. The functionality of the system was decided in collaboration with the supervisors. It was in this process the limitations were set. Then the schedule and plan were carried out by the researcher. Shopping lists, requests for price and offers were also carried out by the researcher. Several of the parts were off the shelf, but some had to be ordered through the university. Calculations and dimensioning of the solar power system for the rooftop system were done before the researcher made an approach to the supplier for ordering. The calculations can be seen in chapter 5.2 named Solar Power.

Considering the Norwegian seasons with low temperatures and the risk of a long winter, the system was split into an indoor lab system and an outdoor rooftop system. This was done to generate test results in a stable indoor environment, alongside testing and improving the system. Due to the weather and snow combined with a long period of low temperature the start of assembling of the rooftop system was delayed to the second week in May 2019. The work with implementing the system from the research project directly to the indoor lab was started the second week in January 2019. The components provided from UiA and the supervisor were the aluminium frame that are shown in figure 1.1 in the introduction, and the amount of tubes that were meant for the plant to grow in. The dimensions of the polyvinyl chloride (PVC) tubes for the system in the lab are  $2400\text{mm} \times 100\text{mm} \times 50\text{mm}$  [75]. The holes in the tubes are  $45\text{mm}$ . This system is called NFT System, and an example with lettuce can be seen in figure 4.1.



Figure 4.1: NFT system with 12 hole tubes filled with lettuce

A 3D model of one tube for the lab can also be seen in figure 5.12 in chapter 5.5, and drawings with detailed dimensions can be seen in appendix A.0.3. Only one of the tubes in the lab was used regard this thesis. The tubes are filled with water from the top in one end, and drained under at the other end as shown in figure 4.2. The water is recycled in 25L water containers as shown in figure 4.3. Also a stationary computer for Labview and logging, lights, water containers, tubes, seeds, pumps, hoses and a tub for use when planting the seeds, was provided by UiA and the supervisors. Labview is the software used for controlling all the components and storing and distributing the data that are collected. Labview has been learned by the researcher along the way.

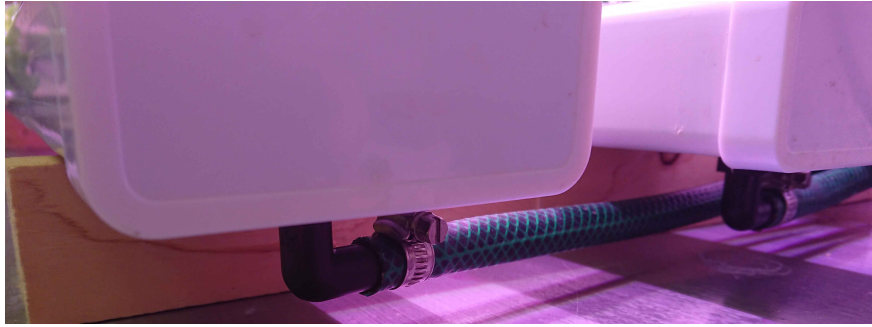


Figure 4.2: Tubes that are drained from the underside



Figure 4.3: Water containers for the hydroponic system



The lights for the main system in the lab are from Intravisjon and are shown in figure 4.4. These lights have the specifications of max 2,8A and 135W. The lights are measured to  $166 \mu\text{molm}^{-2}\text{s}^{-1}$  with a quantum meter with separate sensor from apogee instruments as shown in figure 4.5.



Figure 4.4: Growing lights for the main hydroponic system in the lab



Figure 4.5: Quantum meter with separate sensor from apogee instruments

Before the plants are moved into the tubes they are planted in a small plastic container with a plastic floorboard inside. The seeds spend two weeks sprouting before moving into the tubes. The outer dimensions for the container are  $640\text{mm} \times 490\text{mm} \times 130\text{mm}$  and  $590\text{mm} \times 440\text{mm} \times 130\text{mm}$  for the inside, and the plastic floorboard lifts the plants in the proper height. This makes the rock wool just touch the water with nutrient so it can absorb it slowly. The water is filled up to approximately  $65\text{mm}$ . The container also have an air pump connected, supplying oxygen to the water. The lights used for the tub have the model number 2G11 and uses 26W. The lights are measured to  $302 \mu\text{molm}^{-2}\text{s}^{-1}$



Figure 4.6: Small plastic container with air pump, growing lights and one and two weeks old plants

The rooftop system is shown in figure 4.7, and the plants spend four weeks in the tubes before harvesting. In this system there are two water containers and six tubes. The system is divided in two, with three of the tubes connected to one of the water container each. This means that there will be two control systems for the roof top system, and one for the indoor lab system. Potassium and calcium will only be real time measured in one of the systems.



Figure 4.7: Rooftop system with two water containers and six tubes

### 4.3 Choice of components

The choice of components was as mentioned chosen along the way and based on low maintenance, cost, robustness, size, compatibility, availability and area effective. myRio was chosen and used because it is excellent for use with prototyping and it gives a broad range of analogue and digital in- and outputs. myRio is part of National Instruments and is supported by Labview, which is a graphical programming software. Based on this, Labview is a natural choice regards to programming language for use to receive data from the sensors, probes and electrodes for control of the pumps. As this thesis is focusing on two separate systems, one indoor system built and used from January to April, and one outdoor rooftop system built and used from May. The Labview code made from myRio has developed along the way. At the start of the thesis Arduino was used for calibration because the supplier already has a premade code made in *C* for this purpose. At the end in May there was implemented functionality for this in the Labview code. The myRio can supply both 3,3V and 5V to the relays that control pumps. myRio and the other components like pumps etc are compatible with 12V. The supply of 12V from the solar power system has been an important factor for choice of components. Fuses and voltage regulators have been used where it is needed to protect the electronics and supply the system with stable power. For measuring EC, pH and individual nutrition, the choice of components fell on EC and pH probes from Atlas-Scientific, and individual nutrition electrodes from Vernier. The main reason for this is low price compared to industrial probes, and the probes from Vernier and Atlas are designed for educational use. Circulation and peristaltic liquid pump were chosen based on compatibility with 12V and easy accessibility as off shelf component. The solar power system was ordered from 2Soler which is a company located in Farsund approximately two hours drive from Grimstad [76]. The choice of system including solar modules, batteries and power regulator were chosen based on nearby location of the vendor and low cost. A solar system also has low maintenance with no moving parts.

### 4.4 Assembling the system and programming Labview

As mentioned in chapter 4.2 the weather was a big concern with regards to when it was possible to start assembling the rooftop system. The solar power system was ordered and delivered in December, but stored at UiA near the lab until May because of unsuitable weather. Because of low temperatures and bad weather it was not possible to start working with the rooftop system before May, and the focus was until this point on the system at the lab inside the University. The time available at the lab made it possible to grow three crops with lettuce, and the results are shown in chapter 5.8.1. At the rooftop, four crops where started but these will not be done before June. The assembling of the electronics used for testing in the research project for the control system in the enclosure box was done in the Christmas holiday, before startup of the spring semester. Some of the design for support brackets and 3D printing were also done in the Christmas holiday. Meanwhile, waiting for spring and sunny days, meetings to deciding the limitations were conducted and the control system from the research project was implemented in the lab for testing. Rockwool in net pots as shown in figure 2.1 in chapter 2.2.1 was chosen as growing medium for the lettuce, and the seeds used are called "Green Batavia" and "Chrisp salad with red leafs". The growing medium, pots and seeds were also supplied from the university. While implementing the control system in the lab, several challenges were discovered, and at the same time ideas regard improvements of functionality were considered. This is described in chapter 5.1. It was also decided through meetings that when the roof top hydroponic system was ready to be assembled, the hydroponic lab system should be discontinued and the parts reused for the roof top hydroponic system. The solar power system was connected in cooperation with electrician, and the electronics and programming have constantly been developed and improved. Learning Labview has



been done by trying and failing together with reading manuals and watching tutorial videos from Youtube. Learning Labview will always be a process that is and will be ongoing as long as the work the software is ongoing. This is due to the constant upgrades, and that it is a big software with more or less endless possibilities.

## 4.5 Calibration

To obtain correct measuring, calibration of temperature sensor, EC and pH probes, and potassium and calcium electrodes are necessary. The following chapters 4.5.1 4.5.2, 4.5.3 4.5.4 are explaining the different calibration procedures, starting with temperature since the pH and EC probe are dependent of measuring temperature to show correct value.

### 4.5.1 Temperature sensor

Temperature measuring is done by using a  $10K\Omega$  NTC connected in series with a  $10K\Omega$  resistor as shown in figure 2.3 in chapter 2.4.2[77]. The NTC also has a tolerance of 1%. The myRio connected to a computer with Labview is reading the voltage measured between the NTC and the resistor, and ground. The myRio can then translate this to a temperature for the user to read from the screen. Calibrating the NTC resistors is done with three different temperatures as shown in table 4.2. The Thermistor Calculator by Stanford Research Systems Inc is also used. The SteinhartHart thermistor equation [34] is used and is shown as equation 2.2 in chapter 2.4.2. The resistance of the thermistor is found by measuring the resistance with a multimeter at the certain temperatures as shown in figure 4.8b and 4.8a. The temperatures  $0^\circ\text{C}$ ,  $20^\circ\text{C}$ ,  $29^\circ\text{C}$  are found by first using ice water to achieve  $0^\circ\text{C}$ . Then adding hot water to the thermometer displays  $20^\circ\text{C}$  and  $29^\circ\text{C}$ . Each temperature are measured after 1 minute after the water is added to make sure the water is mixed, and the temperature is stable. The three different temperatures and the resistance are shown in table 4.2. The calibration values from the calculator are shown in figure 4.9, showing the A, B and C coefficients are  $A=2.11e^{-3}$ ,  $B=0.75e^{-4}$  and  $C=7.84e^{-7}$ .



(a) Calibration of temperature sensor with  $0^\circ\text{C}$



(b) Zoomed in picture of calibration of temperature sensor with  $0^\circ\text{C}$

Figure 4.8: Temperature calibration

Table 4.2: Resistance and temperature for NTC.

RESISTANCE VALUE	TEMPERATURE
23000 $\Omega$	0 $^{\circ}\text{C}$
9805 $\Omega$	20 $^{\circ}\text{C}$
6690 $\Omega$	29 $^{\circ}\text{C}$

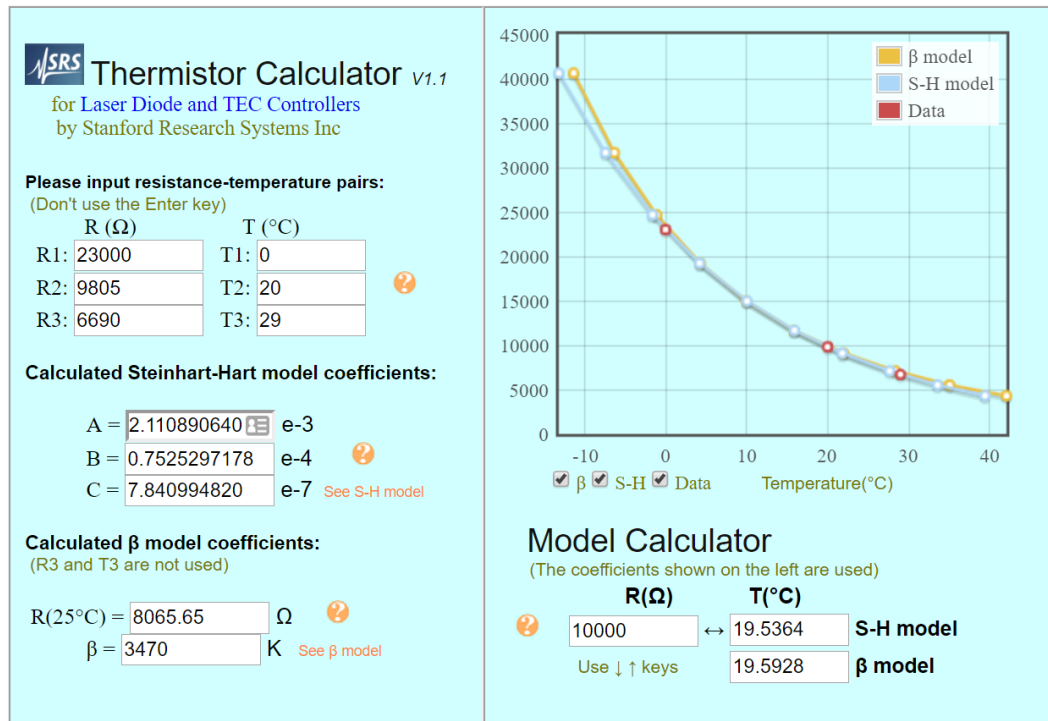


Figure 4.9: Calibration temperature sensor 1 and 2 [8]

## 4.5.2 Calibration of pH probes

The probes to measure the PH value are from Atlas Scientific, and as mentioned in chapter 2.7.2 the probe has a range from 0 til 14 on the pH-scale. A picture of the pH probe can be seen in figure 4.10 Calibration of pH was done in room temperature with an Arduino microcontroller. The microcontroller supply 5V operating voltage to an EZO circuit from Atlas Scientific, that reads and transmits the signal from the probe to the microcontroller trough UART [9]. When measuring pH and EC at the same time the values from the EZO circuit became unstable. After approximately one week with testing the problem got solved with implementing voltage isolators for both pH and EC. The reason for this is that both probes detects and uses small voltages to generate a value for the EZO circuit, for the myRio to read. When voltage isolator is used will the operating voltage into the voltage isolator from the Arduino become 5V, and out from the voltage isolator to the EZO circuit it will be 3,3V [78]. The default temperature compensation for the probe is set to 25  $^{\circ}\text{C}$  with 5V in the EZO circuit, and the temperature tolerance for the probe and circuit is  $\pm 2^{\circ}\text{C}$  from 25  $^{\circ}\text{C}$  [9]. The temperature calibration was not taken into account for growing crops in the lab because of stable temperature. It was also not taken into account for growing crops on the rooftop hydroponic system regards to making a simplified Labview code. For calibration the supplied example code written in C from the supplier Atlas Scientific was used for the Arduino for calibration when the testing was ongoing in the lab, and through Labview when hydroponic rooftop system was assembled on the roof. The calibrations are stored in the circuits ready for use with the myRio after the calibration. The pH calibration was done using

three different reference liquids. The liquid with lowest pH value is red. This liquid has a pH value of 4. The yellow which is the neutral liquid has a value for 7, and the blue with highest value has pH value of 10. An extract of the pH calibration results with Arduino and *C* can be seen in table 4.3. The calibration procedure is to put the probe into the three calibration solutions in the order 7, 4 and 10. For each time given the command of storing the reference value, it can be seen in the table that the EZO circuit respond with \*OK when the value is stored. The probe has to be cleaned with distilled water between each value.



Figure 4.10: pH sensor from Atlas Scientific [9]

Table 4.3: An extract of the pH calibration results

Storing calibration for pH = 7	Storing calibration for pH = 4	Storing calibration for pH = 10
6.998	3.995	10.001
6.998	3.997	10.001
6.998	3.998	10.001
6.998	3.998	10.001
6.998	3.998	10.001
6.998	3.997	10.001
6.997	3.997	10.001
6.997	3.997	10.001
6.997	3.996	*OK
6.998	*OK	10.000
6.998	4.000	10.002
*OK	4.000	10.001
7.000	4.001	10.001
7.001	4.003	10.001
7.001	4.005	10.003
7.002	4.004	10.004

### 4.5.3 Calibration of EC probe

The probe used for calibration from Atlas Scientific is called Conductivity probe K 0.1 and can be seen in figure 4.11 [2]. The calibration of the EC probes is also done in room temperature with an Arduino microprocessor and the *C* language with 5V supplied voltage to the EZO circuits. The EZO circuits for EC has the same criteria as the EZO circuits for pH. This means when the voltage isolators are used, the voltage supplied to the EZO circuits is 3.3V [78]. Temperature compensation was also here not taken into account. The EC probe was calibrated with a conductivity liquid with  $84\mu\text{s}/\text{cm}$  as a lower calibration point and  $1413\mu\text{s}/\text{cm}$  as a higher calibration point when used with the indoor hydroponic system. For the outdoor hydroponic

system calibrating with the calibration liquids in Labview and not through Arduino was less successful, and the system became unstable. The liquids were replaced and instead of two point calibration, one point calibration was done by measuring the EC value with the HQ40D from Hach. As mentioned in chapter 2.7.3, HQ40D is a professional portable reading devices for pH, EC, Oxygen and should be considered correct. The EC value was used as a reference for the Atlas Scientific probe. An extract of the calibration results for the two point calibration can be seen in table 4.4 The one point Labview calibration needs more testing over time before a stable calibration result can be given. The calibration shown in the table 4.4 is for the K 1.0 EC probe from Atlas with  $12\ 880\ \mu\text{s}/\text{cm}$  as a lower calibration point, and  $80\ 000\ \mu\text{s}/\text{cm}$  as a higher calibration point. This probe was tested and used in the hydroponic system in the lab for a period. The calibration procedure with Arduino and *C* is to put the probe into the two calibration solutions in the order 12880 and 80 000. Dry calibration needs to be stored before the storing of calibration solutions. For each time given the command of storing the reference value, it can be seen in the table that the EZO circuit respond with \*OK when the value is stored. The probe has to be cleaned with distilled water between each value. The procedure for calibrating the K 0.1 probe with  $84\ \mu\text{s}/\text{cm}$  as a lower calibration point and  $1413\ \mu\text{s}/\text{cm}$  as a higher calibration point is the same.



Figure 4.11: EC K 0.1 sensor from Atlas Scientific [2]

Table 4.4: An extract of the EC calibration results

Storing dry calibration for EC = 0	Storing calibration for EC = 12 880	Storing calibration for EC = 80 000
EC:0.00	EC:0.00	EC:80190
TDS:	TDS:	TDS:
SAL:	SAL:	SAL:
GRAV:	GRAV:	GRAV:
EC:0.00	*OK	EC:80240
TDS:	EC:12880	TDS:
SAL:	TDS:	SAL:
GRAV:	SAL:	GRAV:
*OK	GRAV:	*OK
EC:0.00	EC:12880	EC:80010
TDS:	TDS:	TDS:
SAL:	SAL:	SAL:
GRAV:	GRAV:	GRAV:
EC:0.00	EC:12880	EC:80030
TDS:	TDS:	TDS:
SAL:	SAL:	SAL:
GRAV:	GRAV:	GRAV:

#### 4.5.4 Calibration of potassium and calcium electrodes

In addition to EC the possibility to measure some of the individual elements are present. Potassium (K) and Calcium (Ca) are important elements that are beneficial to monitor. To measure potassium a probe called Go Direct® Potassium Ion-Selective Electrode is used and shown in figure 4.12a [10]. The potassium probe has a range from 1–39,000  $mg/L$  (or ppm), and the accuracy for the electrode is  $\pm 10\%$  with a pH range from 2 to 12 with no pH compensation. Calcium is measured with The Go Direct Calcium Ion-Selective Electrode that is used and shown in figure 4.12b. The calcium probe has a range from 1–40,000  $mg/L$ , and the accuracy for the electrode is  $\pm 10\%$  with a pH range from 2 to 8 with no pH compensation. Both electrodes can transfer data through both USB and Bluetooth, and they are delivered already calibrated from the supplier. However, the readings from the electrodes were checked, re-calibrated and controlled to be sure the electrode was within the acceptable area. The potassium electrode was checked with potassium chloride liquid(low) with a  $10PPM K^+$ , and a liquid(high) with  $1000PPM K^+$ . The calcium electrode was checked with a  $10PPM Ca^+$  liquid for low value and a  $1000PPM Ca^+$  liquid for high. The electrodes do not need to be temperature compensated and can be calibrated inside, for then to be brought outside for measuring. The calibration was done with Graphical Analysis 4. Starting the calibration procedure from Vernier, there was discovered a bug in the software by the researcher. The researcher used a Norwegian version of the software, while the supplier and the written manuals were referring to the English manuals where there was meant to be an option with a text box where new calibration values could be written. This option with text box was meant to give the electrode new calibration values. This text box was not available in the Norwegian version, and due to the mail correspondence between the researcher and the supplier, Vernier chose to release a software update for the Norwegian version of Graphical Analysis 4.



(a) Calcium Ion-selective electrode



(b) Potassium Ion-selective electrode

Figure 4.12: Calcium and Potassium Ion-selective electrodes from Vernier.[10]

The calibrations are done by soaking the electrode into the calibration liquids as described above. The electrode tip also need to be rinsed before each time. After the calibrations were performed, the electrodes was checked by measuring the liquids for 60 seconds. The Y axis shows  $mg/L$ . The results can as mentioned be seen in figure 4.13, 4.14, 4.15 and 4.16. It can be seen that the graph for potassium is more or less stable and near the calibration values. The graph for calcium for 1000PPM are also near the calibration values after 50 seconds. The graph for calcium with 10PPM is a bit more of target. This calibration value was harder to achieve correctly.

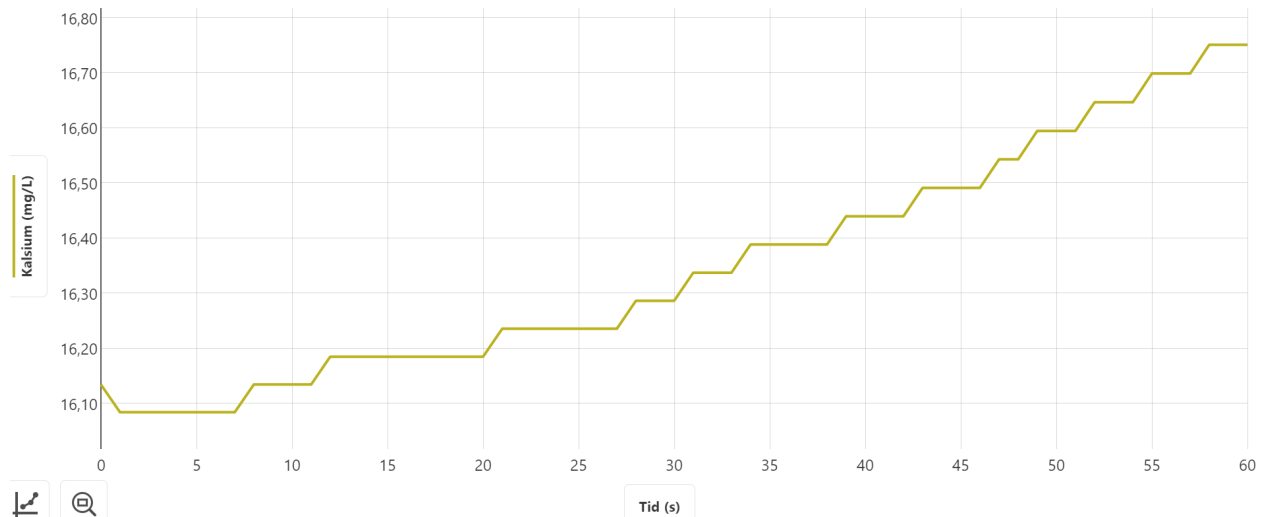


Figure 4.13: Calibration control of calcium probe from Vernier with 10PPM

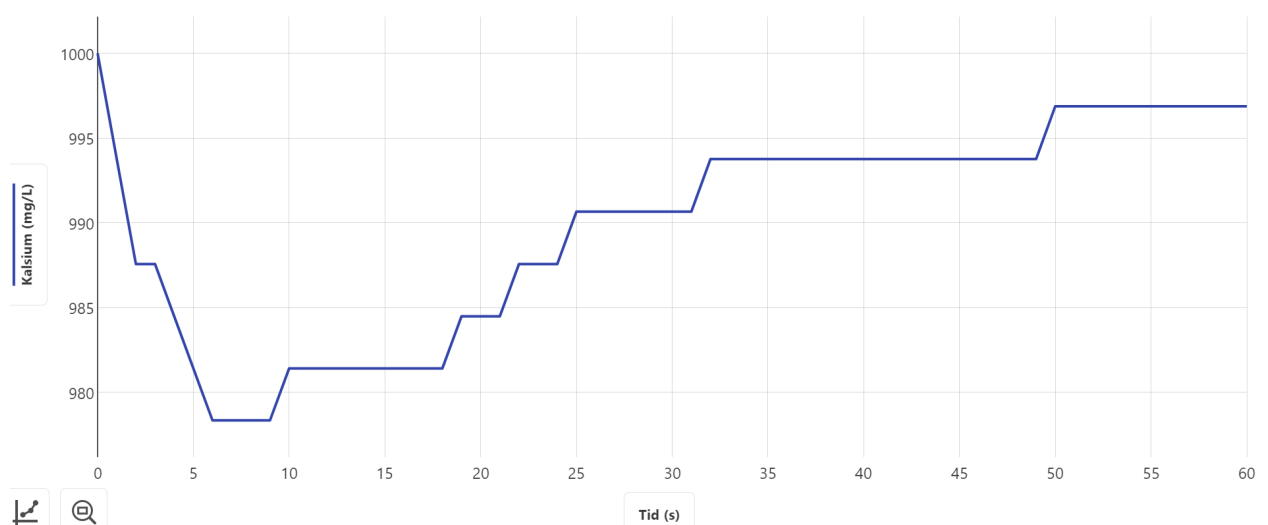


Figure 4.14: Calibration control of calcium probe from Vernier with 1000PPM

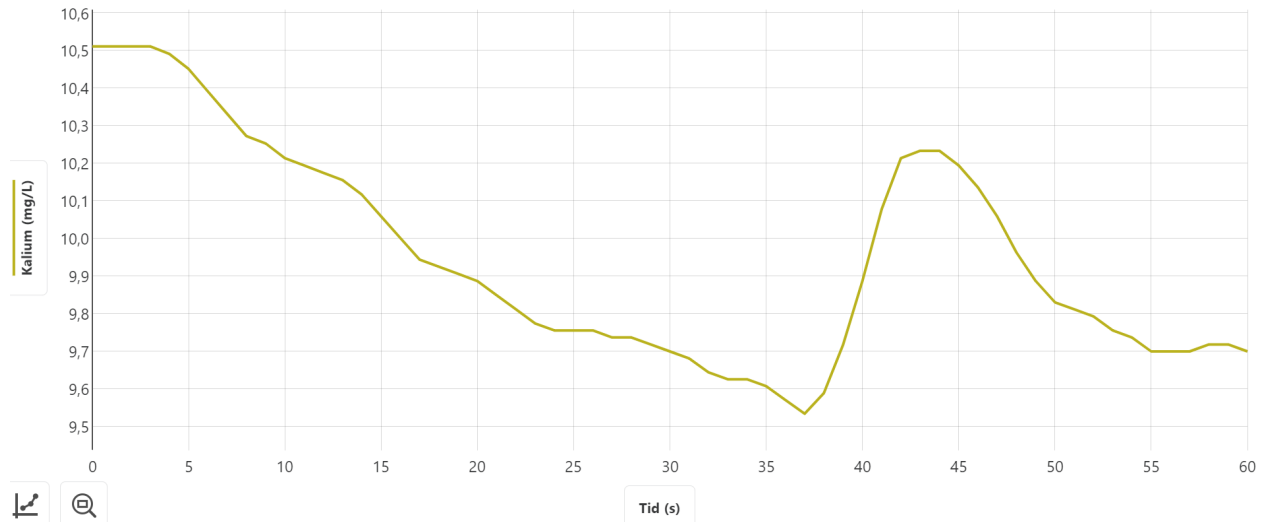


Figure 4.15: Calibration control of potassium probe from Vernier with 10PPM

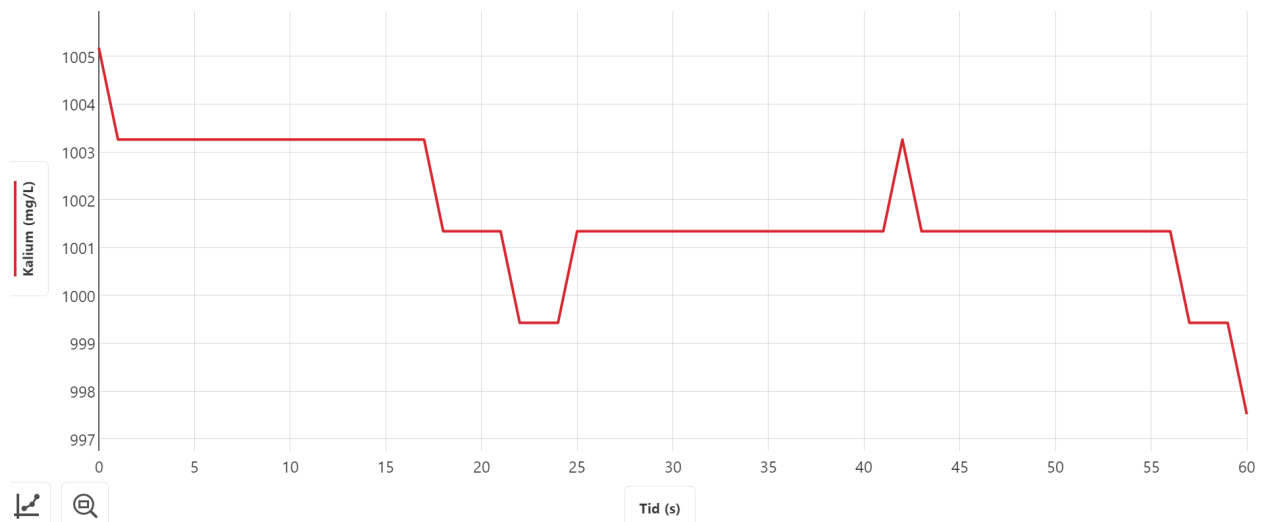


Figure 4.16: Calibration control of potassium probe from Vernier with 1000PPM

The results for potassium- and calcium-ion measurements from the crops in the lab are gathered running the software Graphical Analysis 4 from the supplier. The measurements are done over 180 seconds, and the average is calculated in the software to give a more correct value for comparison. The standard deviation is also shown. The results are presented in chapter 5.8.3. For the rooftop hydroponic system the measuring in the potassium- and calcium-ion are implemented in the Labview code, but needs more testing over a longer period of time to generate results for a full crop.

# Chapter 5

## Results and discussion

### 5.1 Challenges

Starting up the system in the lab in January there were immediately at the start discovered errors, weaknesses and ideas for improvements. The biggest challenges regard to the control system that was discovered was logging of data, as mentioned in chapter 4.5.3, stable readings from pH and EC at the same time and stable connection to the myRio and the probes for individual nutrition. Regards to the time limit several problems needed to be solved in parallel. The challenge was the USB connection problems with the myRio. This was hard to handle because the fault was irregular. Connection through Wi-Fi was not an option because then it would probably need clearances from the universities IT department and it was preferred to have wired communication for secure, stable and easier access. There were no signal on the roof to the Wi-Fi that is available for students. The possibility of installing a local wireless network only for the hydroponic system was considered unnecessary complex and would also probably need clearances from the University, and the system installed on the lab needed to work for the roof top system. So with this in mind the solution needed to work for booth the lab and roof top hydroponic system. Trying to solve this, a lot of observation over time was needed to see if the system was interrupted by loss of communication. A challenge with the rooftop system was to log all the data with a stationary computer. A stationary computer is often big and there was no option to keep the computer on the roof. This generated a limitation regarding to that communication which needed to work from the roof and down one floor to a storage room. In the storage room the computer was set up and connected, and TeamViewer was installed for easier online control and monitoring of the system. After much testing, the solution became an active USB cable. The active USB cable was used because the communication was lost with passive cables if the length was more than a couple of metres. The reason for this could be no shield and/or trouble with interference, lack of signal repeaters or no voltage isolator. The reason was not investigated further. The researcher got help from an electrician to pull the cables from the hydroponic rooftop system to the fourth floor. The active USB cable was in the start powered by power banks for testing, but these were replaced later with power from the solar power. This was done to create a permanent power supply.

There were also discovered two problems with the connection of the Vernier electrodes. They were successfully connecting through USB when using the cable that followed the product. But using any extension cable they also, like myRio, had trouble communicating through USB. An attempt to try to solve this was made by ordering a Bluetooth dongle, because they are Bluetooth compatible. The challenge was discovered when they did communicate through Bluetooth with laptops, but not with the stationary computer and the



Bluetooth dongle. After an email correspondence with the supplier the conclusion was that Vernier did not have the possibility to update drivers for all Bluetooth dongles, and this probably was an unknown third party dongle. So this Bluetooth dongle was not compatible. After ordering another Bluetooth dongle, this time from ASUS which are a more known brand, connection through Bluetooth was established. This was first tested in the lab, but later implemented on the roof with the active USB cable sharing connection with the myRios through the ASUS USB dongle connected in the USB hub as shown in figure 5.11 in chapter 5.4. When installed together with the roof top hydroponic system, the probes ran out of power so the final solution was to also connect these to the active USB cable through a USB hub.

As mentioned previously in chapter 4.2, Labview is the software used for controlling all the components, storing and distributing the data that is collected. The logging of data was also a bigger issue. As mentioned in chapter 2.5 the operating system for myRio is Linux which makes it hard to directly log files to the computer. As also mentioned in chapter 4.2 the researcher has been learning Labview along the way, so functionality has been discovered continuously. The option for solving this is to create a log file on the myRio itself, or make a Main Vi connecting all the sub VIs together and storing all the information in one or more files through the main VI. Another option is also to store files in a IoT cloud. This was solved by combining all these three solutions to make sure no data is lost. Unfortunately the solution is implemented at the end of the project. Logging of pH, EC and water temperature for the system in the lab has been done in a semi automatically way. There was not made any solution for the logging challenge at the start other then list every measurement in a table inside the Labview software. This was because the researcher did not have sufficient knowledge of Labview at this time. For each time the myRio stopped, the data was manually copied to an Excel sheet and stored, generating several files and loss of data each time the myRio lost connection. The loss of connection for the myRio also made the Labview VI for measuring potassium and calcium unstable. To make secure data along the way these data have been done manually through Verniers software Vernier Graphical Analysis. The results are shown in table 5.8.3. There was also made four separate measures from samples which can be seen in chapter 5.8.2 comparing pH and EC to the professional portable reading devices HQ40D from Hach. Potassium and calcium were also measured and compared to analysis result from Eurofins. The challenges regard stable readings from pH and EC at the same time were after much testing solved by implementing a voltage isolator for each component.

As mentioned in chapter 4.2, weather was a concern. Due to the snow combined with a long period of low temperature the start of assembling of the rooftop system was delayed to the second week in May 2019. This together with a Labview code that became bigger than planned and more and more advanced, the researcher had to ask for help and consultancies from a friend which has more experience and knowledge with programming. The friend helped to carry out the plan together with the researcher regards to assembling the system. This was done to manage to have a fully functional hydroponic system ready before deadline. The researcher also needed to apply for that the deadline date was delayed one week because of the weather delayed startup of the assembly. The delay was approved by the university.

## 5.2 Solar Power

The rooftop hydroponic system is dependent on a steady power source, and to be non dependent of the power grid. The roof on the J-building is also suited for solar panels based on that some of the space on the building are already used for other solar panels. This made the choice fell on using solar power. The components bought for powering the hydroponic system are based on the calculations that follows this chapter.

### 5.2.1 Calculations

The components that consumes most power are peristaltic liquid pump, circulation pump, power supply for myRio and probes as shown in table 5.1. The specifications are taken from the data provided with the product, except for the current for peristaltic liquid pump. The current for this item was not found, and had to be measured by a Unit-T UT210D 200A AC/DC Mini Clamp meter. Watt per item is calculated using equation 2.11 in chapter 2.6, and total watt is calculated by multiplying the quantity with watt per item. The sum of watt total can be seen in table 5.2. This table also shows watt hour, which are calculated by multiplying watt total with T (time used each day) as shown in equation 2.12 in chapter 2.6. For peristaltic liquid pump this have to be converted to seconds as shown in equation 2.13.

Table 5.1: Power consumption overview

Item:	Spec:	Watt per item:	Quantity:	Total watt:
Peristaltic liquid pump	12V/0,7A	8,4W	6	50,4W
Circulation pump	12V/2A	24W	2	48W
Power supply for myRio	12V/0,3A	3,6W	2	7,2W
Probes	5V/5,12A	0,0256W	4	0,1024W

Table 5.2: Overview of power consumption per day(24 hours)

Item:	Watt total:	Time used each day	Watt hour (Wh)
Peristaltic liquid pump	50,4W	Maximum 10 sec. each 30 minutes	0,01Wh
Circulation pump	48W	12 hours a day	576Wh
Power supply for myRio	7,2W	24 hours a day	172,8Wh
Probes	0,1024W	24 hours a day	2,4576Wh
Sum	106W	-	751Wh

Table 5.3 shows max and total current. The max current and total ampere hour(*Ah*) are calculated by using the equations 2.10 in chapter 2.6, dividing total watt on 12V, and total *Ah* is calculated dividing watt hour by 12V.

Table 5.3: Max current and total ampere hour(*Ah*) per day(24 hours)

Max current with 12V:	Total ampere hour ( <i>Ah</i> ) ved 12V:
8,8A	63Ah

### 5.2.2 Simulation

Drawings and simulations are done with PV-Sol and PV-Sol Standalone. Both software are from Valentine software. The drawings are only made to illustrate the setup without dimensions. The frame for the hydroponic system can be seen with dimensions in appendix A.0.2. Figure 5.1 shows a model of the J-building the hydroponic rooftop system is located on. Figure 5.3 shows a zoomed in model of the hydroponic rooftop system and three solar panel used for supplying the system with power. The tilting of the solar panels is not shown in the picture, but is set to 60° to benefit from the evening sun. The Azimuth angle is set to zero based on that the building only has a small Azimuth angle and that small variations have low impact on the irradiation.

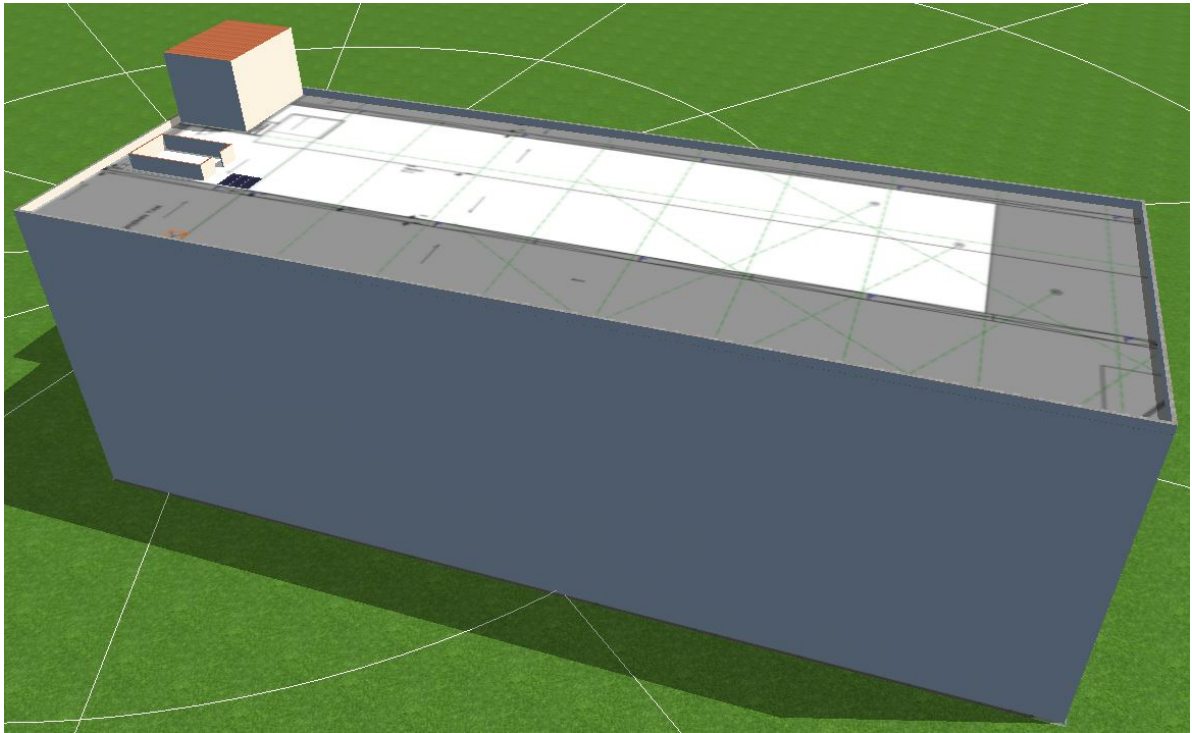


Figure 5.1: Overview of the solar panel installed on the building

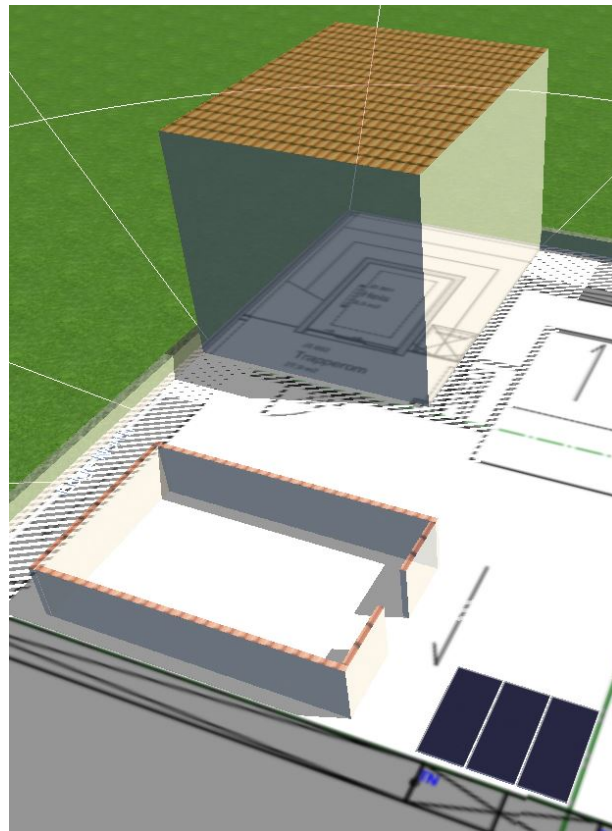


Figure 5.2: Zoomed in overview of the solar panel installed on the building

### 5.2.3 Data

The simulation loads used in PV-Sol Standalone are based on the total watt calculations in table 5.2 and the total time the components are used. The values for how long they are used are given in table 5.2 and the period is from start of April to end of September. The rest of the year the hydroponic system is shut down. The system is dimensioned for these six months and that it can handle some days without sunshine. The software calculates the annual consumption for each load and the total annual energy requirement, and the values can be seen in figure 5.3.

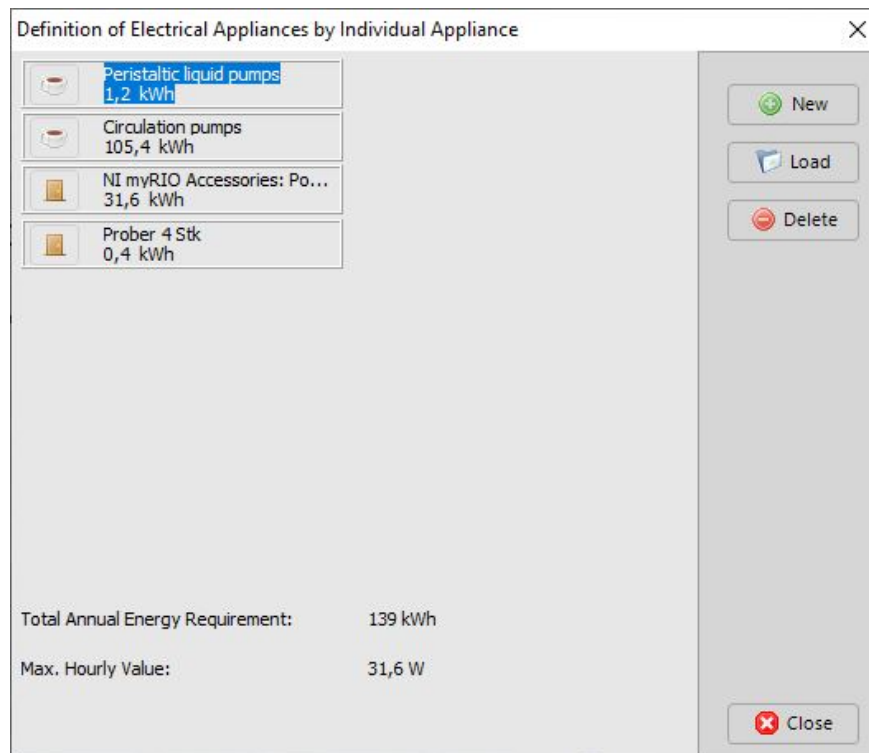


Figure 5.3: Overview of loads for the solar power system

The setup for the system can be seen in figure 5.5. The parameters for the simulation that are selected for PV-Sol Standalone is one array with three solar modules connected in parallel. Due to Kirchoff's law in chapter 2.6 the voltage is the same for all the panels and the current is multiplied, which gives effective charging of the two batteries in series controlled by the regulator. The specs from the data sheets are used for configuring the modules, batteries and the regulator in PV-Sol Standalone. The data sheets for the solar modules, batteries and regulators can be seen in appendices A.0.6, A.0.7 and A.0.8. The total simulation results can be seen in figure 5.5, and it can be seen that from PV array irradiation of  $3561,7kWh$   $412,60kWh$  is utilized. This gives an PV array efficiency of 11,6 percent for the PV array. The datasheet for the modules gives a PV array of 15,35 percent which is higher than compared to the simulation. The system with full load consume  $138,7kWh$  at max, which gives a system efficiency of 3,9 percent. It can also be seen in the simulation results that the performance ratio is 24,5 percent.

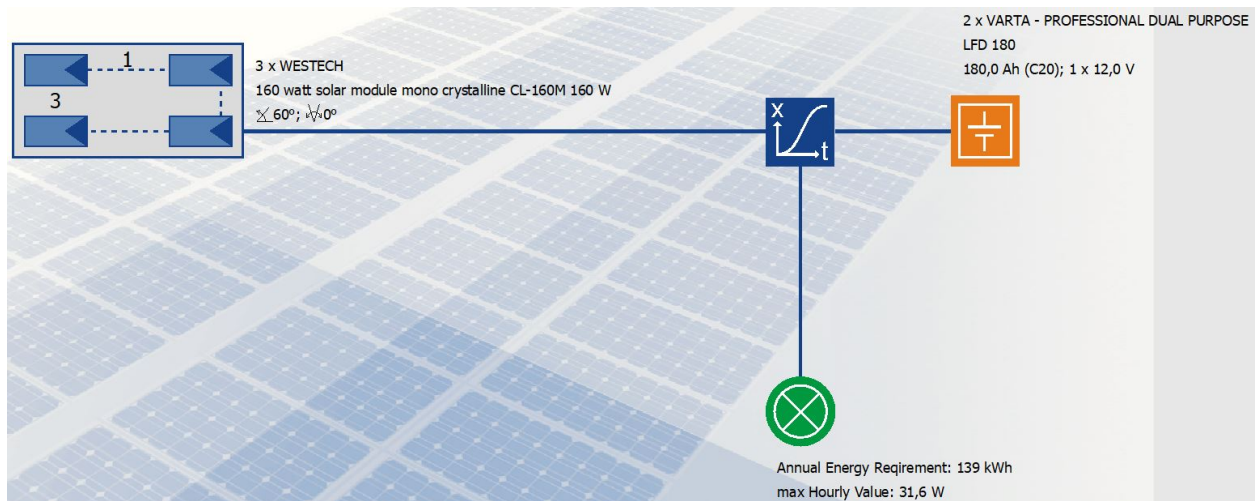


Figure 5.4: Simulation result of the solar power system

Location:	Grimstad
Climate Data Record:	Grimstad (1991-2010)
PV Output:	480,0 Wp
Gross/Active PV Surface Area:	3,02 / 3,02 m <sup>2</sup>
<hr/>	
PV Array Irradiation:	3 561,7 kWh
Energy Produced by PV Array:	412,60 kWh
Consumption Requirement:	138,70 kWh
Consumption Covered by Solar Energy:	138,69 kWh
Consumption Not Covered by System:	0,0 kWh
<hr/>	
Solar Fraction:	100,0 %
Performance Ratio:	24,5 %
Specific Annual Yield:	288,9 kWh/kWp
CO2 Emissions Avoided:	85 kg/a
System Efficiency:	3,9 %
PV Array Efficiency:	11,6 %

Figure 5.5: Simulation result of the solar power system

### 5.3 Mineral solution

To regulate the pH value 6,5%  $HNO_3$  (Nitric acid) is used. This is used as an acid to lower the pH value and is pumped into the water reservoir if the pH value is too high. The nutrition used for the system is named Nutri-A and Nutri-B from Panponic. Nutri-A consists of phosphorus, potassium, magnesium and sulfur. Nutri-B consists of nitrogen in form of  $NO_3^-$  and  $NH_4^+$ , calcium, chelated iron, zinc, boron, copper, molybdenum and mangan [79]. In figure 5.8, 5.9 in chapter 5.4 these chemicals are named B1 and B2. By mixing 4ml of both components it will give EC of 1,0-1,2mS/cm and pH value of 5,7-6,0 [79].

## 5.4 Hydroponic system

Figure 5.6 and 5.7 shows drawings of the rooftop hydroponic system. The system consists of rectangular PVC tubes mounted on a rack with required technical equipment for monitoring and control. The total size of the structure is approximately 5 metres long and 3 metres wide. Each tube is approximately 4 metres long and have 20 holes for plants to grow in. Full drawings can be seen in appendices A.0.2.

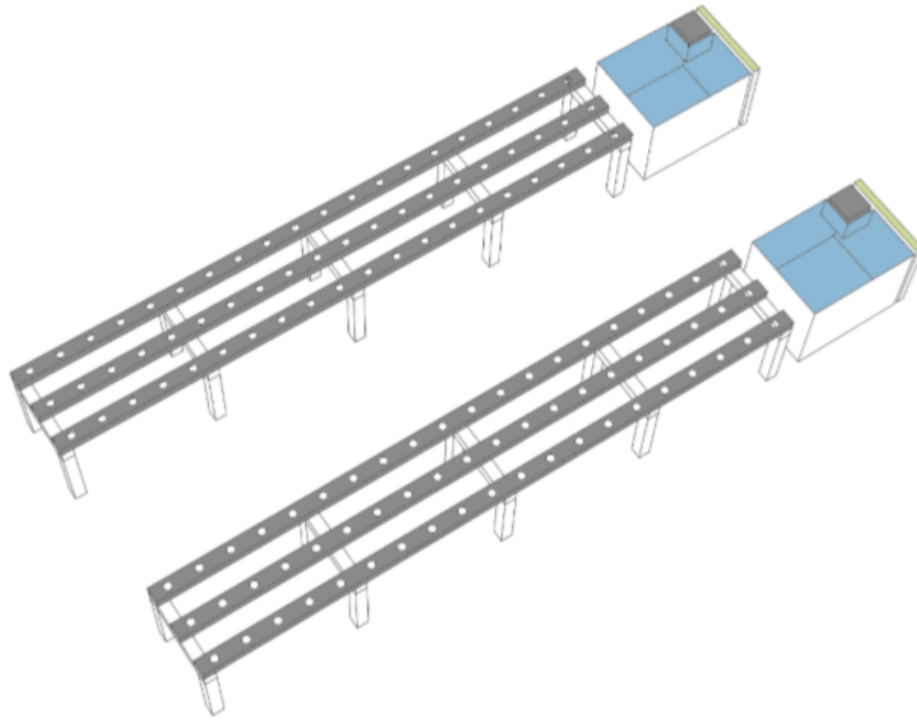


Figure 5.6: Drawing A of the rooftop hydroponic system [11]

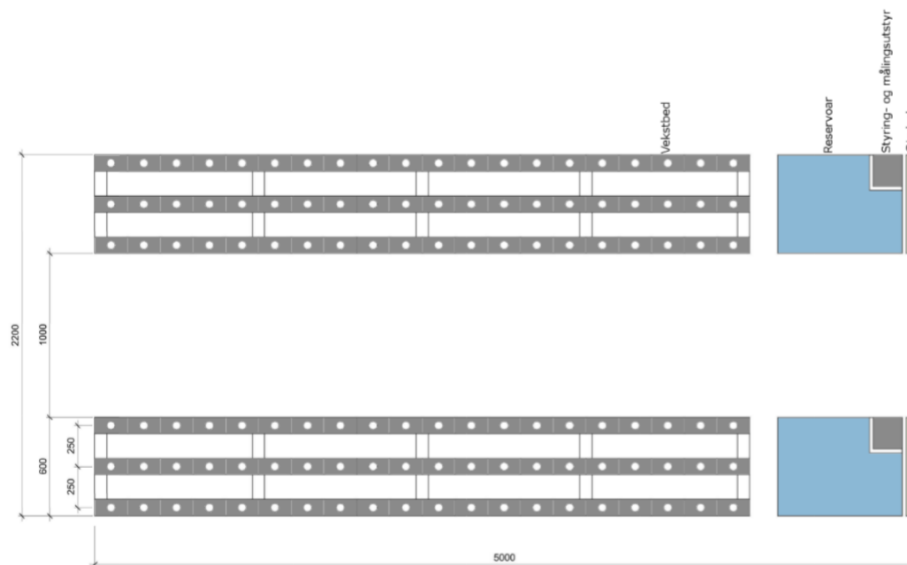


Figure 5.7: Drawing B of the rooftop hydroponic system [11]



The system created for the lab for testing is a simplify version of the rooftop system, and is shown in figure 5.8. The physical differences is that the roof top system is bigger and is split in two. Each of the two parts have three tubes. The water reservoir for the system in the lab is 30 litres compared to the water reservoir for the rooftop systems that are 100 litres for each reservoir. The system in the lab is also a single system with one unit, and the tube for the plants is 2,4 metres long. Full drawings are created by the researcher and can be seen in appendices A.0.3. For the system at the lab pump 1 circulates the water, and pump 2 to 4 supply the necessary additives due to the set point. The control system for tank 2 also measure air temperature. Figure 5.9 shows how the two rooftop hydroponic systems are connected to the nutrition pumps and acid. Pump 1 and 2 secure circulation of water from the reservoir, and the sensors for both systems measure temperature, pH and EC. In tank 2 the Ion concentration for potassium and calcium are also measured. Based on the data from the sensors, pump 3 to 8 supply the necessary additives to secure that the values are correct due to the set point.

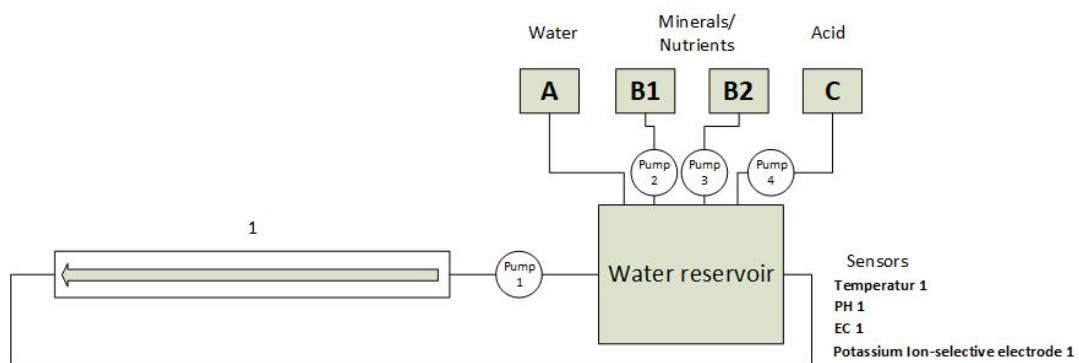


Figure 5.8: Block diagram of the lab system with single units

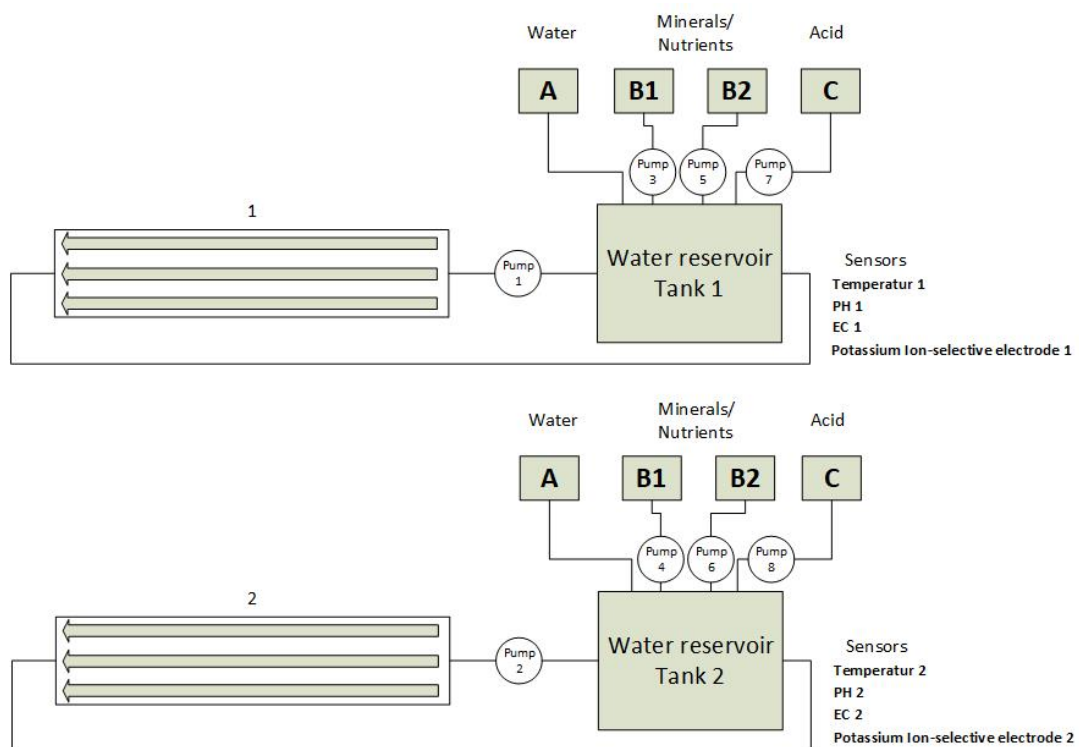


Figure 5.9: Block diagram of the rooftop system with double units

Connection diagram of the control system in the lab and on the rooftop are shown in figure 5.10 and 5.11. myRio are in both systems connected through USB and the probes from Vernier was as mentioned before after much testing connected through USB. At the start Bluetooth was used. When the computer was used in the lab there was not made a finished IoT solution. This was made and finished alongside the assembling of the rooftop hydroponic system.

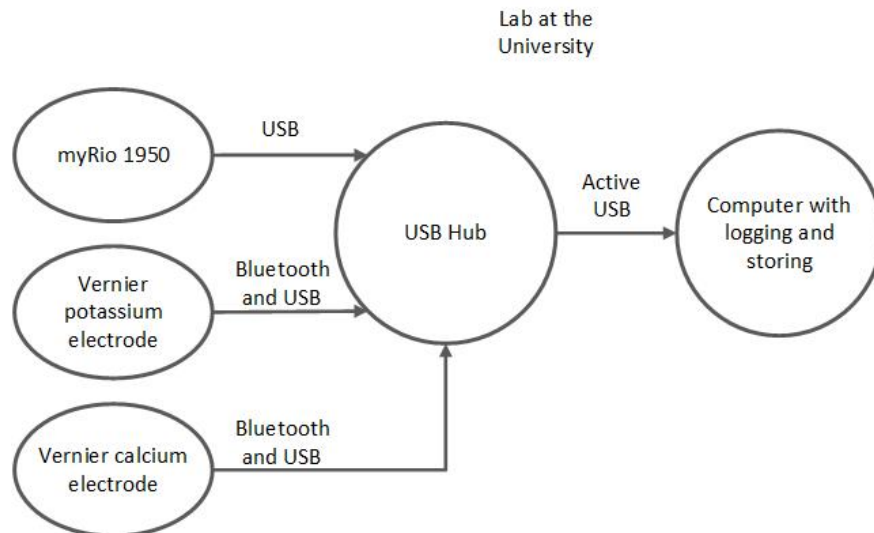


Figure 5.10: Device connection diagram for the hydroponic system in the lab

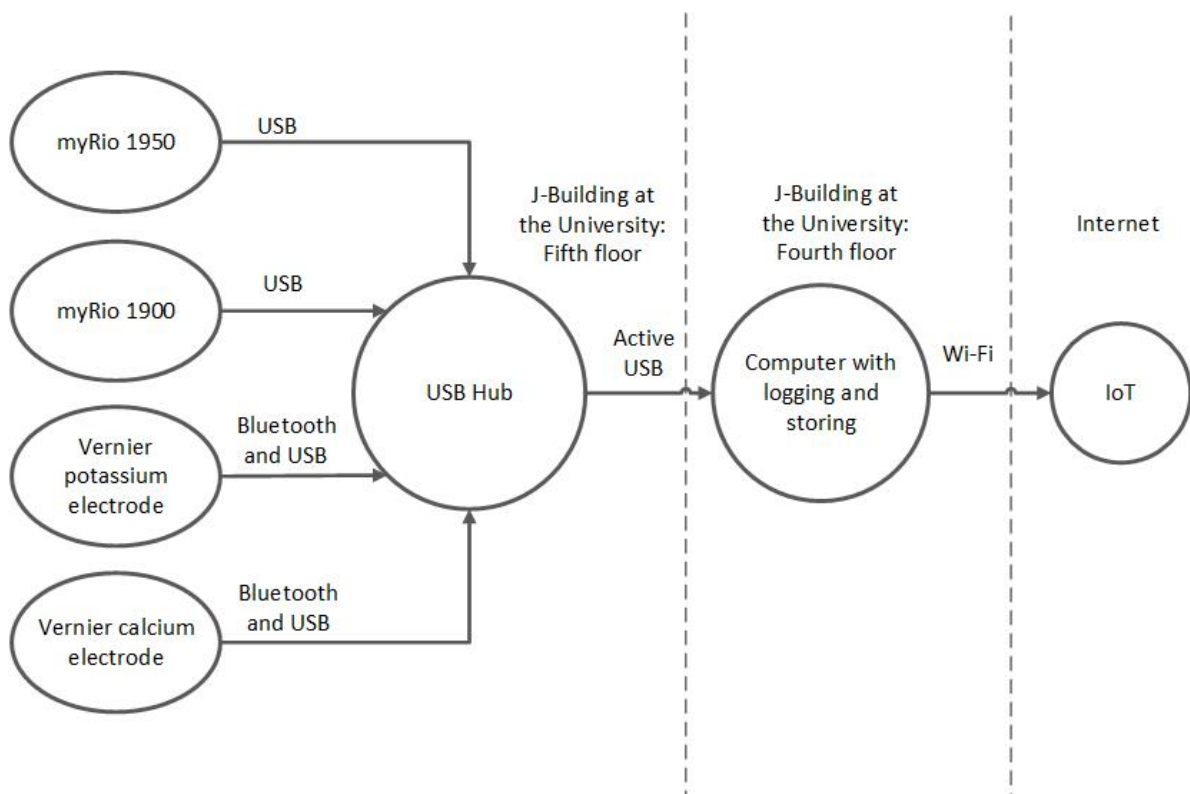


Figure 5.11: Device connection diagram for the rooftop hydroponic system



## 5.5 Casing and 3D modeling

Designing and building the electronics for the systems, several custom made parts where needed. These parts were drawn by the researcher and 3D printed for use with in the system. There was also made a drawing of the PVC tube from the lab to show the measurements. This can be seen in figure 5.12. A full drawing of the tube with end piece can be seen in appendices A.0.3.

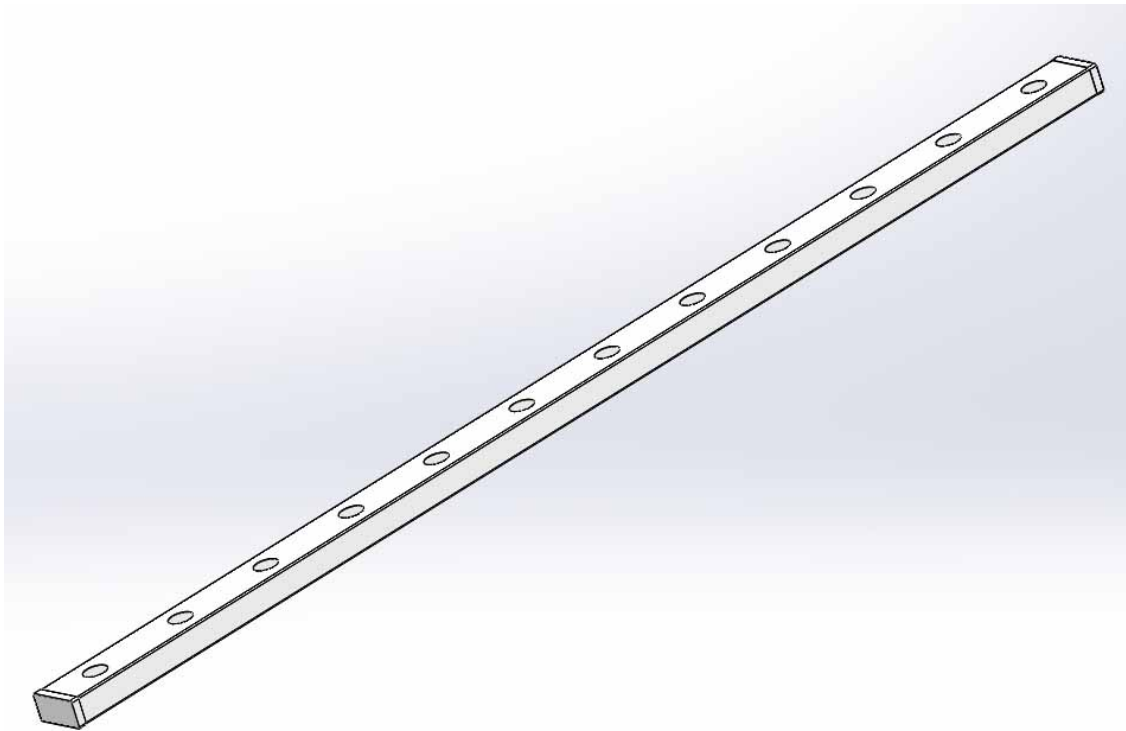


Figure 5.12: Assembly of tube with end piece

In the hydroponic system at the lab it was sometimes hard to get stable readings from the probes, especially before the voltage isolator were installed. This could to a certain extent be solved by measuring EC, potassium and calcium in a isolated plastic cup, which became a joint between the hoses. It was therefore created a drawing of a holder which could hold three probes in the cup for measure EC, potassium and calcium. pH was at this point measured directly in the tube to reduce that the EC and the pH probe would affect each other. The 3D drawing of the holder are shown in figure 5.12 and a picture of the 3D printed holder and the probes can be seen in figure 5.13.

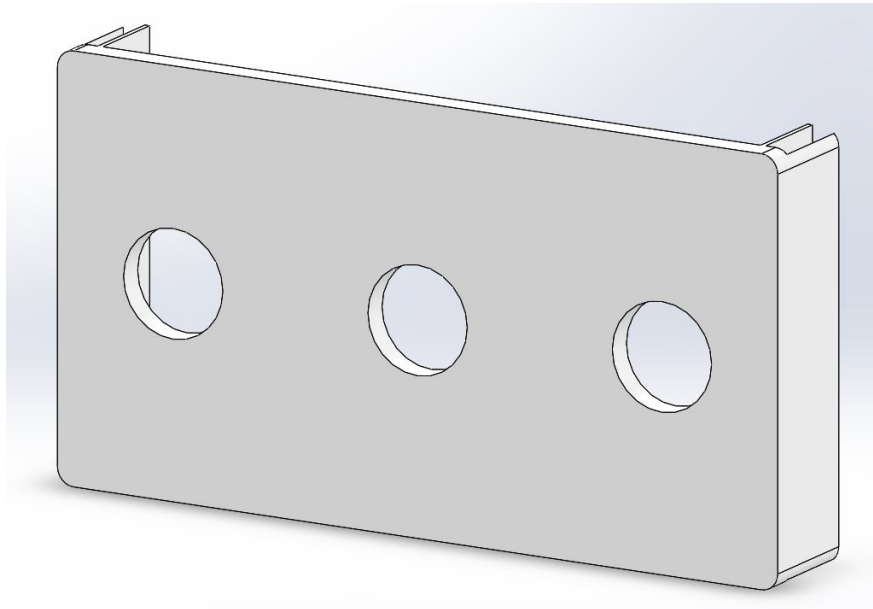


Figure 5.13: Holder for probes



Figure 5.14: Tube with holder and probes

Each system had relays controlled by a myRio. The relays needed to be assembled in the box together with the other electronic components. For this purpose there was made a bracket with support cylinders. The 3D model of the bracket can be seen in figure 5.15, and a picture from the 3D printing software can be seen in figure 5.16. The support cylinders are shown in figure 5.17 and figure 5.18. The finished 3D printed model with relays are shown in figure 5.19 and 5.20

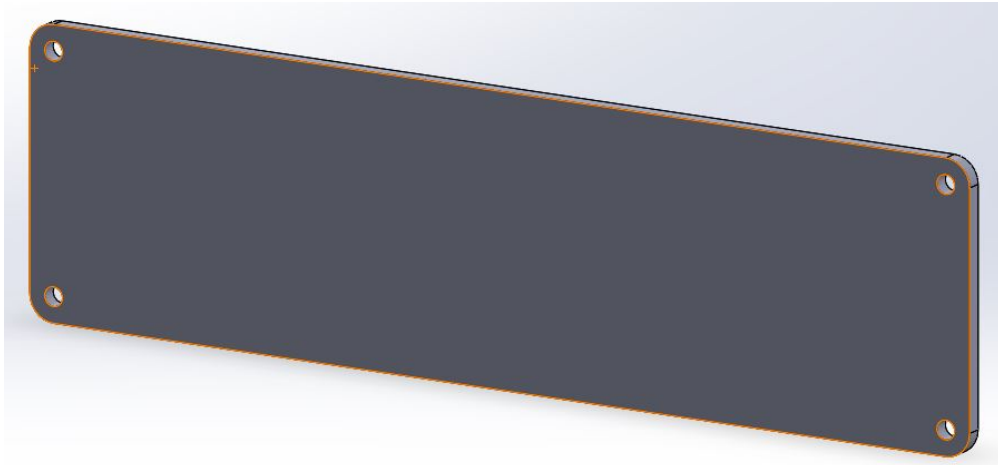


Figure 5.15: Bracket for relays

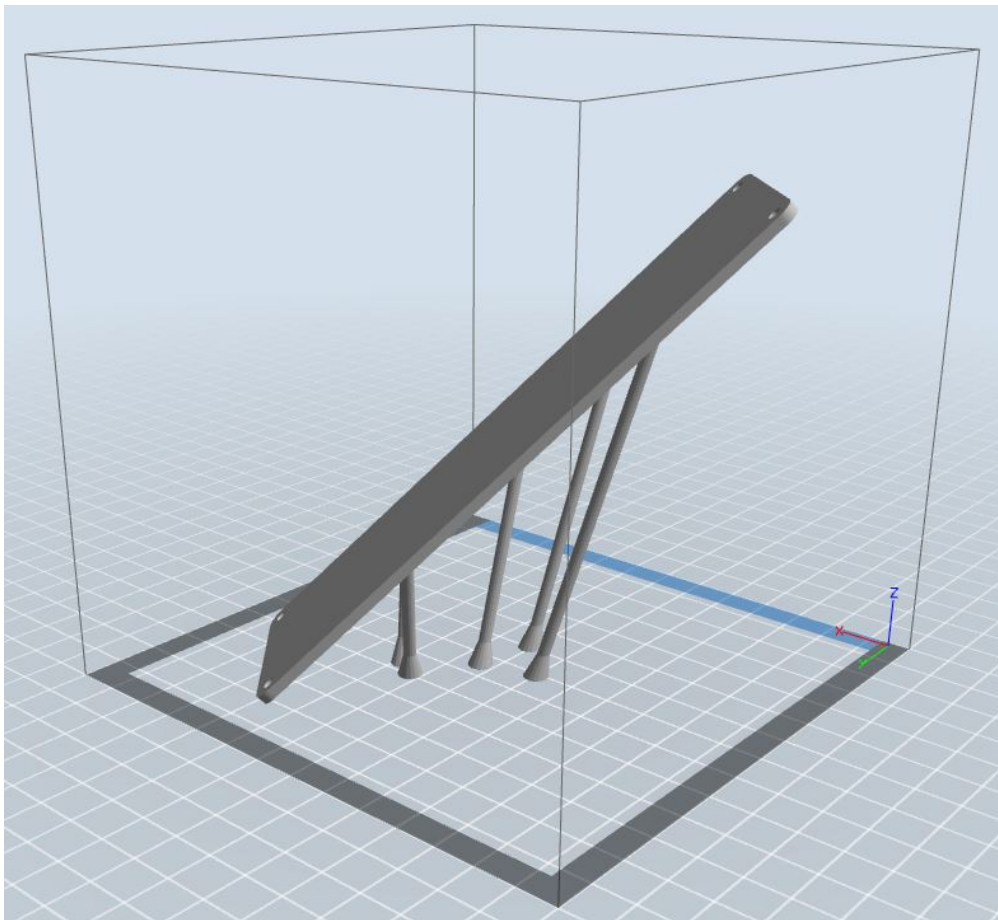


Figure 5.16: Bracket for relays before printing

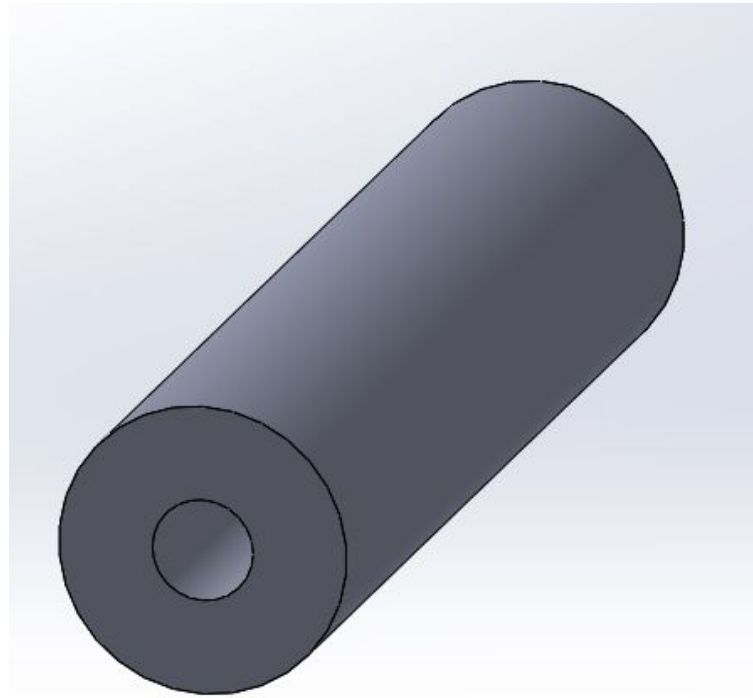


Figure 5.17: Support for bracket

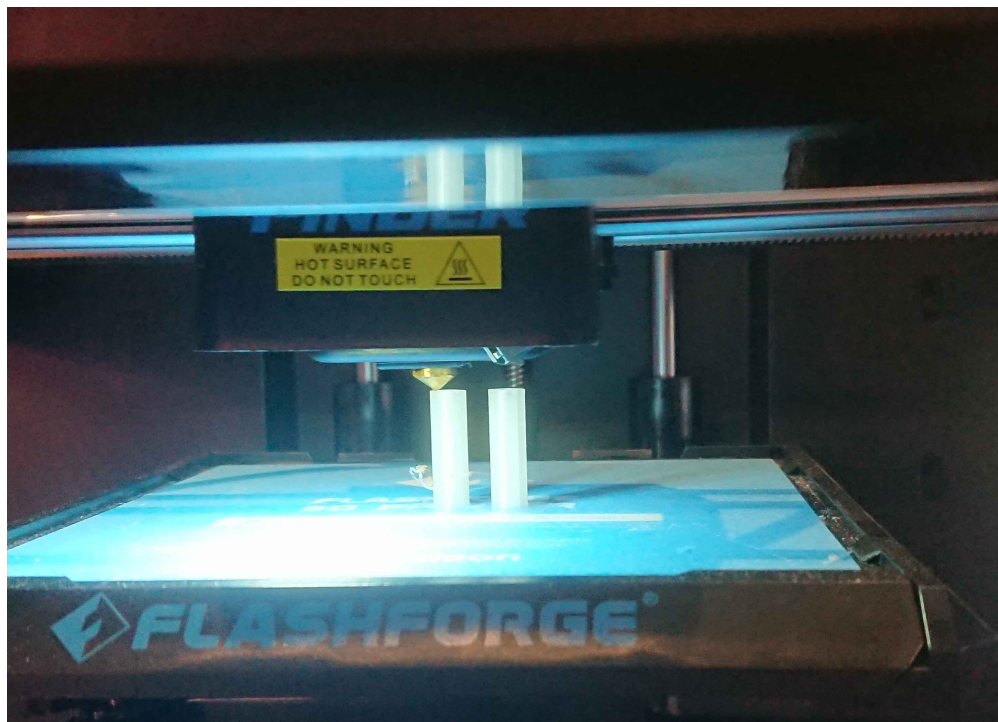


Figure 5.18: 3D Printing of support for bracket



Figure 5.19: Fully assembled bracket with relays



Figure 5.20: Fully assembled bracket with relays attached in the box

## 5.6 Electronics

As shown in figure 5.21, the potassium and calcium ion-selective electrodes and myRio connects to a computer through USB ports. myRio provides several analog input (AI), analog output (AO)), digital input and output (DIO). The temperature-sensors for water and air are connected to the myRio through analog pin B/AI03 and B/AI05 at myRio. The water level sensor is connected to B/AI02. Both the EC and pH-probe communicates with myRio through EZO circuits through UART and need to be powered by 5V as shown in figure 5.21. The pumps are controlled by relays which is normally open. With signal on the relays inputs, the relays connect the pumps to the 12V battery. The relays use 5V supplied from the myRio to operate. The connections are equal for both myRios.



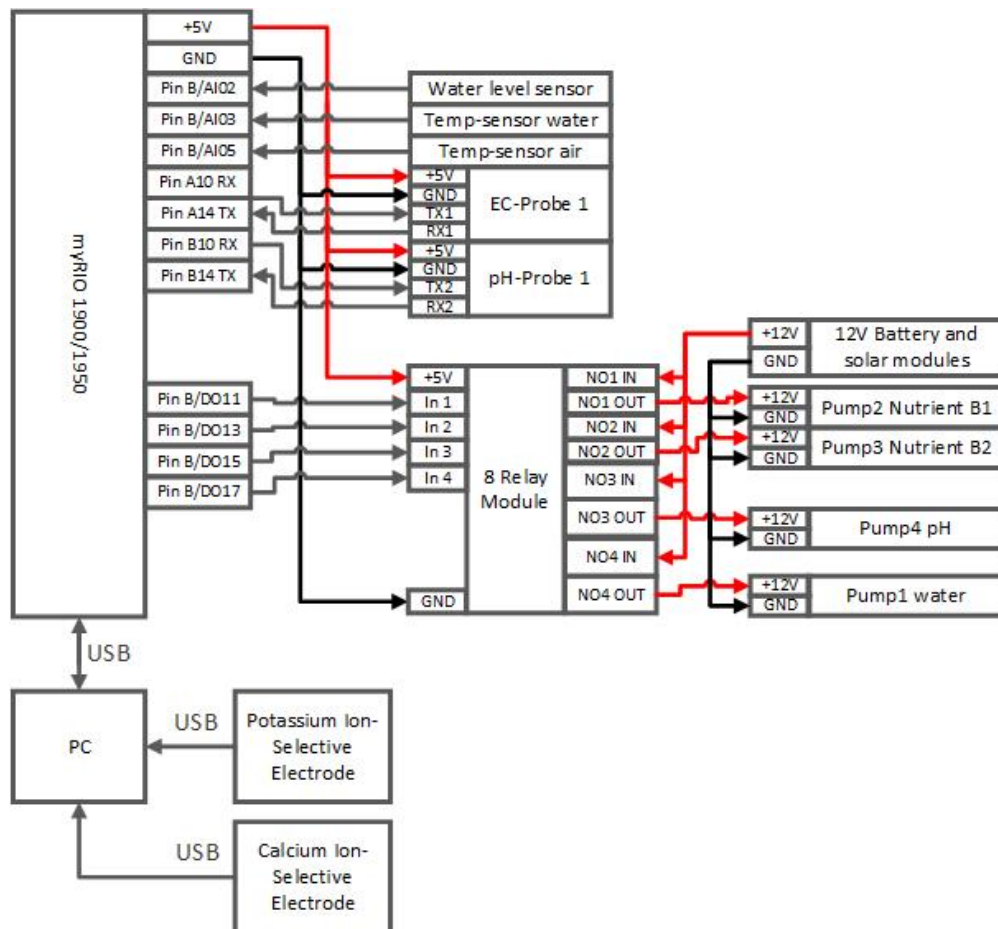


Figure 5.21: Connections diagram of the lab system with myRio, sensors, relays and pumps.

## 5.7 Software and code

The system used for the lab was an improved version of the system created in the research project, including the Labview code. The control panel can be seen in figure 5.22, added to the code was a table for logging with date and time, temperature, EC and pH. The table was also logging when the pumps were turned on and off. These result are shown in chapter 5.8.4. For the system to be fully functioning for the roof top system the Labview code had to be further improved. There was added functionality to calibrate EC, and pH value directly in the main panel. Air temperature and water level sensor were added to the system. Purge buttons for the all pumps and safety switch for nutrition and acid pumps were also added. A overview of the control panel can be seen in figure 5.30. Real time measuring of calcium and potassium were added to the system and can be seen in figure 5.30. An improvement of the code was to use a timer based on program cycle every second. During the cycle all measurements are taken and pre-processing done and the controlled mechanism evaluated. Temperature compensation for the ph and EC probes was not considered implemented at this stage.

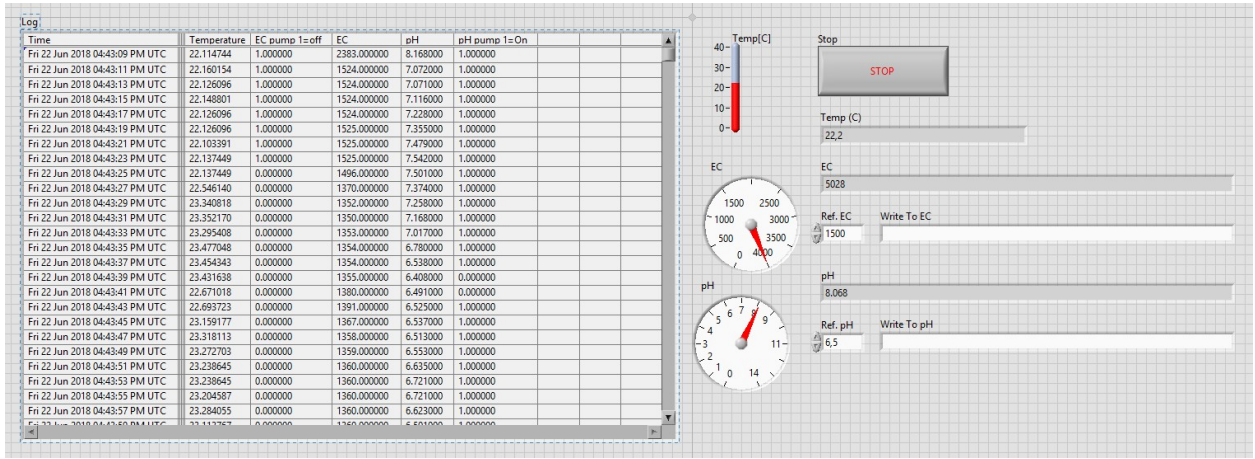


Figure 5.22: Control panel for real time measuring of EC and pH in the lab

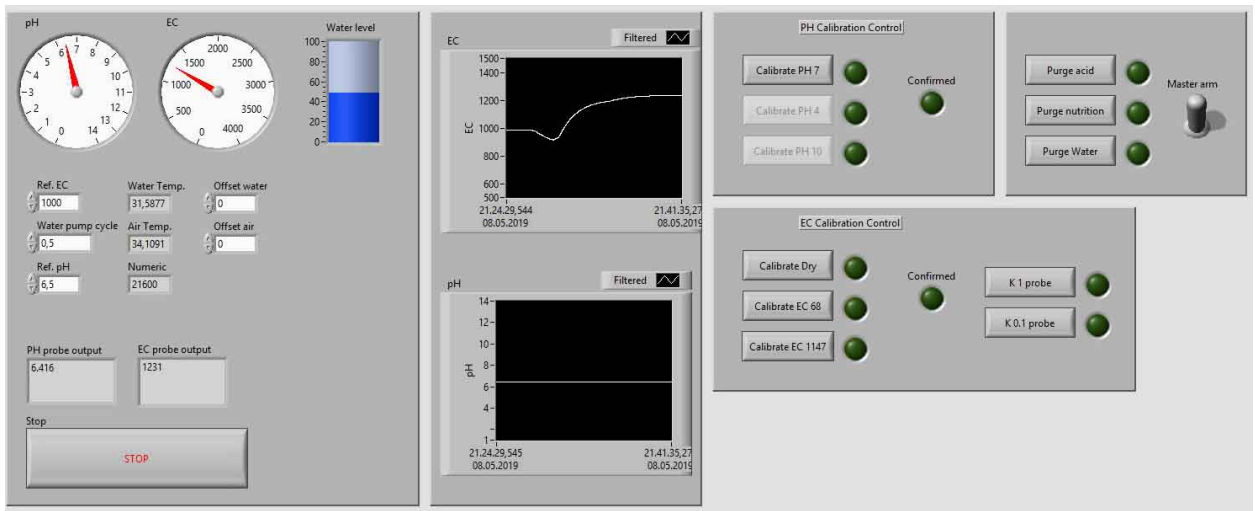


Figure 5.23: Control panel for real time measuring of EC and pH

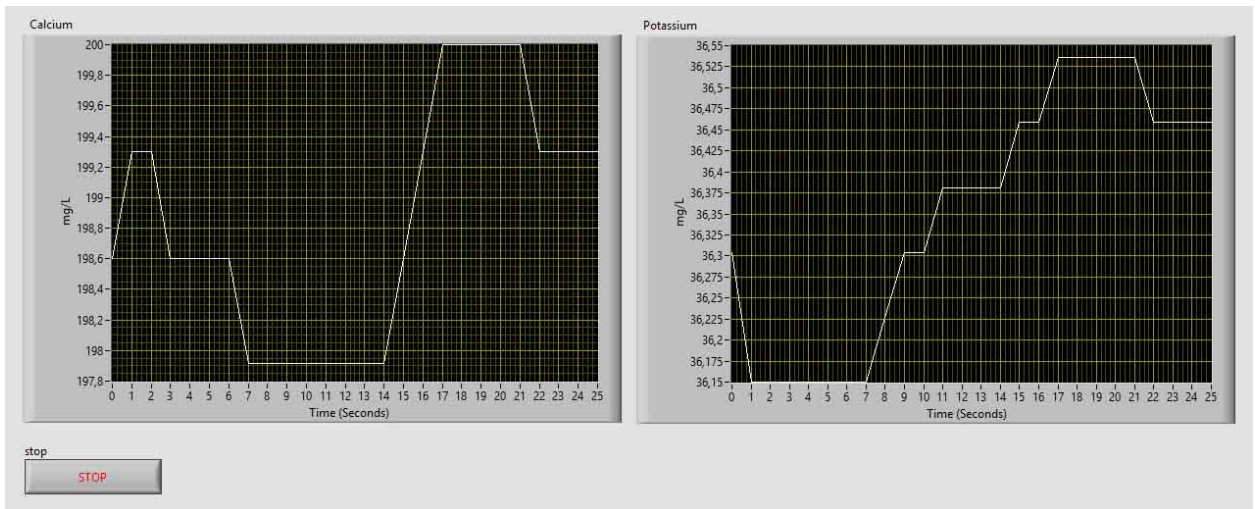


Figure 5.24: Real time measuring of calcium and potassium

The flowchart for the water pump controller runs a code that cycles the water pump on and off in 15 minutes cycles with 50% duty cycle. A purge button is provided for overriding the timer for testing purposes. The program flow is shown in figure 5.25.

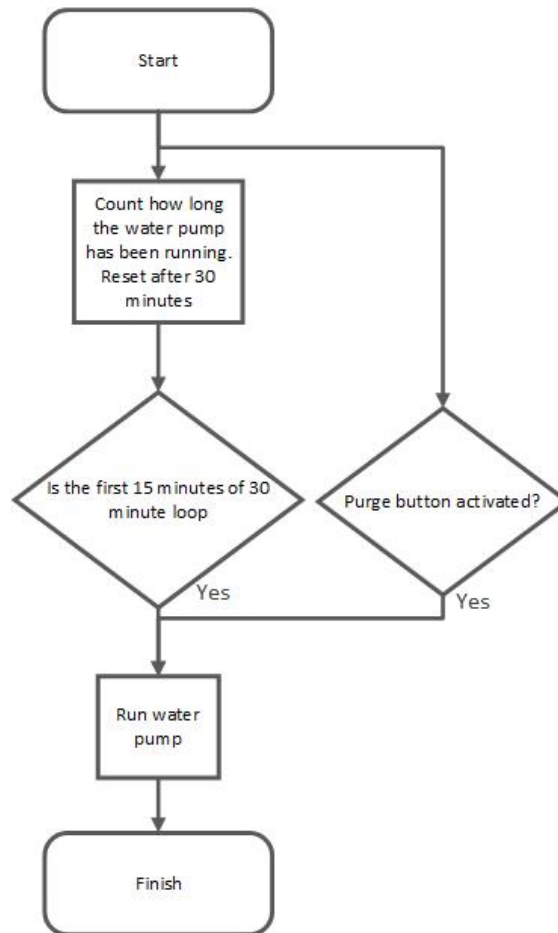


Figure 5.25: Flowchart for water pump

The flowchart for pH and EC runs a code that controls the level of additives (nutrition and acid). The controller works by using a timer where it adds small amount of additives in 10 minutes cycles. The pump runs for 7 seconds in each cycle thereby allowing proper mixing of the additives. EC and pH probes are used for measure nutrition level and acidity. When pH probe measure acidity levels above a set threshold, in this case 6,5 for lettuce, the acid pump is allowed to start adding acid depending on the timer. The pump is only allowed to run if it is below the acidity threshold. For the nutrition additives the probe is evaluated if it is bellow its set threshold. In this case for lettuce a value of  $1000\text{mg/L}$  is used. A purge button for each of the additives are provided for overriding the timer for testing purposes and to purge the hoses. A safety switch for additives is provided for testing purposes. The program flow is shown in figure 5.26.



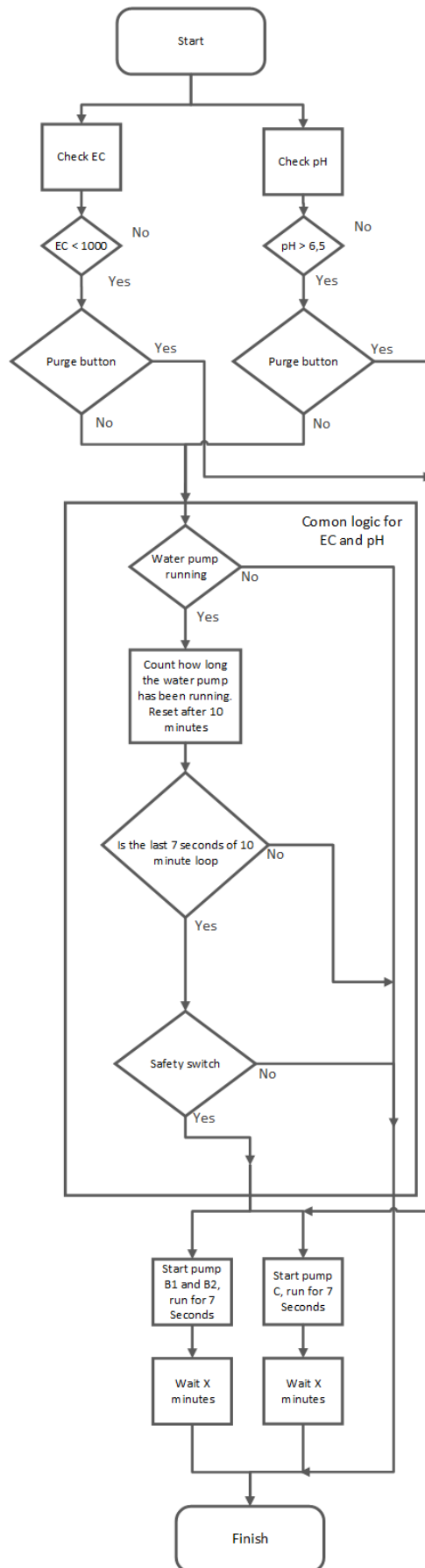


Figure 5.26: Flowchart for pH and EC

Figure 5.27 shows the principle in the IoT setup within the control system. Three sub VIs provide the main VI with data, which is transferred to InfluxDB and made available through Grafana. This provides the possibility of easy monitoring, data storage and warnings in case the system needs supervision. This gives the benefit of running a large set of hydroponics systems without the need of daily inspections.

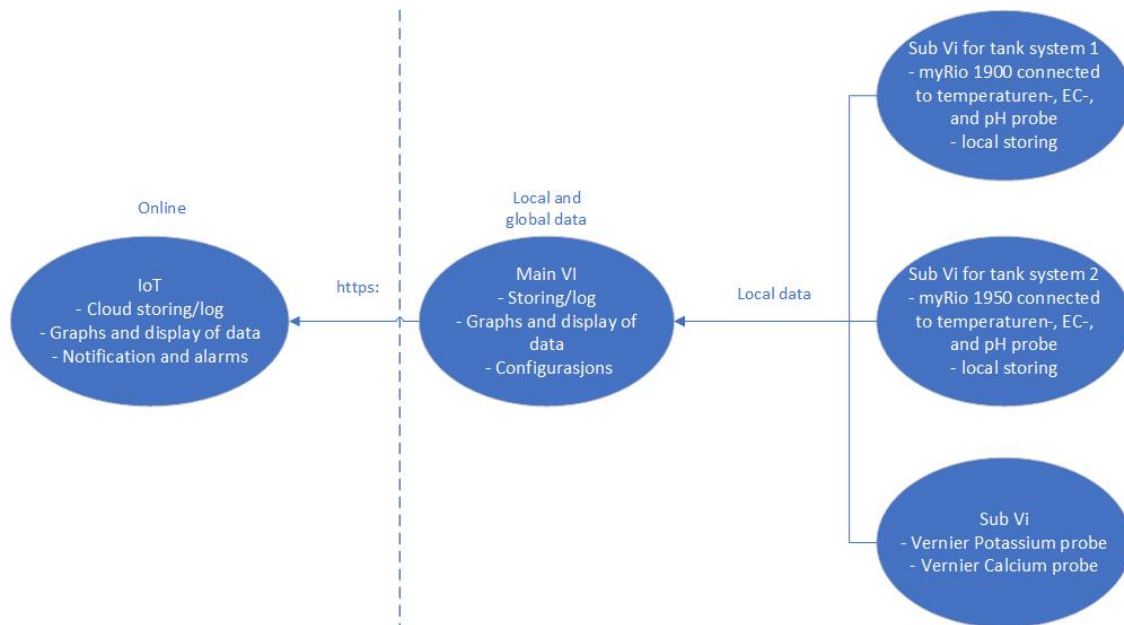


Figure 5.27: Principle of the IoT setup

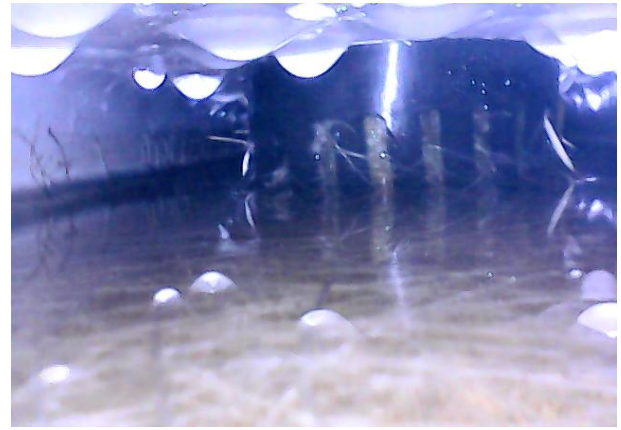
## 5.8 Plants and data

### 5.8.1 Plants planted in the indoor lab hydroponic system

Optimal growth depends on several factors like nutrition, pH value, lights and temperature. In the hydroponic systems the plants are watered in cycles. For the system in the lab and as seen in figures 5.28 the plant is soaked even if the pump is not running. This is of course dependent of the tubes and how high or low the water outlet is. With low water outlet and higher slope less water will remain in the tube. To keep optimal growth it is important to keep the cycles active, but due to the low slope the plant will not dry out if the system is stopped. Optimal lights and temperature are also important. If some of the variables is not optimal abnormalities in grown may occur as shown in figure 5.29a. With optimal growth the result may be a full grown and healthy crop. An example for a healthy lettuce are shown in figure 5.29. Full code for myRio can be downloaded here: <https://www.sendspace.com/file/exlulz>



(a) Pot with low water level when the pump is not active



(b) Pot with high water level when the pump is active

Figure 5.28: In figure 5.28a the water level is low before the water pump is active, and in figure 5.28 the water level is high during circulation of water.



(a) Plant with discolored leaves



(b) Harvested salad

Figure 5.29: Plant with discolored leaves and a fully grown healthy lettuce

In the hydroponic system in the lab the first crop was planted 21st of January. The crop gave 11 healthy lettuce with a weight from 125g to 251,7g, and the amount of days before cultivation was 28. The data are shown in table 5.4. The second crop was planted 22th of February. This crop grew uneven. The first part was harvested after 39 days and gave three salads with a weight from 145g to 166,5g. The second part of the crop was harvested after 52 days, almost twice as long as the first crop from 21th of January. The weights were from 206,3g to 362,6g, and the detailed data are shown in table 5.5. One of the seeds also had problems to grow, so it was replanted several times. First when then the seed was planted 1th of March

it started to grow, and after 61 one days this lettuce was harvested as shown in table 5.6. This is more then double of the time needed to harvest the first crop planted 21th of January. This lettuce had a weight of 275,5g. The last crop was plants 29th of March and was harvested after 38 days. This crop gave 10 healthy lettuce with a weight from 116,5g to 245,5g. This data can also be seen in table 5.7.

Table 5.4: Plants that were planted 21th of January

Date planted:	Date harvested:	Amount of days for cultivation	Weight:
25.01.2019	21.02.2019	28	251,7g
25.01.2019	21.02.2019	28	244,0g
25.01.2019	21.02.2019	28	237,0g
25.01.2019	21.02.2019	28	203,3g
25.01.2019	21.02.2019	28	176,2g
25.01.2019	21.02.2019	28	175,6g
25.01.2019	21.02.2019	28	167,0g
25.01.2019	21.02.2019	28	162,0g
25.01.2019	21.02.2019	28	159,0g
25.01.2019	21.02.2019	28	136,7g
25.01.2019	21.02.2019	28	125,0g

Table 5.5: Plants that were planted 22th of February

Date planted:	Date harvested:	Amount of days for cultivation	Weight:
22.02.2019	29.03.2019	39	166,5g
22.02.2019	29.03.2019	39	162,5g
22.02.2019	29.03.2019	39	145,0g
22.02.2019	11.04.2019	52	362,6g
22.02.2019	11.04.2019	52	248,0g
22.02.2019	11.04.2019	52	210,0g
22.02.2019	11.04.2019	52	206,3g

Table 5.6: Plants that were planted 1th of March

Date planted:	Date harvested:	Amount of days for cultivation	Weight:
01.03.2019	30.04.2019	61	275,5g

Table 5.7: Plants that were planted 29th of March

Date planted:	Date harvested:	Amount of days for cultivation	Weight:
29.03.2019	06.05.2019	38	116,5g
29.03.2019	06.05.2019	38	157,4g
29.03.2019	06.05.2019	38	181,0g
29.03.2019	06.05.2019	38	188,9g
29.03.2019	06.05.2019	38	195,3g
29.03.2019	06.05.2019	38	196,5g
29.03.2019	06.05.2019	38	199,0g
29.03.2019	06.05.2019	38	212,4g
29.03.2019	06.05.2019	38	222,7g
29.03.2019	06.05.2019	38	245,5g

### 5.8.2 Sample comparison of selective-ions measured by Vernier electrodes and lab results from Eurofins

The values in table 5.8 are used to compare the measurements from the probes in the hydroponic system in the lab with HQ40d reading devices from Hatch to validate the data. The values for pH is almost equal but it can be seen that the values for EC are a little different. The difference or error in values are still not considered critical for the lettuce.

Table 5.8: Log for pH and EC tests that are sent to lab

Date:	EC(Labview):	EC(HQ40d):	pH(Labview):	pH(HQ40d):
23.04.2019	1867( $\mu S$ )	1969( $\mu S$ )	5,67	5,64
25.04.2019	1592( $\mu S$ )	1705( $\mu S$ )	5,57	5,54
30.04.2019	1550( $\mu S$ )	1733( $\mu S$ )	7,26	7,27
06.05.2019	1381( $\mu S$ )	1453( $\mu S$ )	6,28	5,46

The values in table 5.9 are for comparing the electrodes from vernier, with samples sent to a professional lab called Eurofins to validate the data. The values are different, but the trends are still the same, except from the value for calcium measured 30th of April. The reason for this may be faults from measuring with the electrode from Vernier.

Table 5.9: Log for potassium and calcium tests that are sent to lab

Date:	Potassium (Electrode from Vernier):	Potassium (Eurofins):	Calcium (Electrode from Vernier):	Calcium (Eurofins):
23.04.2019	27,049 <i>mg/L</i>	69 <i>mg/L</i>	204,652 <i>mg/L</i>	280 <i>mg/L</i>
25.04.2019	25,393 <i>mg/L</i>	65 <i>mg/L</i>	175,201 <i>mg/L</i>	220 <i>mg/L</i>
30.04.2019	0,000 <i>mg/L</i>	0,1 <i>mg/L</i>	101,483 <i>mg/L</i>	270 <i>mg/L</i>
06.05.2019	20,015 <i>mg/L</i>	31 <i>mg/L</i>	166,792 <i>mg/L</i>	210 <i>mg/L</i>

### 5.8.3 Log for potassium and calcium measured by Vernier probes

From table 5.10 we can see that potassium are decreasing over time, and that calcium both accumulates and decreases. The calcium electrode was not purchased from the start as it can be seen that the results for calcium starts at 22th of March. The potassium decreases until 27th of February. As seen in table 5.11 water was refilled both 20th and 22th of February with more water 20th of February than usual. This may be the reason for why the potassium value accumulates again. After 27th of February the value for potassium starts to decrease again all the way until 15th of April. As seen in table 5.11 the water are again refilled and changed more than usual from 8th of March which also here may be the reason for the potassium slightly accumulates. From the results it may seems that not enough water was changed to keep the potassium value stable and high enough. The value for calcium seems to decrease enough with change and refill of water to keep the value stable.

Table 5.10: Log for potassium and calcium measured by Vernier probes

Date:	Mean value: Potassium( <i>mg/L</i> ):	Standard deviation: Potassium( <i>mg/L</i> ):	Mean value: Calcium( <i>mg/L</i> ):	Standard deviation: Calcium( <i>mg/L</i> ):
21.01.2019	135,468	4,699	-	-
31.01.2019	130,552	2,332	-	-
04.02.2019	122,546	3,321	-	-
05.02.2019	117,074	2,153	-	-
10.02.2019	91,435	0,518	-	-
11.02.2019	84,469	11,785	-	-
11.02.2019	47,593	19,108	-	-
15.02.2019	65,698	1,415	-	-
18.02.2019	22,984	0,869	-	-
19.02.2019	54,444	0,668	-	-
20.02.2019	32,689	0,357	-	-
21.02.2019	42,520	0,807	-	-
22.02.2019	34,226	2,854	-	-
27.02.2019	81,280	8,481	-	-
28.02.2019	57,646	0,570	-	-
01.03.2019	49,587	1,990	-	-
01.03.2019	41,051	1,090	-	-
05.03.2019	39,000	0,226	-	-
07.03.2019	35,019	0,200	-	-
11.03.2019	36,452	1,812	-	-
14.03.2019	30,305	1,517	-	-
15.03.2019	22,985	1,129	-	-
18.03.2019	20,823	0,910	-	-
18.03.2019	39,970	1,608	-	-
20.03.2019	18,633	0,225	-	-
21.03.2019	38,836	0,533	-	-
22.03.2019	34,265	0,642	239,391	13,115
25.03.2019	28,883	0,776	317,975	8,343
27.03.2019	11,467	0,201	263,497	6,352
29.03.2019	0,816	0,033	263,092	10,067
01.04.2019	0,129	0,013	266,533	10,356
02.04.2019	0,019	0,000	263,244	6,226
03.04.2019	3,025	0,100	275,291	1,316
08.04.2019	3,174	0,061	322,311	2,618
11.04.2019	0,840	0,013	271,466	6,124
11.04.2019	0,000	0,000	249,727	0,860
12.04.2019	10,605	0,369	129,906	2,447
15.04.2019	26,294	1,008	141,116	3,423
23.04.2019	27,049	0,165	204,652	0,612
23.04.2019	14,629	0,693	159,734	1,326
25.04.2019	25,393	0,255	175,201	1,659
30.04.2019	0,019	0,000	101,483	2,124
01.05.2019	0,396	0,126	169,501	1,206
03.05.2019	0,024	0,000	191,688	4,374

Table 5.11: Log for refilling water in laboratory hydroponic system

Date:	Water changed:	Water added:	Comment:
04.02.2019	2,0L	-	Water with nutrient
11.02.2019	2,0L	-	Water with nutrient
18.02.2019	2,0L	7,5L	Water with nutrient
20.02.2019	-	3,5L	Water with nutrient
22.02.2019	-	1,0L	Water with nutrient
01.03.2019	2,0L	2,0L	Water without nutrient
05.03.2019	2,0L	1,0L	Water without nutrient
07.03.2019	-	1,0L	Water without nutrient
11.03.2019	2,0L	2,0L	Water without nutrient
15.03.2019	-	2,0L	Water without nutrient
18.03.2019	2,0L	1,0L	Water without nutrient
20.03.2019	-	1,0L	Water without nutrient
22.03.2019	-	1,0L	Water without nutrient
25.03.2019	2,0L	1,0L	Water without nutrient
27.03.2019	-	1,0L	Water without nutrient
01.04.2019	2,0L	1,0L	Water without nutrient
03.04.2019	-	2,0L	Water without nutrient
08.04.2019	2,0L	4,0L	Water without nutrient
11.04.2019	2,0L	4,0L	Water without nutrient
15.04.2019	2,0L	2,0L	Water without nutrient
23.04.2019	2,0L	4,5L	Water without nutrient, added after ester holiday, so an extra amount is needed
25.04.2019	-	3,0L	Water without nutrient

### 5.8.4 Log for pH, EC and temperature

The full data set of the small hydroponic system from lab is shown in figure 5.30 for EC and pH, 5.31 for temperature and number of water refills, 5.32 for additives pump cycles. The full table is shown in appendices A.0.9. The dataset is sampled with  $1Hz$  and is resampled up to three days. The resampled data is averaged and is shown together with the standard deviation for EC and pH and temperature. The dataset has time periods with missing information due to loss of data communication. This also created a bigger spread in standard deviation because of the value is not converging to the true value of the re-initialization.

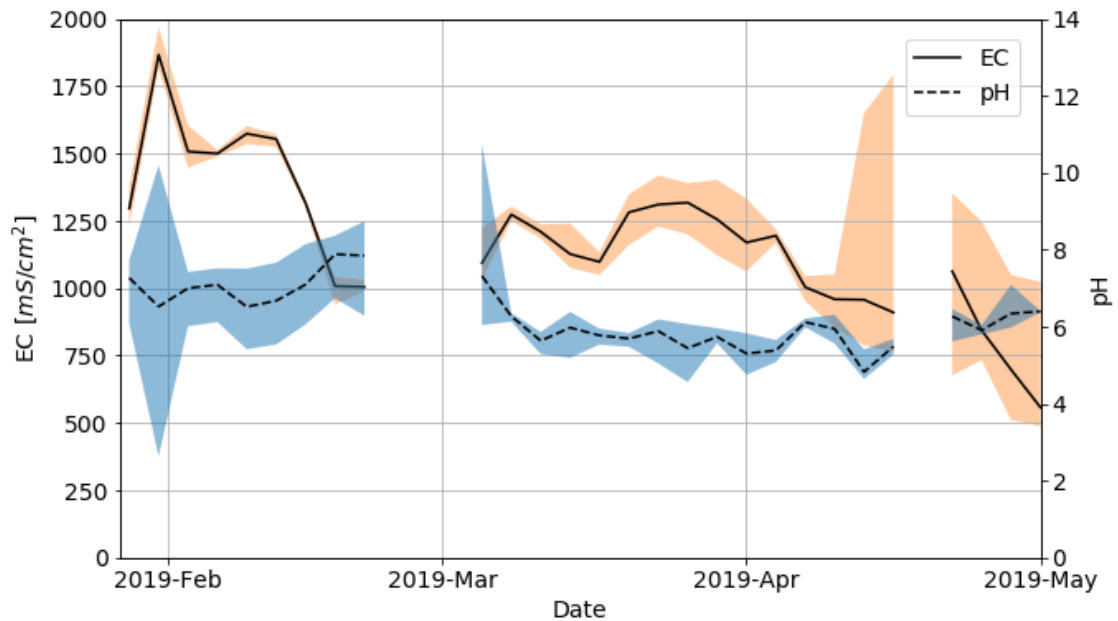


Figure 5.30: EC and pH for entire period with uncertainty band

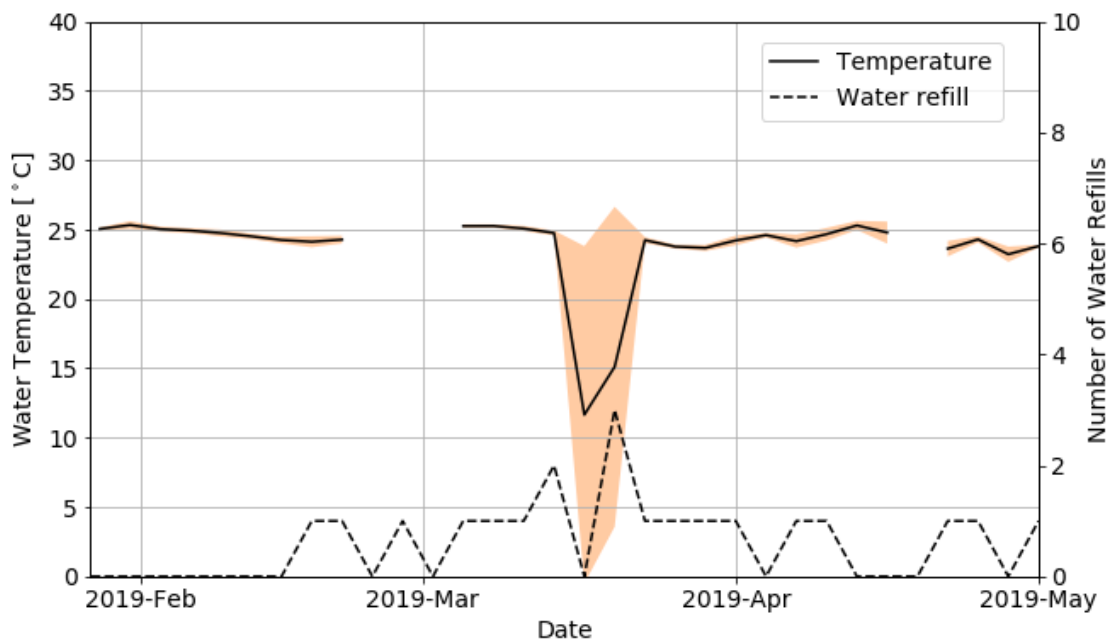


Figure 5.31: Temperature and water refill



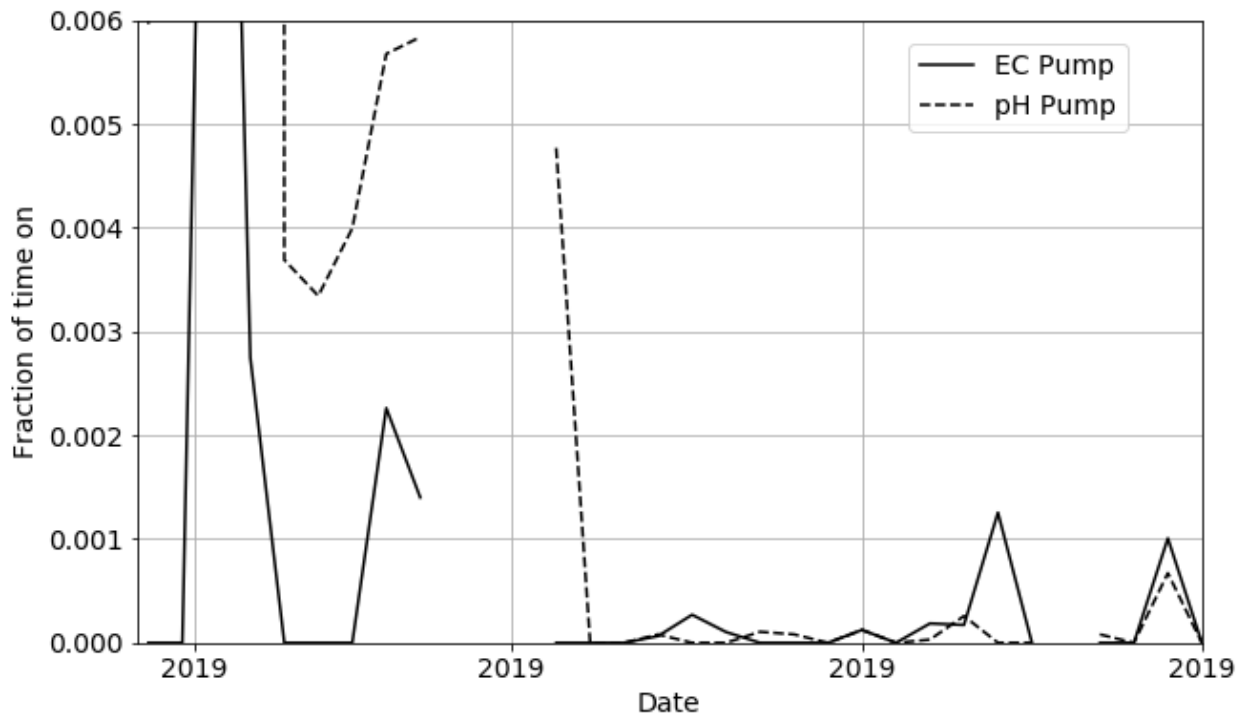


Figure 5.32: EC and pH pump on time

In figures 5.33 and 5.34 a smaller time sample has been extracted to show the control mechanism and response. Figure 5.34 shows the additive pumps run in small periods. In figure 5.33 we can see the corresponding response to nutrition an acid added to the water reservoir.

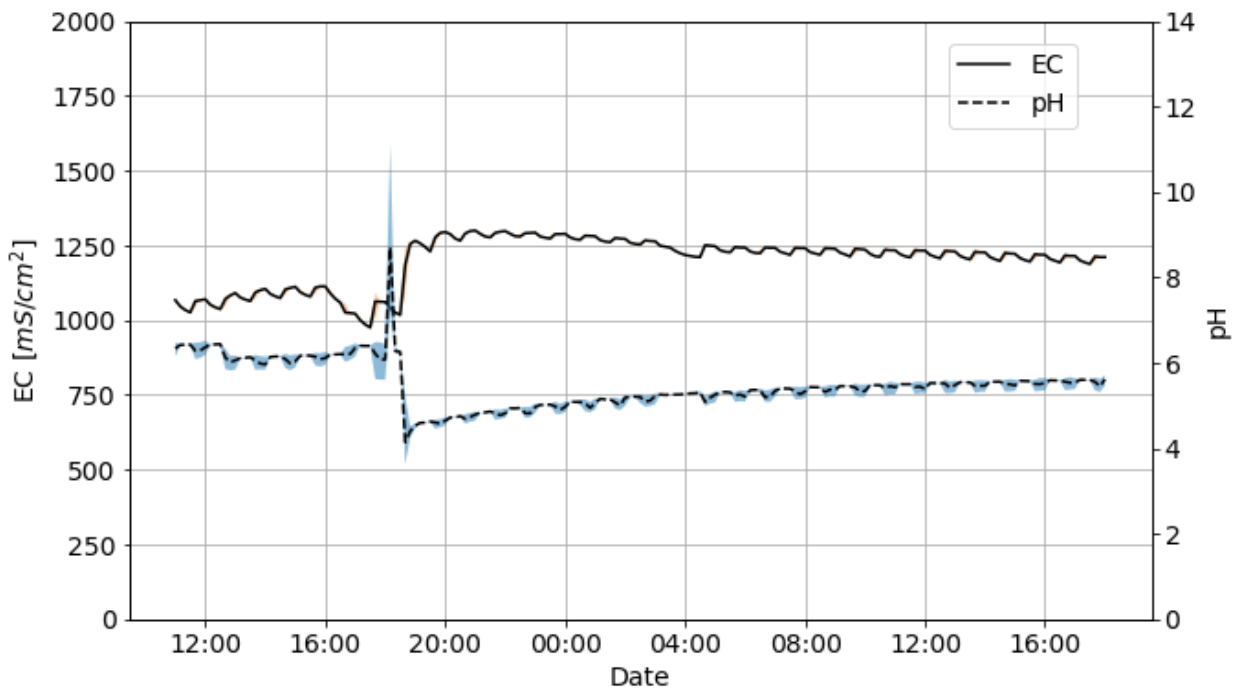


Figure 5.33: EC and pH for entire period with uncertainty band

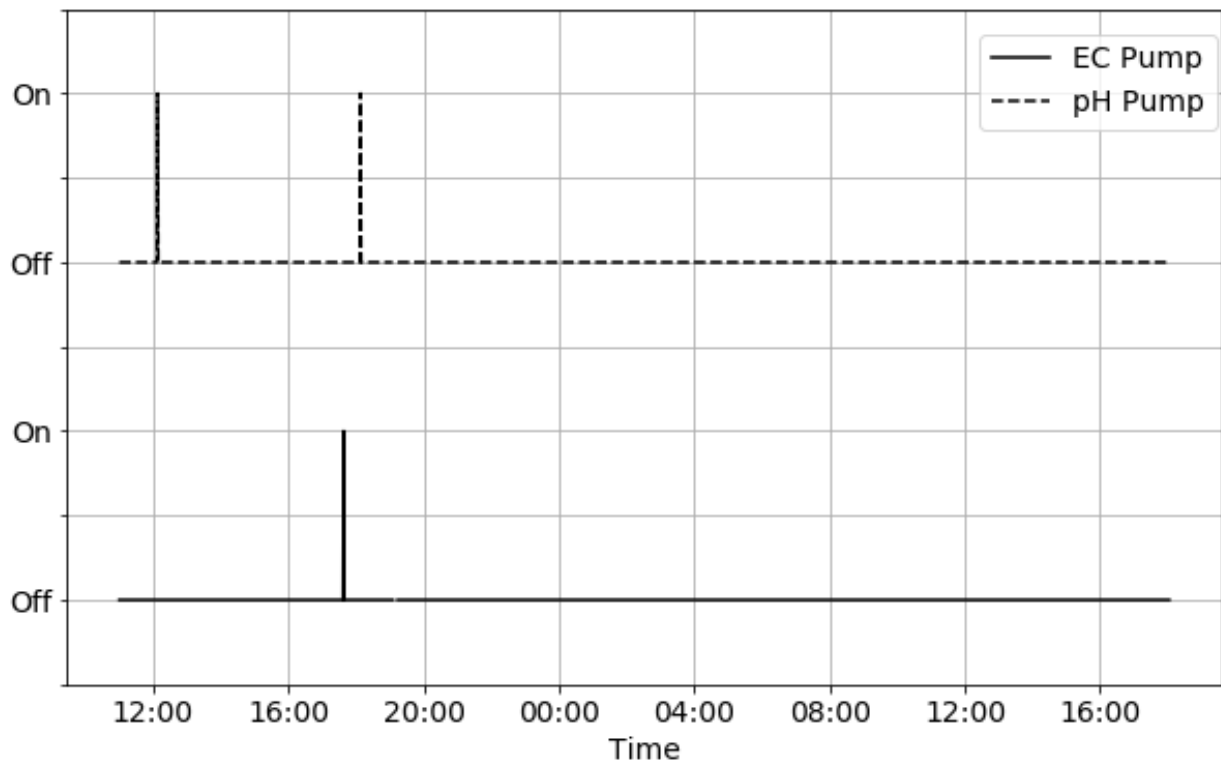


Figure 5.34: EC and pH pump on time Small time period

The roof top hydroponic system needs to be tested over time to generate crops and results. However from the hydroponic system from the lab it can be seen that monitoring and regulating pH, EC and individual nutrients can be done. Comparing the crops towards each other and with the measurements from the potassium and calcium change and refill of water seems necessary. This is because to avoid accumulation of calcium, and low values of potassium. An advantage with real time measurements compared to waiting for tests sent to a lab is the time that is saved waiting for the results. The values may have changed before the values are received from the lab. As the EC measures several nutrients, lack of or accumulation of individual nutrients can lead to abnormal growth as seen in figure 5.29a. With regards to this when building the hydroponic system on the roof at the university, the system should be fully functional and up to date regard to state of the art component listed in chapter 2.7. The researcher is not an expert in neither biology or programming, etc so there are possibilities for measuring, programming and connection errors along the way as the systems have been built and used.

# Chapter 6

## Conclusion

The research question for this report is: How can an automated system for control of nutrient concentration and pH in a solar powered hydroponic system be developed, implemented and verified? The following sub-questions should also be answered:

- How can an operational hydroponic control and monitoring system be designed and implemented?
- How can a functional solutions for automatization and off-grid operation of an outdoor hydroponic system be designed and implemented?
- What is the benefit of measuring individual nutrients, and how can this contribute to optimization of a hydroponic system?
- Which improvement, beyond current practice, can be implemented in the future?

It can be concluded that the main research question have been answered by developing, building and implementing two hydroponic systems. On indoor system in the lab, and one outdoor on the roof. Both systems are tested in greater or less extent and verified working with measuring temperature, pH, EC and individual nutrients. The systems are considered fully functional. Both system produce data, but the roof top hydroponic system need more time to generate data that can be compared to the data from the lab or against each other. The solar power system is also verified and considered as working as it has been powering the rooftop system from the startup in May without issues.

The sub-question of: How can an operational hydroponic control and monitoring system be designed and implemented? has been answered by improving the system made in the research project, which was meant as a start for the master thesis. The functionality and limitations was decided in corporation with the supervisors through meetings, E-mails and conversations along the way. The system was planed to primarily measure pH, EC and the two individual nutrients potassium and calcium. This were designed and implemented. Temperature compensation for the ph and EC probes was not implemented at this stage.

The sub-question of: How can a functional solutions for automatization and off-grid operation of an outdoor hydroponic system be designed and implemented? was also answered by manage to power the roof top system with solar power. Solar power was suggested at the start of the thesis based on comparability, area effectiveness and low maintenance. The system was planed by calculating the foundation of values the simulation software PV-Sol Standalone need to perform the simulation of a solar power system. Based on the values and the simulation, a solar panel system was ordered and installed. Based on providing the roof top hydroponic system with power through May without issues, it was considered that the solar power system was also working.

The sub-question: What is the benefit of measuring individual nutrients, and how can this contribute to optimization of a hydroponic system? was answered by real time measures of both potassium and calcium. As shown in chapter 5.8.3 there may be a connection of accumulation of calcium and lack of potassium with abnormal growth. By continue using ion-selective electrode to measure individual nutrients the investigated should continue further. Due to the results in 5.8.3 changing and refilling water systematically may reduce or counteract lack or accumulation of certain nutrients, which is an important factor for optimization. To supply the plants with the correct amount of nutrition will most likely promote growth. Another advantage with real time measuring is the reduced waiting time for the results. Sending samples to a lab will use more time than generating the results at once. The validity will depending on the accuracy for the real time measuring, compared to the results from the lab. The result from the lab may be more accurate.

The sub-question: Which improvement, beyond current practice, can be implemented in the future? are answered by researching the state of the art technology. There are several more probes for individual measuring of nutrients, and there are also a leaf sensor that may beneficial regards monitoring the health of the plants. With the already implemented water sensor for the roof top hydroponic system, refilling of water collected from rain is also possible to implement with a controlled valve. Other micro controller may be a better option than the myRio due to capacity, power consumption and price. Details regards this is not investigated further, but should be in the future.

As a conclusion the research question have been answered due to several challenges along the way. The challenges have been solved or worked around with different solutions. The learning outcome has for the researcher been large due to that this is a cross-disciplinary task with biology, electronics, computer programming, micro controllers and more.

# Chapter 7

## Recommendations

### 7.1 Recommendations

It is recommended to continue to improve the already made program in Labview together with the physical system. There are several areas to focus on like controlling the refilling of water, improving accuracy of the probes, including new sensors like leaf sensor, humidity, preparation in advanced based on weather prediction from online services, and more. It may also be an advantage to implement feed forward loop regards nutrient and acid based on historical data. If the pH accumulates as an result of pouring nutrient, some seconds of pouring acid after would also may be beneficial, depending on the data. This should be investigated further. Other micro controller may be a better option than the myRio due to capacity, power consumption and price. This should be investigated in the future.

Regards the IoT part there can be several improvements included like for example detection of abnormalities in the IoT part with notifications. If this is done the people that ensures operation and maintenance can easier focus on the part of the system that needs attention. This will free up time that is normally used for following the different systems. There should also be carried out a full Life Cycle Analysis to compare how a hydroponic system can reduce  $CO_2$  emission compared to normal traditional crops with transport into cities. This would be regards to the bigger picture.

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# Appendix A

## Appendices

- A.0.1 Analyserapport fra Eurofins for potassium and calcium
- A.0.2 Drawings of the experimental rooftop hydroponic system
- A.0.3 Drawing of tube and end piece
- A.0.4 Drawing of support bracket for probes
- A.0.5 Drawing of support bracket for relay and support for bracket
- A.0.6 Datasheet: Westeck 160W Monokristalline Solar Module
- A.0.7 Datasheet: EPEVER ViewStar VS3024AU Battery PWM charge controller
- A.0.8 Datasheet: VARTA PROFESSIONAL DUAL PURPOSE LFD 180 Battery
- A.0.9 Log for pH, EC and temperature

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**AR-19-MG-001668-01**

**EUNOKR-00035573**

Prøvemottak: 16.05.2019

Temperatur:

Analyseperiode: 16.05.2019-24.05.2019

Referanse: Arbeidsordre:

501176-102

## ANALYSERAPPORT

Prøvenr.:	<b>434-2019-0516-027</b>	Prøvetakingsdato:	23.04.2019
Prøvetype:	Annet urent vann	Prøvetaker:	Helge Liltved
Prøvemerkning:	1. 23/04	Analysestartdato:	16.05.2019

Analyse	Resultat	Enhet	LOQ	MU	Metode
a) Kalium (K), direkte	69	mg/l	0.1	15%	According NEN EN ISO 17294-2
a) Kalsium (Ca), direkte	280	mg/l	0.05	15%	According NEN EN ISO 17294-2

Prøvenr.:	<b>434-2019-0516-028</b>	Prøvetakingsdato:	25.04.2019
Prøvetype:	Annet urent vann	Prøvetaker:	Helge Liltved
Prøvemerkning:	2. 25/4	Analysestartdato:	16.05.2019

Analyse	Resultat	Enhet	LOQ	MU	Metode
a) Kalium (K), direkte	65	mg/l	0.1	15%	According NEN EN ISO 17294-2
a) Kalsium (Ca), direkte	220	mg/l	0.05	15%	According NEN EN ISO 17294-2

Prøvenr.:	<b>434-2019-0516-029</b>	Prøvetakingsdato:	30.04.2019
Prøvetype:	Annet urent vann	Prøvetaker:	Helge Liltved
Prøvemerkning:	3. 30/4	Analysestartdato:	16.05.2019

Analyse	Resultat	Enhet	LOQ	MU	Metode
a) Kalium (K), direkte	< 0.10	mg/l	0.1		According NEN EN ISO 17294-2
a) Kalsium (Ca), direkte	270	mg/l	0.05	15%	According NEN EN ISO 17294-2

Prøvenr.:	<b>434-2019-0516-030</b>	Prøvetakingsdato:	06.05.2019
Prøvetype:	Annet urent vann	Prøvetaker:	Helge Liltved
Prøvemerkning:	4. 6/5	Analysestartdato:	16.05.2019

Analyse	Resultat	Enhet	LOQ	MU	Metode
a) Kalium (K), direkte	31	mg/l	0.1	15%	According NEN EN ISO 17294-2
a) Kalsium (Ca), direkte	210	mg/l	0.05	15%	According NEN EN ISO 17294-2

### Tegnforklaring:

\* Ikke omfattet av akkrediteringen LOQ: Kvantifiseringsgrense MU: Måleusikkerhet

&lt;: Mindre enn &gt;: Større enn nd: Ikke påvist. Bakteriologiske resultater angitt som &lt;1,&lt;50 e.l. betyr 'ikke påvist'.

Måleusikkerhet er ikke tatt hensyn til ved vurdering av om resultatet er utenfor grenseverdi/ -området og er angitt med dekningsfaktor k=2.

For mikrobiologiske analyser oppgis konfidensintervallet. Ytterligere opplysninger om måleusikkerhet fås ved henvendelse til laboratoriet.

Rapporten må ikke gjengis, unntatt i sin helhet, uten laboratoriets skriftlige godkjenning. Resultatene gjelder kun for de(n) undersøkte prøven(e).

**Utførende laboratorium/ Underleverandør:**

a) Eurofins Environment Sweden AB (Lidköping), Box 887, Sjöhogsg. 3, SE-53119, Lidköping ISO/IEC 17025:2005 SWEDAC 1125,

**Kopi til:**

Ellen Christina Bjørkmo (bjoell@hotmail.com)

**Kristiansand 24.05.2019**

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Nermina Trnka

Produksjonsleder

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**Tegnforklaring:**

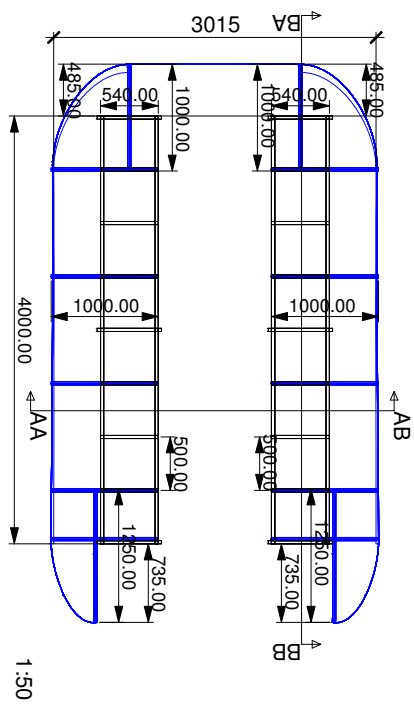
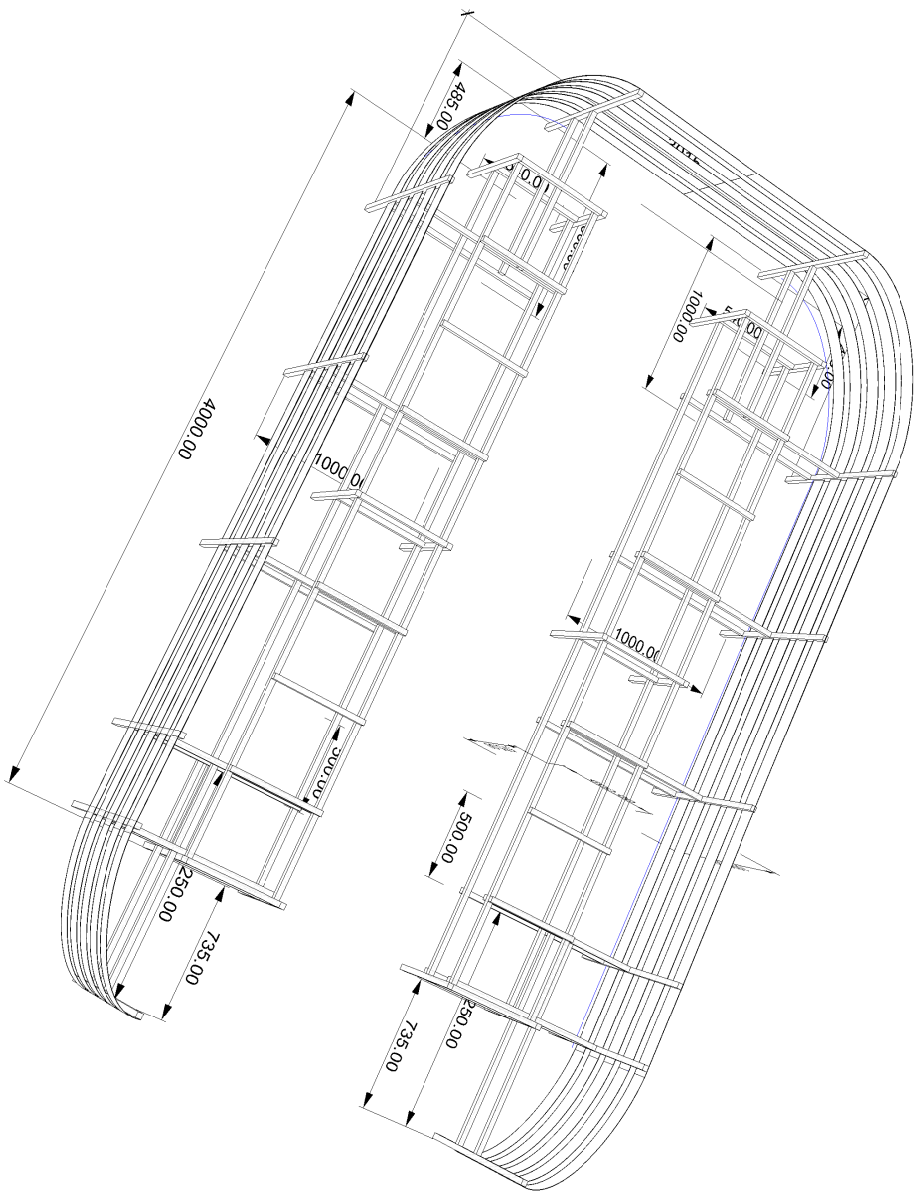
\* Ikke omfattet av akkrediteringen      LOQ: Kvantifiseringsgrense      MU: Måleusikkerhet

<: Mindre enn      >: Større enn      nd: Ikke påvist.      Bakteriologiske resultater angitt som <1,<50 e.l. betyr 'ikke påvist'.

Måleusikkerhet er ikke tatt hensyn til ved vurdering av om resultatet er utenfor grenseverdi/ -området og er angitt med dekningsfaktor k=2.

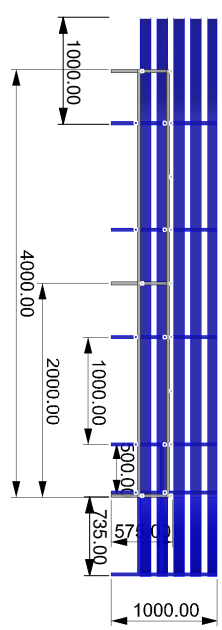
For mikrobiologiske analyser oppgis konfidensintervallet. Ytterligere opplysninger om måleusikkerhet fås ved henvendelse til laboratoriet.

Rapporten må ikke gjengis, unntatt i sin helhet, uten laboratoriets skriftlige godkjenning. Resultatene gjelder kun for de(n) undersøkte prøven(e).



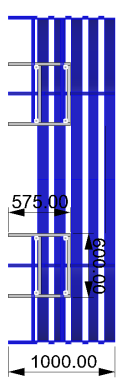
Snitt BA-BB

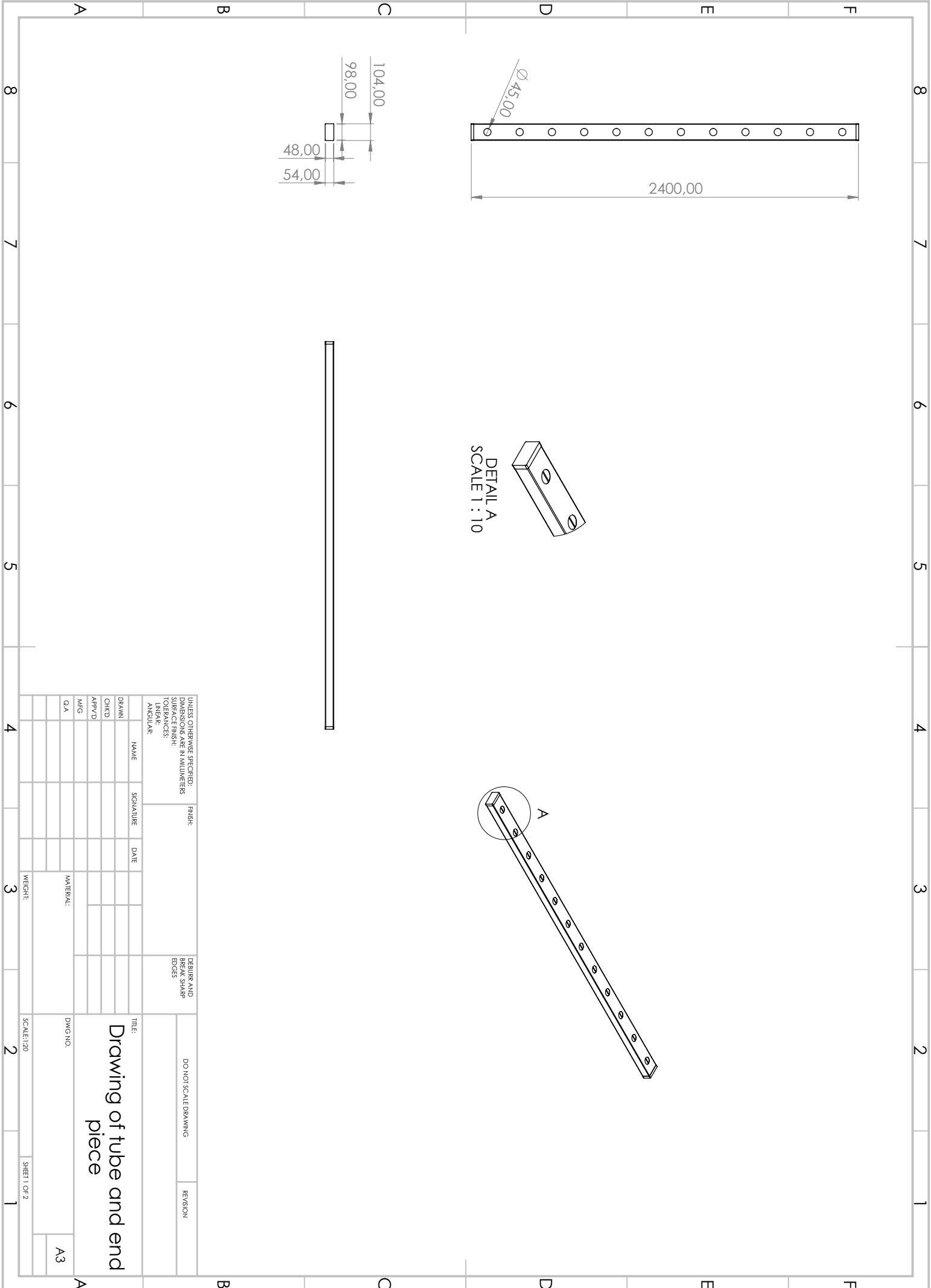
1:50



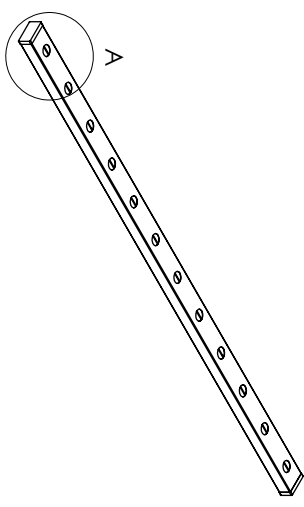
Snitt AA-AB

1:50





DETAIL A  
SCALE 1 : 10



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS		FINISH:		DEBURR AND BREAK SHARP EDGES	
SURFACE FINISH:					
TOLERANCES:					
LUNAR:					
ANODAR:					
DRANN	NAME	SIGNATURE	DATE		
CHK'D					
APRVD					
MFG					
QA					

TITLE:  
**Drawing of tube and end  
piece**

DO NOT SCALE DRAWING

REVISION

A3

WEIGHT:

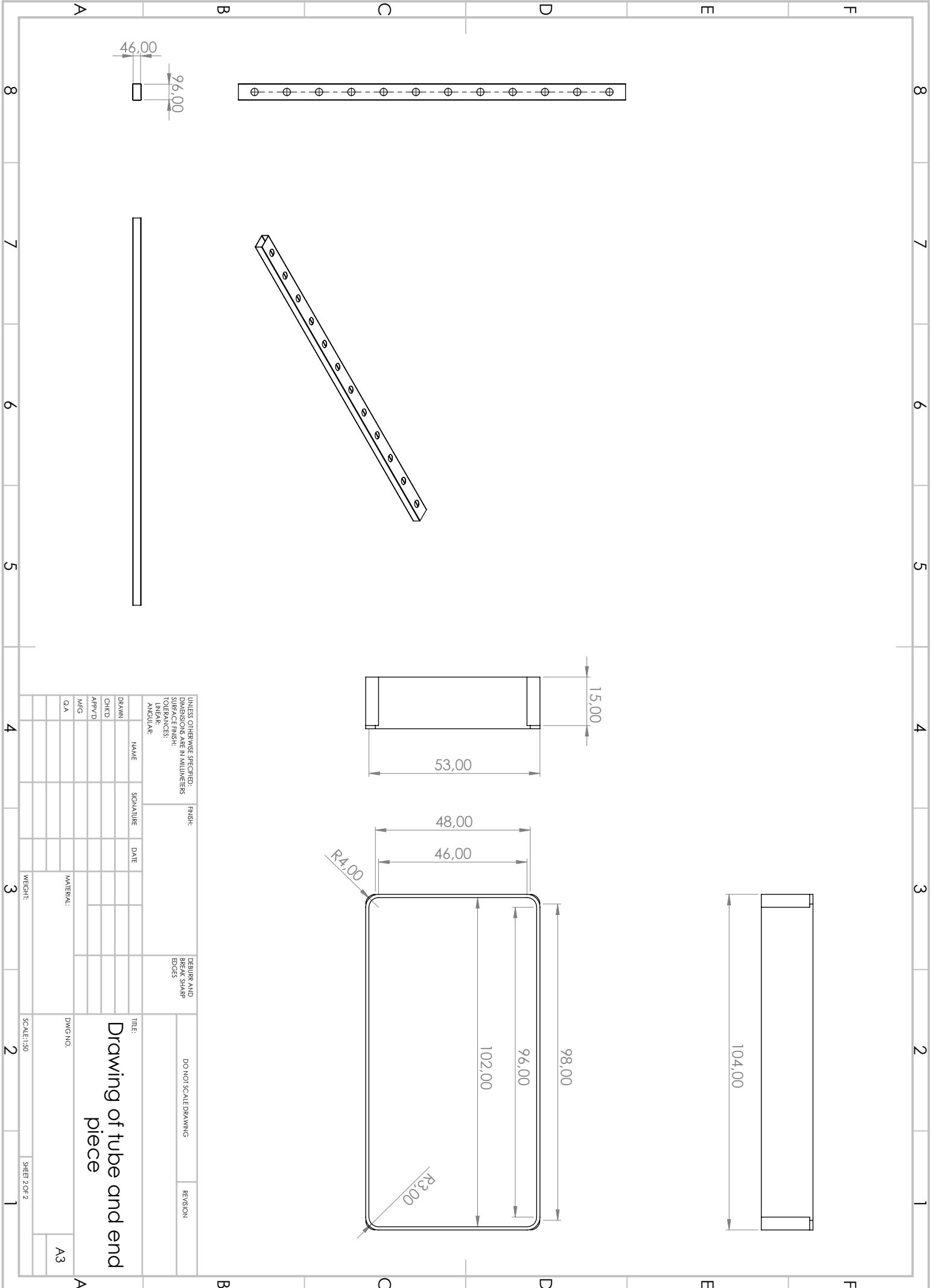
SCALE: 1:20

SHEET 1 OF 2

8 7 6 5 4 3 2 1

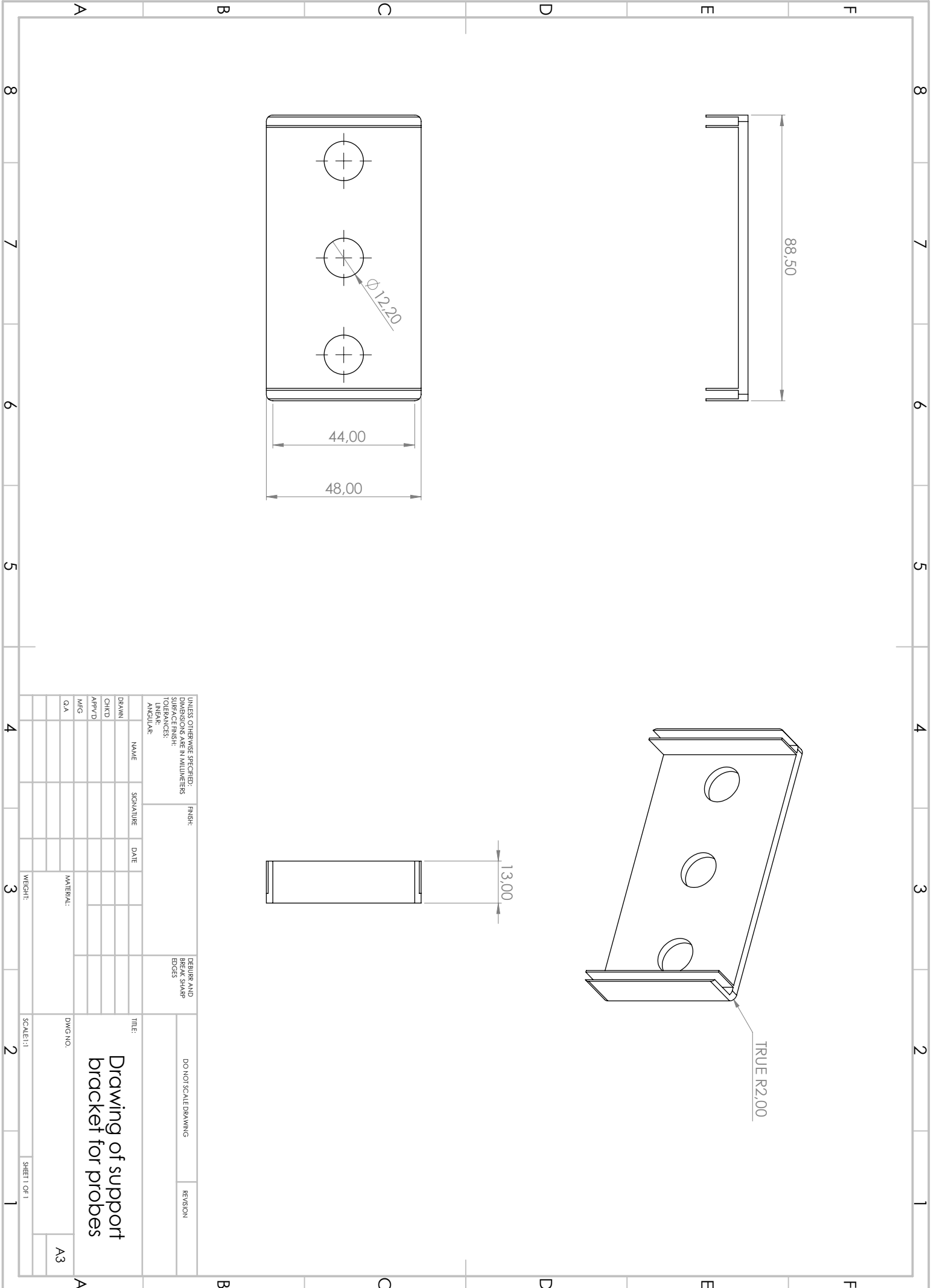
A B C D E F

A B C D E F



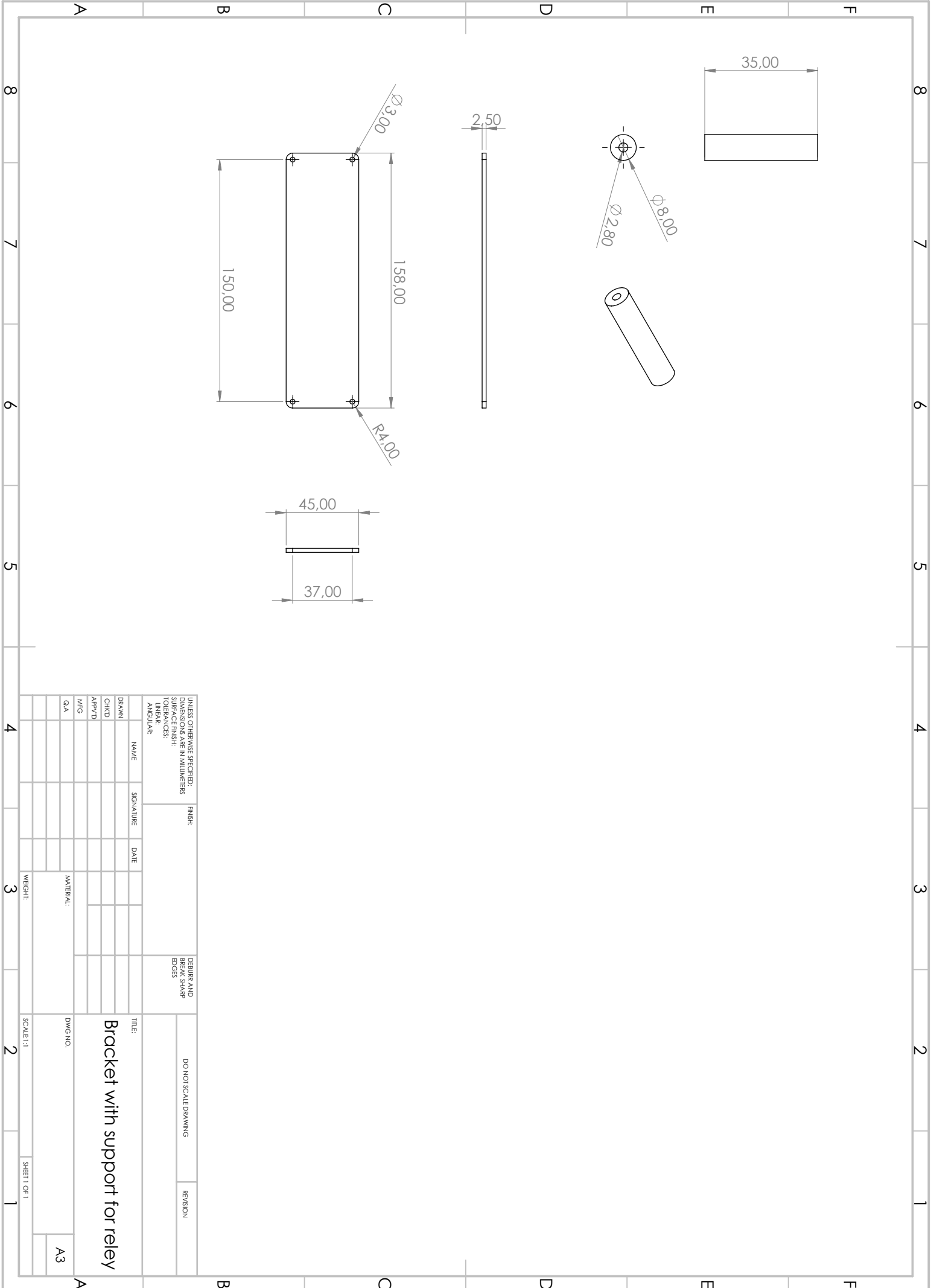
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS			FINISH:			DEBURR AND BREAK SHARP EDGES		
SURFACE FINISH:						DO NOT SCALE DRAWING		
TOLERANCES:						REVISION		
LINEAR:								
ANGULAR:								
NAME	SIGNATURE	DATE	TITLE:			DWG NO.		
DRAWN			Drawing of tube and end piece			SCALE: 1:30		
CHK'D						SHEET 2 OF 2		
APPR'D						A3		
MFG								
QA								
MATERIAL:			WEIGHT:					





UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS		FINISH:		DEBURR AND BREAK SHARP EDGES	
SURFACE FINISH: TOLERANCES: LUNAR: MODULE:					
NAME	SIGNATURE	DATE	TITLE:		
DRAWN			<b>Drawing of support bracket for probes</b>		
CHK'D					
APPR'D					
MFG					
QA					
MATERIAL:			DWG NO:	DO NOT SCALE DRAWING	
WEIGHT:			SCALE: 1:1	REVISION	
			SHEET 1 OF 1		

A3



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LUNAR: AMODLAR:		FINISH:	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
DRAWN	NAME	SIGNATURE	DATE	TITLE:	
CHK'D				<b>Bracket with support for reley</b>	
APPR'D					
MFG					
QA					
				DWG NO.:	
				MATERIAL:	
				WEIGHT:	
				SCALE: 1:1	SHEET 1 OF 1

**Bracket with support for reley**

A3

## Monokristalline Module Größe: 160 Watt

### Technische Daten



Spitzenleistung(W)	160W
Spannung bei max. Leistung(Vmp)	18,10V
Strom bei max. Leistung(Imp)	8,85A
Leerlaufspannung(Voc)	22,20V
Kurzschlußstrom(Isc)	9,60A
Zellwirkungsgrad(%)	18,48%
Modulwirkungsgrad(%)	15,35%
Leistungstoleranz	0%+3%
NOCT(normale Zelltemperatur)	45°C +/-2°C

### Vorteile

- hocheffiziente Solarzellen mit hoher Transmission und texturiertem Glas liefern hohe Effizienz für Module;
- Bypass-Dioden minimieren den Leistungsabfall bei Verschattung;
- Gehärtetes Glas, EVA-Kunststoff und witterungsbeständige Folie, plus Aluminiumrahmen für den Langzeiteinsatz im Außenbereich;
- Module unabhängig getestet, um die Konformität mit Normen und Zertifikaten zu garantieren;
- Fertigung nach ISO 9001 zertifiziertem Qualitäts-Managementsystem-Normen.



### Anwendungen

- On-Grid Dächer /Privathäuser
- On-grid Gewerbe / Industrie Dächern
- Solarkraftwerke
- Off-Grid Inselanlagen

### Temperaturkoeffizienten

Temperaturkoeffizient	Isc(%) °C	+0.04
Temperaturkoeffizient	Voc(%) °C	-0.35
Temperaturkoeffizient	Pm(%) °C	-0.45
Temperaturkoeffizient	Im(%) °C	+0.04
Temperaturkoeffizient	Vm(%) °C	-0.35

## Monokristalline Module

### Größe: 160 Watt

#### Technische Daten

Solarzelle	125*125 Mono
Anzahl der Zellen(Stück)	4*9
Modulgröße(mm)	1480*680*35
Glasstärke(mm)	3.2
Maximale Tragkraft der Oberfläche	2400-5400Pa
Zulässige Belastung durch Hagel	23m/s ,7.53g
Gewicht pro Stück(KG)	11,50
Bypass- Dioden Rating(A)	10
Rahmen(Aluprofile.)	35 mm
Rückseitenfolie (Typ)	TPT
Temperaturbereich	-40°C bis +80°C
Anschluss	70-76%
Standard Testbedingungen	AM1.5 1000W/3; 25 +/-2 °C

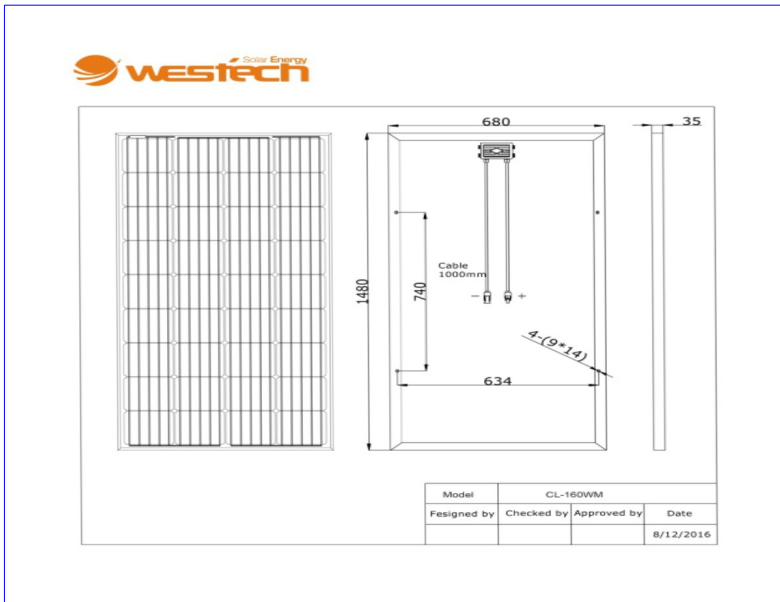
#### Verpackung

Verpackung	Holzkasten/ Palette/ Karton
Stück pro	1 Stück im Karton

#### Projektbild



#### Konstruktionszeichnungen



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Daten in diesem Datenblatt können bei technischen Änderungen ohne Vorankündigung geändert werden.



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## Overview

The ViewStar AU controller is a PWM charge controller with built in LCD display that adopts the most advanced digital technique. The multiple load control modes enable it can be widely used on solar home system, traffic signal, solar street light, solar garden lamp, etc.



## Features

- Adopt high quality components of ST,IR and Infineon, make sure product using lifespan
- Terminals have UL and VDE certification, the product is more safer and more reliable
- Controller can work continuously at full load within the environment temperature range from -25 to 55 °C
- 3-Stage intelligent PWM charging: Bulk, Boost/Equalize, Float
- Support 3 charging options: Sealed, Gel, and Flooded
- LCD display design, dynamically displaying device's operating data and working condition
- Double USB design, the power supply charge for electronic equipment
- With humanized button settings, operation will be more comfortable and convenient
- Multiple load control modes
- Energy statistics function
- Battery temperature compensation function
- Extensive Electronic protection



Solar Car



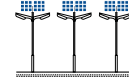
Solar Home



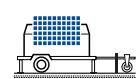
Solar Backpack



Solar Boat



Solar Street Light



Solar Power Generator

## Technical specifications

Model	VS1024AU VS2024AU VS3024AU VS3048AU VS4524AU VS4548AU VS6024AU VS6048AU							
Nominal system voltage	12/24VDCAuto			12/24/36/48 VDC Auto	12/24VDC Auto	12/24/36/48 VDC Auto	12/24VDC Auto	12/24/36/48 VDC Auto
Battery input voltage range	9V ~ 32V			9V ~ 64V	9V ~ 32V	9V ~ 64V	9V ~ 32V	9V ~ 64V
Rated charge/discharge current	10A@55°C	20A@55°C	30A@55°C		45A@55°C		60A@55°C	
Max. PV open circuit voltage	50V			96V	50V	96V	50V	96V
Battery type	Sealed(Default) / Gel / Flooded							
Equalize Charging Voltage※	Sealed:14.6V/ Gel: No/ Flooded:14.8V							
Boost Charging Voltage※	Sealed:14.4V/ Gel:14.2V/ Flooded:14.6V							
Float Charging Voltage※	Sealed/Gel/Flooded:13.8V							
Low Voltage Reconnect Voltage※	Sealed/Gel/Flooded:12.6V							
Low Voltage Disconnect Voltage※	Sealed/Gel/Flooded:11.1V							
Self-consumption	≤9.2mA/12V;≤11.7mA/24V; ≤14.5mA/36V;≤17mA/48V							
Temperature compensation coefficient	-3mV/°C/2V ( 25°C )							
Charge circuit voltage drop	≤0.29V							
Discharge circuit voltage drop	≤0.16V							
LCD temperature range	-20°C ~ +70°C							
Working environment temperature	-25°C ~ +55°C(Product can work continuously at full load)							
Relative humidity	≤95%, N.C.							
Enclosure	IP30							
Grounding	Common Positive							
USB output	5VDC/2.4A(Total)							
Overall dimension(mm)	142x85x41.5	160x94.9x49.3	181x100.9x59.8		194x118.4x63.8		214x128.7x72.2	
Mounting dimension	130x60mm	148x70mm	172x80mm		185x90mm		205x100mm	
Mounting hole size	Φ4.5mm		Φ5mm		Φ5mm		Φ5mm	
Terminals	4mm <sup>2</sup> /12AWG	10mm <sup>2</sup> /8AWG	16mm <sup>2</sup> /6AWG		16mm <sup>2</sup> /6AWG		25mm <sup>2</sup> /4AWG	
weight	0.22kg	0.35kg	0.55kg	0.58kg	0.76kg	0.88kg	1.02kg	1.04kg

※ Above the parameters are in 12V system at 25°C, twice in 24Vsystem, triple in 36V system and quadruple in 48V system



## PROFESSIONAL DUAL PURPOSE

### De viktigste fordelene

- Beregnet på eldre bobiler, campingvogner og båter



Hvis du vil ha mer informasjon, besøk nettsiden [www.varta-automotive.com](http://www.varta-automotive.com)

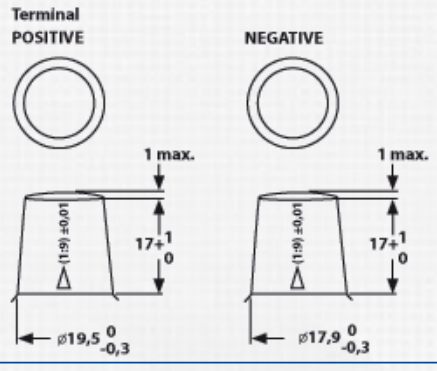
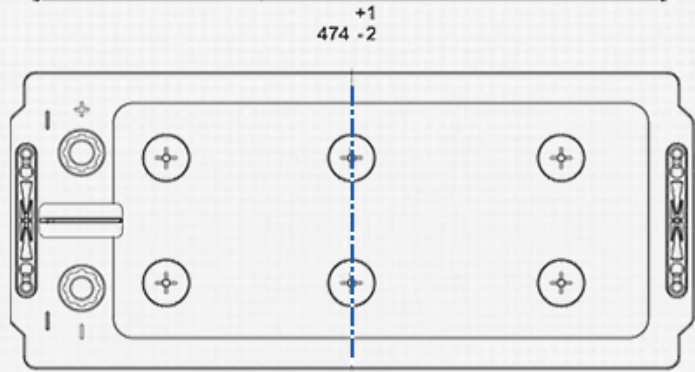
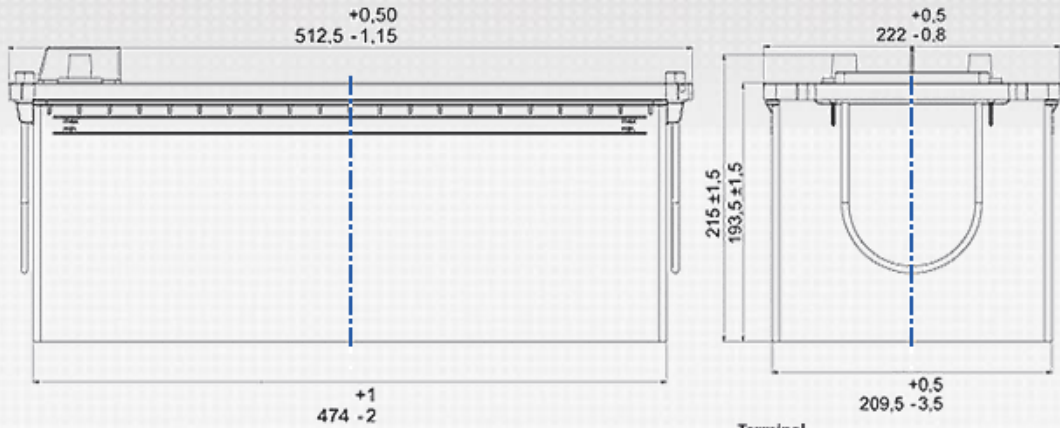
### OBESTILLINGSINFORMASJON

ETN:	930 180 100
Artikkelnummer:	930 180 100 B91 2
VARTA kortnummer:	LFD 180
Strekkode:	4016987141144
Emballasje:	1
Antall på pall:	21

### TEKNISK INFORMASJON

Spenning [V]:	12	Høyde [mm]:	223
Batterikapasitet [Ah]:	180	Festeknast:	B00
Batterikapasitet 5h [Ah]:	153	Polstilling:	3
Kaldstartstrøm EN [A]:	1000	Poltype:	1
Marine Cranking Amps (SAE) @ 0°C:	1250	Størrelse på hus:	B
Lengde [mm]:	513	Vekt [tomt]:	45,1
Bredde [mm]:	223		





Date	EC mean	pH mean	Temp. mean	EC Pump Frac.	pH pump Frac.	EC std.	pH std.	Temp. std.
2019-01-13	1333.047	6.904	25.666	NaN	7.054e-01	11.425	0.795	0.130
2019-01-16	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2019-01-19	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2019-01-22	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2019-01-25	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2019-01-28	1302.375	6.903	25.049	0.000e+00	5.962e-03	72.741	0.822	0.111
2019-01-31	1891.868	6.415	25.330	0.000e+00	5.136e-01	76.815	3.779	0.283
2019-02-03	1526.308	6.719	25.035	1.531e-02	8.428e-01	78.382	0.704	0.185
2019-02-06	1501.240	6.820	24.925	2.748e-03	6.895e-01	12.180	0.698	0.179
2019-02-09	1568.744	6.464	24.750	0.000e+00	3.689e-03	33.426	1.046	0.254
2019-02-12	1548.255	6.601	24.515	0.000e+00	3.343e-03	23.289	1.064	0.199
2019-02-15	1316.801	7.102	24.247	0.000e+00	3.994e-03	15.518	1.044	0.255
2019-02-18	990.866	7.554	24.124	2.262e-03	5.675e-03	50.992	0.813	0.401
2019-02-21	1008.668	7.513	24.278	1.401e-03	5.836e-03	21.084	1.226	0.279
2019-02-24	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2019-02-27	1040.953	7.277	24.623	0.000e+00	5.361e-03	5.411	0.779	0.218
2019-03-02	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2019-03-05	1127.692	8.397	25.255	0.000e+00	4.768e-03	95.140	2.349	0.124
2019-03-08	1276.634	6.242	25.259	0.000e+00	0.000e+00	26.486	0.112	0.122
2019-03-11	1211.435	5.579	25.075	0.000e+00	0.000e+00	26.836	0.286	0.191
2019-03-14	1158.123	5.789	24.754	6.458e-05	8.072e-05	82.096	0.597	0.178
2019-03-17	1091.222	5.743	11.651	2.703e-04	0.000e+00	42.295	0.207	12.158
2019-03-20	1254.420	5.656	15.107	1.034e-04	0.000e+00	94.002	0.178	11.534
2019-03-23	1323.855	5.619	24.238	0.000e+00	1.060e-04	94.623	0.571	0.221
2019-03-26	1295.134	5.316	23.771	0.000e+00	8.105e-05	94.948	0.752	0.146
2019-03-29	1262.573	5.766	23.679	0.000e+00	0.000e+00	139.599	0.196	0.224
2019-04-01	1197.445	5.291	24.219	1.237e-04	1.237e-04	134.752	0.539	0.351
2019-04-04	1194.186	5.369	24.601	0.000e+00	0.000e+00	24.868	0.286	0.173
2019-04-07	999.036	6.100	24.166	1.866e-04	3.109e-05	46.239	0.114	0.470
2019-04-10	952.773	5.938	24.667	1.720e-04	2.580e-04	98.354	0.374	0.459
2019-04-13	1219.447	5.027	25.300	1.255e-03	0.000e+00	430.418	0.383	0.323
2019-04-16	1277.606	5.478	24.786	0.000e+00	0.000e+00	514.500	0.204	0.794
2019-04-19	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
2019-04-22	1014.238	6.043	23.624	0.000e+00	8.091e-05	337.853	0.422	0.562
2019-04-25	990.950	5.921	24.294	0.000e+00	0.000e+00	257.061	0.120	0.224
2019-04-28	780.653	6.534	23.222	1.007e-03	6.713e-04	268.917	0.551	0.550
2019-05-01	755.491	6.394	23.805	0.000e+00	0.000e+00	268.369	0.019	0.098