A Hydroponic-Greenhouse System for Israeli Urban Agriculture

An Interactive Qualifying Project Report

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By:

Kelly Heffernan   Rayden Morley   Natanel Pinkhasov   Sean Nuzio

Sponsored by:

Dr. Maor Zlotzever, founder of the Mityaalim Foundation

Date: May 5th, 2023

Prof. Svetlana Nikitina, Advisor   Prof. Ivan Mardilovich, Advisor

Table of Contents

Abstract

In Israel, rising transportation costs have contributed to fresh produce turning from a nutritional necessity to a luxury. Factors such as scarce rainwater, concrete highrise buildings, and strong windstorms make Israel an ideal candidate for alternative agriculture methods. Tasked by the Mityaalim Foundation, our team developed an engineering plan for an urban rooftop Israeli hydroponic garden within a greenhouse. Our blueprints and instructional handbooks for the hydroponics system and greenhouse were developed through researching current methods and interviewing agricultural experts in Israel. These feature accessibility, affordability, modularity, and ease of use. Our plan will be placed on an open-source website to provide how-to instructions on growing fresh produce via hydroponics.

Acknowledgements

We would like to sincerely thank our advisors, Professors Svetlana Nikitina and Ivan Mardilovich for their continuous help and support. We would also like to thank everyone from the Mityaalim Foundation in Israel who made this project a possibility. In particular, we are grateful to our sponsor Dr. Maor Zlotzever, founder of the Mityaalim Foundation, for his guidance. Thank you to Braude College of Engineering for their generous accommodations and resources during our stay in Israel. Additionally, we would like to thank the hydroponic farms LivinGreen and Givat Yoav for graciously allowing us to tour their facilities and interview them. Lastly, we would like to thank Haifa University for their collaboration on this project.

Executive Summary

Our project goal was to design an accessible, sustainable, inexpensive and modular hydroponics system within a greenhouse. Not only were we responsible for designing the system, but also writing handbooks on the assembly and operation of both the greenhouse and hydroponic system. Ultimately, the design was to be built on an Israeli urban rooftop, while the handbooks would be published on an open access website. Israel is faced with rising food prices in part due to the reliance on imports of produce as well as increasing transportation costs. In a country where arable land is scarce, alternative agriculture methods like hydroponics present an attractive solution. Since most buildings in Israel are made of concrete, our project could offer a unique opportunity to place a fully operational greenhouse and hydroponics operation on the rooftops of urban buildings.

The first step in creating our engineering plan and handbooks was to research existing methods of hydroponics around the world. We eventually settled on the nutrient film technique (NFT), as this was the most applicable to our project. We chose a greenhouse design based on the samples sent to us by our sponsor, Dr. Zlotzever. The materials for our greenhouse design were chosen based on their availability in Israel.

Using the computer aided design (CAD) software, Solidworks 2022, we designed our hydroponics system and greenhouse structure. The hydroponics system is comprised of an A-frame shape capable of growing 64 crops in total. It also consists of two 50 liter water tanks for either side of the A-frame. Within each of the tanks sits a water pump, pH probe, and EC probe. The hydroponic system is made from unplasticized polyvinyl chloride (U-PVC) pipe, and the water tank can be made from any opaque material available to the system user. To complement our hydroponic system design, we also wrote a handbook on how to assemble and operate the system. This contains information on supplementary materials needed, such as germination trays and nutrient solutions. Similarly, we also wrote a handbook for the assembly and maintenance of the greenhouse structure. Our 15 square meter greenhouse is intended to be used by both individuals and commercial operations. The greenhouse is designed with an aluminum frame and polycarbonate (PC) walls. Within the greenhouse is a psychrometer, to measure humidity and temperature. For larger operations, people can construct multiple greenhouses and grow unique crops within each, as well as setting particular growing conditions

For future investors or people who may want to use our design, we included a cost analysis of materials required for both the greenhouse and the hydroponic system within this report. This cost analysis was compiled using local Israeli suppliers, so all costs are represented in Israeli shekels (ILS).

Project Goals and Objectives

Our sponsor, Dr. Maor Zlotzever, founder of the Mityaalim Foundation, tasked us with developing design plans for both a fully functional greenhouse and hydroponics system. The Mityaalim Foundation is a private philanthropic foundation that works to promote financial education and ecological economics. Hydroponics provides many ecological and economic advantages that anyone can benefit from by utilizing our system. To this end, our objectives were as follows:

1. Evaluate and research current methods of hydroponics in Israel
2. Create a CAD design of a hydroponic system and greenhouse structure for an Israeli urban rooftop
3. Write a handbook discussing how to assemble and operate the hydroponic system, and a second handbook on how to assemble the greenhouse structure
4. Develop a cost analysis in shekels for materials needed for the designs

With these objectives in mind, our ultimate goal was for our designs to be sustainable, inexpensive, modular for different roof varieties, and accessible.

Methods

To research and evaluate current hydroponic methods within Israel, our team utilized current hydroponic examples sent to us by our sponsor, online agricultural forums, and several research papers. After comparing methods through our research, we settled on NFT for best suiting Israel's dry and arid climate.

We used the CAD software Solidworks 2022 to design our hydroponic system and greenhouse structure. One of our goals while designing our hydroponic system was to maximize crop yield. To accomplish this, each growing channel was offset vertically and horizontally from the last, ensuring each plant receives equal sunlight. Another goal of ours was for the system to be easy to operate and maintain, therefore rubber gaskets were chosen as the growing channel sealant instead of pipe cement. Sealing the system with rubber gaskets allows for it to be easily disassembled and reassembled when needed. With similar goals for our greenhouse design in mind, we wanted the structure to be easily assembled by someone without any prior engineering or construction experience. We also designed our greenhouse to withstand the strong winds and temperatures of Israel without deteriorating.

While writing the handbooks, to ensure accessibility, we presented as many alternatives as possible to our specifications. We were driven by the idea that even those who do not have access to the same materials would still be able to use components of our designs. Our handbooks were designed and formatted using Adobe InDesign, allowing for a professional, easy to understand format that can be easily transferred to the open source website. We scheduled interviews with several hydroponic experts in Israel not only to expand knowledge, but also to gain their insight on our design and handbooks. After the interviews we used what we learned to revise and update our CAD designs and handbooks.

To develop our cost analysis, we researched both global and local suppliers in Israel, sourcing the required materials as we completed our design. Our cost analysis can be seen in section 4.6, where we establish the total cost for our design and the cost for each component.

Results

Through rendering via Photoview360 on SolidWorks, images of the hydroponic system and the greenhouse structure were generated. Using these images, we then compiled a series of assembly instructions to be used in our handbooks. For the hydroponic system handbook, these assembly instructions were broken into smaller sections for each half of the system. For the greenhouse handbook, the instructions were included as a series of drawings from SolidWorks. Within the hydroponic handbook, there were also instructions on how to germinate, transplant, and harvest, as well as maintain the system.

Conclusions and Final Recommendations

Our project objectives were met through designing a hydroponic system, a greenhouse structure, creating handbooks for both, and compiling a cost analysis of our materials.

Due to time constraints, none of our designs could be assembled or tested. If this project were to be continued, all designs should be assembled, ensuring all assembly steps are accurate, and tested for effectiveness and efficiency. These tests should be completed before implementing our designs into a large scale project. In the future, to increase the sustainability of our designs, we would like to add solar panels and a rainwater collection device to our greenhouse in an effort to have a net zero carbon footprint. Additionally, alternative techniques of hydroponics may be explored in future iterations of this project.

Our designs have been put together to minimize negative ethical considerations.

Authorship

Report Authorship

Author(s):	**Report Chapter, Section:**	**Deliverables**
Sean Nuzio *Edited all sections*	Abstract, Executive Summary (All sections), Background (2.1, 2.2, 2.3, 2.4), Methodology (3.1, 3.4, 3.5), Results and Discussion (4.1, 4.2, 4.4), References	Hydroponic Handbook Writer
Rayden Morley	Executive Summary (All sections), Introduction (1.1), Methodology (3.4), Results and Discussion (4.1, 4.4), Future Recommendations (5.1)	Hydroponic System Designer, Greenhouse System Designer
Natanel Pinkhasov	Background (2.1)	Handbooks Designer
Kelly Heffernan *Edited all sections*	Abstract, Acknowledgements, Executive Summary (All sections), Introduction (All sections), Background (2.5, 2.6), Methodology (3.2, 3.3.), Results & Discussion (4.3), Future Recommendations (All sections), Conclusions (All sections), References	Hydroponic Handbook Writer

Chapter 1: An Introduction to Accessible Hydroponics in Israel

Within the last year in Israel, the cost of food has increased by 10%.[1] As the cost of food continues to rise, alternative agricultural methods are being explored to ensure all people have access to fresh vegetables and fruits. This is relevant in urban settings, where transportation of produce from distant farmlands adds significantly to the cost of food.[2] If people in urban environments had the knowledge to build their own agricultural systems directly within the city, they could eliminate the cost of transportation while ensuring a continuous supply of fresh produce.

As part of our Interactive Qualifying Project (IQP) at Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts, our team of four students designed a hydroponic system within a greenhouse for buildings in Israel. We traveled to Israel to meet with our project sponsor, Dr. Zlotzever – founder of the Mityaalim Foundation. The Mityaalim Foundation is a sustainable technologies social initiative based in Haifa, Israel, that aims to develop and provide economic management tools. Their team tasked us with developing a rooftop hydroponics operation to make food accessible to people in urban environments.

In this project, we aimed to develop two open source handbooks on an alternative agricultural method: hydroponics. In the first handbook, there are complete instructions on how to assemble a hydroponics system on a city rooftop, as well as how to successfully operate the system to grow produce. The second handbook consists of instructions on the greenhouse assembly, as well as maintenance of the structure. Our largest goal for our project was to design a sustainable, effective, modular and easy to use system.

In order to test whether our handbook fulfilled those four goals, we partnered with LivinGreen, an Israeli hydroponics research facility and commercial supplier. We informally interviewed them on their expertise to improve our system designs and handbooks. We also toured a commercial hydroponics operation in the Galilee area. At this facility, we again informally interviewed their experts once again to improve our designs. The culmination of our project came when our handbooks were published to an open source website, where anyone interested in building a rooftop hydroponics farm has free access to them. The workflow our project followed can be seen in figure 1 below.

Figure 1: This diagram shows the final direction our methodology took during this project.

1.1 Limitations to our Project

The greatest limitation to our project was being unable to construct a prototype of our designs. Due to this, we could not fully flesh out our assembly instructions or system design. Therefore, there may be missing assembly steps or components, all of which could have only been determined through the construction of a prototype.

Since we had no prototype, we were unable to show our designs to the hydroponics experts we interviewed. Without a peer review system, the efficacy of our designs was hindered. Having experts in hydroponics or greenhouse design look at our work could have given us many new ideas, and helped circumvent some issues we had in researching our designs. Initially, our methodology was supposed to be an iterative process, in which each draft of our designs were sent out to our partners and critiqued, and then sent back to us for improvement. Due to time constraints, our methodology became linear, in which we made one design draft.

Our project was also limited by not being as sustainable as it could be. Our hydroponic system requires the use of electricity from an exterior source. It would have been ideal if we had been able to also design a solar panel system in conjunction with the greenhouse, to make our design 100% eco-friendly. Likewise, if we had been able to add a rainwater collection system, that also would have improved our design's sustainability.

Chapter 2: A Brief Background on Hydroponics Farming

2.1 A Global Issue of Sustainable Crop Cultivation

Despite significant advancements in global technology within the last century, crop cultivation remains a challenge in many parts of the world.[3] Cultivation is a time-consuming and resource-intensive process that can be too demanding to maintain in many cases.[3] In some of Earth's most extreme environments, the land and climate serve as obstacles to crop cultivation for the local communities.[3]

Many countries like Israel are reliant upon importing food from elsewhere to meet the needs of their growing populations.[3] However, due to extensive import operations, the quality and freshness of the food comes into question as these lengthy processes can put the food at risk of becoming spoiled or damaged.

Additionally, modern farmers have begun utilizing dangerous pesticides and insecticides in efforts to keep their crops free of animals and insects.[3] With growing demand for food production, farmers have invested more resources into their operations as controlling the environment has become increasingly taxing.

Furthermore, as the demand for food increases, cropland availability decreases.[3] As shown in Figure 2 below, urbanization and growing populations rapidly cause the conversion of agricultural land to residential areas.[4] Thus, traditional agricultural methods are becoming unsustainable and need to be remediated.

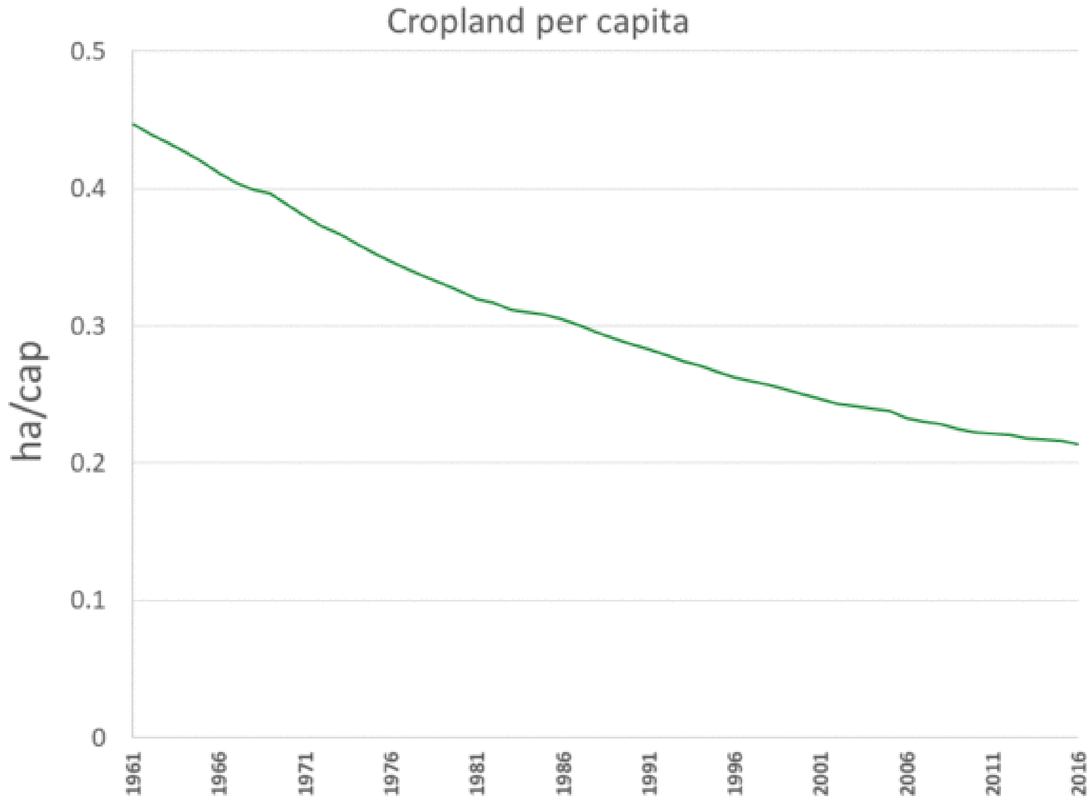


Figure 2: This graph from the Food and Agriculture Organization of the United Nations[5] shows a rapid downward trend between available cropland and population growth through 1961 to 2016 globally.

Along with unsustainability, another drawback to traditional agriculture methods includes its dependence on the economy. During a 2016 IQP based in Greece[6], the research team discovered that due to an economic downturn, much of the population became reliant upon food banks and charities to accommodate for the severe food discrepancies. The long-term impact of these economic conditions resulted in a noticeable decrease in vegetable consumption amongst the local population. From 2006 to 2011 vegetable consumption decreased by 82%, 51%, and 69% in lower, middle, and higher socioeconomic conditions respectively.[6] This ultimately correlated with an 18% increase in obesity during that time frame in their country.[6] Despite these challenges, this period evoked a significant amount of volunteerism that led many unemployed citizens to start their own small-scale, portable food banks.[6]

The situation in Greece stands as a case study for what kinds of conditions can be expected in countries struggling with traditional agricultural methods. As a species we must begin looking at alternative, more technologically-advanced, urban-friendly, and sustainable methods of producing crops.

2.2 Defining Hydroponics Systems

The term *hydroponics* is derived from the Greek words "hydro", meaning water, and "ponos", meaning working, which translates to "working water".[6] Invented about 2600 years ago, hydroponic systems grow plants by substituting soil with nutrient-rich water solutions, providing higher yield rates than traditional farming methods.[6]

In a 2015 study on growing lettuce, researchers found that hydroponic systems were able to offer eleven times the yield of traditional soil-based operations.[6] Globally, hydroponic systems tend to yield at least twenty percent more produce than conventional soil-based operations.[4] This is partially due to the high-density planting environment that hydroponic systems offer. With hydroponics, there are ample amounts of nutrients and water available to the crops that can be replenished through automation. Therefore, the only constraining factor becomes the availability of sunlight. In contrast, standard soil-based agriculture has a higher limit on the nutrients and water available to crops that must be manually replenished.

In terms of popularity and applications, hydroponic systems have been utilized globally both in private and commercial sectors. In the commercial world, these systems are implemented in greenhouses to grow a variety of fruits, vegetables, and herbs. On the other end of the spectrum, hydroponics still thrives as a hobbyist culture where interested people experiment on their own with many different variables, such as growth mediums, lighting, and climate conditions.[6]

Additionally, the benefits of hydroponic systems extend well beyond spatial optimization as they are well regarded for their ease of customization and user control. Conditions such as pH, water flow, lighting, temperature, and nutrient levels can be modified at will, making these arrangements ideal for in-lab research, real-time monitoring, and data collection.

2.3 Economic Benefits of Hydroponic Systems

In a 2002 study published by the Urban Agriculture Network[7], Geoff Wilson examines the potential profitability of rooftop microfarms in Australia. The operation has the aim of providing a wider range of organic produce to local restaurants through the use of organic hydroponics systems. In an effort to weave in more economic elements and benefits to the community, the project integrated sustainable practices around the local area to gauge the effect of their project.

In this study, the researchers also developed a cost-benefit analysis for their system. By tracking the estimated costs of implementing a rooftop hydroponics system, others interested in recreating the system can know how much money they may need to implement it. Tracking costs also allows for someone who is modifying the design to know what the cost difference would be.

Transportation adds greatly to the cost of produce. Compounded by rising gas prices[8], high transportation costs have become an obstacle for those in urban areas. However, the cost of transportation can be eliminated by growing food directly on local rooftops, which would bring the cost of food down.

2.4 Different Hydroponic Techniques

When developing the design of a hydroponics system, it is important to consider the various different hydroponic techniques. The main hydroponic techniques include nutrient film technique, dynamic root floating technique (DRFT), water culture technique, and ebb and flow technique.

2.4.1 Nutrient Film Technique

The NFT is one of the most popular hydroponics systems in modern use. In a NFT system, plants are suspended above a channel of continuously circulated nutrient solution. The solution is then collected from the channel into a holding tank, where it can be recycled and pumped back into the system. This technique works best with large root system plants since crops will only grow if their roots can reach the flowing nutrient solution below. However, if the plant roots are too large, they may cause an obstruction in the channel, but this can be remediated through the use of a filter and proper root care.[9, 10]

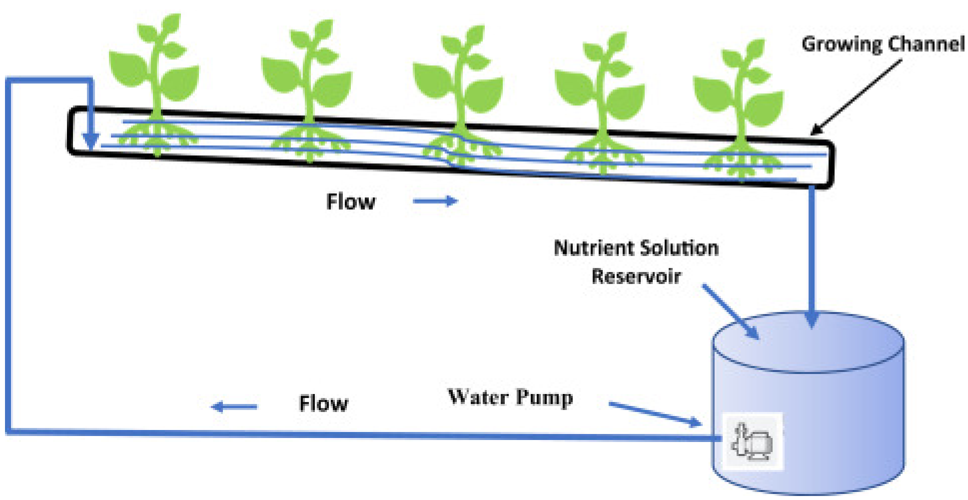


Figure 3: This schematic[11] shows the general design of a NFT system.

2.4.2 Dynamic Root Floating Technique

Dynamic root floating technique (DRFT) is very similar to NFT, with the main difference being the pump within a DRFT system does not run continuously. In an effort to alter the depth of the solution in the channel, a DRFT system will constantly activate and deactivate the pump. Alternatively, the same effect can be generated if the pump remains activated and a drainage system is installed. Standard DRFT systems are built with concave panels, which allows for more space above the solution. This supports the growth and development of aeroroots above the solution, and optimizes the plants' oxygen intake. Due to this extra space within the channels, DRFT systems are unique in their ability to maintain temperatures within the channel. This is achieved through lining the solution channels with insulating materials, making the DRFT system ideal for areas with more extreme climates.[9]

2.4.3 Water Culture Technique

The water culture technique is a stillwater system in which the crops float on a basin of still solution. Similarly to the two previous systems, the crop roots hang freely into the nutrient solution. However, due to the still nature of the solution within the basin, this technique struggles with root aeration. To counteract this, aerators may be added to the water. These aerators pump oxygen into the nutrient solution, providing the crops with the oxygen they need for proper growth. Alternatively, a pump may be installed to circulate the solution. However, due to the size and shape of the system, this option is not as effective as installing an aerator. Ultimately, this system is not effective for larger crops or crops with extended cultivation periods.[9]

2.4.4 Ebb and Flow Technique

Lastly, the ebb and flow technique, similar to the water culture technique, consists of plants floating on a basin of nutrient solution. However, in the ebb and flow technique, the solution is continuously pumped into the basin, and is then allowed to gradually drain from the basin. This exposes the roots, oxygening the system, allowing them to receive more oxygen than that in a traditional water culture system.[9]

Ultimately, a NFT system is most applicable to this project. The NFT system allows for the most variability within the system design, is space conscious, and does not have any major limitations on crops that can be grown.

2.5 Hydroponic Crop Selection and Growing Requirements

While deciding which plants to grow in a hydroponic operation, one must consider factors like plant size, cultivation period, nutrient requirements, climate, and water restrictions. In Barcelona, Spain, a group of researchers conducted several experiments in order to identify year-round eco-efficient crop combinations for rooftop greenhouses. Given the similarities in climate, location, and water limitations to Israel, the results from these experiments can be utilized to help guide the crop decisions for this project.

In the Barcelona experiments[12], twenty-five crop cycles were performed with seven different species. Tomato, pepper and chard plants yielded the most crops on average throughout the three year span. However, the chard and pepper plants only lasted for one cycle while the tomato and lettuce plants lasted for five. These experiments also found that the lettuce and arugula plants had reduced environmental effects, as compared to the tomato, pepper and chard plants.

Although the Barcelona experiments provide numerical data to help guide the crop decisions of the project, there are other factors to be considered. The Barcelona experiments were completed in a traditional agricultural greenhouse. Our project uses a hydroponic system, meaning root size, plant structure and water use efficiency must also be considered. For example, for a NFT system in Israel, crops such as the chard and pepper plant would not be effective due to their short cultivation period. While the tomato plant does not share these disadvantages, it is large and relatively lacking in water use efficiency. Comparatively, the lettuce, spinach and arugula plants lasted for multiple cycles, are not large plants, and boast the best water use efficiency numbers of any crops grown for the Barcelona experiments. These three plants were also able to utilize one-hundred percent of rainwater, which is the main source of recycled water in Israel.[12]

Within a hydroponics system, crops must be grown in a suitable pH level and temperature, have access to sunlight, water, and essential nutrients, and be protected from damaging winds. The ideal pH level for each plant type varies slightly, but for most plants occurs between a pH level of 6.5 to 7.5.[13] In a hydroponics system, a pH probe can be used to measure these levels to ensure constancy, while fertilizers can also be purchased to ensure plants have access to nutrients.

The three essential nutrients for crops are nitrogen, phosphorus, and potassium. Other less essential nutrients required include magnesium, sulfur, and calcium. In much smaller quantities, crops require boron, chlorine, manganese, iron, nickel, copper, zinc, and molybdenum.[14] Crops may die if they do not receive enough of these nutrients, but can also be damaged by disproportionate levels of these nutrients. These nutrients are purchased as chemical compounds, usually salts, either in fertilizer or naturally in the environment. For instance, plants obtain hydrogen in the compound water (H_2O), and nitrogen through nitrates (NO3-). The chemical compounds and salts must be dissolved in water for the plants to be able to uptake them.

Crops assimilate these nutrients through osmosis. High concentrations of nutrients in solution outside of the plant's roots move to areas of lower concentration within the plant's roots and cells. For this reason, nutrients must be in liquid for the plant to take them up. Likewise, having a slightly acidic or neutral pH makes it easier for plants to uptake nutrients, as they are not fighting the effects of osmosis from free hydrogen ions or hydroxide anions in the water.

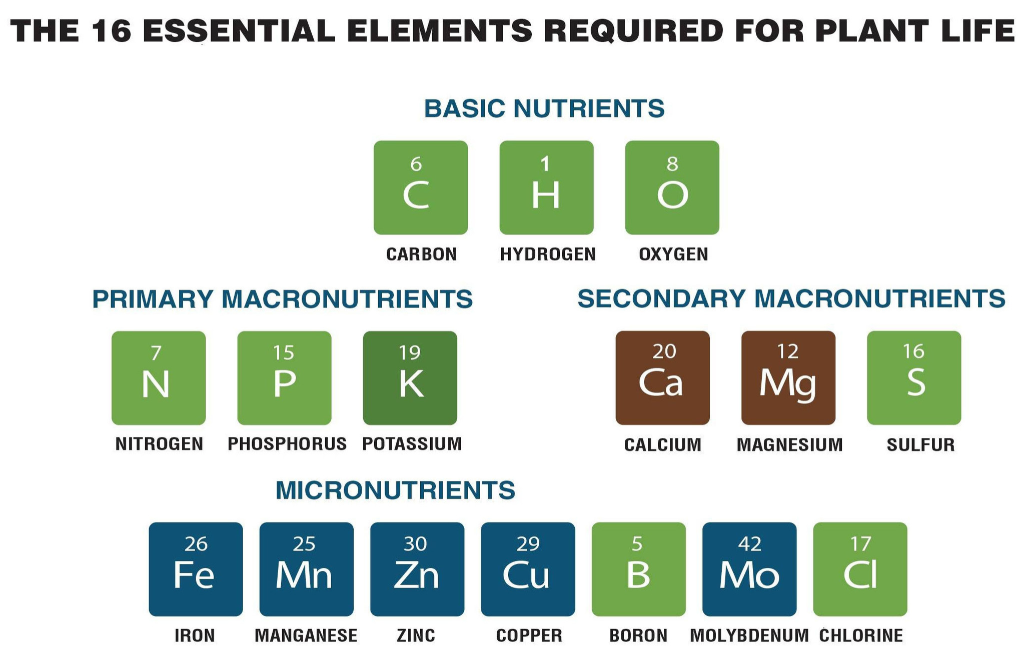


Figure 4: This figure[15] lists the essential nutrients for a hydroponic system.

2.6 Hydroponics in Israel

Due to the arid desert climate of Israel, Israeli people have made numerous innovations in water sustainability.[16] For instance, the development of an agricultural method called drip irrigation is used to mitigate water loss due to evaporation. In this method, water is applied directly to the roots of plants. Additionally, almost 100% of waste water in Israel is purified and recycled to be used again in agriculture.[16]

As agriculture in Israel already embraces sustainability, hydroponics present a compelling addition to this ideal. Recycled waste water would be ideal to use in a hydroponics system, since the water has already been tested for purity as well as levels of various chemicals . The NFT also minimizes water loss through the water being in a closed, contained system. Additionally, the water in a hydroponics system can be recycled endlessly, as long as more nutrients are added when necessary and extra water added in as the plants use it.

As stated previously, in Israel food costs have skyrocketed during this past year. If people had access to rooftop hydroponic systems in areas far from farming communities, they could have more secure food sources at lower costs. Hydroponics also presents a method of community togetherness, as the residents of an apartment complex could all help farm collectively on their roof.

In Israel, due to resource limitation, most buildings are multiple stories and are primarily made of concrete. Concrete rooftops present an excellent space to place a hydroponic system and greenhouse structure, as they are capable of withstanding substantial structural loads.

The numerous benefits of hydroponics explored here inspired our design of a rooftop hydroponic system for a standard city building in Israel. Our design attempts to take the constraints of farming in the desert, such as occasional severe wind storms, high temperature, low humidity, and unreliable rainstorms, and provide solutions for each problem. As our target audience is both individual growers and people who may want to scale up to commercial sized operations, we aspired to make our design accessible for the average person. To this end, we have written handbooks detailing both our greenhouse and hydroponic design. These handbooks include details on the assembly and operation of both designs. Although there are many free resources for hydroponics, through our research we found none that instruct people on how to build an urban rooftop garden on the scale of 500 square meters. It is our hope that the size, ease of operation, and easily understandable handbooks could help people to have better access to food in urban areas, while minimizing any negative environmental impacts that traditional agriculture often brings.

Chapter 3: The Methodology of Designing a Fully Functional Rooftop Hydroponics Garden

3.1 Identifying the Necessary Components

After acknowledging that a NFT hydroponics system is most desirable, the next step was to compile a list of all the materials and components required for the assembly of the system. First, the skeleton of the system will be made from U-PVC piping. Polyvinyl chloride (PVC) is the third largest produced synthetic plastic polymer in the world.[17,18,19]PVC is also inexpensive and easy to produce which makes it ideal for an accessible open source hydroponics design. U-PVC is a strong, rigid, and long lasting variation of PVC, making it a desirable choice for the skeleton of our hydroponic design.[17,18,19]

Another necessary component is the nutrient solution basin. This basin can be any high opacity container capable of holding a minimum of 50 liters of fluid. The basin must be made of an opaque material to ensure that no light reaches the solution inside. If a clear basin is used, bacteria and algae may start to grow inside the nutrient solution, causing blockages and damage to the system or pump[20,21]. Within the basin sits the water pump, as well as the pH and electrical conductivity (EC) probe. The pH and EC probes are responsible for measuring conditions critical to proper crop growth. The water pump must be capable of continuously pumping the nutrient solution throughout the system at an average rate of twenty liters per hour and a lifting height of at least 1.8m. Attached to the water pump, via internal and external fittings, is the solution tubing. This tubing is what will carry the water from the reservoir into the system, via the pump.[20,21,22] Lastly, not attached to the system, sits the psychrometer. The psychrometer is responsible for measuring humidity and temperature of the greenhouse. Similar to the probes within the system, the psychrometer measures conditions essential to healthy crop growth.

To transform the U-PVC frame into a hydroponics system, net pots are required. The net pots are what will hold the crop within the hydroponics system. However, the net pots alone cannot hold the crops properly, so a growth medium is needed.The medium sits at the bottom of the net pots, and can vary in material from rock wool, expanded clay aggregate, perlite, or coconut fiber. The growth medium provides stability to the crops, acting as a structure for which the roots may grow around. Lastly, to hold the frame together, rubber gaskets are necessary[2]. Rubber gaskets will be used as sealants between the U-PVC pipes and fittings. While pipe cement is a fantastic sealing option, using rubber gaskets allows for the system to be fully deconstructable, while still preventing leaks or clogs.[20,21]

The last components required are not used within the hydroponic system. Instead, the components are required for proper germination of the crops. A plastic tray is used as a base for the crops to germinate. These trays will hold rockwool cubes and water, which are used to sprout the seeds.This allows the seeds to start growing in a controlled environment. While the seeds are germinating, the tray will be covered with a plastic dome. This will create a miniature "greenhouse effect", allowing for accelerated growth of the seeds. The seeds will then be transferred into an empty plastic tray where they will continue to germinate. Once more, this tray will be covered with the plastic dome, allowing for continued growth. After the germination process is finished the seeds will be ready to be transferred into the net pots in the hydroponic system.[20,21,22]

The only materials required for the greenhouse are aluminum tubing, polycarbonate (PC) panels, and concrete. The frame of the greenhouse will be made from the aluminum tubing, while the PC panels will form the walls and roof. Aluminum is an easily accessible, lightweight, strong structural material, making it ideal for our design. PC is able to transmit up to 90% light while blocking up to 100% of ultraviolet (UV) radiation.[18,19] Combined with its lightweight and heat resistance, PC is the perfect material for the greenhouse construction. PC panels are available as either single-pane or double-pane. Although double-pane panels provide greater insulation, they also boast higher maintenance costs, therefore double-pane panels should only be used when heating and cooling costs are a concern.

3.2 Literature Review for Report and Operational Development

In order to guide our hydroponic operation design, we first examined other designs from previous IQP groups as well as hydroponic guides available online. We used the online WPI IQP database to search for the other groups who had built hydroponics or other agriculture systems in previous years. We utilized Google Scholar to find research articles, and various sources on hydroponics. Inspiration from the knowledge obtained through these sources can be seen throughout our designs and handbooks.

Another important source of literature utilized in the development of our handbooks and designs was a Google Drive folder sent by our sponsor, Dr. Zlotzever. The folder contained numerous documents in Hebrew from previous hydroponic projects Dr. Zlotzever had sponsored. After using a translator on all the documents, we found tips for system design, plant cultivation, and materials.

3.3 Interviews

We first determined interviews as the best way to revise our designs and handbooks. The subjects of our interviews were LivinGreen, a hydroponics supplier and educational organization in Israel, and a large scale commercial hydroponics farm in Negev. Our sponsor Dr. Zlotzever put us in contact with these organizations, and was responsible for scheduling our interviews with them.

After being informed of who our interview subjects were, we developed and wrote questions specific to each group. After writing our interview questions in English, the questions were sent to Dr. Zlotzever for both approval and translation. A written list of all the interview questions, in both Hebrew and English, can be found in Appendix A. In order to comply with the code of ethics set out by WPI, we wrote an interview consent form. Once more requested that Dr. Zlotzever translate the consent form into Hebrew. A finalized copy of the consent form in English can be seen in Appendix B. Our interview with the commercial farmers in Negev was scheduled for April 28th and the LivinGreen interview for May 1st.

During our interviews, we began by introducing ourselves and giving our interview subjects the consent form. If they decided to sign it, we began the interview. These were scheduled to take between 30 to 60 minutes. Although we will have access to our interviewee's names, their identifying information was kept confidential in our data reports and presentations.

3.4 CAD Design of a NFT Hydroponics System

The hydroponics system consisted of a PVC frame, PVC growing channels, two 50ml opaque solution tanks, two water pumps, four meters of water tubing, two pH probes, two EC probes, a psychrometer, and the nutrient solution. On the cover of the solution tanks sat a permanently fixed reducer adapter, similar to that on the top growing channel. To connect the top growing channels to the solution tanks, we used two meters of the water tube, with each end attached to one of the reducer adapters. To connect the bottom growing channels to the solution tanks, we drilled a 110mm hole in the tank cover, into which the bottom growing channel flowed. Within each of the solution tanks there was one water pump, one pH probe, one EC probe, and an appropriate amount of the nutrient solution. The psychrometer was not physically attached to the system, but rather hung in the greenhouse.

While the frame was constructed using general PVC piping, the growing channels were made specifically with U-PVC piping. For the frame, exactly 9.688m of 32mm PVC piping along with various 32mm PVC fittings are required. The frame fittings are as follows: twenty tee fittings, six 45°-elbow fittings, and four cap fittings. To permanently seal the frame together, pipe cement was used with all fittings.

The growing channels required exactly 12.720m of 110mm U-PVC piping along with several 110mm U-PVC fittings. The fittings required for the growing channels are as follows: fourteen 90°-elbow fittings, and two reducer adapter cap fittings for the top growing channel. Drilled into each growing channel are eight evenly spaced 80mm holes. Since we did not want to permanently seal the growing channels, 110mm rubber gaskets were used with all the fittings. The growing channels were connected, with specific spacing in mind to ensure all crops receive ample lighting. There was approximately a 2°-3° slope incorporated into the spacing, allowing for gravity to move the solution down the system.[28] The properly connected growing channels are then able to comfortably sit on the frame due to the built in supports. In totality, the fully constructed hydroponic system occupies a floor space of approximately 0.228m^2 with a height of 1.5m. The system spans approximately 2.3m in length and 1.3m in width.

To model our design we used Solidworks 2022. Within Solidworks not only did we develop the 3D model of our system design, but we also generated assembly instructions. These instructions then served as visual aids in our system's handbook.

3.5 CAD Design of Greenhouse Structure

The greenhouse structure was made from an aluminum frame and single-pane PC panels, all on top of a 500m^2 concrete base. Each greenhouse structure occupied a 15m^2 area on the concrete base. We also designed windows, vents, and space for movability.

In an effort to have a seamless connection between our greenhouse and hydroponics design, we also used Solidworks 2022 to model the greenhouse structure. Similar to the hydroponics system, we used Solidworks to generate assembly instructions for the greenhouse structure. Finally, these were then integrated into the structure's handbook as visual aids.

Chapter 4: Results and Discussion

4.1 Hydroponic Handbook

As previously stated, the goal with our hydroponics system was for the design to be accessible, sustainable, inexpensive and modular. In order to achieve accessibility and affordability, we designed our system using inexpensive, easy-to-find materials. In efforts to design a sustainable and modular system, we developed a triangular prism design (2.3 meters x 1.3 meter x 1.5 meters). In this design, each row is equally offset to allow for direct sunlight to reach every crop, ensuring system efficiency. Additionally, by not permanently fixing the growing channels to the support frame, our design allows for easy disassembly and maintenance. We also included the use of a pH probe, an EC probe, and a psychrometer within the system design. These all serve to monitor the current conditions within the system, ensuring proper growth can occur.

Our hydroponic handbook was developed for both commercial growers and people with no prior experience. By reading our handbook, they will learn how to assemble, operate and maintain our hydroponic system. Our handbook consisted of 40 pages which included instructive text and visuals. The handbook had information on the required materials as well as alternative solutions to the suggested design. The handbook also discussed effective operation methods to ensure efficient crop production. Finally, the handbook had a section on maintenance to keep the system fully operational. Our handbook was fully researched and referenced for people who wish to learn more. Please see appendix D for our hydroponics system handbook.

Figure 5: 3D Render of our Hydroponics System from Solidworks.

4.2 Greenhouse Handbook

Figure 6: Screenshot of the cover of our greenhouse assembly handbook.

We developed our greenhouse to be lightweight, accessible, inexpensive and of a rigid design. We chose aluminum for the frame to be lightweight, affordable, and accessible. By attaching the frame to the concrete base, we guaranteed the structure's rigidity, ensuring its strength against high winds. We chose PC panels to form the structure's walls, as it is inexpensive, and easily accessible around the world. The PC panels have the rigidity to face strong winds, and the natural properties to generate a strong greenhouse effect. Integrated into the walls of the structure are several PC panel vents to help with temperature and humidity control.

Similar to our hydroponic handbook, our greenhouse handbook was developed for those with no prior experience, teaching them how to assemble, and maintain our greenhouse structure. Our handbook was fully researched and referenced for people who wish to learn more. Please see appendix C for our greenhouse structure handbook.

4.3 Interview Results

On April 28th, we toured a commercial hydroponic facility in the Golan Heights. At this facility, we conducted informal interviews with one of the co-owners as he showed us their hydroponic system set up within a large greenhouse. We compiled the most relevant information we learned from him in table 1 below and also took photos (see appendix C).We used these photos in both our hydroponics and greenhouse handbooks. Information we learned during our tour was used to modify our handbooks and designs.

On May 1st, we toured LivinGreen. At this tour, we learned about other hydroponics techniques, and received some feedback on our designs. This information and how we used it is compiled below in table 2.

Table 1: This table shows the cause and effect nature of the information we learned in our interviews, and how we used it.

Information From Golan Tour	**How We Used It**
Filter system in water pump	Added in a section to our hydroponic handbook on using filters
Nutrients are from chemical compounds, usually salts	Corrected our writing to reflect this fact
Mesh panels are better for greenhouses on the ground that do not experience so much wind	We are sticking with our PC panel design
Solar panels are put on the roof of other surrounding buildings	We suggested putting solar panels on the surrounding floor of the roof that is not being utilized as greenhouse floor

Table 2: This tables shows how we used each piece of information or helpful critique we received from LivinGreen.

Information from LivinGreen	**How We Used It**
Learned about aquaponics, deep water culture, and ebb and flow	We would like to see these used in future directions
Do not go over 20 meters of PVC with a single inlet of water	Our design is well under this requirement, so we kept our PVC length as it is
Maximize space between rows	Kept our design with the offset PVC pipe
Put sun-lover plants on the top rows, and shady plants on the bottom rows	Added in a section to our hydroponic manual about planting crops on the level best for their light requirement

4.4 Cost Analysis

Material	Quantity	Cost per Unit	Total Cost
Rockwool Plug	64 units	0.40 ILS	25.60 ILS
pH Probe	2 units	185.07 ILS	370.14 ILS
Electrical Conductivity Probe	2 units	169.00 ILS	338.00 ILS
Plastic Tray/Dome	6 units	10.93 ILS	65.58 ILS
Zip Tie	20 units	0.07 ILS	1.46 ILS
U-PVC 110mm	12.720 meters	54.97 ILS	702.00 ILS
U-PVC 32mm	9.688 meters	20.17 ILS	195.41 ILS
Rubber Gasket	30 units	1.86 ILS	55.80 ILS
Pipe Cement	1 unit	256.00 ILS	256.00 ILS
Water Basin	1 unit	399.90 ILS	399.99 ILS
Nutrient Solution	1 liter	2.51 ILS	82.83 ILS
Psychrometer	2 units	98.39 ILS	196.78 ILS
Water Pump	2 units	155.31 ILS	310.62 ILS
Net Pump	64 units	0.66 ILS	42.24 ILS
Water Tube	4 meters	5.00 ILS	10.00 ILS
Greenhouse	1 unit	12000.00 ILS	12000 ILS
Concrete	1.524 cubic meters	NA	1565.65 ILS
pH Adjuster	1 unit	70.42 ILS	70.42 ILS

Type of System	**Total Cost**
One growing unit	3,000 ILS
One greenhouse with one growing unit	17,000 ILS
One greenhouse with two growing units	20,000 ILS
24 greenhouses with two growing units each (within 500 m^2)	480,000 ILS

Chapter 5: Recommendations for Future System Implementation

5.1 Hydroponics System Future Recommendations

In the future, we would like to see our hydroponic system built in full and tested with crops. This would allow us to identify weaknesses in our design, and create improvements. We estimate that a two month period of building and growing would be sufficient to identify any weaknesses. Implementation of various low cost and low complexity automation components to the system could also help improve the maintenance and efficiency of the system. A suggested improvement could be a float sensor that alerts the farmers when the water level in the water reservoir needs replenishing.

Figure 7: This is an example of a basic float switch in practice[29].

5.2 Greenhouse System Future Recommendations

Our system could be greatly improved by becoming 100% sustainable. We would like to add solar panels to the ground of the surrounding greenhouse area to supply power to our water pumps. Solar panels have already been implemented in greenhouse designs worldwide, as shown below.

Figure 8: This image, from ILoveManchester.com[30], shows a current rooftop solar panel powered hydroponic garden in Manchester, England. In future designs of our system, we would like to implement a similar set up to become fully sustainable.

We would also like to add some sort of rainwater collection device. Although our design was made with the arid climate of Israel in mind, any rainwater that comes down could still be collected and utilized. This could easily be done by adding gutters to the sides of the roof of our greenhouse, and connecting a tube from the gutters to a covered water barrel (see figure 9 below).

Figure 9: This image from DenGarden.com[31] shows an example of a gutter rainwater collection system that could be implemented in future greenhouse designs. The most important aspects shown are that the barrel and gutters are fully closed and opaque. This prevents the growth of algae, which are deleterious to a hydroponic system.

If building their own greenhouse is not feasible, users can also purchase a premade greenhouse of their choice. Our sponsor recommends greenhouses produced by a company called Canopia, whose products served as the basis for our greenhouse design. Their greenhouses start at 12,999 ILS, and come equipped with all the essential components necessary to house a successful hydroponic operation, in addition to providing other valuable tools to make the system more sustainable, such as rainwater collection systems and drainage pipes. Please see appendix C for our greenhouse assembly handbook.

We would also like to research other methods of hydroponics further, and see how they could be incorporated into our designs. When we toured LivinGreen, we saw other techniques like deep water culture and aquaponics. It would be interesting to diversify our plans to appeal to a wider audience and also to be more accessible.

Chapter 6: Final Deliverables and Ethical Considerations

6.1 Deliverables to our Sponsor: CAD Designs and Handbooks

During the course of this project, we created a CAD of a hydroponic system. This unit can grow up to 64 individual plants, and contains places for water tanks and probes for constant monitoring of the system. We also generated a CAD of a greenhouse with dimensional specifications.

To aid users in implementing our designs, we wrote two handbooks. Our first handbook, entitled "Hydroponic Assembly and Instructional Handbook", gives instructions on how to build and operate our hydroponic growing unit. Our second handbook, entitled "Greenhouse Design and Assembly Handbook", describes how to build our greenhouse on an urban rooftop.

6.2 Ethical Considerations of our Project

As our handbooks and computer aided design visuals will be uploaded to an open access website, we hope that these will help to one day make food more accessible to people. We attempted in our project to provide alternative materials and solutions for people who may not be able to find products such as pH probes or rockwool cubes in their country.

Hydroponics, combined with solar panels in our future designs, provides an excellent way for farming to have a net zero carbon footprint on Earth. Hydroponics also presents a way for people to bond together in their community in the common goal of feeding their loved ones. Through hydroponics, people can build towards more sustainable agriculture and more secure food chains that cannot be influenced by unpredictable weather.

References

1. i24NEWS. (n.d.). *i24NEWS*. https://www.i24news.tv/en/news/israel/economy/1672557688-israelis-start-2023-with-all-around-price-hikes

2. Santos, C. Y. (2022, November 4). *Transport costs increase in food transportation*. CleanGreens. https://www.cleangreens.ch/aeroponics-posts/transport-costs-increase-in-food-transportation

3. Sustainable Vs. Conventional Agriculture | Environmental Topics and Essays. (n.d.). https://you.stonybrook.edu/environment/sustainable-vs-conventional-agriculture/

4. Gyanendra, S. S., Alshamsi, R., & Sergi, B. S. (2021). Business valuation strategy for new hydroponic farm development – a proposal towards sustainable agriculture development in United Arab Emirates. [Risk evaluation strategy - hydroponics in UAE] British Food Journal, 123(4), 1560-1577. https://doi.org/10.1108/BFJ-06-2020-0557

5. *Land Use in Agriculture by the Numbers*. (2020, May 7). Food and Agriculture Organization of the United Nations. https://www.fao.org/sustainability/news/detail/en/c/1274219/
6. Bray, Ouellette, L. M., Esco, E. P., & Burr, A. M. (2016). Opportunities for Urban Agriculture: Balcony Hydroponics in Thessaloniki. Worcester Polytechnic Institute.

7. Wilson, G. (2002, August). *Can Urban Rooftop Microfarms be Profitable?* Urban Agriculture Online. Retrieved January 31, 2023, from

https://www.alnap.org/system/files/content/resource/files/main/can-urban-rooftop-micro farms-be-profitable.pdf

8. Barrett, B. N. (2022, August 26). *Why are global gas prices so high?* BBC News. https://www.bbc.com/news/explainers-62644537

9. Betti, C., Frank, H., Pavlov, A., & Strano, S. (2022). Hydroponics System to Reduce Armenian Food Scarcity. *Worcester Polytechnic Institute*.

10. Ortiz, A. D., Schreiber, E. A., Von Roth, G., & Rotatori, H. A. (2008). Hydroponic Farming in Mahasarakham: Integrating Hydroponics into the Agricultural Curriculum While Introducing Entrepreneurial Skills. *Worcester Polytechnic Institute*

11. Niu, G., & Masabni, J. G. (2022). *Hydroponics*. In Elsevier eBooks (pp. 153–166). Elsevier BV. https://doi.org/10.1016/b978-0-323-85152-7.00023-9

12. Rufí-Salís, M., Petit-Boix, A., Villalba, G., Ercilla-Montserrat, M., Sanjuan-Delmás, D., Parada, F., Arcas, V., Muñoz-Liesa, J., & Gabarrell, X. (2020). Identifying eco-efficient year-round crop combinations for rooftop greenhouse agriculture. The International Journal of Life Cycle Assessment, 25(3), 564–576. https://doi.org/10.1007/s11367-019-01724-5

13. *Soil pH and the Availability of Plant Nutrients | Nutrient Stewardship*. (n.d.). https://nutrientstewardship.org/implementation/soil-ph-and-the-availability-of-plant-nutr ients/#:~:text=It%20has%20been%20determined%20that,compatible%20to%20plant%2 0root%20growth

14. Trees.com Staff. (2022, December 20). *Hydroponic Nutrient Solution - The Essential Guide - Trees.com*. Trees.com. https://www.trees.com/gardening-and-landscaping/hydroponic-nutrient-guide

15. Slims Place. (n.d.). *What are the 16 essential nutrients that plant uses?* https://www.slimsplace.uk/blogs/knowledge-center/what-are-the-16-essential-nutrients-that-plant-use/

16. Constantinoiu, M. (2023b, February 28). *How Israel used innovation to beat its water crisis - ISRAEL21c*. ISRAEL21c. https://www.israel21c.org/how-israel-used-innovation-to-beat-its-water-crisis/

17. *Polyvinyl Chloride - Chemical Safety Facts*. (2022, October 14). Chemical Safety Facts. https://www.chemicalsafetyfacts.org/chemicals/polyvinyl-chloride/

18. *Polyvinyl Chloride (PVC) Plastic: Uses, Properties, Benefits & Toxicity*. (n.d.). https://omnexus.specialchem.com/selection-guide/polyvinyl-chloride-pvc-plastic

19. *PVC and Organic Gardening: Is PVC Safe to Use?* (2022, October 5). Accessible Gardens. https://accessiblegardens.org/pvc-and-organic-gardening-is-pvc-safe-to-use/

20. Instructables. (2017). PVC Hydroponics Unit. *Instructables*. https://www.instructables.com/PVC-Hydroponics-Unit/

21. Jagdish. (2023, January 26). How to Build a Hydroponic Unit with PVC Pipes: DIY in Simple Steps. *Agri Farming*. https://www.agrifarming.in/how-to-build-a-hydroponic-unit-with-pvc-pipes-diy-in-simple-steps#:~:text=The%20ultimate%20result%20should%20be%20a%203%201%2F2,reserv

22. Jamie. (2022, February 10). NFT Hydroponics: Basics, Setup, Pros/Cons, FAQ. *WhyFarmIt*. https://whyfarmit.com/nft-hydroponics/

23. Admin. (2020). How Hygrometers Work. *Hygrometer.net*. https://hygrometer.net/hygrometers-work/

24. The Editors of Encyclopaedia Britannica. (1998, July 20). *Psychrometer | instrument*. Encyclopedia Britannica. https://www.britannica.com/technology/psychrometer

25. *Greenhouse Building Materials: Should I Choose Glass, Polycarbonate, or Poly Film?* (2022, February 25). Dengarden. https://dengarden.com/landscaping/greenhouse-glass-guide

26. *Polycarbonate (PC) - Properties, Uses, & Structure - Guide*. (n.d.). https://omnexus.specialchem.com/selection-guide/polycarbonate-pc-plastic

27. Tammy. (2018, September 3). *Double Polyfilm Greenhouse - Grow Your Own Food Anywhere*. Grow Your Own Food Anywhere. https://www.blog.advancegreenhouses.com/double-polyfilm-greenhouse/#:~:text=Double%20polyfilm%20greenhouses%20consist%20of%202%20layers%20of,you%20up%20to%2040%25%20of%20your%20energy%20costs.

28. Al-Tawaha, A. R., Al-Karaki, G., Al-Tawaha, A. R., Sirajuddin, S. N., Makhadmeh, I., Wahab, P. E. M., Youssef, R. A., Al Sultan, W. & Massadeh, A. (2018). Effect of water fl ow rate on quantity and quality of lettuce (Lactuca sativa L.) in nutrient fi lm technique (NFT) under hydroponics conditions. Bulgarian Journal of Agricultural Science, 24(5), 793–800

29. *File:Mechanical float switch waterpool.jpg - Wikimedia Commons*. (2019, May 13). https://commons.wikimedia.org/wiki/File:Mechanical_float_switch_waterpool.jpg

30. Mcr, I. L. (2016, August 24). The Printworks' solar powered hydroponics system is a first in Manchester. *I Love Manchester*. https://ilovemanchester.com/the-printworks-solar-powered-hydroponics-system-is-a-first-in-manchester

31. Martin, B. (2022, February 10). *Everything you need to know about trapping rainwater*. DenGarden.com. https://dengarden.com/misc/Everything-you-need-to-know-about-Trapping-Rainwater

Appendix A: Interview Questions in English and Hebrew

Interview Format and Questions in English

Format of Interviews: We will schedule either on Zoom or in person interviews with our partners at LivinGreen, and the two other farms. Our interviews will be led by one member of our group who asks the questions, but all group members will be present. The team members who lead interviews will rotate in this order: Kelly, Natanel, Rayden, Sean. These interviews will be scheduled for half hour to one hour time slots, if possible with our partners.

LivinGreen Questions:

- Initial Questions (for design inspiration)
    - What are some techniques you have found are the most effective?
    - Which crops are the most popular for your clients in Israel?
    - Do you think the nutrient film technique is accessible to most people who have never done hydroponics before?
    - Do you recommend trimming the roots of plants in a NFT system?
    - Do you recommend pre-mixed fertilizer solution for use in hydroponics systems?
    - Do you believe a rainwater collection system is useful for a hydroponics system?
- Supplemental Questions (for design improvement)
    - What do you think about our design plans?
    - Do you think our design will be functional?
    - How could we improve our design?
    - Do you think our design is accessible?

Commercial Farmer Questions:

- How do you keep your business sustainable at the commercial level?
- Do you have experience growing leafy greens? If so, what has been the best nutrient solution to use for them?
- On average, how much money would you say you spend on water usage, per year?
- What do you think the environmental impact of your commercial hydroponics farm is? Do you think this is less or more than a traditional agricultural farm?

Small Scale Farmer Questions:

- How do you best navigate the arid climate of Israel?
- How do you keep your business affordable?
- What is the most important aspect of farming?
- What motivates you to cultivate crops?

Interview Questions in Hebrew (Handout to give to our contacts before we interview them):

LivinGreen Questions:

- Initial Questions (for design inspiration)
    - What techniques are best for hydroponics? For example, nutrient film technique, ebb and flow
        - אילו טכניקות הכי טובות להידרופוניקה? לדוגמה, טכניקת סרטים תזונתיים, גאות ושפל
    - Which crops are the best in Israel for hydroponics?
        - אילו גידולים הם הטובים ביותר בישראל להידרופוניק?

- Do you think the nutrient film technique is accessible to most people who have never done hydroponics before?
  - האם אתה חושב שטכניקת הסרט התזונתי נגישה לרוב האנשים שמעולם לא עשו הידרופוניקה לפני כן?
- Do you recommend trimming the roots of plants in a NFT system?
  - האם אתה ממליץ לקצץ את שורשי הצמחים במערכת NFT?
- Do you recommend pre-mixed fertilizer solutions for use in a hydroponic system?
  - האם אתה ממליץ על פתרונות דשן מעורבים מראש לשימוש במערכת הידרופונית?
- Do you believe a rainwater collection system is useful for a hydroponics system?
  - האם אתה מאמין שמערכת איסוף מי גשמים שימושית למערכת הידרופוניקה?

- Supplemental Questions (for design improvement)
  - What do you think about our design plans?
    - מה אתה חושב על תוכניות העיצוב שלנו?
  - Do you think our design will be functional?
    - האם אתה חושב שהעיצוב שלנו יהיה פונקציונלי?
  - How could we improve our design?
    - איך נוכל לשפר את העיצוב שלנו?
  - Do you think our design is accessible?
    - האם לדעתכם העיצוב שלנו נגיש?

Commercial Farmer Questions:

- How do you keep your business sustainable at the commercial level?
  - איך אתה שומר על קיימא של העסק שלך ברמה המסחרית?
- Do you have experience growing lettuce or cucumbers? If so, what are the best nutrient solutions to use for them?
  - יש לך ניסיון בגידול חסה או מלפפונים? אם כן, מהם הפתרונות התזונתיים הטובים ביותר לשימוש עבורם?
- On average, how much money would you say you spend on water usage, per year?
  - בממוצע, כמה כסף היית אומר שאתה מוציא על צריכת מים, בשנה?
- How do you prevent pests from destroying your crops?
  - איך מונעים ממזיקים להרוס את היבולים שלך?
- What are the easiest crops to grow in a hydroponic system?
  - מהם הגידולים הקלים ביותר לגידול במערכת הידרופונית?

Appendix B: Interview Consent Form

Informed Consent Agreement for Participation in a Research Study

Investigators:

Primary Investigator: Svetlana Nikitina

Email: Svetlana@wpi.edu

Student Investigators: Kelly Heffernan, Rayden Morley, Natanel Pinkhasov, Sean Nuzio

Email: gr-d23haifahydro@wpi.edu

Title of Research Study: Alternative Agriculture: Creating a Fully Functioning Urban Rooftop Hydroponics Operational Model

Sponsor: The Mityaalim Foundation, Israel

Introduction:

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation. Participants in this study must be at least 18 years old.

Purpose of the study and this interview:

The purpose of this study is to create a working hydroponics operational plan for an urban rooftop garden. Our plan will include an engineering plan, instructional handbooks, and an economic cost breakdown. These documents will be published on an open access website at the culmination of our project, to be used by people everywhere.

The purpose of this interview is to learn more about existing hydroponic and agricultural practices in Israel. We will use the information we learn in these interviews to alter our hydroponic operational documents.

Procedures to be followed:

You will be asked a series of questions regarding farming practices in Israel. Please answer these to the best of your ability. If you do not wish to answer a question, please let the interviewer know and that question will be skipped. If for any reason at all you no longer wish to continue the interview, tell any of the investigators present and the interview will be immediately ended. If after the conclusion of the interview you no longer wish for some or all of your answers to be included in our records, please inform the investigator present and we will strike your answers from the record.

Risks to study participants:

There are no risks inherent in this study other than those encountered regularly in everyday life. Participants have the right to end their interview at any time if they want to.

Benefits to research participants and others:

There are no benefits to participants in this interview.

Record keeping and confidentiality:

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury:

As this study presents no risk of injury or harm, no compensation or medical treatment will be provided. In the unlikely event you find yourself injured during our interview, please find suitable medical help immediately. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

Please see the contact information at the top of this page to get in touch with the primary investigator and student investigators. If you wish to contact the IRB Manager or Human

Protection Administrator for Worcester Polytechnic Institute (WPI) their information is here below:

IRB Manager (Ruth McKeogh, Tel. 508 831- 6699, Email: irb@wpi.edu)

Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date: _____________________

Study Participant Signature

____

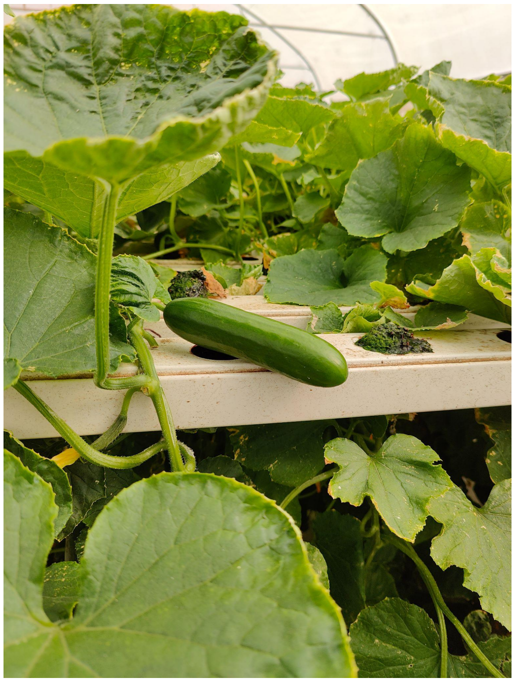
Study Participant Name (Please print)

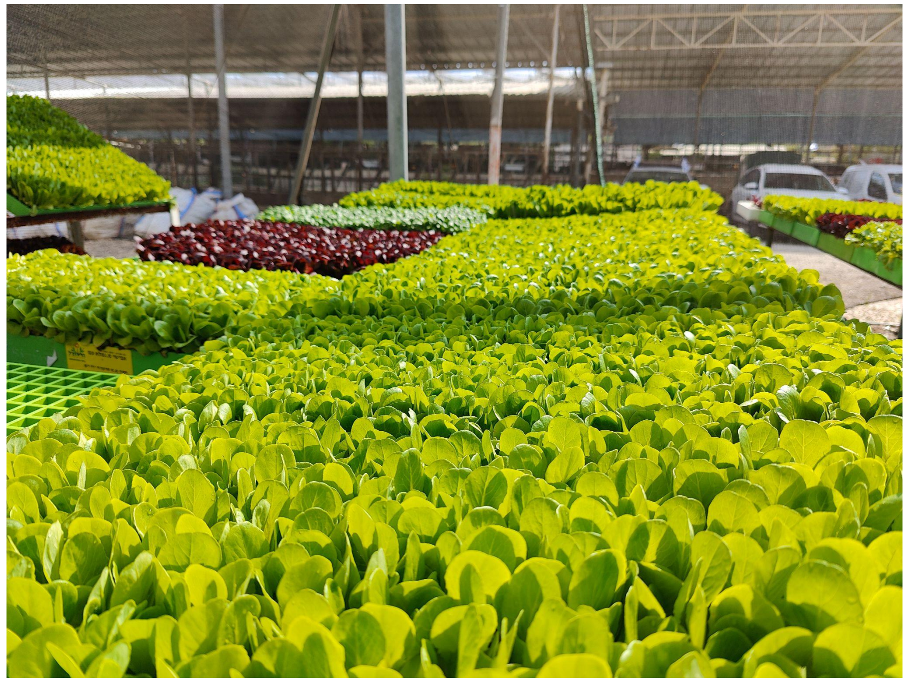
____ Date: _____________________

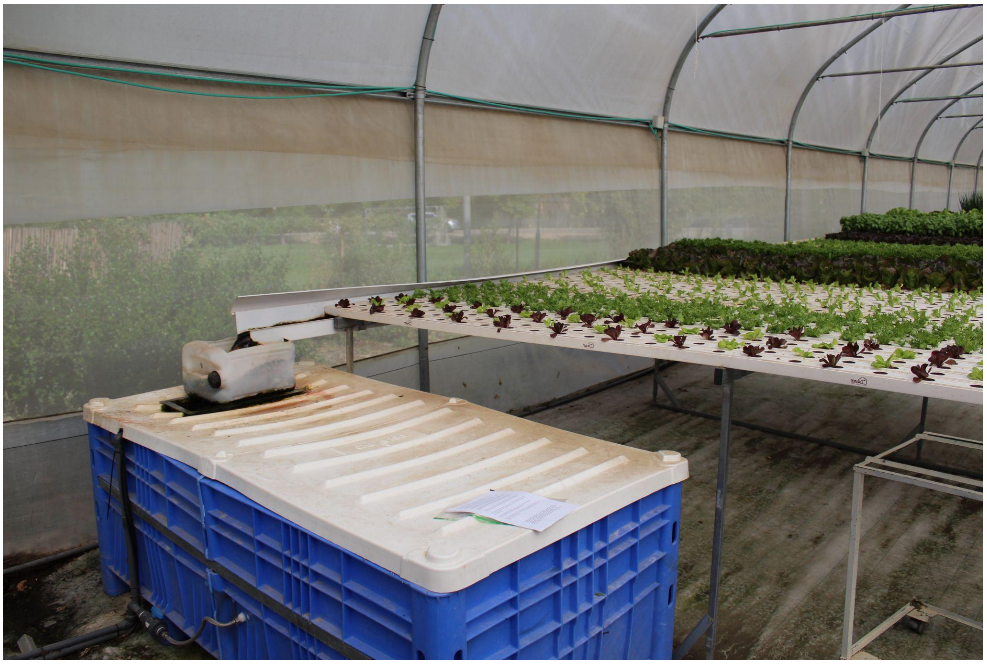
Signature of Person who explained this study

Appendix C: Images from Hydroponics Facility Tours

Commercial Hydroponics Operation in Golan Heights







LivinGreen Tour

Appendix D: Greenhouse Design and Instructional Handbook

HAIFA HYDRO
WORCESTER POLYTECHNIC INSTITUTE

GREENHOUSE

Handbook & Assembly Manual

How to Build Your Own Urban Rooftop **Greenhouse** for a Nutrient Film Technique Hydroponic Operation

An accessible and affordable alternative to rising fresh food costs

INTRO

Purpose

The purpose of this handbook is to guide the general public through the assembly of a greenhouse ideal for the usage of our hydrponic system. The proposed model is designed to house two systems within a 15 m^2 area. This allows users to house up to 128 plants per each greenhouse, with room on either side to still care for the growing plants.

DISCLAIMER

This greenhouse has not been tested or verified for structural stability or safety. Haifa Hydro or any of our associates do not take responsibility for any attempts to manufacture or assemble this greenhouse. Do not attempt to construct this greenhouse without further engineering.

OUTLINE

Overview: Design Plan

OUR DESIGN is for a greenhouse capable of housing up to 128 total plants within two separate hydroponic systems. On either side of each system, there are clearances suitable for users to walk and comfortably tend to their plants. Additionally, our materials are basic enough to be easily substituted by relative equivalents depending on the user's needs and local requirements.

LIVINGREEN

A method tried and tested by our partner, LivinGreen. They are a commercial hydroponic supply and educational business in Israel.

Greenhouse Materials

THE FOLLOWING IS A GENERALIZED LIST of materials required in the construction of the greenhouse structure. It is important to note that these are only the recommended materials. Any materials you are unable to access or acquire may be substituted.

ALUMINUM TUBING [10]

The aluminum tubing is the primary construction material of the greenhouse frame. The base of the frame is to be anchored to the cement foundation to provide additional support and rigidity. If you are not in need of a high strength frame, polyvinyl chloride (PVC) pipes may be used for the frame. The use of alternative materials for the frame may require the use of alternative materials for the greenhouse walls as well.

POLYCARBONATE PANELS [11, 12]

The polycarbonate (PC) panels make up the walls of the greenhouse structure. PC panels are available as both single-pane and double-pane. While double-pane PC panels provide greater insulation, the maintenance costs are more than that of single-pane PC panels. An alternative to PC panels is PC film. PC film may be easier to obtain and install however, it does not insulate as well as PC panels. To remedy this, two layers of PC film may be used to cover the greenhouse. Furthermore, if an air pump was then used to inflate the space between the two layers of PC film, the insulation would be improved.

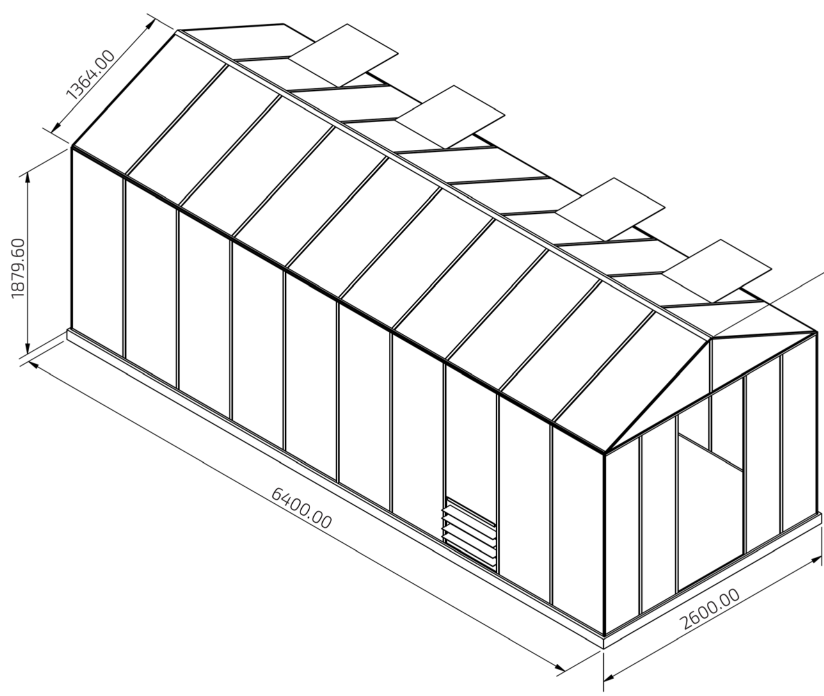
CONCRETE FOUNDATION

The concrete foundation provides structure and support to the greenhouse, keeping it stable during harsh winds. The foundation has a depth of one-hundred millimeters and an area of 15 square meters. The concrete foundation is not a requirement for the greenhouse structure but is highly recommended. An alternative to a concrete foundation would be to use ground anchors on the frame of the greenhouse.

Greenhouse Parts: Assembly Review

USE THE BELOW TECHNICAL DRAWING to review all of the components necessary to construct the proposed greenhouse. All assembly components listed below can be viewed in greater detail in the following pages to assess recommended dimensions.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Foundation		1
2	G1000	MAIN PC PANEL	23
3	G1001	LOWER VENT SLAT	5
4	G1002	PC PANEL ABOVE FLOOR VENT	1
5	G1003	FRONT PC PANEL	4
6	G1005	ANGLED ROOF PC PANEL	4
7	G1006	MAIN ROOF PC PANEL	16
8	G1007	ROOF WINDOW PC PANEL	8
9	G1008	MAIN SUPPORT BEAM	25
10	G1009	MAIN U CHANNEL ANCHOR	4
11	G1010	CORNER MAIN BEAM	4
12	G1011	ROOF ANCHOR CHANNEL	4
13	G1012	CORNER ANCHOR PLATE	7
14	G1013	PC RETENTION PANEL (FRONT/REAR ROOF)	6
15	G1014	FRONT/REAR ROOF SUPPORT BEAM	3
16	G1015	ROOF SUPPORT BEAM	18
17	G1016	ROOF PC RETENTION PANEL	36
18	G1017	LOWER ROOF PC RETENTION PANEL	2
19	G1018	FRONT/REAR SUPPORT BEAM	2
20	G1019	ROOF RIDGE	1
21	G1020	ROOF SUPPORT RUNNER	2
22	G1021	ROOF PC PANEL RETAINER	2
23	G1022	FRONT/REAR ROOF SUPPORT ANCHOR	4
24	G1023	ROOF GUSSET PLATE	2
25	G1024	MAIN PC RETENTION PANEL	58



	NAME	DATE
DRAWN	RM	4/30/23

COMMENTS:

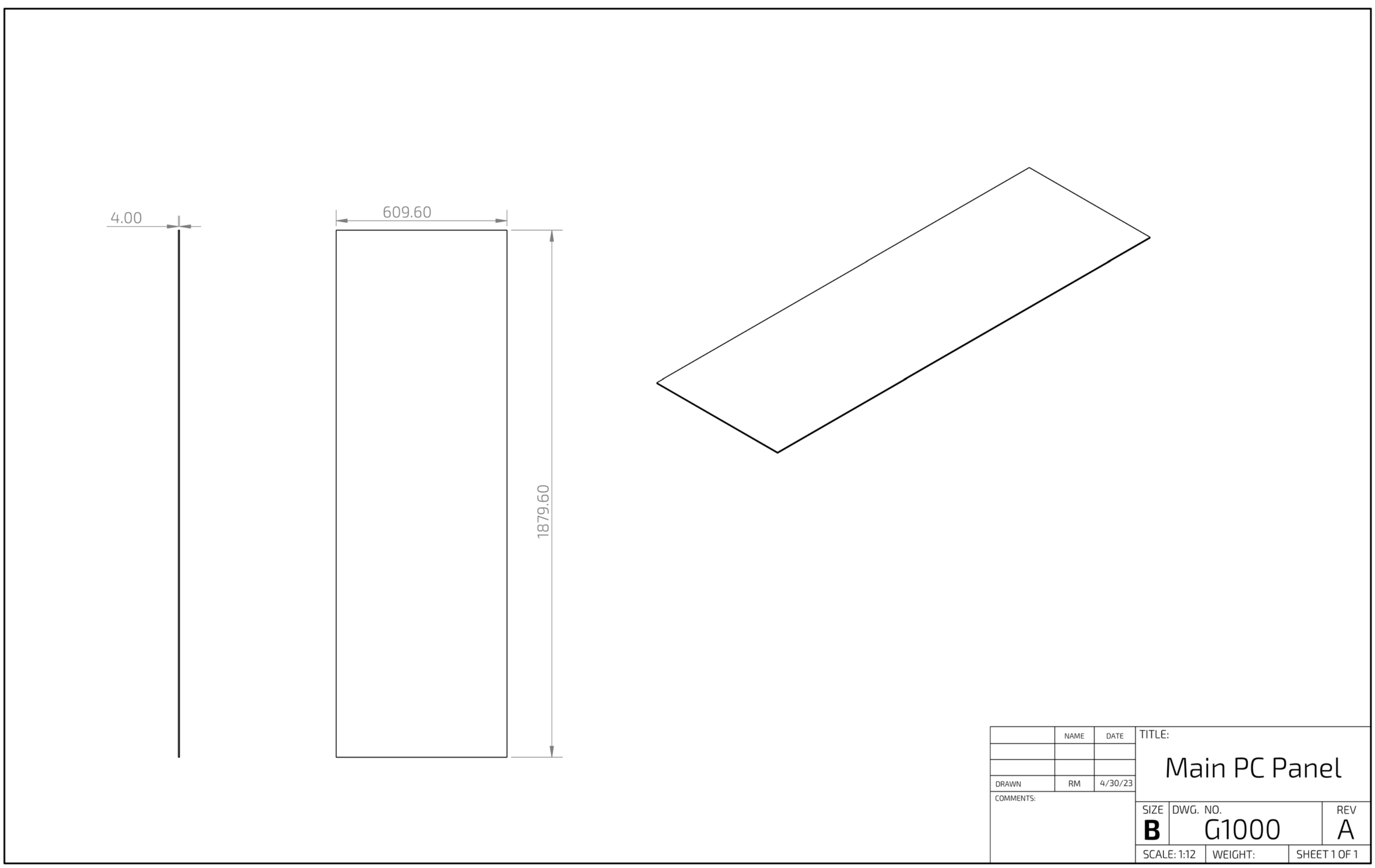
TITLE: Greenhouse Assembly

SIZE: B | DWG. NO.: 1 | REV: A

SCALE: 1:32 | WEIGHT: | SHEET 1 OF 1

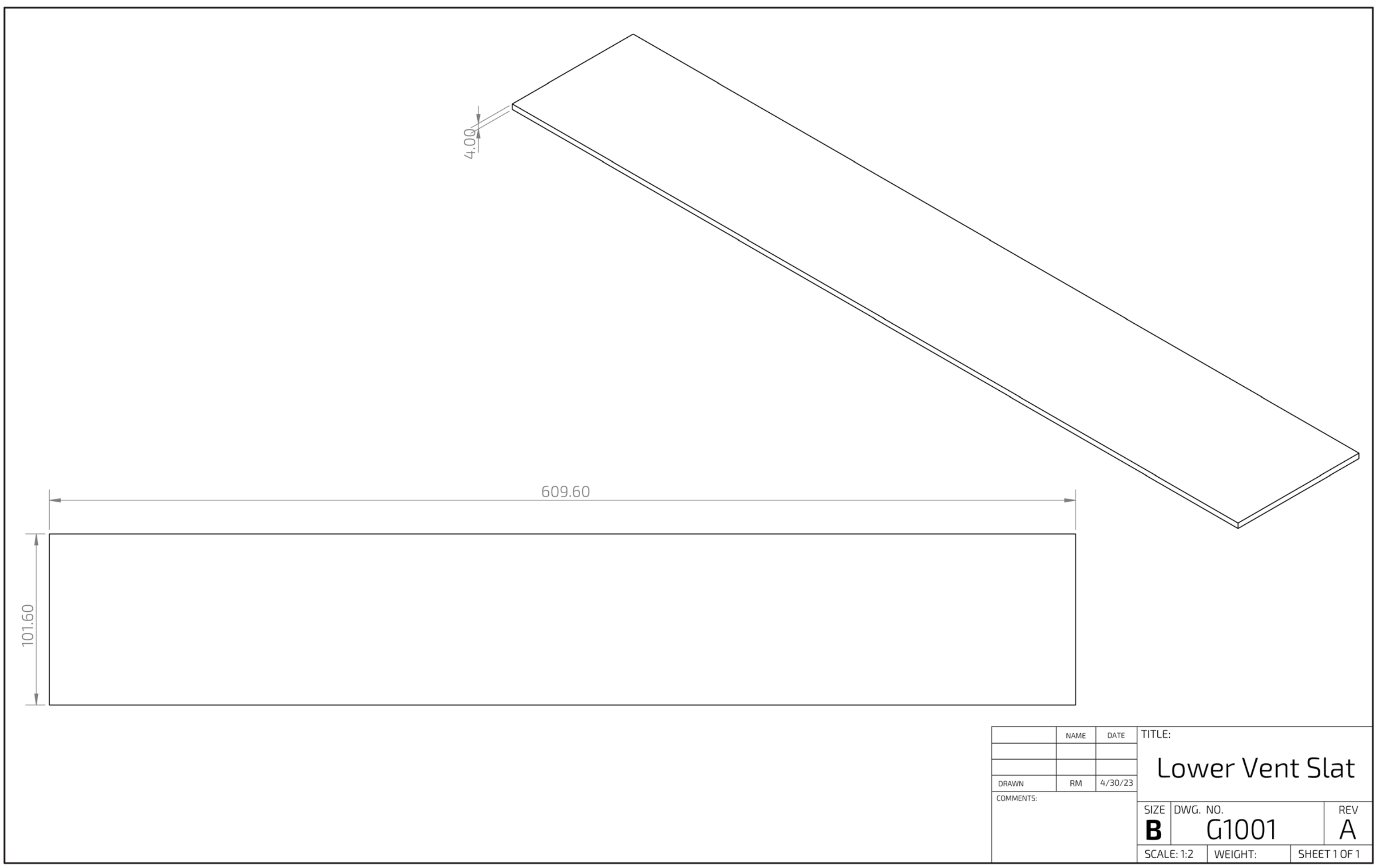
Greenhouse Parts: Main PC Panels

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the main polycarbonate (PC) panels for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



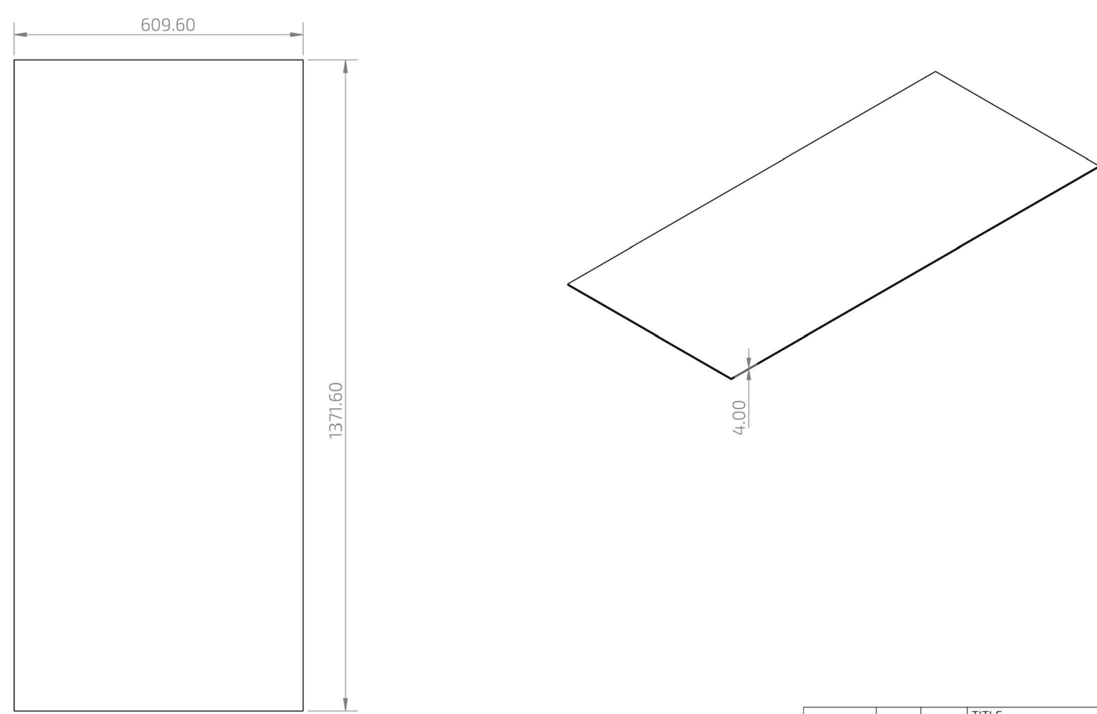
Greenhouse Parts: Lower Vent Slats

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the polycarbonate (PC) air vent slats for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



Greenhouse Parts: PC Panel Above Vent

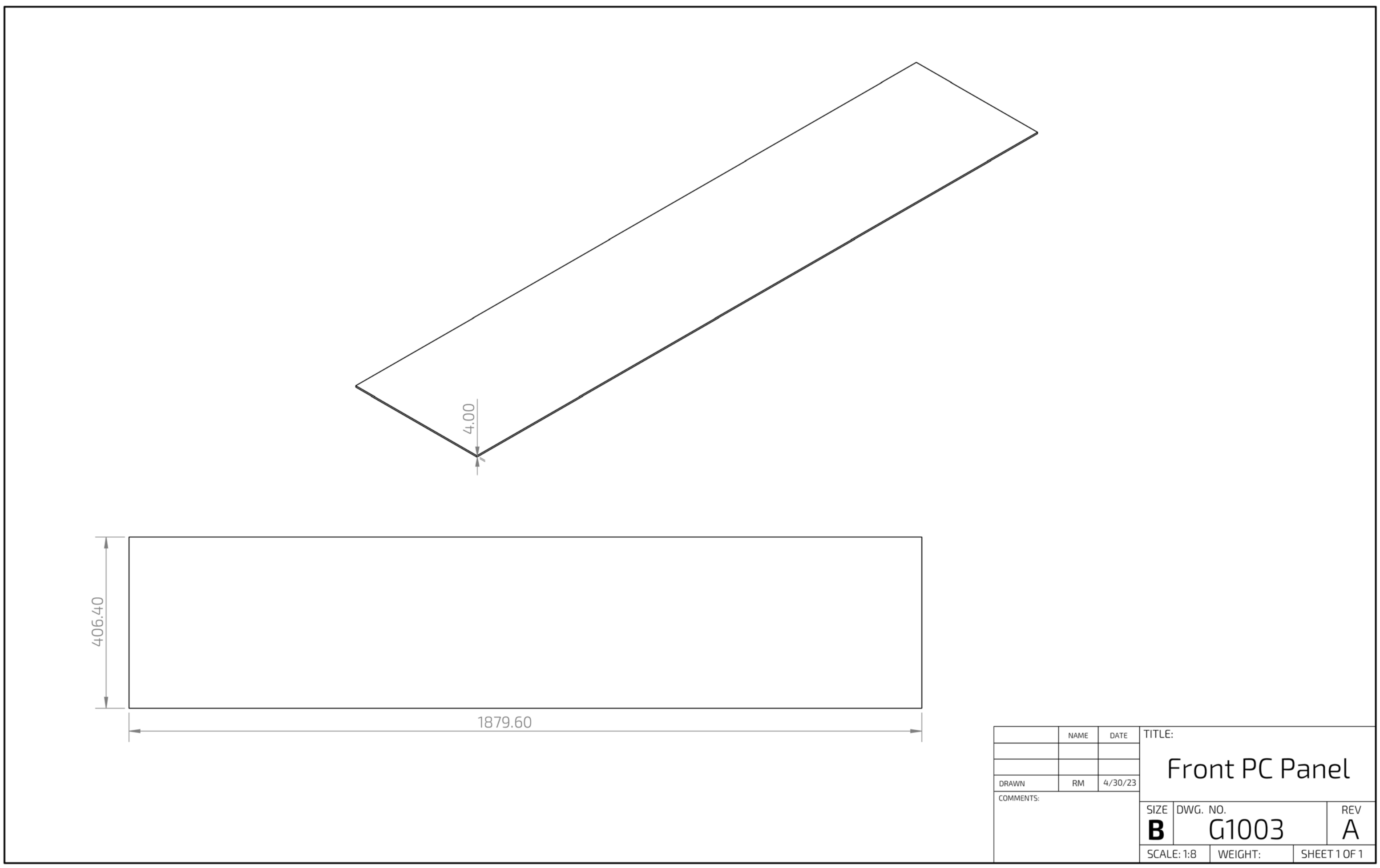
USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the polycarbonate (PC) panel inserted above the vent for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



	NAME	DATE	TITLE: PC Panel Above Floor Vent		
DRAWN	RM	4/30/23			
COMMENTS:			SIZE B	DWG. NO. G1002	REV A
			SCALE: 1:8	WEIGHT:	SHEET 1 OF 1

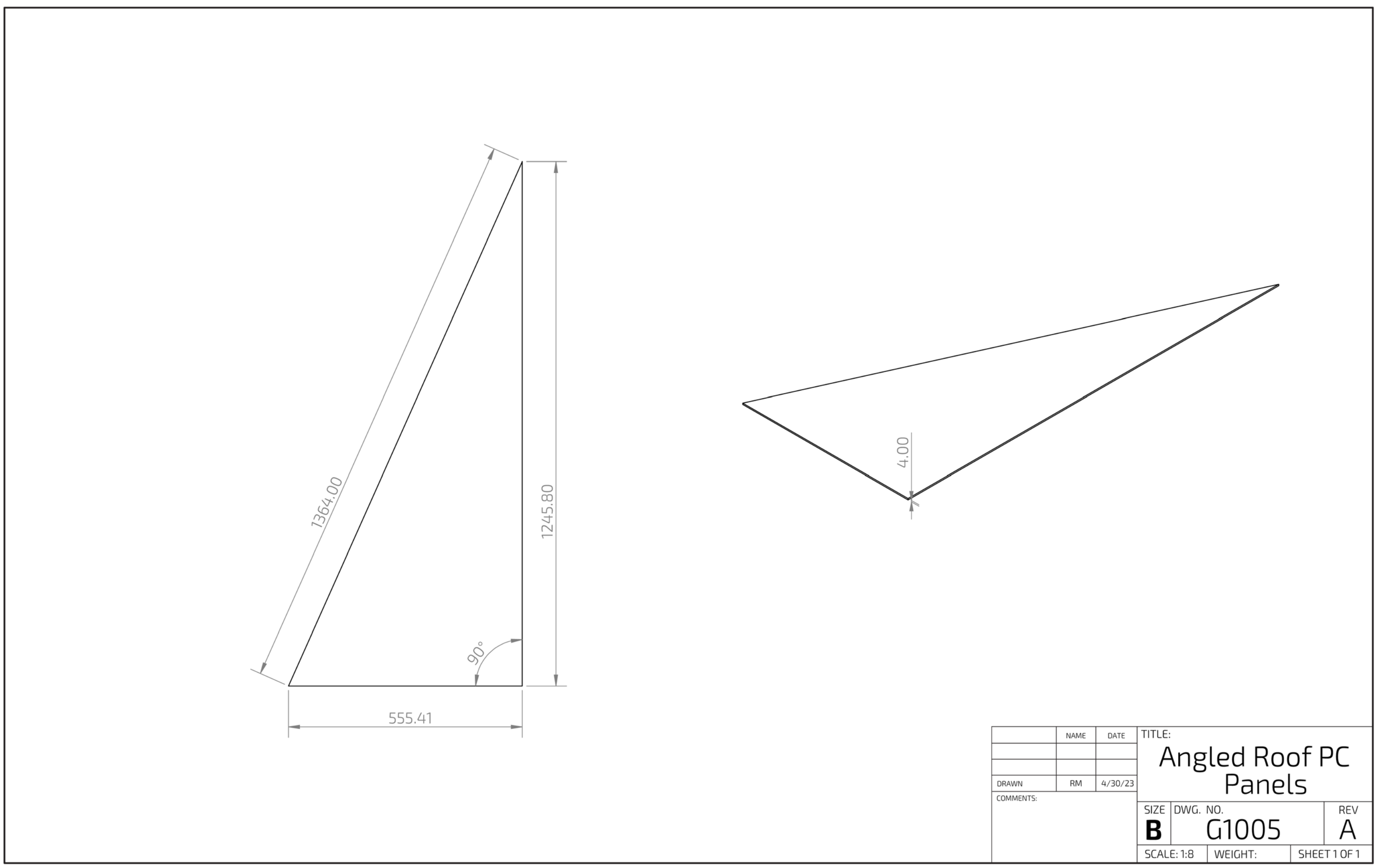
Greenhouse Parts: PC Front Panel

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the polycarbonate (PC) panel for the front of the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



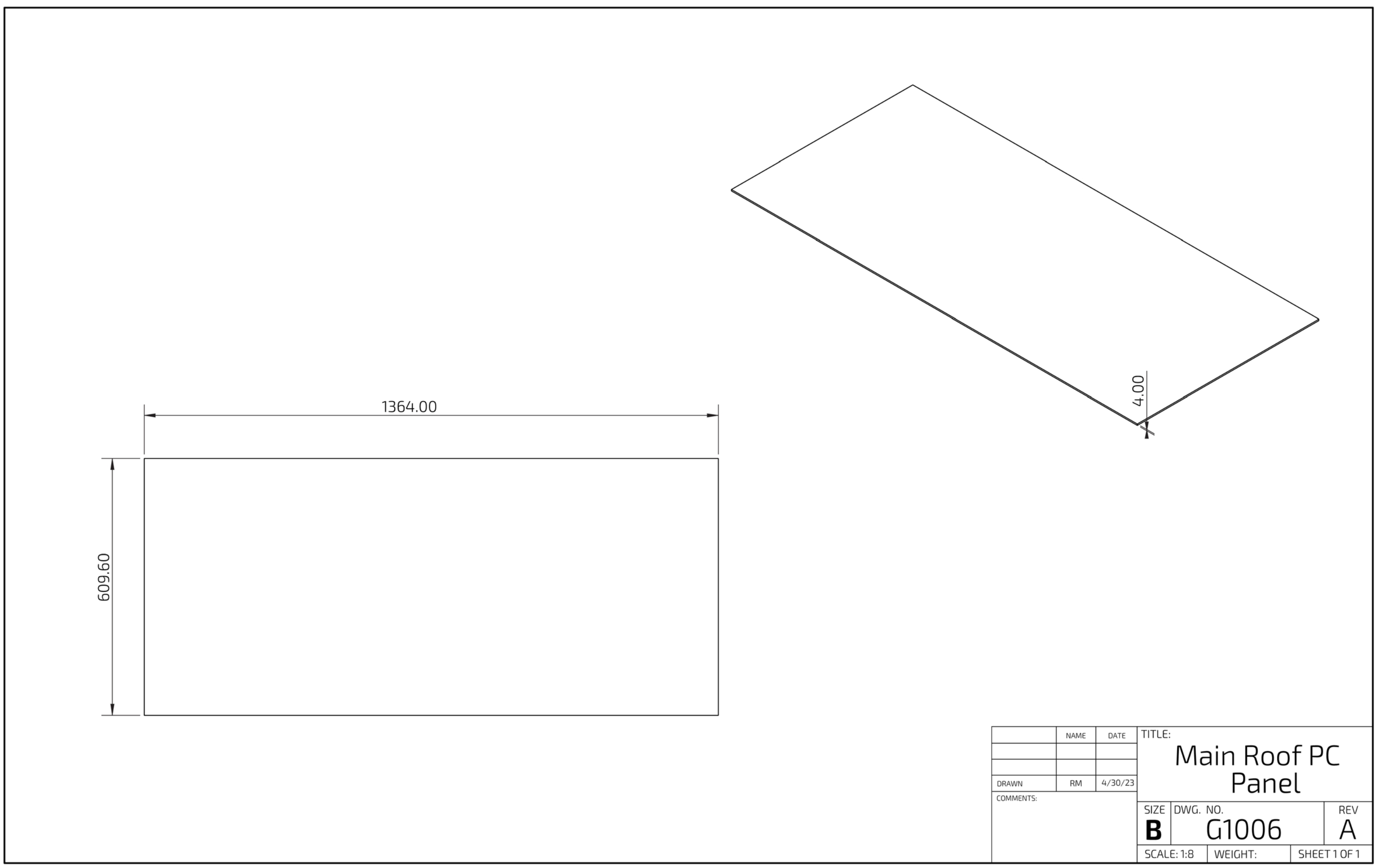
Greenhouse Parts: Angled Roof PC Panels

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the angled polycarbonate (PC) roof panels for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



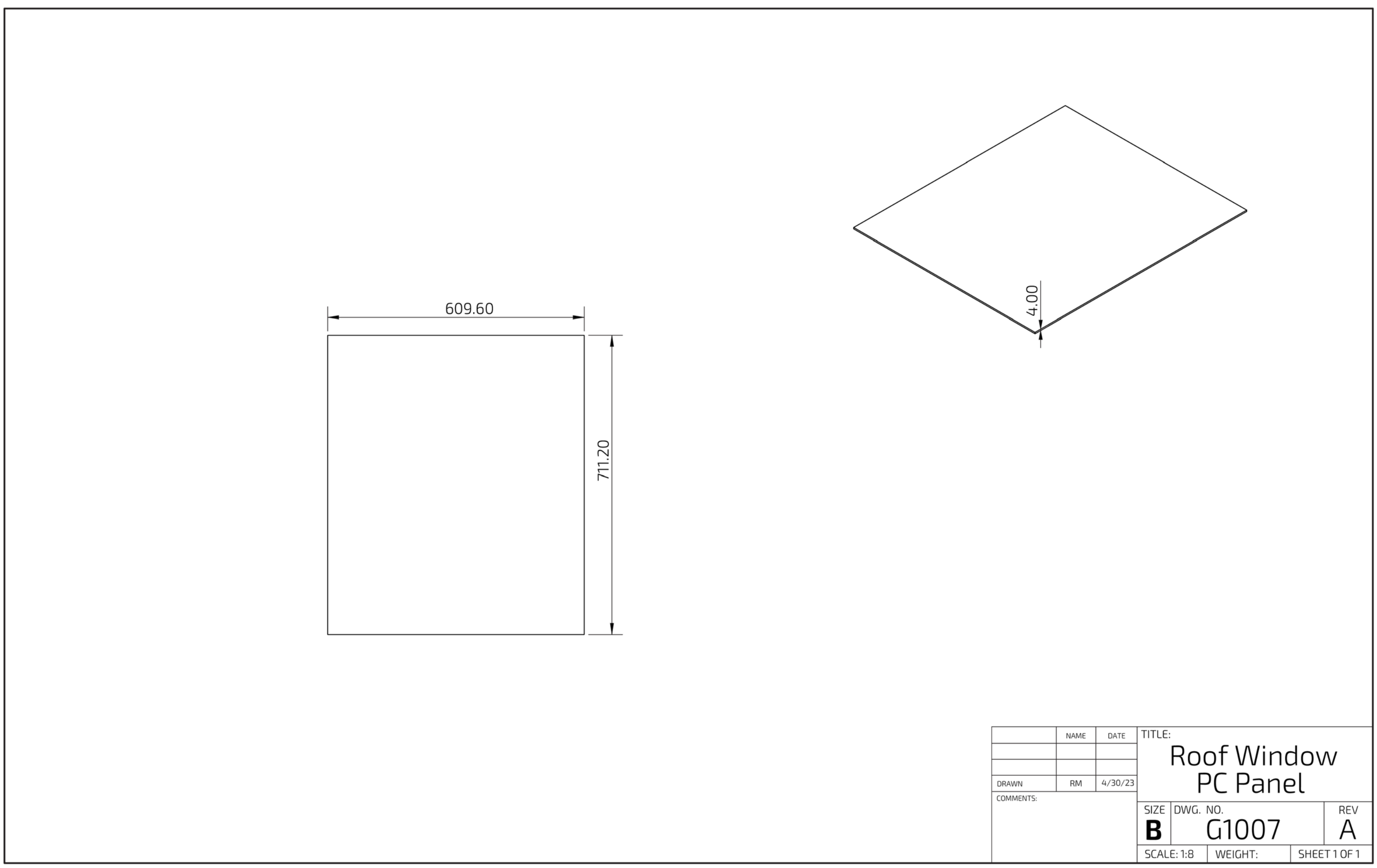
Greenhouse Parts: Main Roof PC Panels

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the main polycarbonate (PC) panels for the roof of the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



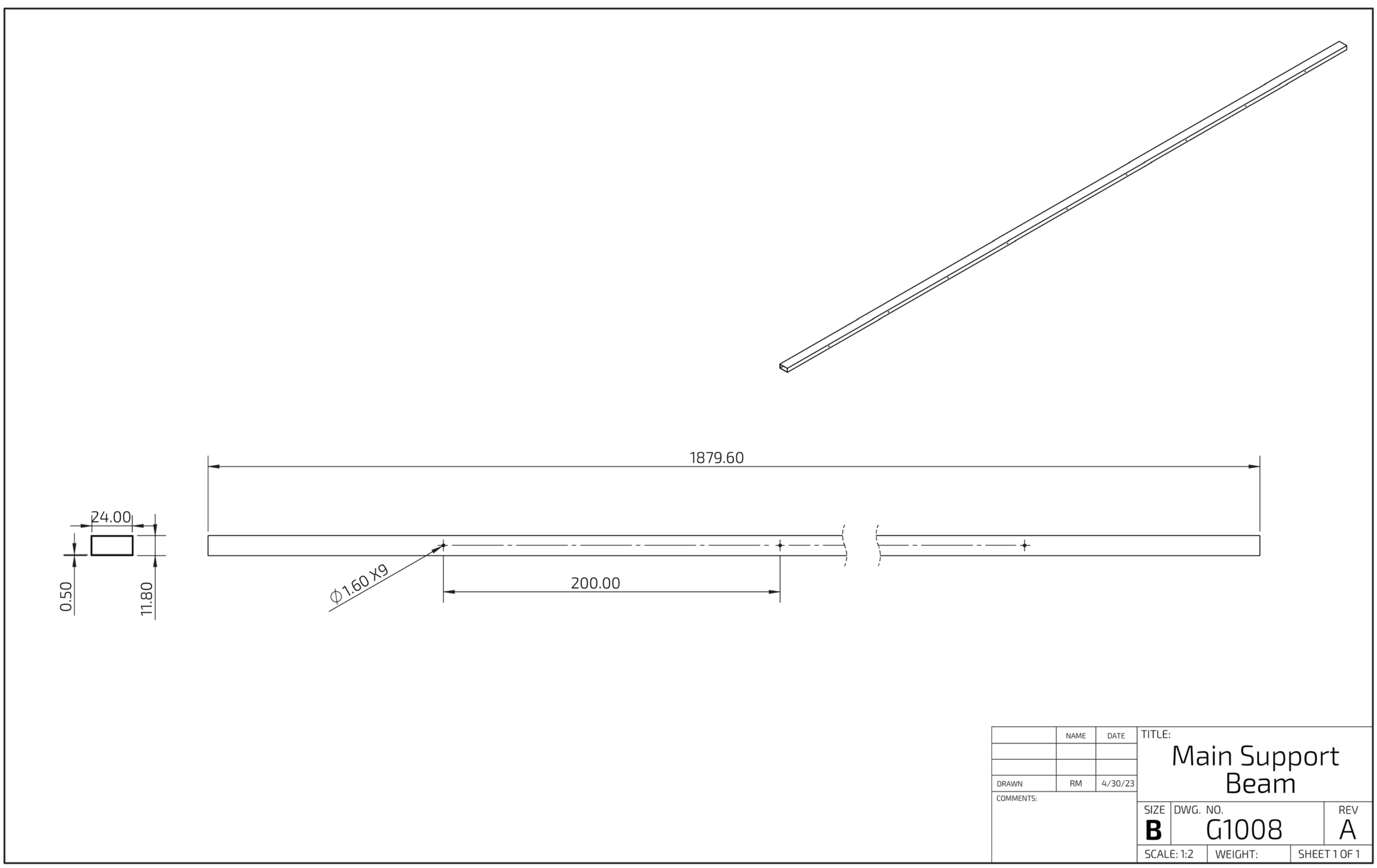
Greenhouse Parts: Roof Window PC Panel

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the polycarbonate (PC) roof window panels for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



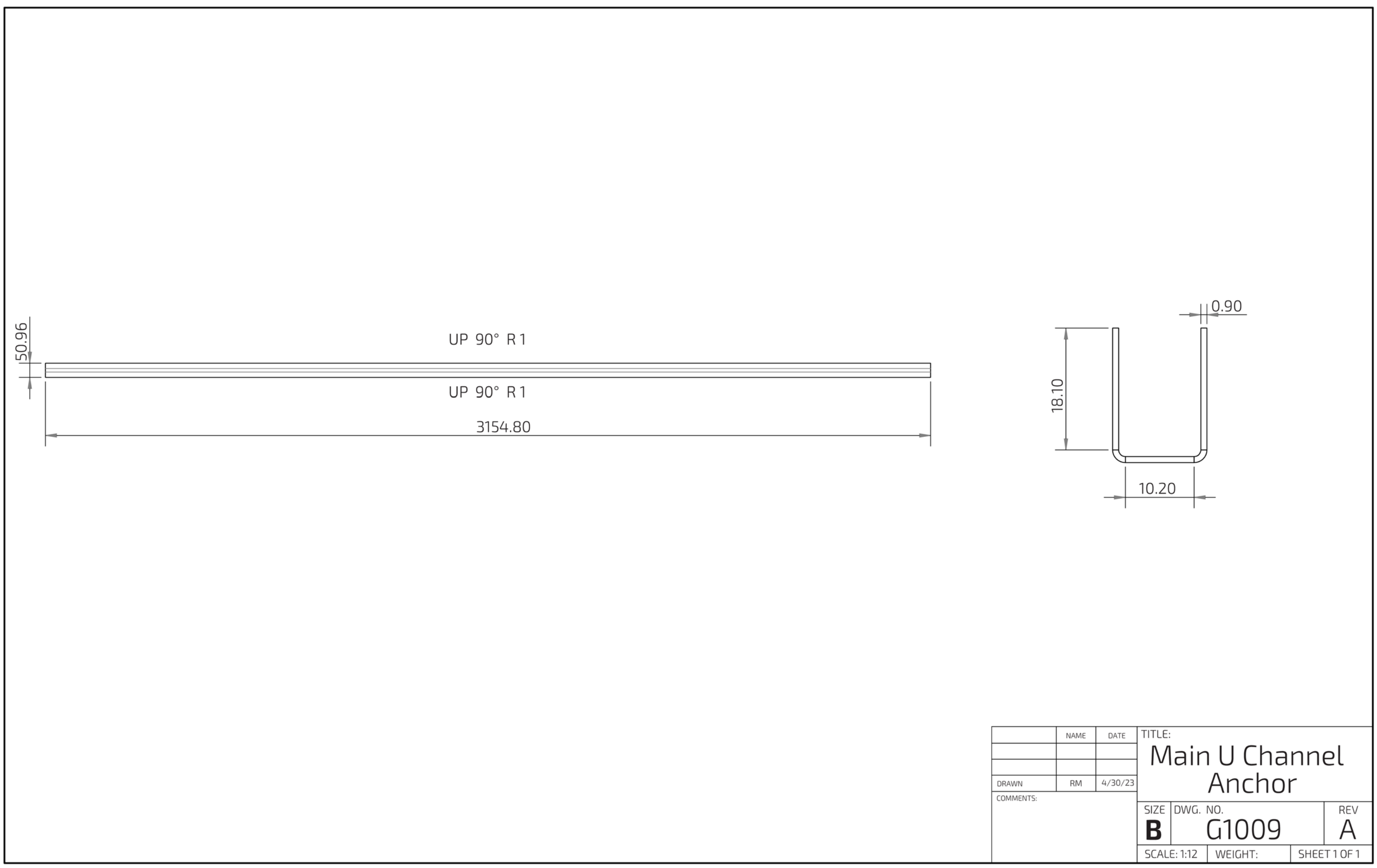
Greenhouse Parts: Main Support Beams

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the main support beams for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



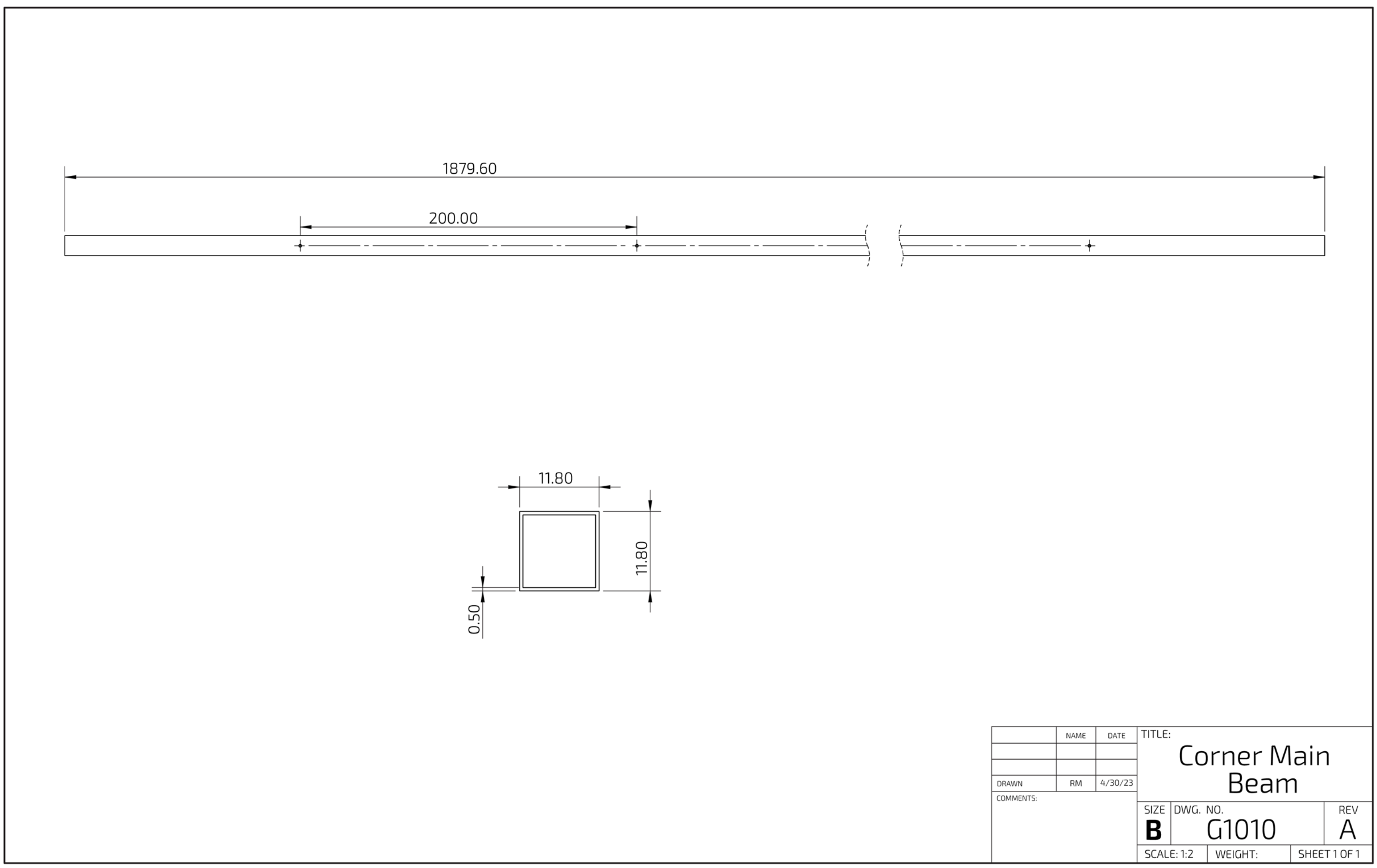
Greenhouse Parts: Main U-Channel Anchor

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the main u-channel anchor for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



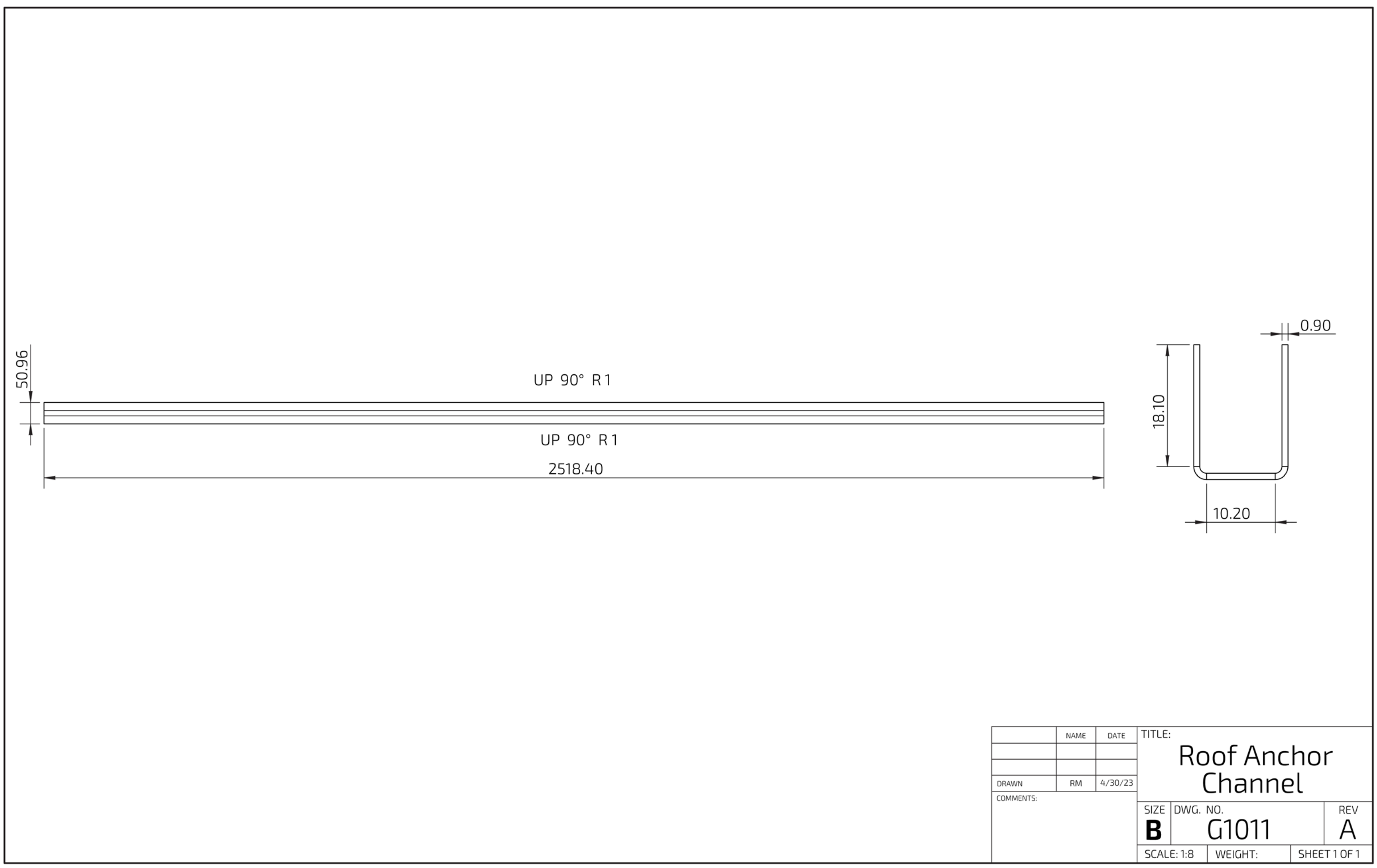
Greenhouse Parts: Main Corner Beams

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the main corner beams for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



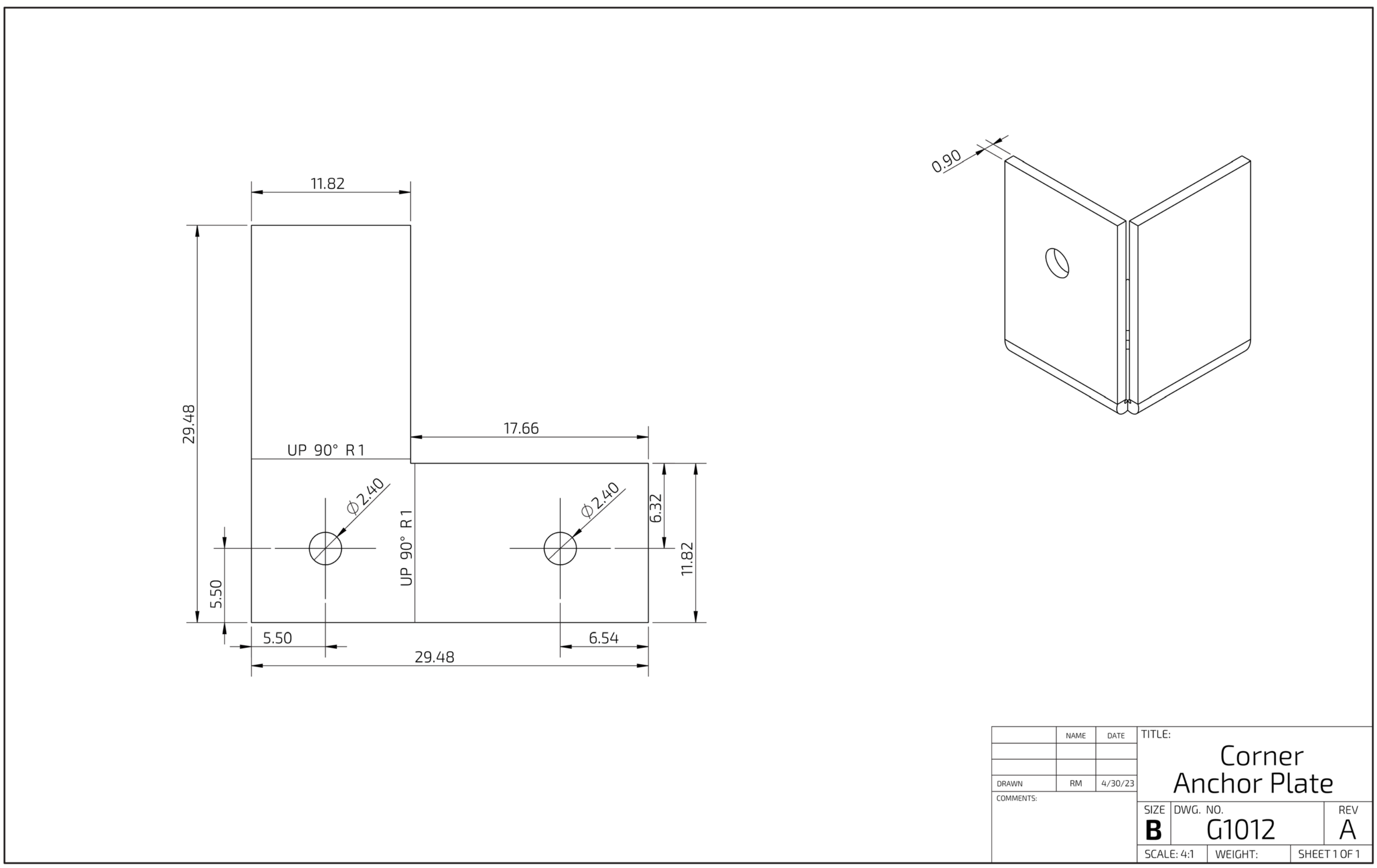
Greenhouse Parts: Roof Anchor Channels

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the roof anchor channels for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



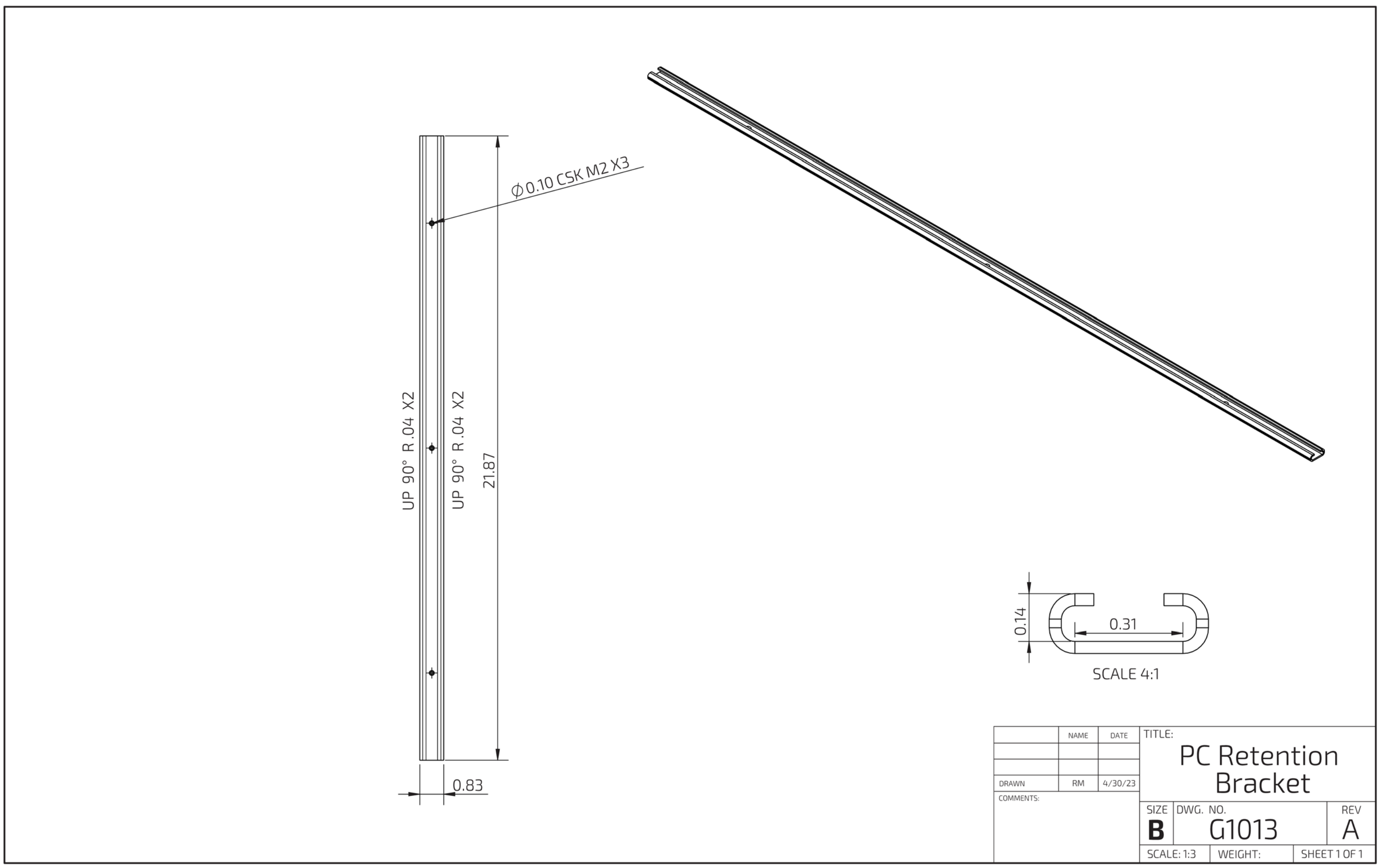
Greenhouse Parts: Corner Anchor Plates

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the corner anchor plates for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



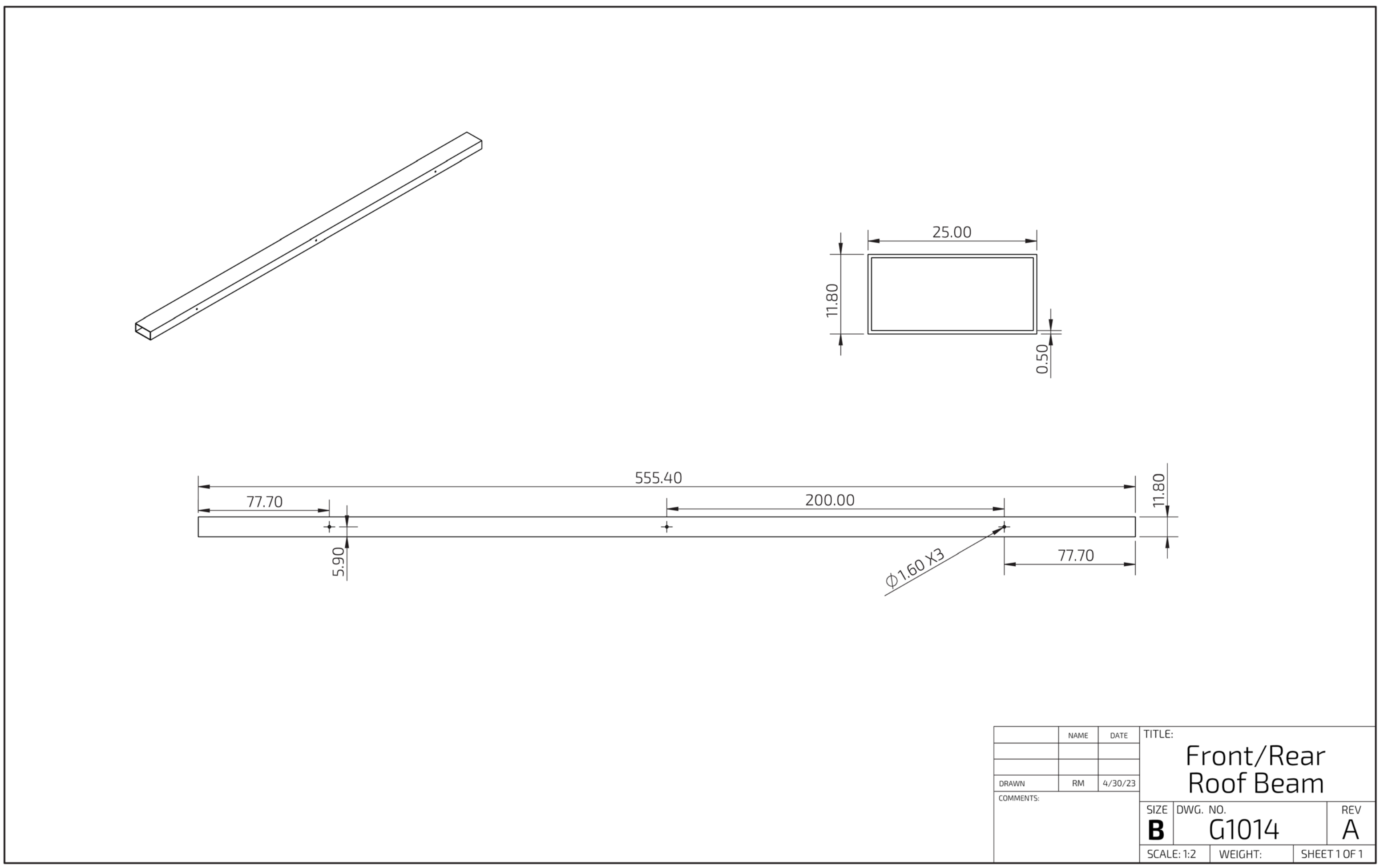
Greenhouse Parts: PC Retention Brackets

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the polycarbonate (PC) panel retention brackets for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



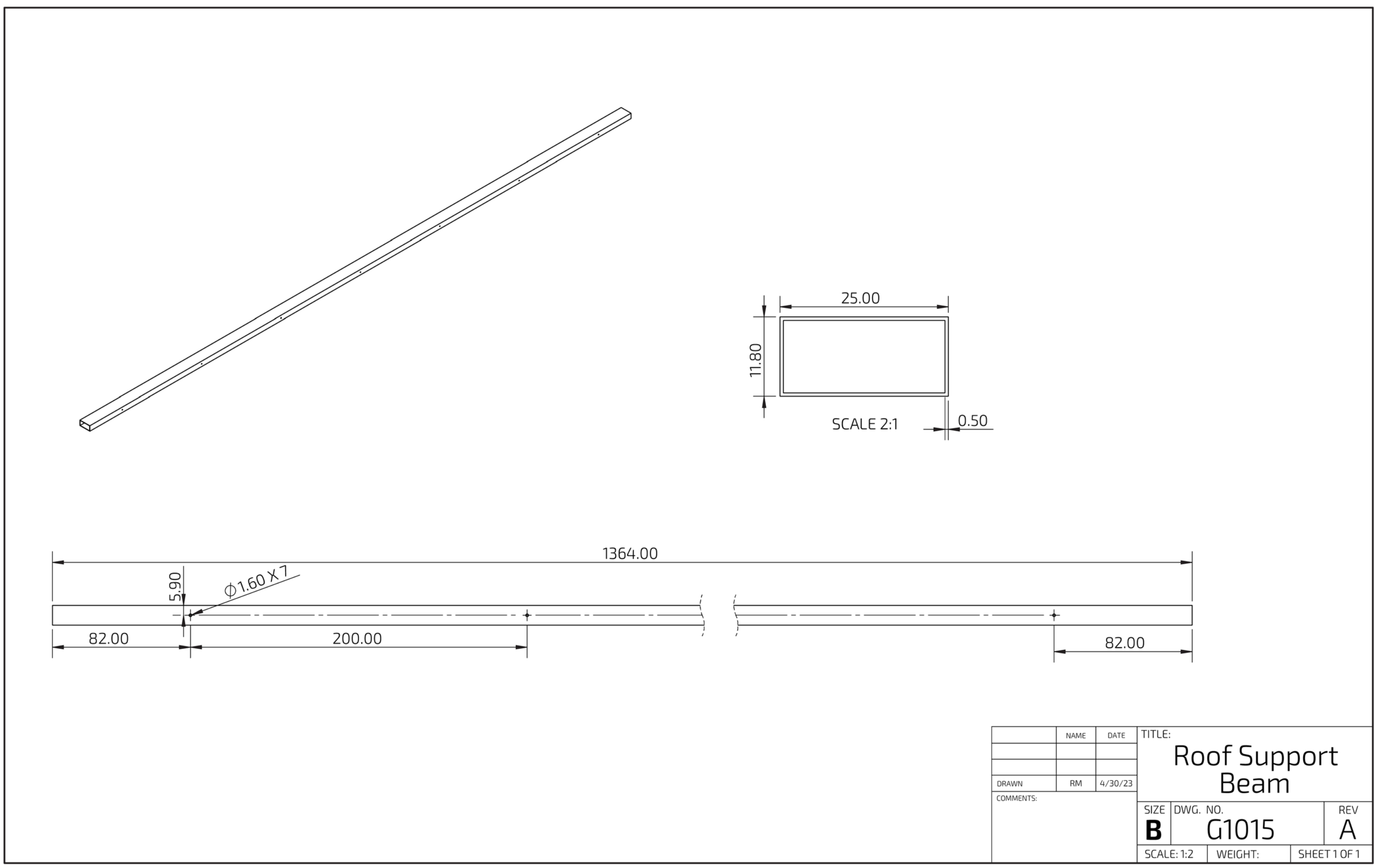
Greenhouse Parts: Front/Rear Roof Beams

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the front/rear roof beams for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



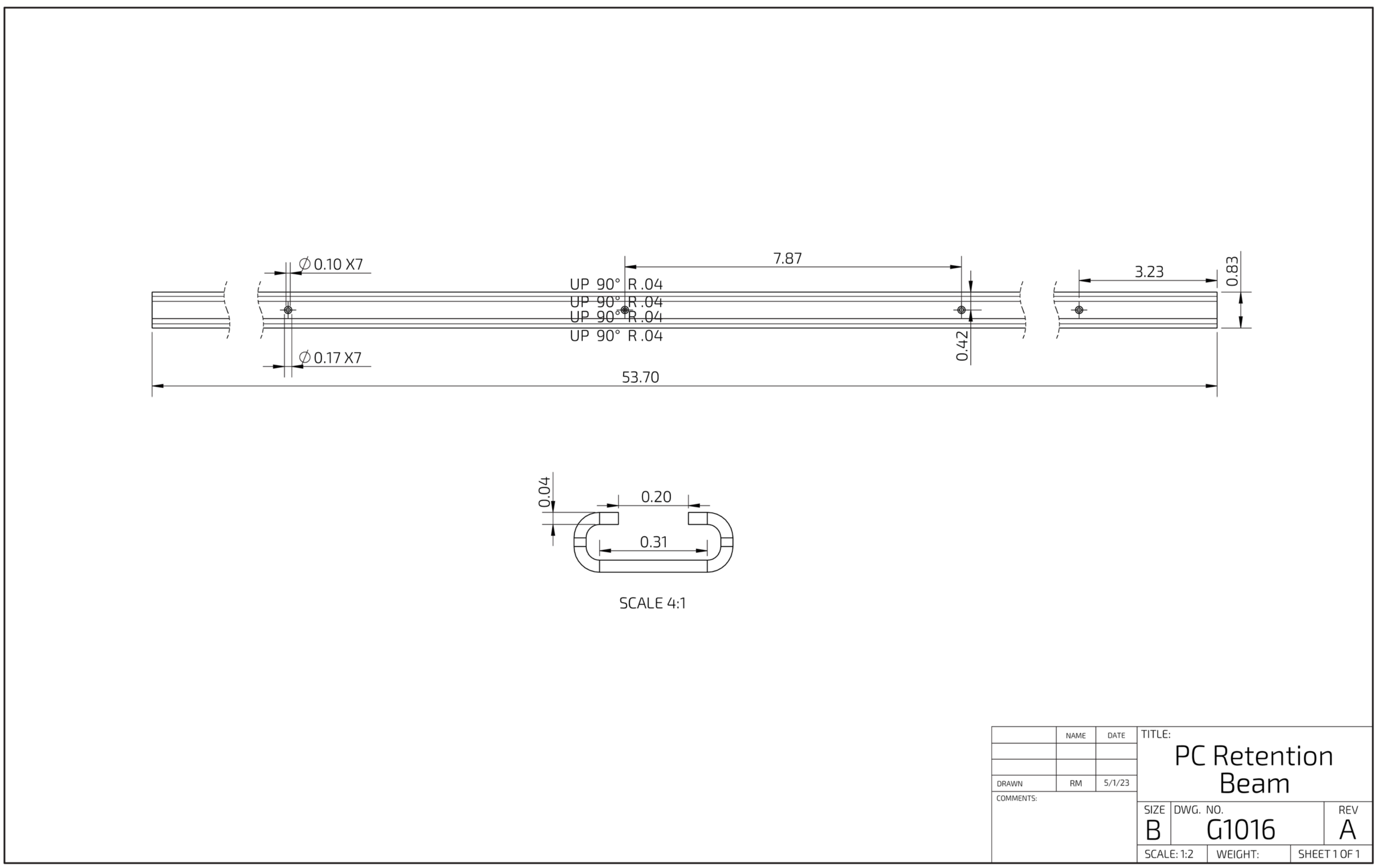
Greenhouse Parts: Roof Support Beams

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the roof support beams for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



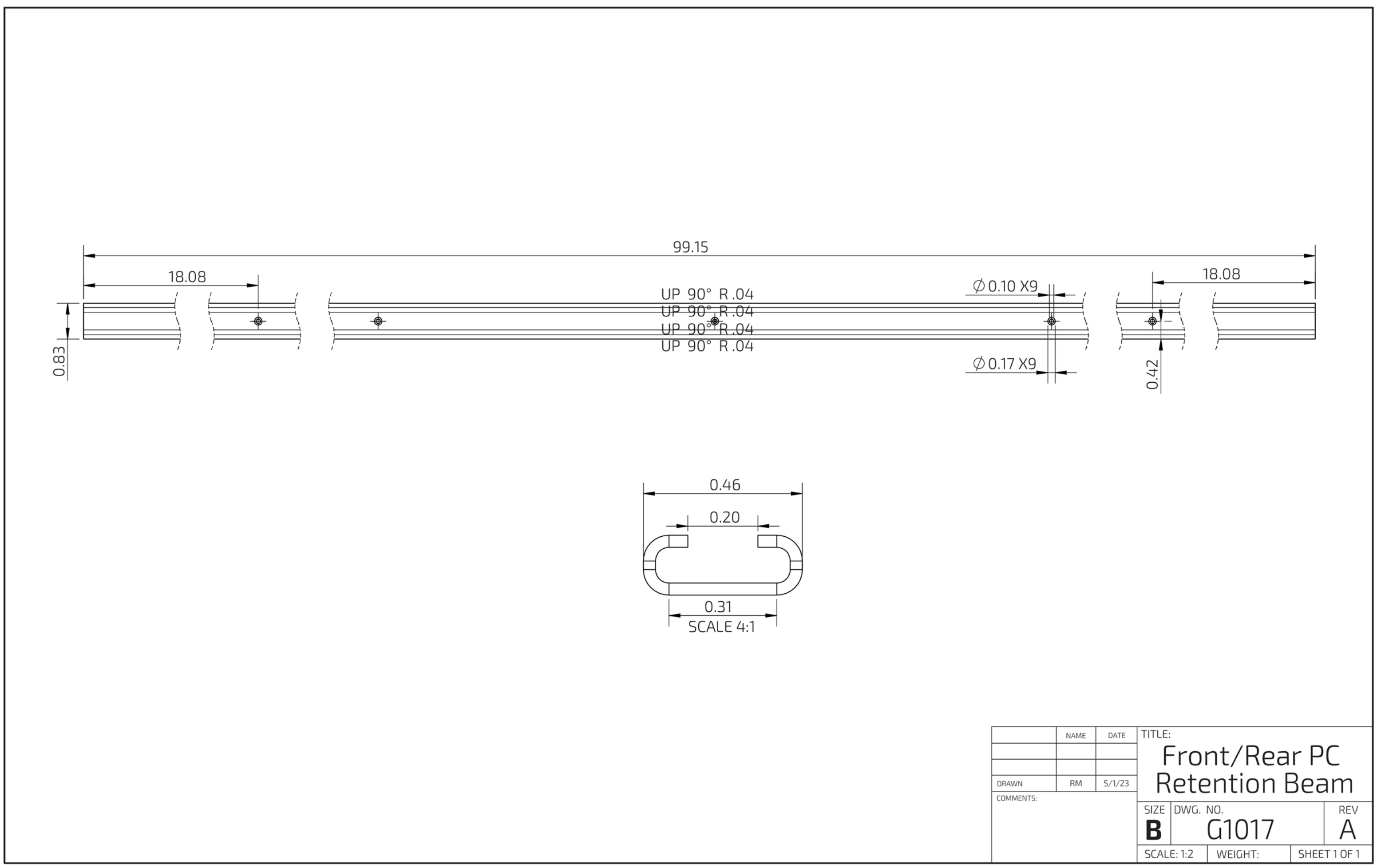
Greenhouse Parts: PC Retention Beams

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the PC retention beams for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



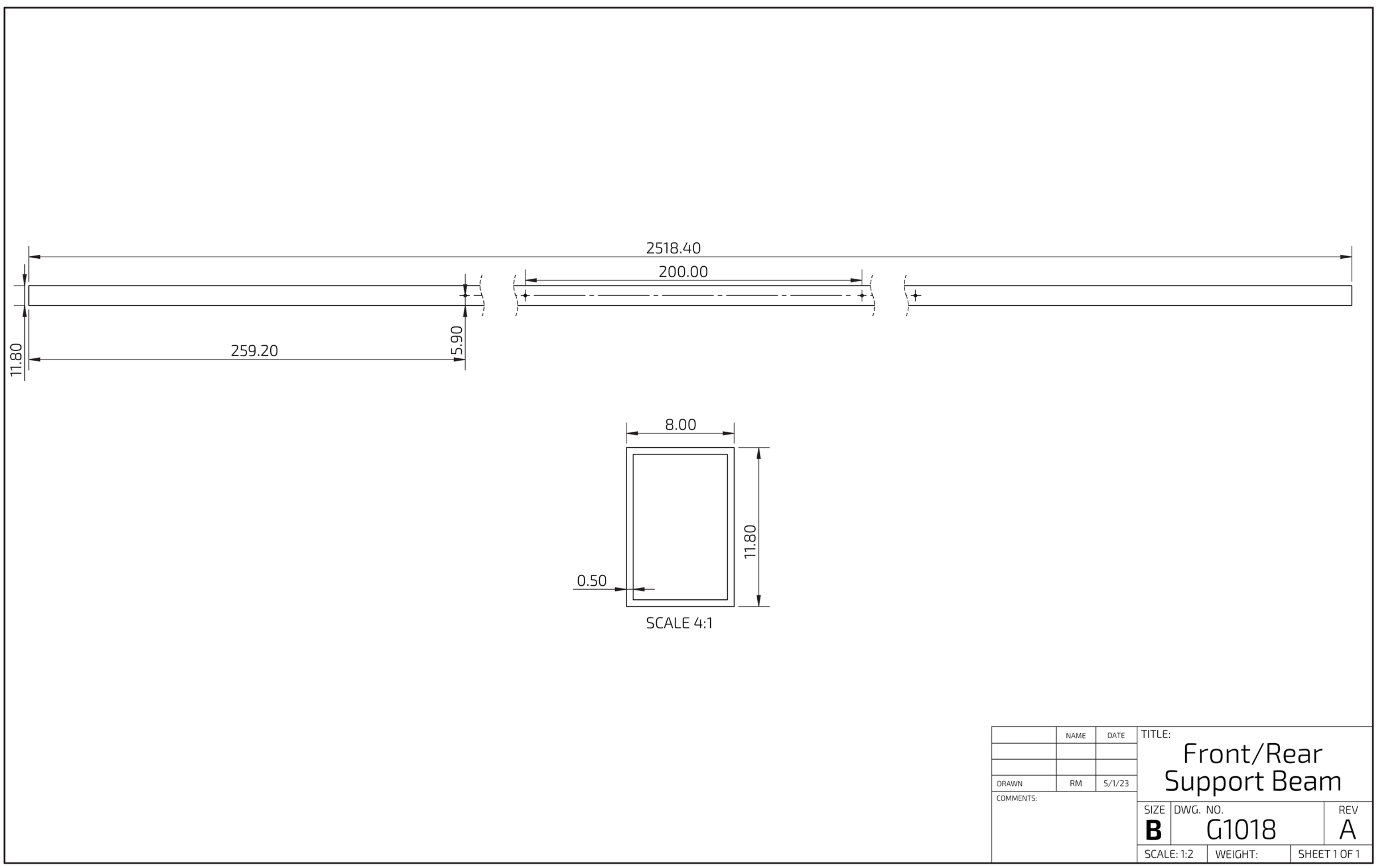
Greenhouse Parts: F/R PC Retention Beam

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the polycarbonate (PC) retention beams for the front and back of the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



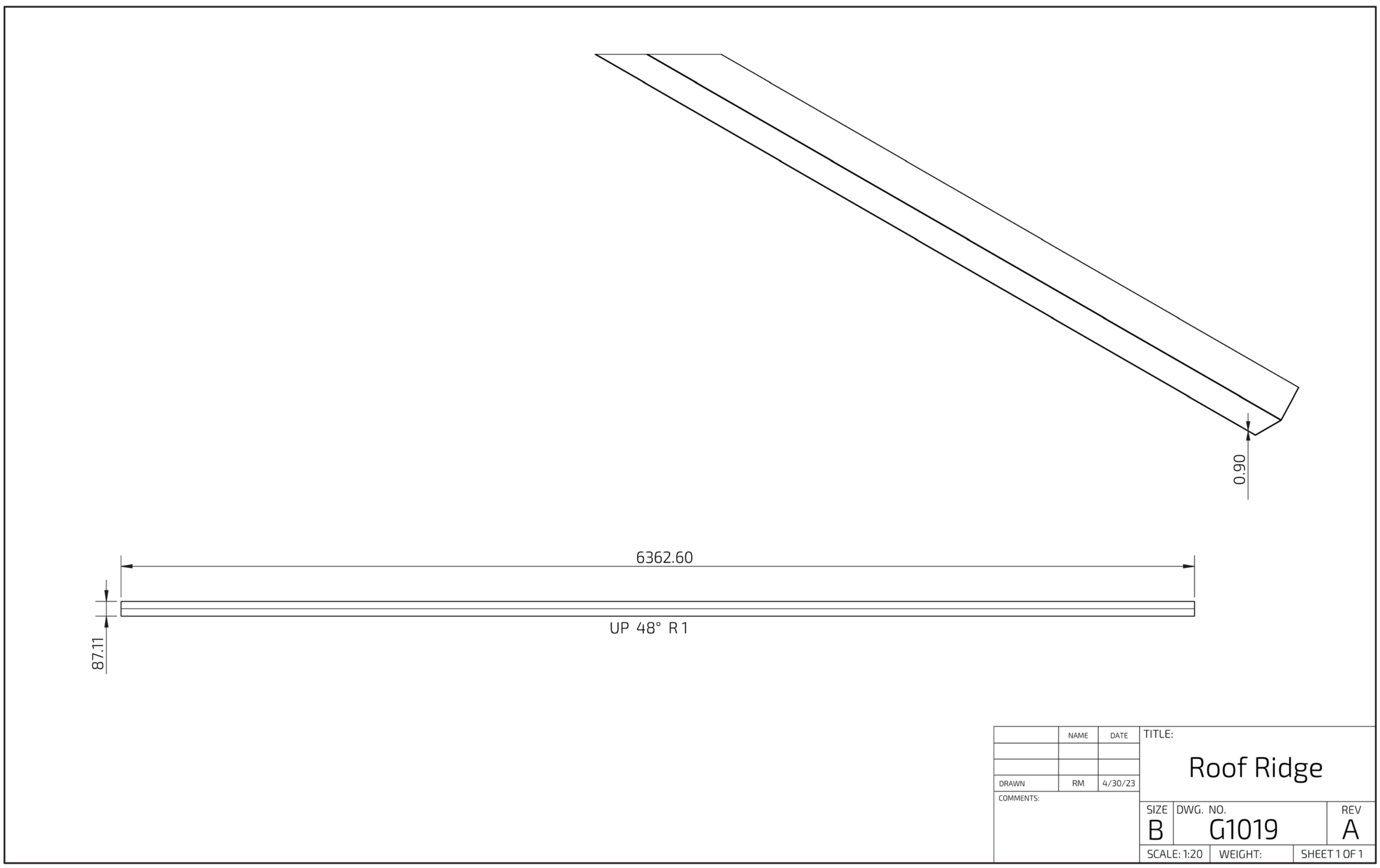
Greenhouse Parts: F/R Support Beams

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the front/rear support beams for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



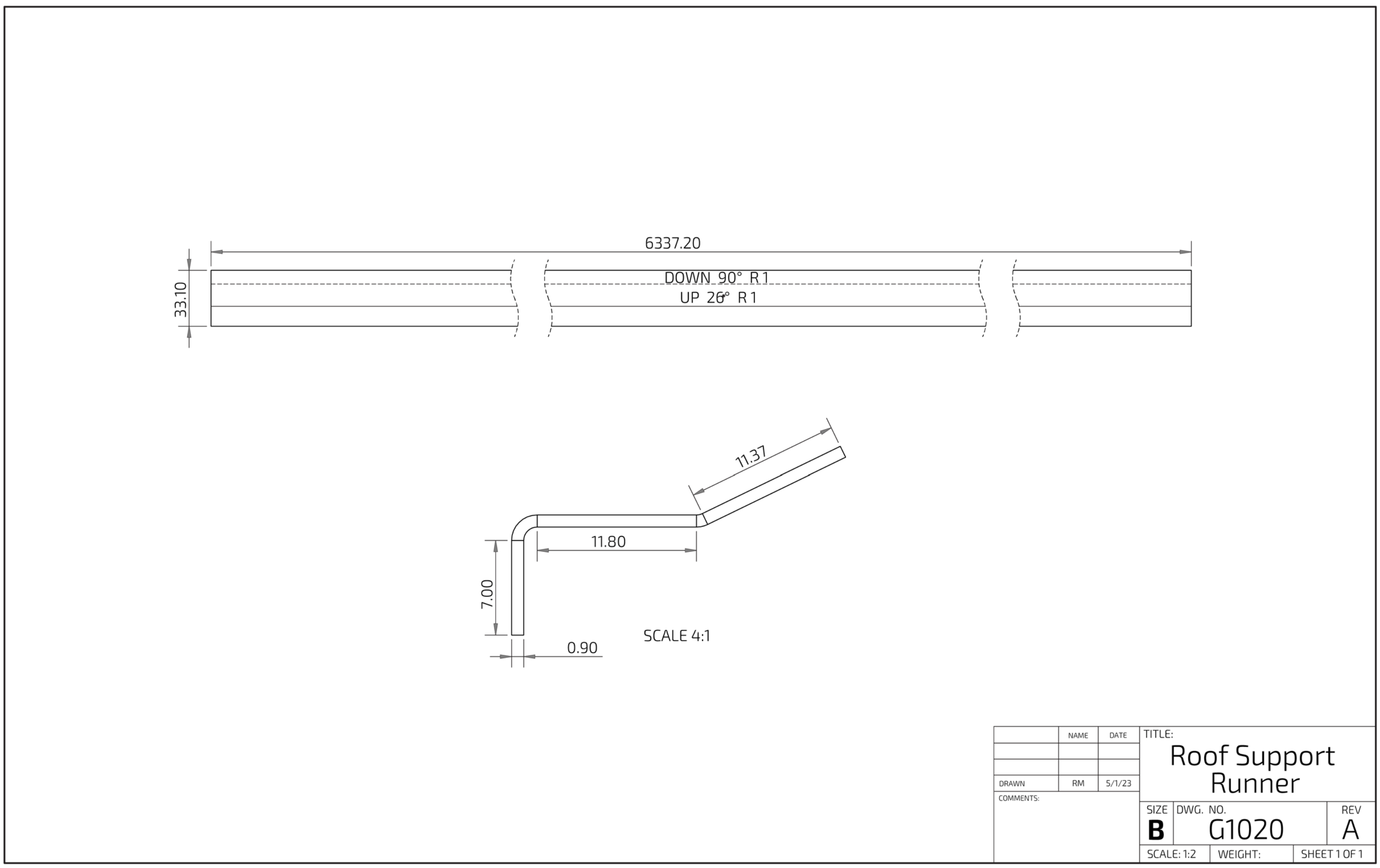
Greenhouse Parts: Roof Ridges

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the roof ridges for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



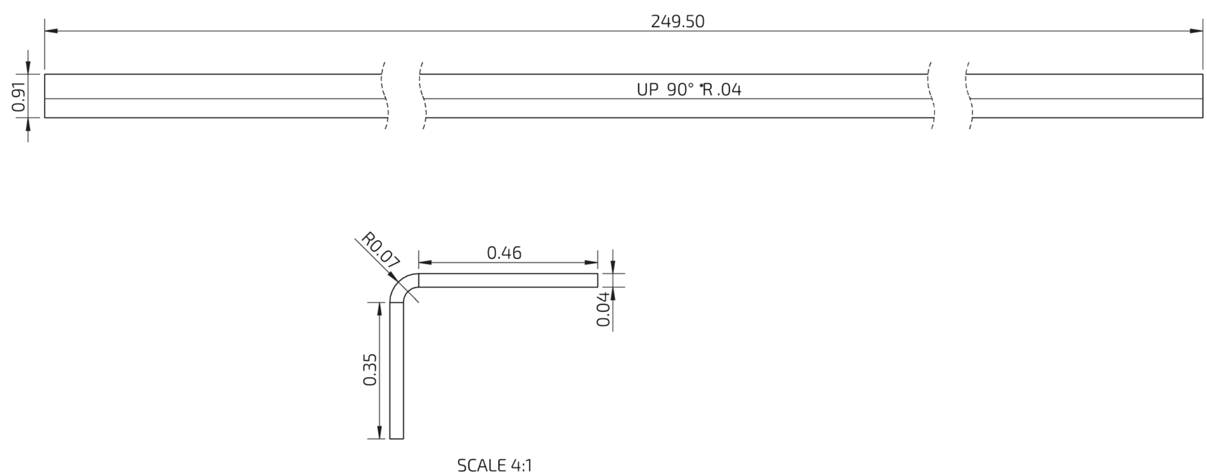
Greenhouse Parts: Roof Support Runners

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the roof support runners for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



Greenhouse Parts: Roof PC Panel Retainers

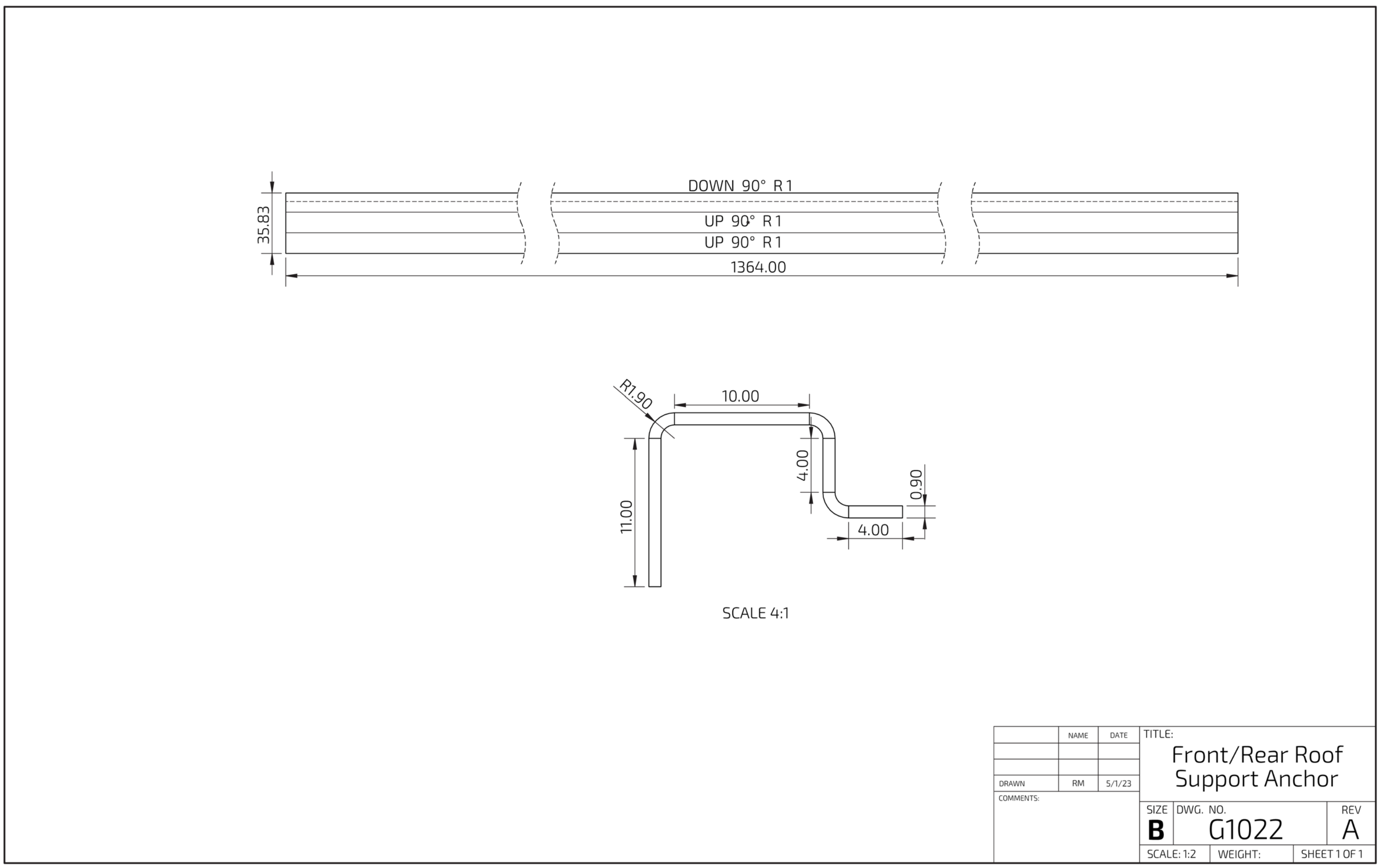
USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the roof polycarbonate (PC) panel retainers for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



	NAME	DATE	TITLE:
DRAWN	RM	5/1/23	Roof PC Panel Retainer
COMMENTS:			SIZE B · DWG. NO. G1021 · REV A
			SCALE: 1:2 · WEIGHT: · SHEET 1 OF 1

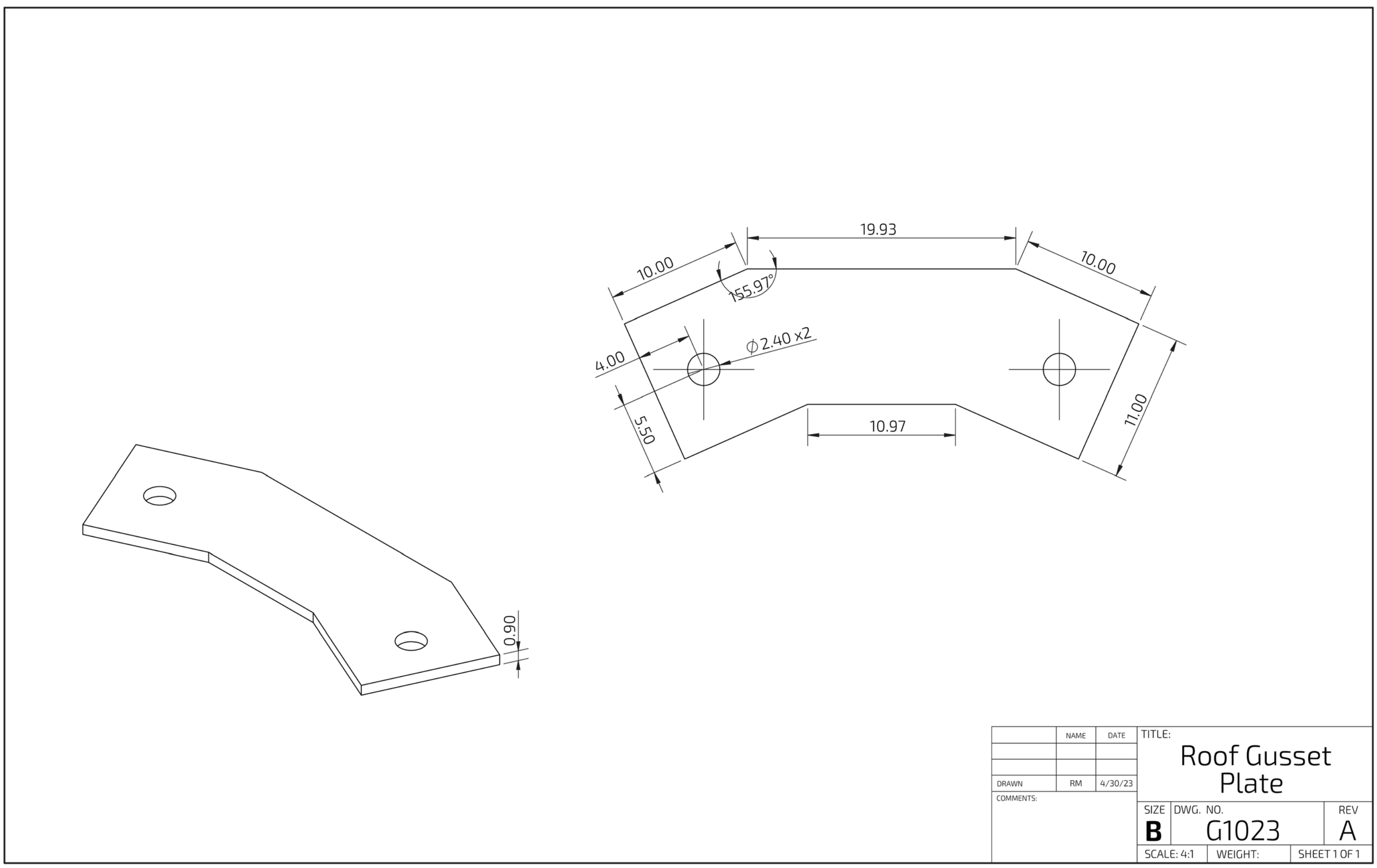
Greenhouse Parts: F/R Roof Support Anchors

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the front/ rear roof support anchors for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



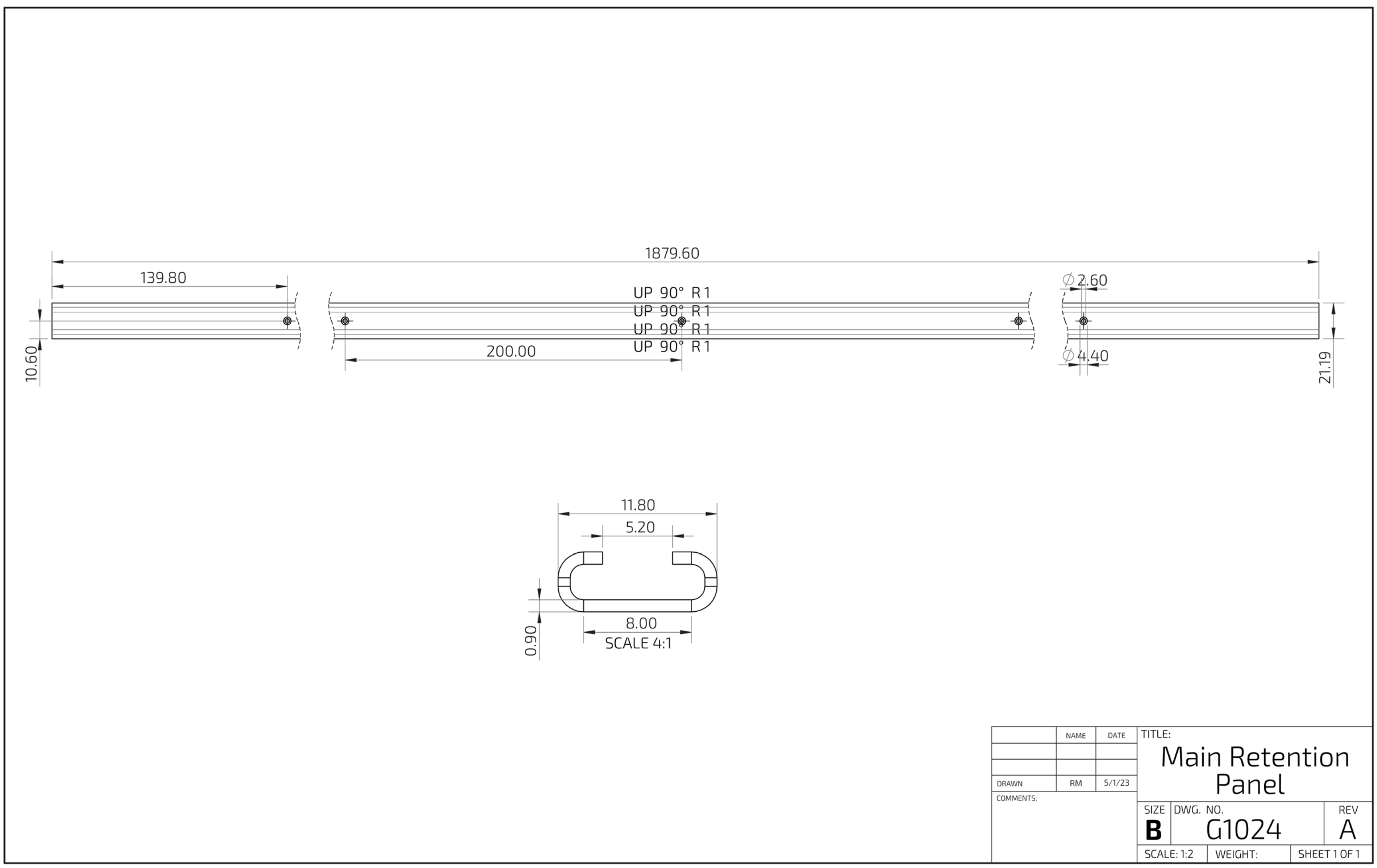
Greenhouse Parts: Roof Gusset Plates

USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the roof gusset plates for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



Greenhouse Parts: Main Retention Panel

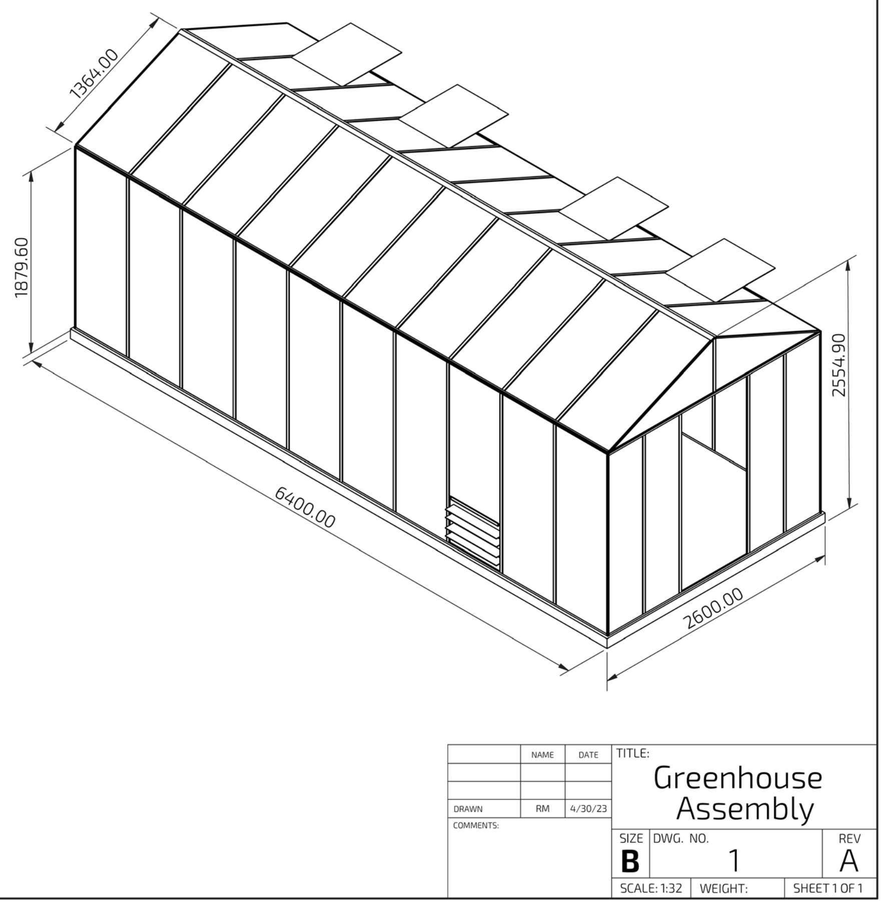
USE THE BELOW TECHNICAL DRAWING to identify, design, and create and/or purchase the main retention panel for the greenhouse assembly. While we recommend the noted material and these dimensions, we welcome users to substitute them as they see fit.



Greenhouse Assembly Instructions

USE THE BELOW TECHNICAL DRAWING to review how all of the components are assembled into the subassemblies that the greenhouse is comprised of. Each subassembly is shown in full detail in the following pages.

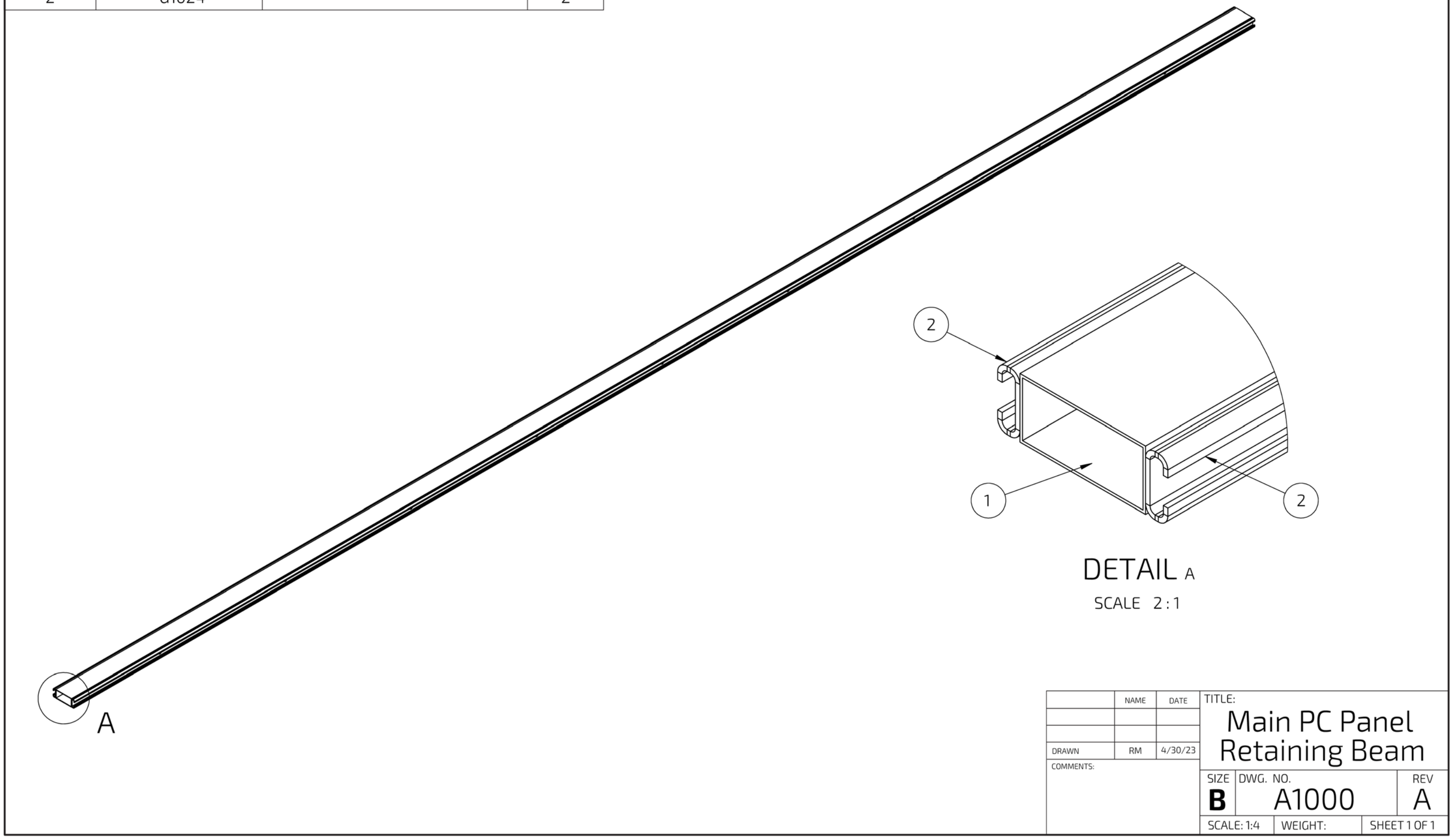
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A1000	MAIN PC RETENSION ASSEMBLY	8
2	A1001	MAIN SIDE WALL	3
3	A1002	CORNER BRACE ASSEMBLY	4
4	A1003	REAR WALL ASSEMBLY	1
5	A1004	FRONT WALL ASSEMBLY	1
6	A1005	ROOF ASSEMBLY	1
7	A1006	SHORT PC RETENSION ASSEMBLY	1
8	Foundation		1
9	G1000	MAIN PC PANEL	4
10	G1001	LOWER VENT SLAT	5
11	G1002	PC PANEL ABOVE LOWER VENT	1
12	G1009	MAIN U CHANNEL ANCHOR	1
13	G1012	CORNER ANCHOR PLATE	7
14	G1020	ROOF SUPPORT RUNNER	2
15	G1021	ROOF PC PANEL RETAINER	2



Subassembly Instructions: Main PC Panel Retainer

THE MAIN PC PANEL RETAINING BEAMS are created by attaching the PC retention panels (G1024) on either side of the main support beam (G1008).

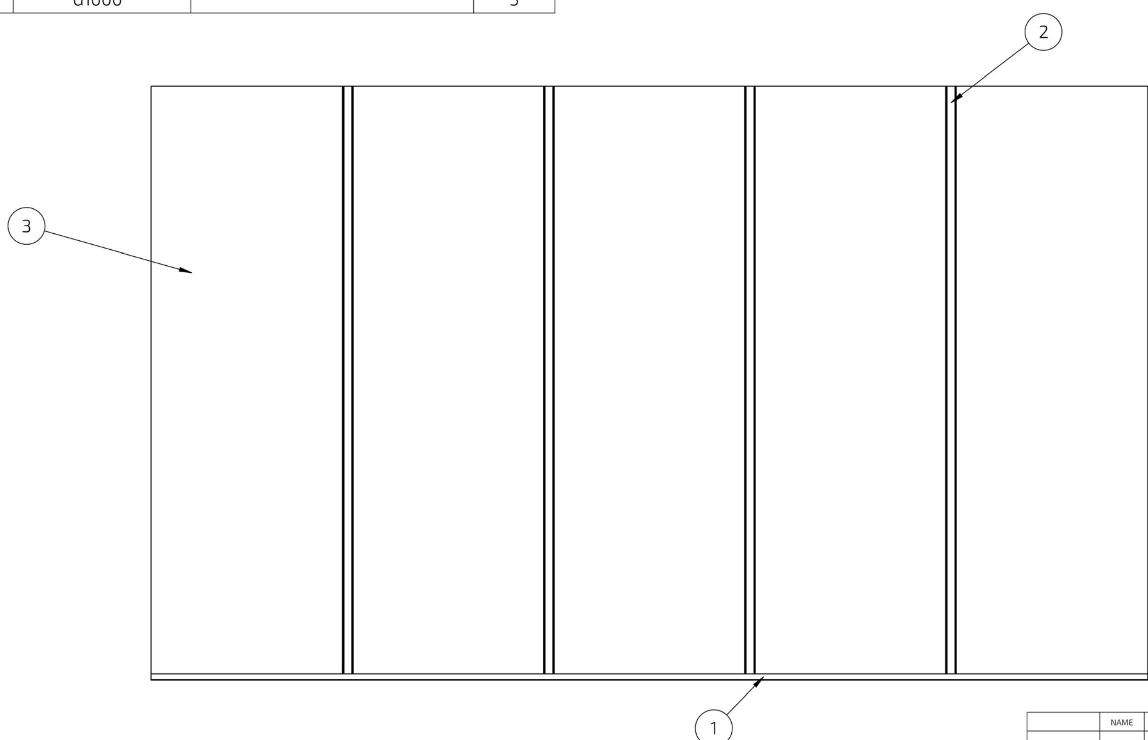
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1008		1
2	G1024		2



Subassembly Instructions: Main Side Wall

THE MAIN SIDE WALLS are created by slotting the main PC panels (G1000) in between the main PC panel retainers made in the previous step, and then slotting the assembly into the main u-channel anchor (G1009). There are 4 total sets of main side panel walls.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1009		1
2	A1000		4
3	G1000		5



	NAME	DATE
DRAWN	RM	4/30/23
COMMENTS:		

TITLE: Main Side Wall

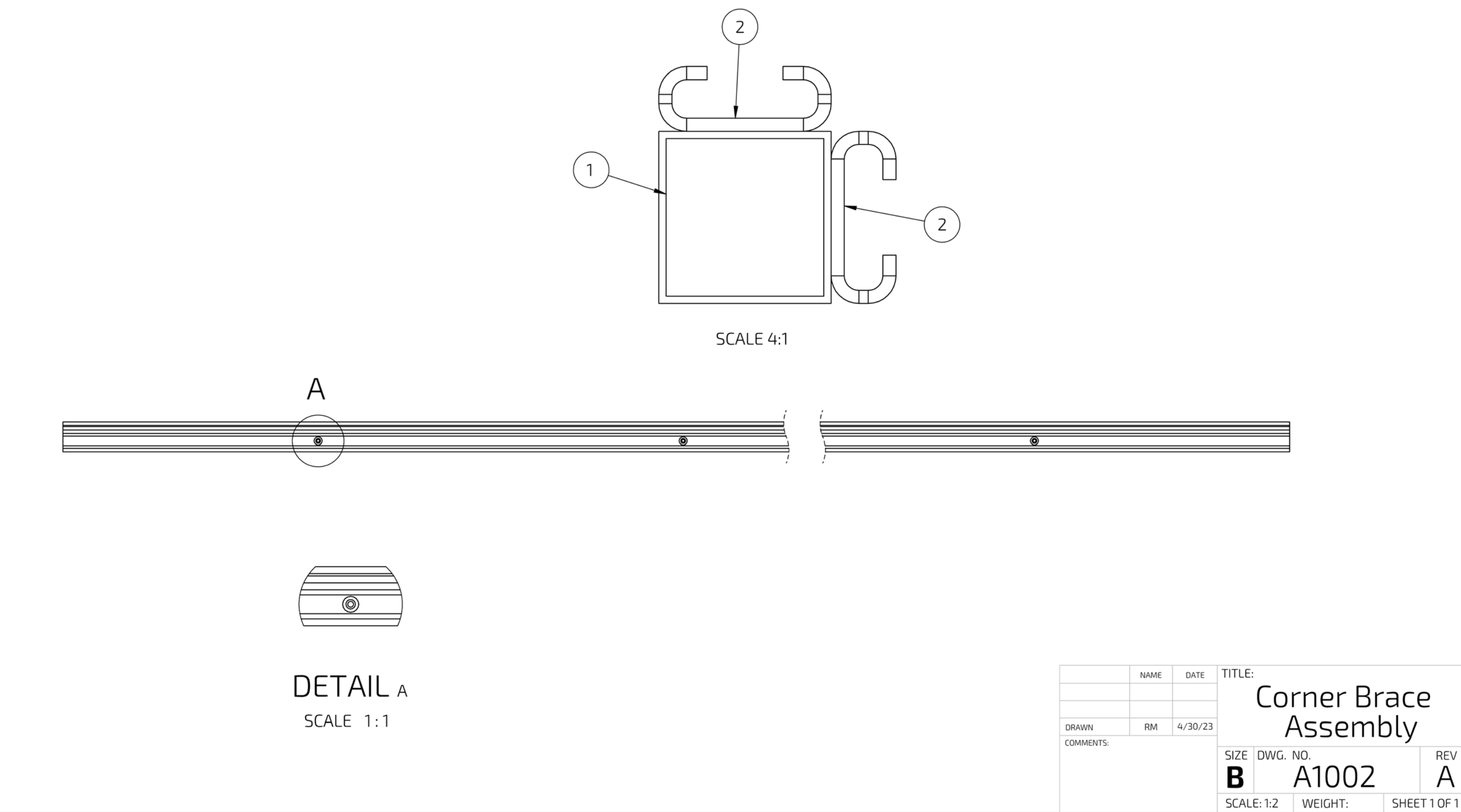
SIZE B | DWG. NO. A1001 | REV A

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1

Subassembly Instructions: Corner Brace Assembly

THE CORNER BRACES are created by attaching the main PC retention panel (G1024) on the greenhouse wall-facing sides of the main corner beam (G1010). This should be repeated four times for each corner of the greenhouse.

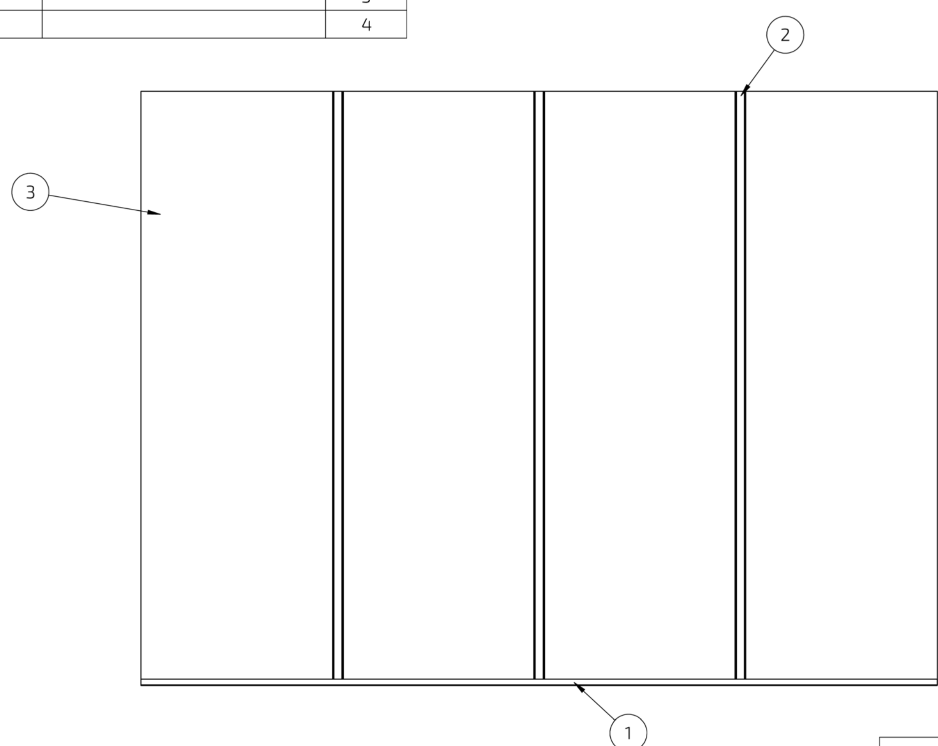
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1010		1
2	G1024		2



Subassembly Instructions: Rear Wall Assembly

THE REAR WALL ASSEMBLY is created by slotting the main PC panels (G1000) into the main PC panel retaining beams (A1000) previously assembled, and then slotting this subassembly into the roof anchor channel (G1011).

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1011		1
2	A1000		3
3	G1000		4



	NAME	DATE
DRAWN	RM	4/30/23

COMMENTS:

TITLE: Rear Wall Assembly

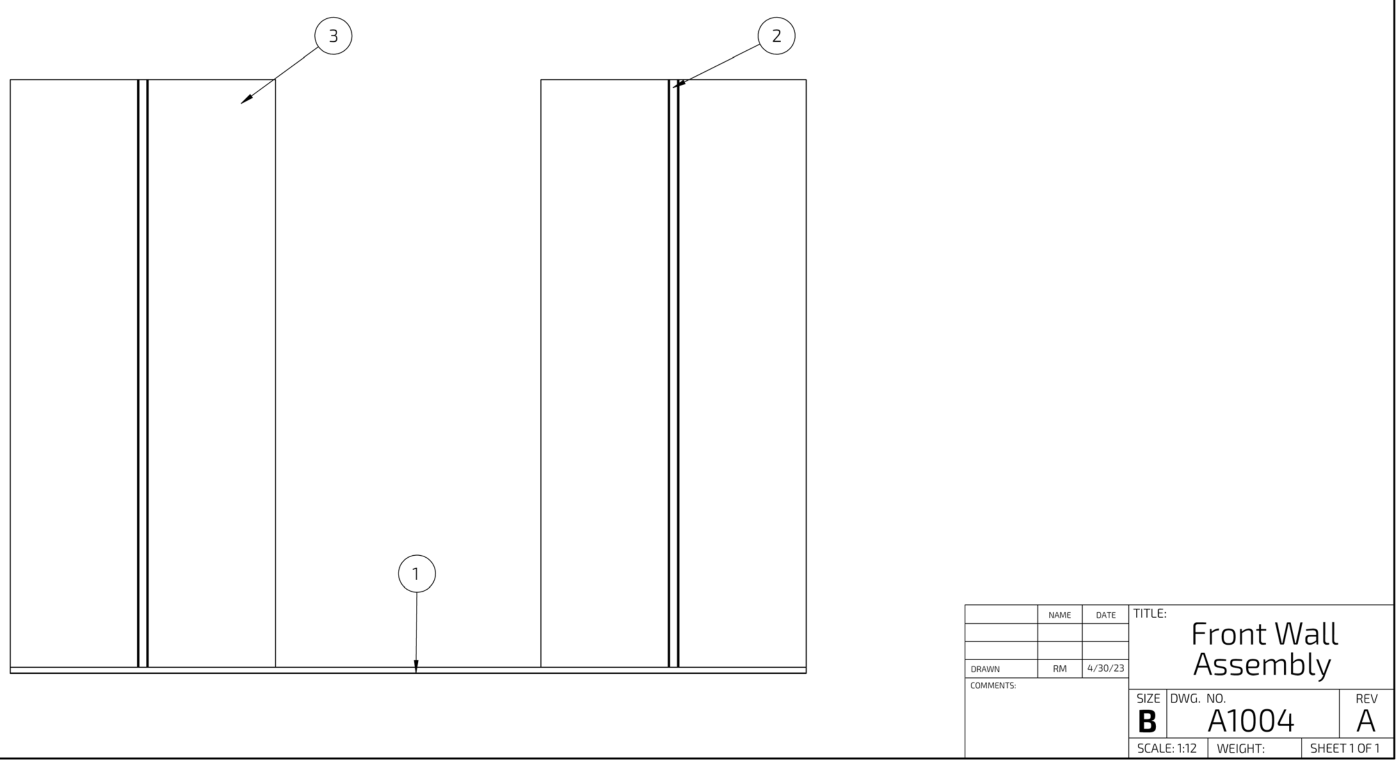
SIZE B | DWG. NO. A1003 | REV A

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1

Subassembly Instructions: Front Wall Assembly

THE FRONT WALL is assembled by slotting a main PC panel retaining beam (A1000) in between two front PC panels (G1003). This is created twice before slotting both sets on either side of the roof anchor channel (G1011).

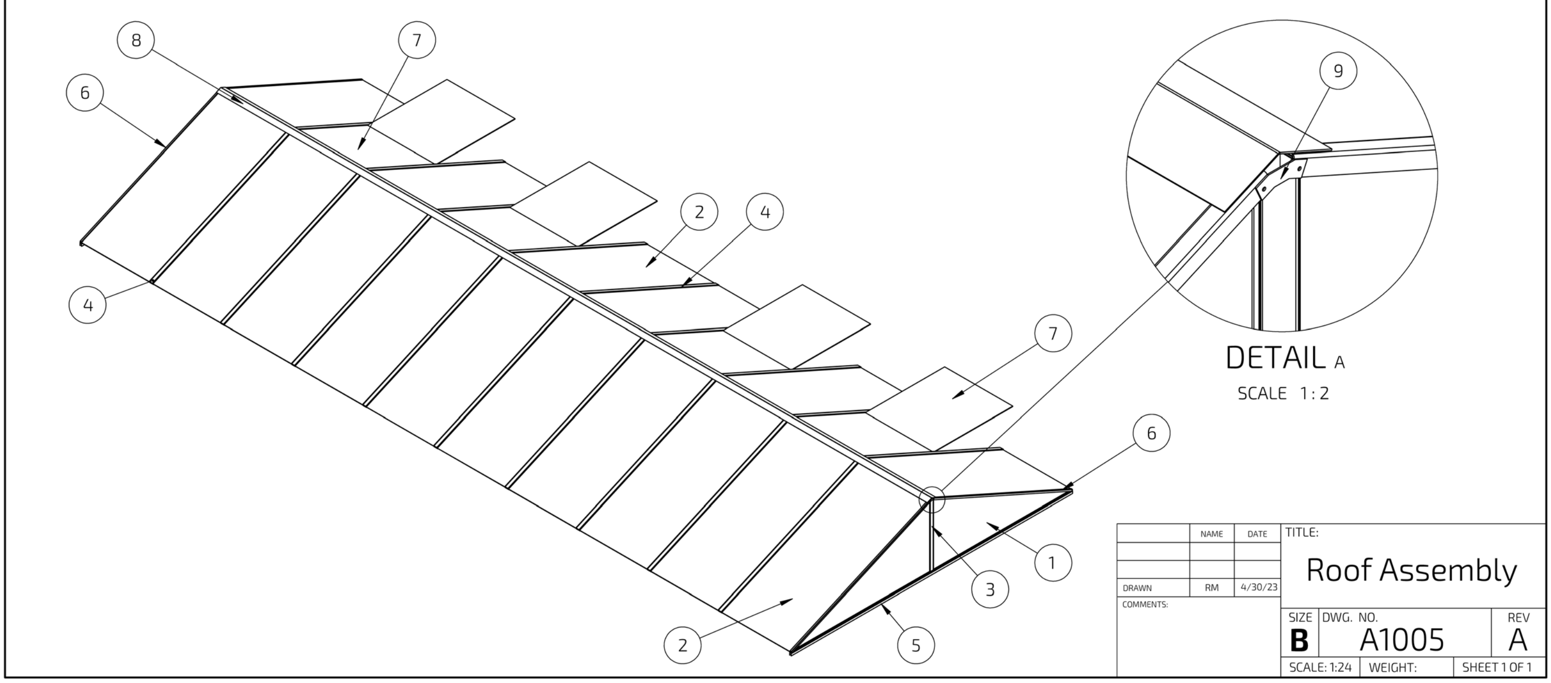
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1011		1
2	A1000		2
3	G1003		4



Subassembly Instructions: Roof Assembly

THE ROOF is assembled by following the diagram below.

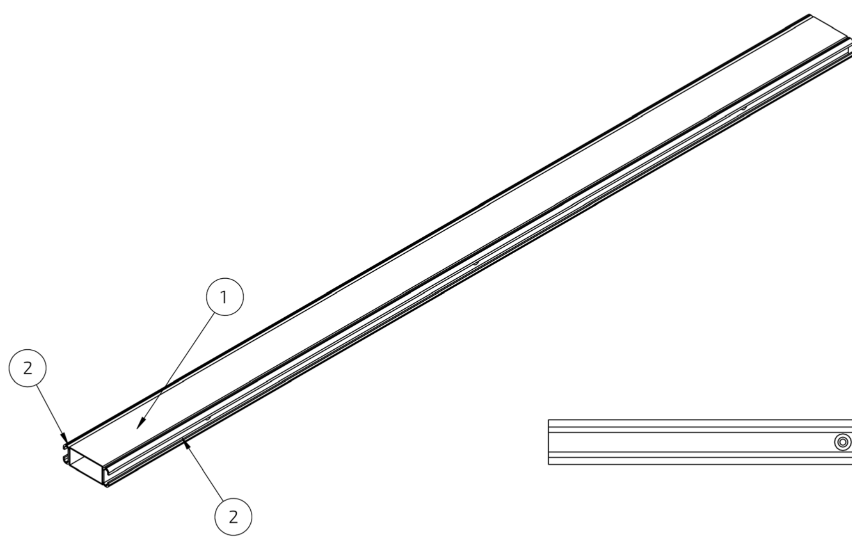
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1005		4
2	G1006		16
3	A1006		2
4	A1007		18
5	A1008		2
6	G1022		4
7	G1007		8
8	G1019		1
9	G1023		2



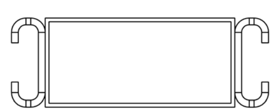
Subassembly Instructions: Short PC Retention Beam

THE SHORT PC PANEL RETENTION BEAM is created by attaching front/rear roof PC retention panels (G1013) on both sides of the front/rear roof support beams (G1014).

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1014		1
2	G1013		2



BREAK VIEW
SCALE 1:1



SCALE 2:1

	NAME	DATE
DRAWN	RM	4/30/23

COMMENTS:

TITLE: Short PC Panel Retention

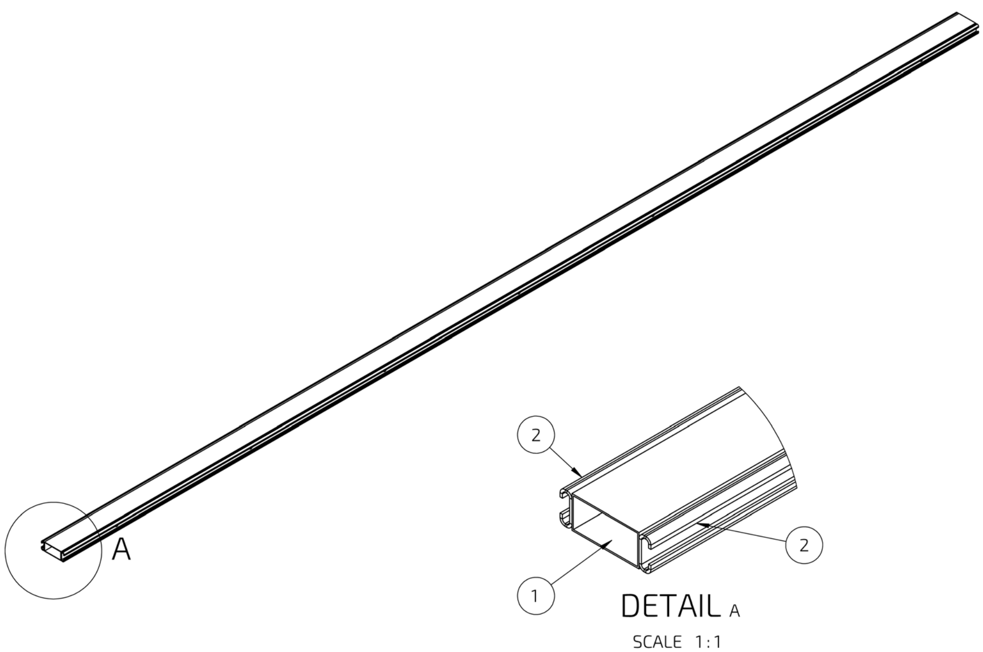
SIZE: B | DWG. NO.: A1006 | REV: A

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

Subassembly Instructions: Roof PC Panel Beams

THE ROOF PC PANEL BEAMS are created by attaching the roof PC retention panels (G1016) on either side of the roof support beams (G1015).

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1015		1
2	G1016		2

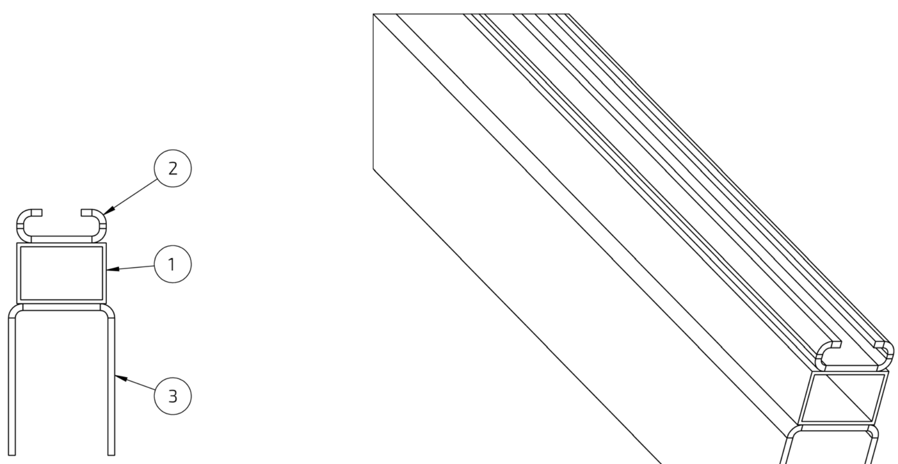


	NAME	DATE	TITLE: Roof PC Panel Beam Assembly
DRAWN	RM	4/30/23	
COMMENTS:			SIZE B · DWG. NO. A1007 · REV A
			SCALE: 1:4 · WEIGHT: · SHEET 1 OF 1

Subassembly Instructions: Roof Anchors

THE ROOF ANCHORS are created by attaching the front/rear support beam (G1018) to the lower roof PC retention panel (G1017) and then attaching the beam-side of this assembly to the roof anchor channel (G1011).

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G1018		1
2	G1017		1
3	G1011		1



	NAME	DATE
DRAWN	RM	4/30/23
COMMENTS:		

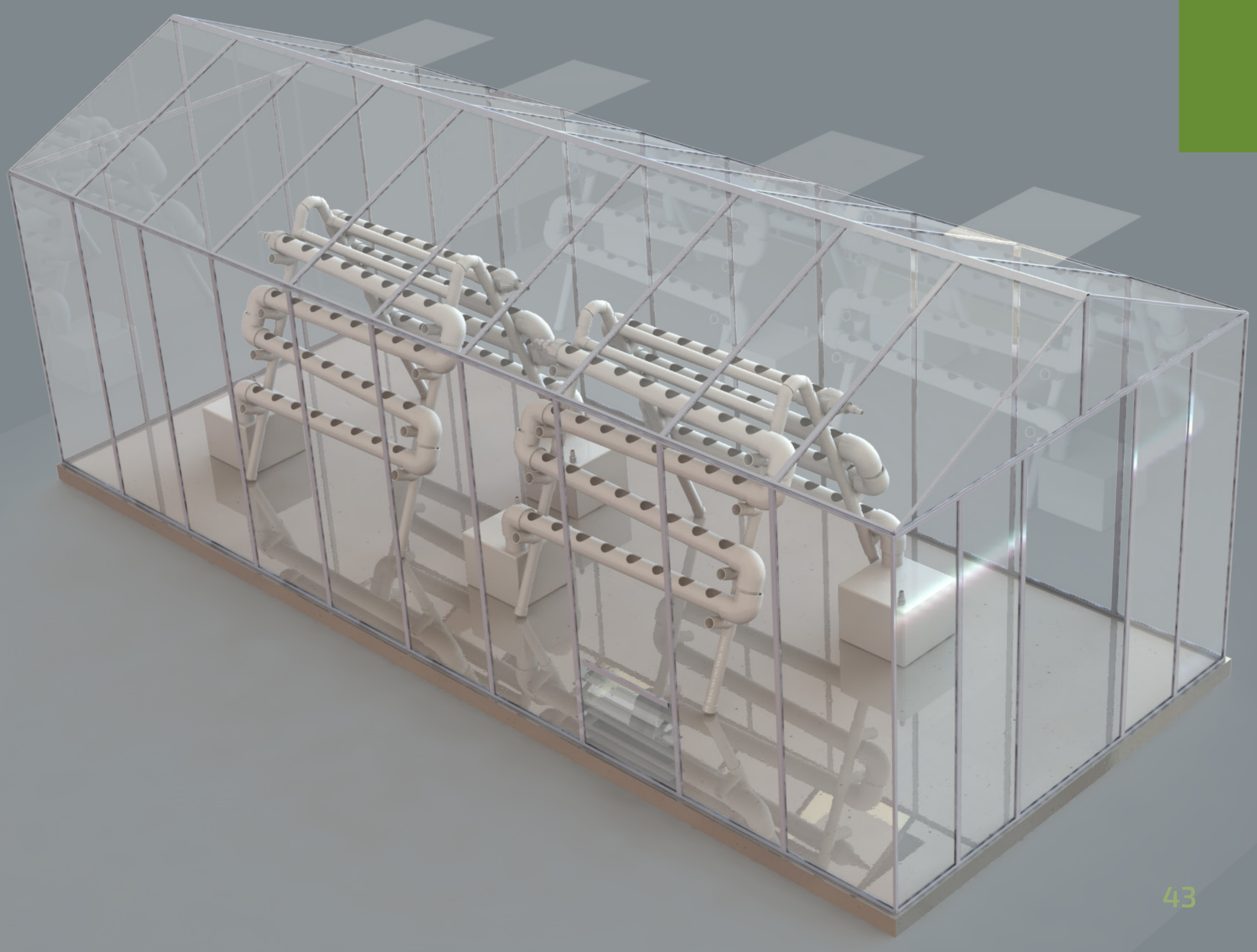
TITLE: Roof Anchor Assembly

SIZE: B | DWG. NO.: A1008 | REV: A

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

Final Assembly

WITH THE GREENHOUSE ASSEMBLY COMPLETE, you are ready to start planting! We recommend assembling the hydroponic systems (see our other handbook) inside of the greenhouse as the complete assembly may not fit through the entrance. Furthermor, we advise regular monitoring and maintenance as needed of the greenhouse structural system to ensure its stability and the user's safety.



Greenhouse Maintenance

GREENHOUSE CLEANING [11]

It is important to clean and sanitize the greenhouse often. Due to the moisture present within the greenhouse, dust and algae may form on the PC panels. With single-pane PC panels, a clean brush and rag may be used to scrap and wipe the panels. If using double-pane PC panels, dust and algae may build up between the pane layers. Unfortunately there is no way to clean or replace these panels without disassembling the greenhouse. However, this is avoidable by ensuring a watertight seal between the PC panels and aluminum beams.

Cleaners such as hydrogen peroxide or bleach may be used to kill the algae growth however, these chemicals may harm the crops as well. If the use of these chemicals are desired, the hydroponic systems should first be removed from the greenhouse. After the greenhouse is cleaned with the chemicals, the entire structure should be washed with clean water. This ensures that no lingering chemicals can damage the crops when they are moved back into the greenhouse.

References

1. Instructables. (2017). PVC Hydroponics Unit. Instructables. https://www.instructables.com/PVC-Hydroponics-Unit/
2. Jagdish. (2023, January 26). How to Build a Hydroponic Unit with PVC Pipes: DIY in Simple Steps. Agri Farming. https://www.agrifarming.in/how-to-build-a-hydroponic-unit-with-pvc-pipes-diy-in-simple-steps#:~:text=The%20ultimate%20result%20should%20be%20a%203%201%2F2,reserv
3. Polyvinyl Chloride - Chemical Safety Facts. (2022, October 14). Chemical Safety Facts. https://www.chemicalsafetyfacts.org/chemicals/polyvinyl-chloride/
4. Polyvinyl Chloride (PVC) Plastic: Uses, Properties, Benefits & Toxicity. (n.d.). https://omnexus.specialchem.com/selection-guide/polyvinyl-chloride-pvc-plastic
5. PVC and Organic Gardening: Is PVC Safe to Use? (2022, October 5). Accessible Gardens. https://accessiblegardens.org/pvc-and-organic-gardening-is-pvc-safe-to-use/
6. Denisa. (2023). Best Hydroponic Growing Medium for Hydroponic Systems. PonicsArea. https://ponicsarea.com/best-hydroponic-growing-medium/#:~:text=10%20Best%20Hydroponic%20Growing%20Media%20Compared%201%201.,material%20that%20has%20no%20negative%20environmental%20impact.%20
7. Jamie. (2022, February 10). NFT Hydroponics: Basics, Setup, Pros/Cons, FAQ. WhyFarmIt. https://whyfarmit.com/nft-hydroponics/
8. Admin. (2020). How Hygrometers Work. Hygrometer.net. https://hygrometer.net/hygrometers-work/
9. The Editors of Encyclopaedia Britannica. (1998, July 20). Psychrometer | instrument. Encyclopedia Britannica. https://www.britannica.com/technology/psychrometer
10. Sohail, U. (2017). This Incredible Rooftop Farm In Israel Grows Thousands Of Organic Vegetables Throughout The Year. Wonderful Engineering. https://wonderfulengineering.com/this-incredible-rooftop-farm-in-israel-grows-thousands-of-organic-vegetables-throughout-the-year/
11. Greenhouse Building Materials: Should I Choose Glass, Polycarbonate, or Poly Film? (2022, February 25). Dengarden. https://dengarden.com/landscaping/greenhouse-glass-guide
12. Polycarbonate (PC) - Properties, Uses, & Structure - Guide. (n.d.). https://omnexus.specialchem.com/selection-guide/polycarbonate-pc-plastic
13. Tammy. (2018, September 3). Double Polyfilm Greenhouse - Grow Your Own Food Anywhere. Grow Your Own Food Anywhere. https://www.blog.advancegreenhouses.com/double-polyfilm-greenhouse/#:~:text=Double%20polyfilm%20greenhouses%20consist%20of%202%20layers%20of,you%20up%20to%2040%25%20of%20your%20energy%20costs.
14. Team, C. (2020, July 15). How To Pick A Tarp For Your Greenhouse DIY Project. CanvasandCanopy.com. https://canvasandcanopy.com/greenhouse-tarp/
15. Rusnak, P. (2019, November 14). Everything You Need to Know About Hydroponic Cucumber Production - Greenhouse Grower. Greenhouse Grower. https://www.greenhousegrower.com/production/everything-you-need-to-know-about-hydroponic-cucumber-production/
16. Market Minute: Record high lettuce market as demand exceeds supply | Produce News. (n.d.). https://theproducenews.com/headlines/market-minute-record-high-lettuce-market-demand-exceeds-supply

17. Dupuis, A., & Technology, E. G. (2023). Hydroponic Lettuce: Everything You Need to Know | Eden Green. Eden Green. https://www.edengreen.com/blog-collection/hydroponic-butterhead-lettuce
18. Romaine Lettuce. (n.d.). walmart.com. https://www.walmart.com/c/kp/romaine-lettuce
19. Butterhead Lettuce. (n.d.). walmart.com. https://www.walmart.com/ip/Butter-Lettuce/44391110
20. Stephens, O. (2022). How To Germinate Seeds For Hydroponics: Step-By-Step. The Hydroponics Planet. https://thehydroponicsplanet.com/how-to-germinate-seeds-for-hydroponics-step-by-step/
21. Valencia, J. (2023, March 20). How to Choose the Best Net Pots for your Hydroponics System. The Greenery. https://www.greeneryretail.com/post/how-to-choose-the-best-net-pots-for-your-hydroponics-system
22. Why Does Soil pH Change? | Soils - Part 4: Soil pH - passel. (n.d.). https://passel2.unl.edu/view/lesson/d2b-52174b1a7/6#:~:text=Native%20vegetation
23. What is pH and Why Does it Rise? A Complete and Updated Guide. (2020, September 7). Happy Hydro. https://www.happyhydro.com/blogs/news/what-is-ph-and-why-does-it-rise#:~:text=Hydroponic%20setups%20are%20likely%20to,its%20acidity%20to%20become%20alkaline
24. Soil pH and the Availability of Plant Nutrients | Nutrient Stewardship. (n.d.). https://nutrientstewardship.org/implementation/soil-ph-and-the-availability-of-plant-nutrients/#:~:text=It%20has%20been%20determined%20that,compatible%20to%20plant%20root%20growth
25. Admin, N. (2021, July 27). Best Temperature for Hydroponics. North Slope Chillers. https://northslopechillers.com/blog/best-temperature-for-hydroponics/#:~:text=Experts%20agree%20that%20the%20best,-roots%20and%20optimal%20nutrient%20absorption
26. Team, A. N. (2022). How To Build Your Own Hydroponics Grow Room – Dialing In Your Temperature and Humidity (part 3). Advanced Nutrients. https://www.advancednutrients.com/articles/grow-room-temperature-humidity/
27. Trees.com Staff. (2022, December 20). Hydroponic Nutrient Solution - The Essential Guide - Trees.com. Trees.com. https://www.trees.com/gardening-and-landscaping/hydroponic-nutrient-guide
28. Smart Garden Guide & Smart Garden Guide. (2019, February 6). Hydroponic Nutrient Solution (Easy Guide) - Smart Garden Guide. Smart Garden Guide. https://smartgardenguide.com/hydroponic-nutrient-solution-easy-guide-2/
29. E. Coli - Health Implications in Recreational and Drinking Water. (n.d.). The Water Project. https://thewaterproject.org/water-scarcity/health-implications-of-e-coli
30. Water Supply | We Grow Hydroponics. (n.d.). https://wegrowhydro.com/water-supply/

HAIFA HYDRO 2023

AN ASSEMBLY MANUAL PREPARED BY KELLY HEFFERNAN, RAYDEN MORLEY, SEAN NUZIO, AND NATANEL PINKHASOV IN COLLABORATION WITH THE MITYAALIM FOUNDATION, THE BRAUDE COLLEGE OF ENGINEERING, HAIFA UNIVERSITY, GIVAT YOAV, LIVINGREEN, AND WORCESTER POLYTECHNIC INSTITUTE.

Appendix E: Hydroponic Assembly and Instructional Handbook

HAIFA HYDRO
WORCESTER POLYTECHNIC INSTITUTE

HYDROPONICS

Handbook & Assembly Manual

How to Build Your Own Urban Rooftop **Hydroponics Garden**, Using the Nutrient Film Technique

An accessible and affordable alternative to rising fresh food costs

00

INTRO

Purpose

The purpose of this handbook is to guide the general public through the assembly, operation and maintenance of a nutrient film technique (NFT) hydroponic system. The proposed model is designed to cultivate 64 crops within a 3m^2 area. This system allows the average property owner or commercial grower to create their own customizable hydroponic operation in a greenhouse or area of their choice.

Why Hydroponics?

Traditional agriculture methods require the use of pesticides that disrupt ecosystems, bodies of water, and swathes of land. These are only some of the issues presented by traditional methods. Hydroponic farming provides solutions to many of these issues. For example, in a hydroponic system, pesticides are used infrequently, the intake rate of nutrients can be controlled and crop diseases are uncommon. As an alternative agricultural method, hydroponics has been proven to reduce waste, yield more produce, and reduce environmental harm.

OUTLINE

Overview: Design Plan

OUR DESIGN is for a nutrient film technique hydroponics system to be installed on a rooftop. The design consists of a modular hydroponics system and a greenhouse enclosure (specifications for which are in our separate manual) that should be scalable to a variety of specifications. The hydroponics system consists of variable length growing channels and a design that allows for a freestanding structure.

LIVINGREEN

A method tried and tested by our partner, LivinGreen. They are a commercial hydroponic supply and educational business in Israel.

Materials Needed: Product Descriptions

THE FOLLOWING is a list of materials required in the construction of the hydroponic system. It is important to note that these are only the recommended materials. Any materials you are unable to access or acquire may be substituted.

ELECTRICAL CONDUCTIVITY PROBE [1, 7]

The electrical conductivity (EC) probe measures detects levels of dissolved nutrient salts within the nutrient solution. Although most crops require 1000 parts per million, ranges will vary depending on the crop grown and nutrient solution used.

GROWTH MEDIUM [6]

The growth medium provides stability to the crops, acting as a structure for which the roots may grow around. While we suggest rock wool, there are several materials that will make a strong growing medium including expanded clay aggregate, perlite, or coconut fiber.

HUMIDITY DOMES [1, 2]

The humidity domes cover the seed trays, retaining moisture and heat during the germination process. Any translucent plastic cover may be used, however, it must be capable of making a complete seal with the seed tray.

NET POTS [1, 2]

The net pots hold the crops and growth medium within the hydroponics system. Net pots are not a necessity for a fully operational hydroponic system but may help reduce growths and blockages from forming within the growing channels. An inexpensive alternative to store bought net pots is a standard 50ml plastic water bottle. By cutting the water bottle in half, and forming several holes in the bottom section, you can make an effective net pot.

NUTRIENT SOLUTION TANKS [1, 2]

The nutrient solution tanks contain the nutrient solution as it is pumped throughout the system. Within the tanks are the water pump, pH probe and EC probe. Any fifty liter opaque container may be used as a nutrient solution tank.

PH PROBE [2, 7]

The pH probe measures the basicity or acidity of the nutrient solution. Within an optimized hydroponic system, an pH range of 6.5 to 7.5 is desired. Alternatively you could use pH test strips, however they are not as accurate or sustainable.

PIPE CEMENT [1, 2]

The pipe cement forms a permanent seal between the PVC pipes and fittings of the system frame. A permanent seal here is recommended as the frame needs to be rigid to support the growing channels. However, if desired, impermanent options, like rubber gaskets, may be used.

POLYVINYL CHLORIDE [4, 5]

Polyvinyl chloride (PVC) is the primary construction material of the hydroponic system. When assembling the frame, any variation of PVC may be used, however for the growing channels only unplasticized polyvinyl chloride (U-PVC) is used.

PSYCHROMETER [8, 9]

The psychrometer measures the relative humidity and temperature of the greenhouse. Alternatively using separate humidity and temperature probes provide the same measurements as one psychrometer.

RUBBER GASKET [1, 2]

The rubber gaskets form an impermanent seal between the U-PVC pipes and fittings of the growing channels. An impermanent seal allows for the growing channels to be fully deconstructable, making system maintenance easier. If desired, pipe cement may be used to form a permanent seal.

SEED TRAYS [1, 2]

The seed trays house the seeds during the germination process, before they are transferred to the hydroponics system. Any watertight tray may be used as a seed tray.

WATER PUMP [1]

The water pump circulates the nutrient solution from within the nutrient solution tank throughout the system. Any fluid pump with an average rate of twenty liters per hour is suitable. We suggest you purchase a water pump with a filter to ensure clean nutrient solution and easier maintenance. You will need a source of electricity to power the water pump.

WATER TUBING [1]

The water tubing carries the nutrient solution from the nutrient solution tank to the top growing channel. Any watertight tubing or hose may be used.

ZIP TIES [2, 7]

The zip ties provide extra support to the hydroponic system, connecting the U-PVC growing channels to the PVC frame. Using zip ties are not required, however they ensure the U-PVC pipes will not deform, or shift over time, while still providing the impermeability needed for maintenance. Alternatives to zip ties include: rubber bands, string or any other fastening material.

Assembly Items: System Frame

THE BELOW ASSEMBLY ITEMS are suggested for the construction of the hydroponic system frame. While we recommend these products specifically, the user is free to substitute products per their specific needs and requirements.

	**Polyvinyl Chloride (PVC) Pipe** 32mm diameter	QUANTITY 10 m
	**Polyvinyl Chloride (PVC) Pipe T Fitting** 32mm diameter	QUANTITY 20
	**Polyvinyl Chloride (PVC) Pipe 45° Elbow Fitting** 32mm diameter	QUANTITY 4
	**Polyvinyl Chloride (PVC) Pipe 45° Elbow Fitting** 32mm diameter, Female to Male	QUANTITY 2
	**Polyvinyl Chloride (PVC) Pipe Cap Fitting** 32mm diameter	QUANTITY 4

Assembly Items: Growing Channel

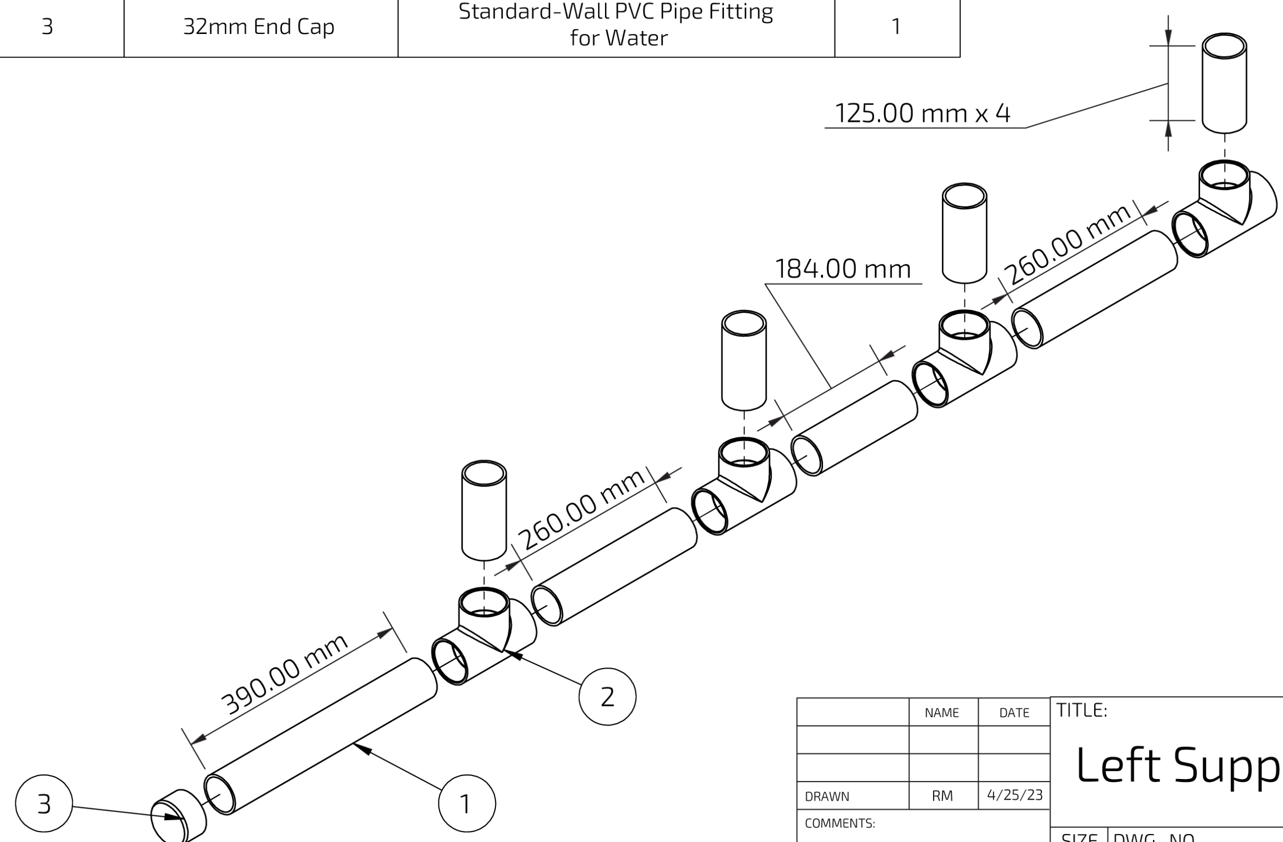
THE BELOW ASSEMBLY ITEMS are suggested for the construction of the hydroponic growing channels. While we recommend these products specifically, the user is free to substitute products per their specific needs and requirements.

	**Polyvinyl Chloride (PVC) Pipe** 110mm diameter	QUANTITY 13 m
	**Polyvinyl Chloride (PVC) Pipe 90° Elbow Fitting** 110mm diameter	QUANTITY 14
	**Rubber Gaskets** 110mm diameter	QUANTITY 16
	**Reducer Pump Fittings** 110mm diameter	QUANTITY 2

Hydroponic System: Left Leg Assemblies

FOLLOW THE BELOW INSTRUCTIONS and diagrams to assemble the left leg structure of the hydroponic system. Note that TWO of these assemblies should be created. We recommend cutting all PVC pipe components to the approximate sizes drawn below. Please remember to use pipe cement to seal all permanent pipe to fitting connections.

ITEM NO.	PART	DESCRIPTION	QTY.
1	32mm Dia PVC	Standard-Wall Unthreaded Rigid PVC Pipe for Water	8
2	32mm Dia T Fitting	Standard-Wall PVC Pipe Fitting for Water	4
3	32mm End Cap	Standard-Wall PVC Pipe Fitting for Water	1



	NAME	DATE
DRAWN	RM	4/25/23

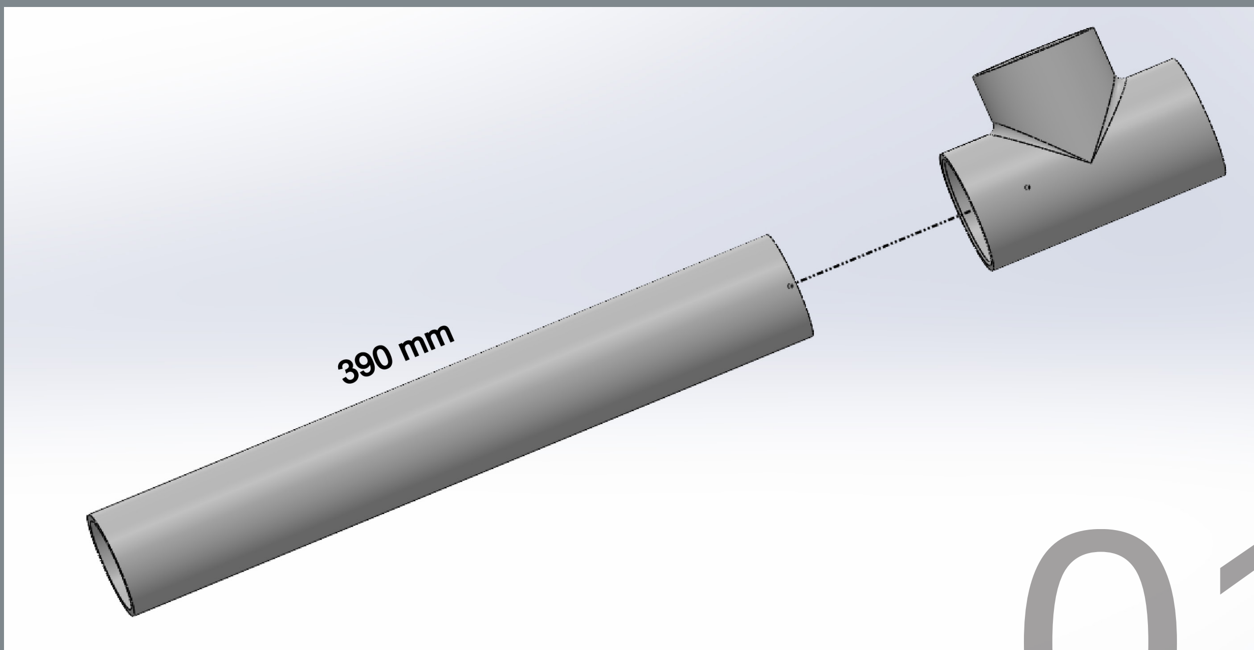
COMMENTS:

TITLE: Left Support Leg

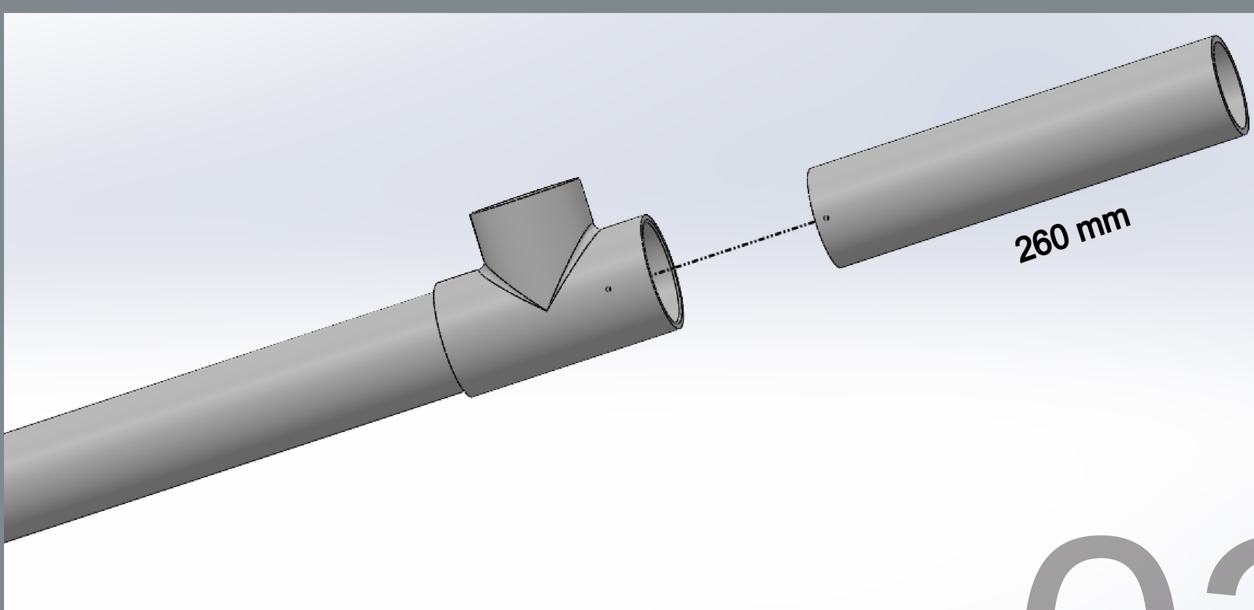
SIZE A | DWG. NO. 1 | REV A

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

SUPPORT FRAME: LEFT LEG ASSEMBLIES

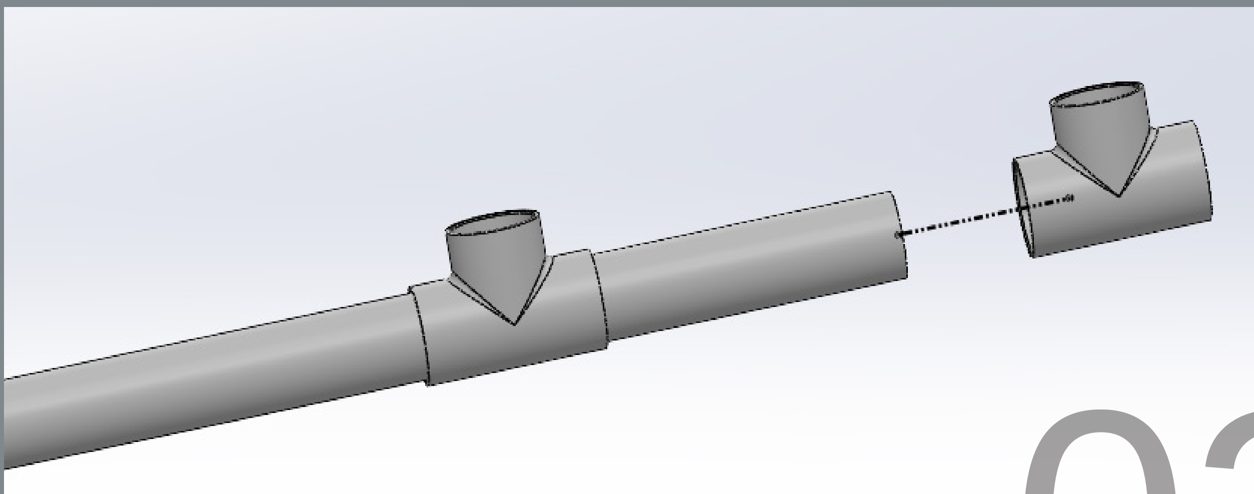


01

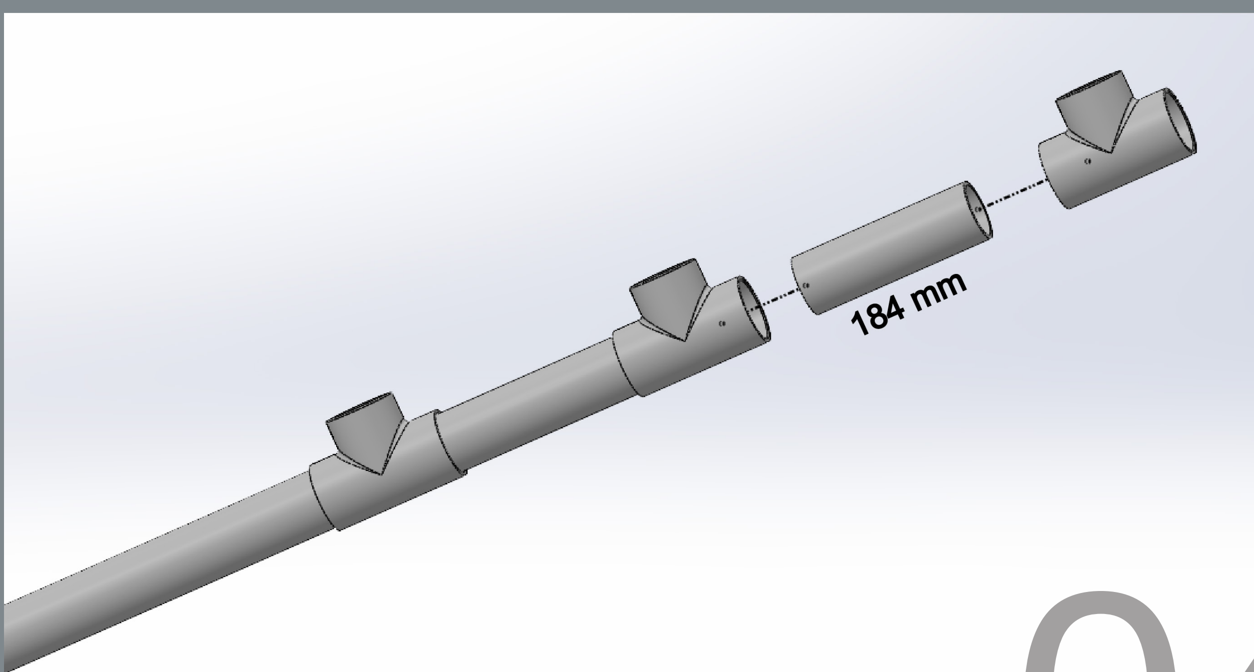


02

SUPPORT FRAME: LEFT LEG ASSEMBLIES

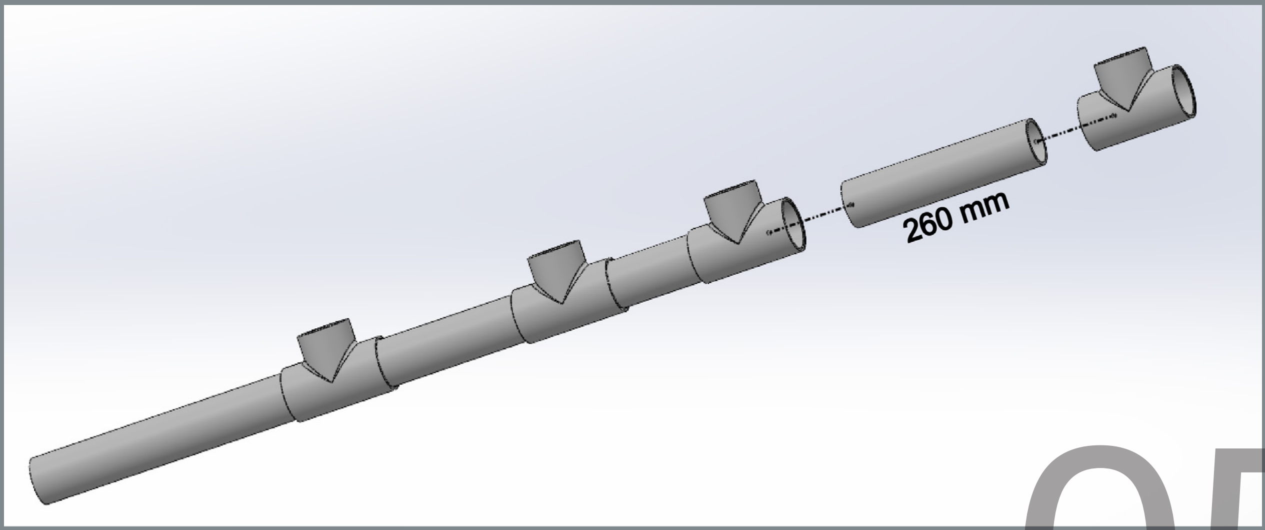


03

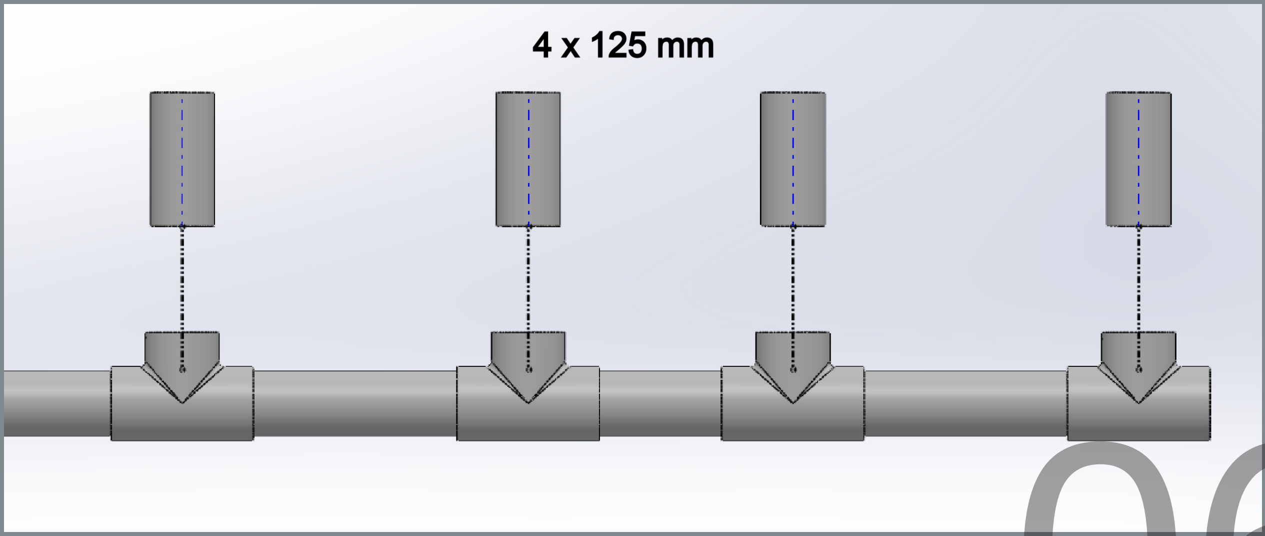


04

SUPPORT FRAME: LEFT LEG ASSEMBLIES

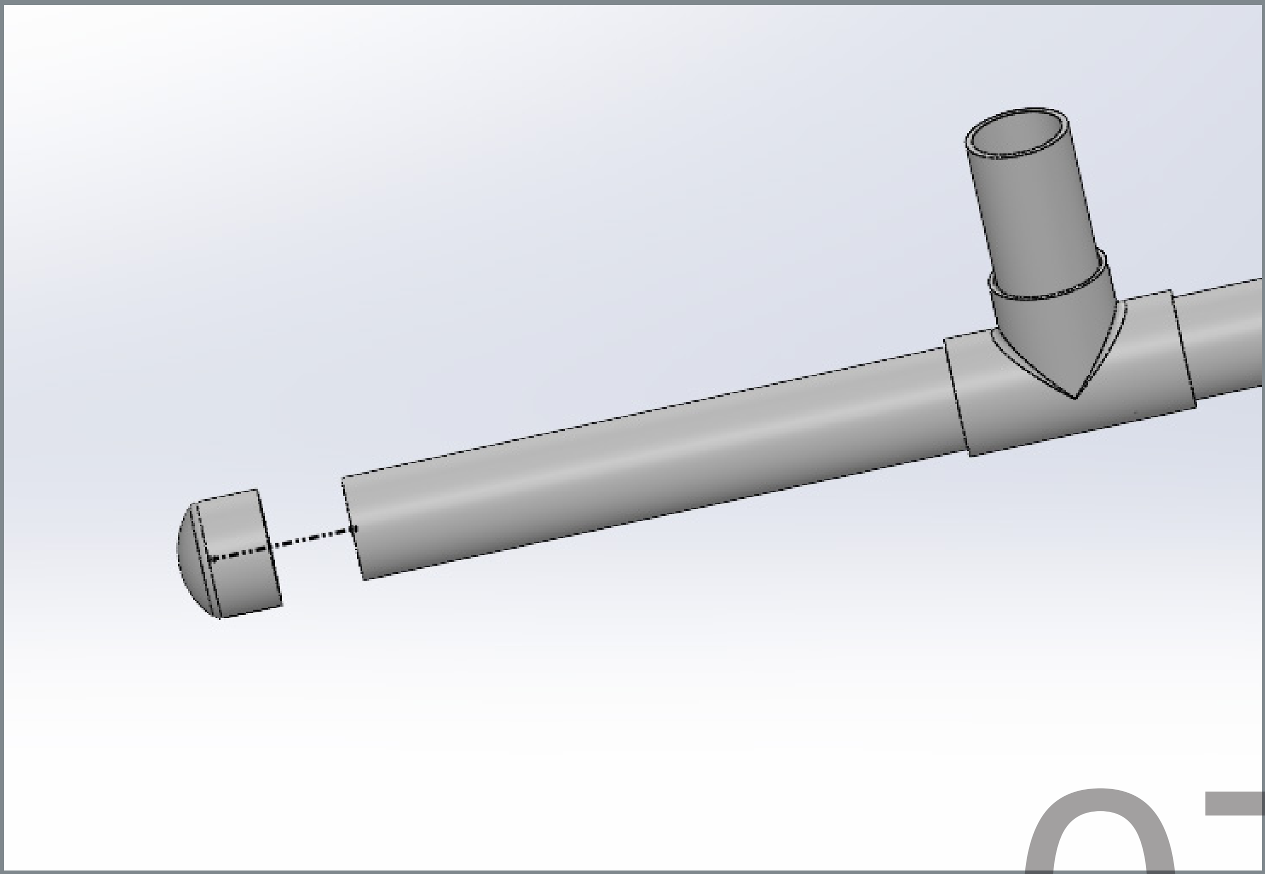


05



06

SUPPORT FRAME: LEFT LEG ASSEMBLIES

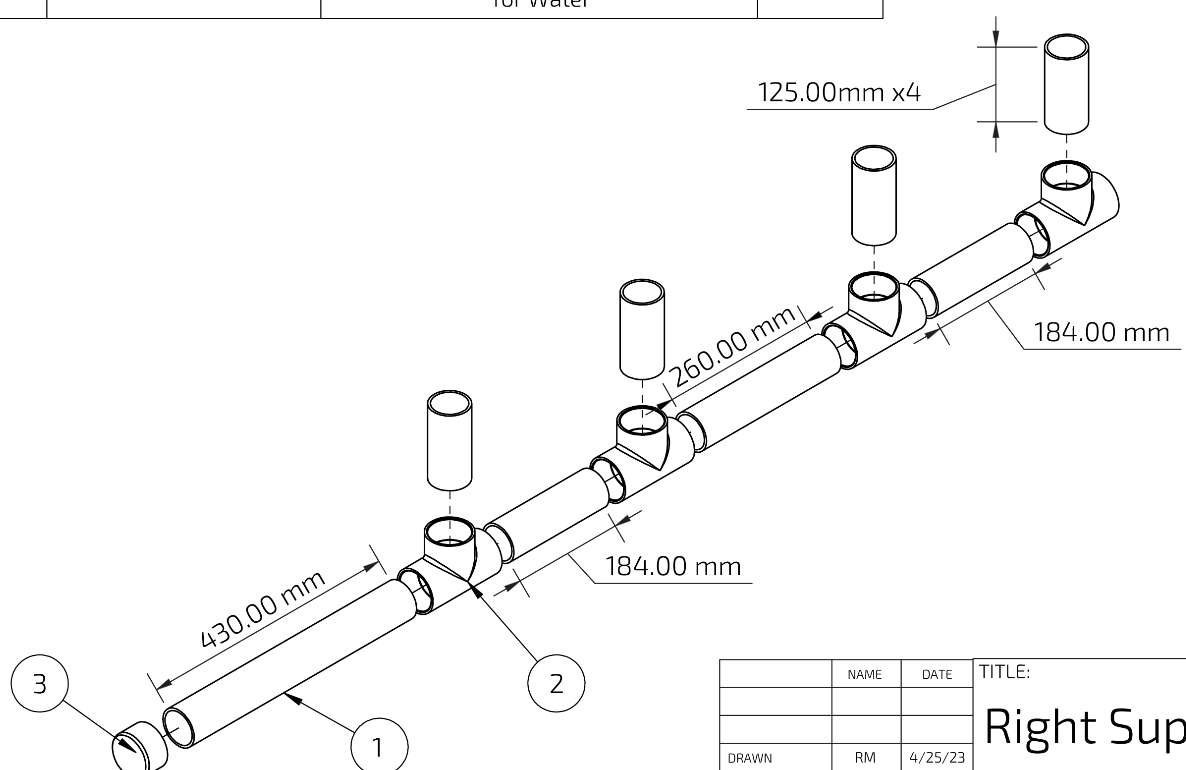


07

Hydroponic System: Right Leg Assemblies

FOLLOW THE BELOW INSTRUCTIONS and diagrams to assemble the right leg structure of the hydroponic system. Note that TWO of these assemblies should be created. We recommend cutting all PVC pipe components to the approximate sizes drawn below. Please remember to use pipe cement to seal all permanent pipe to fitting connections.

ITEM NO.	PART	DESCRIPTION	QTY.
1	32mm Dia PVC	Standard-Wall Unthreaded Rigid PVC Pipe for Water	8
2	32mm Dia T Fitting	Standard-Wall PVC Pipe Fitting for Water	4
3	32mm End Cap	Standard-Wall PVC Pipe Fitting for Water	1



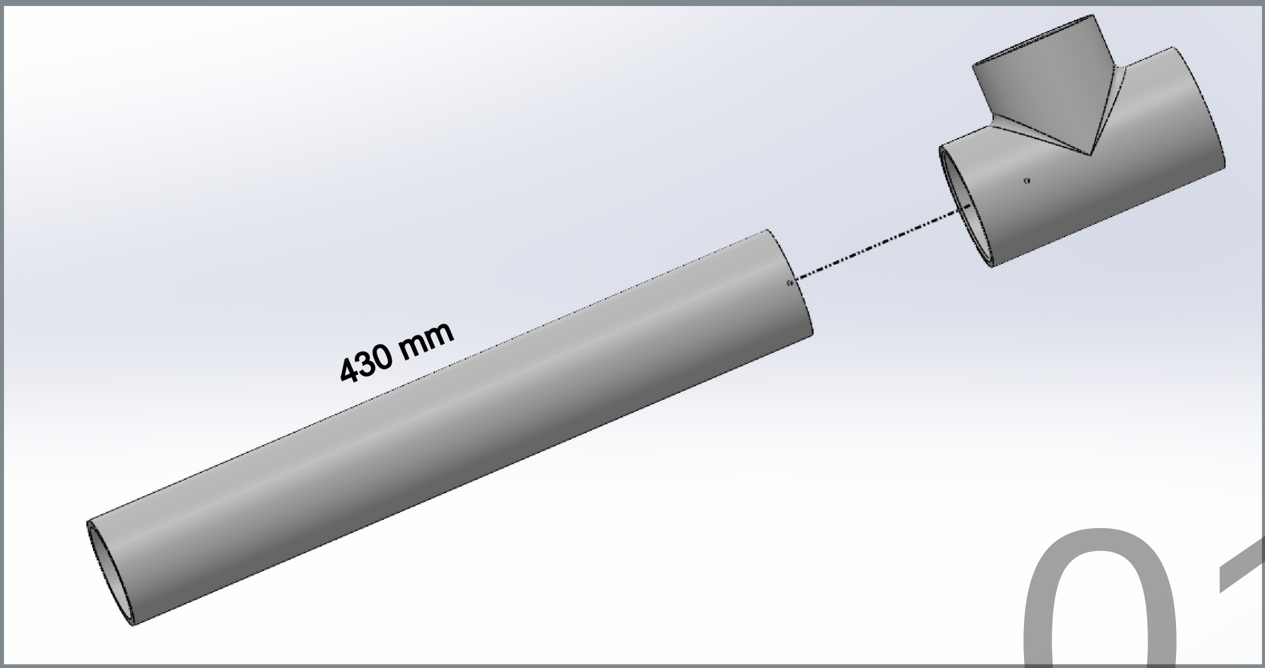
	NAME	DATE
DRAWN	RM	4/25/23
COMMENTS:		

TITLE:

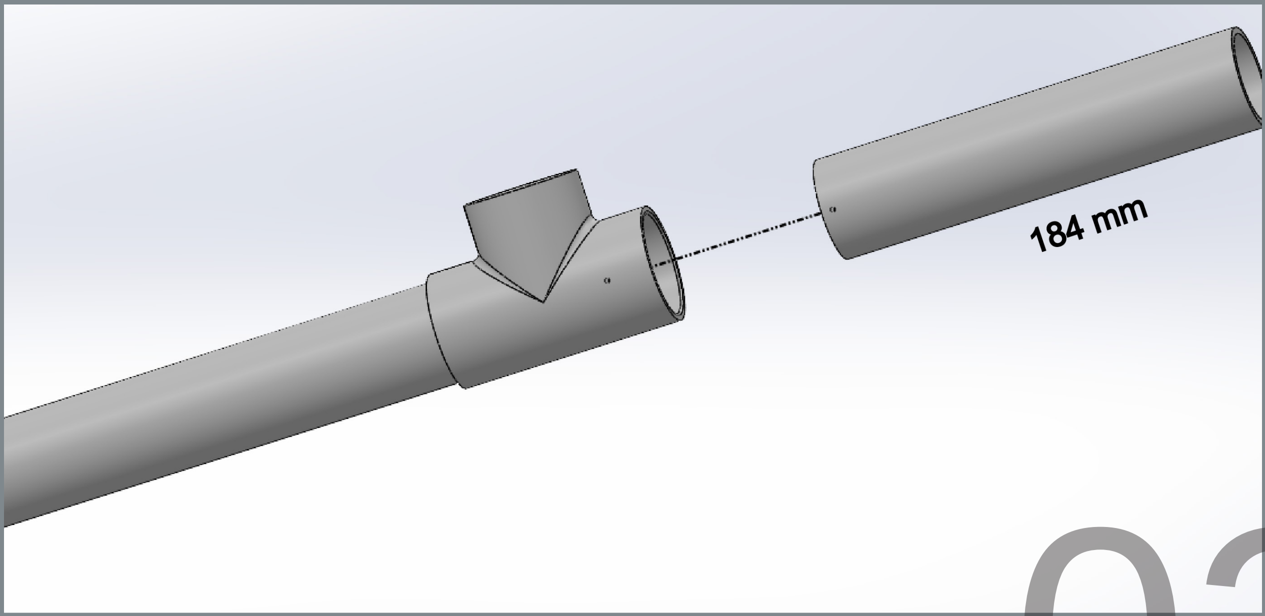
Right Support Leg

SIZE	DWG. NO.	REV
A	2	A
SCALE: 1:8	WEIGHT:	SHEET 1 OF 1

SUPPORT FRAME: RIGHT LEG ASSEMBLIES

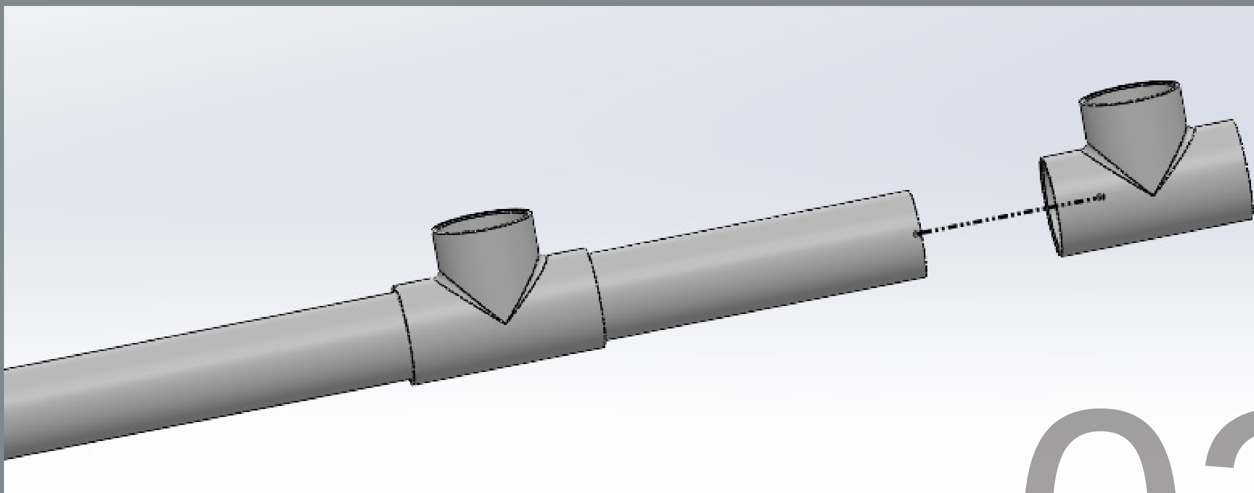


01

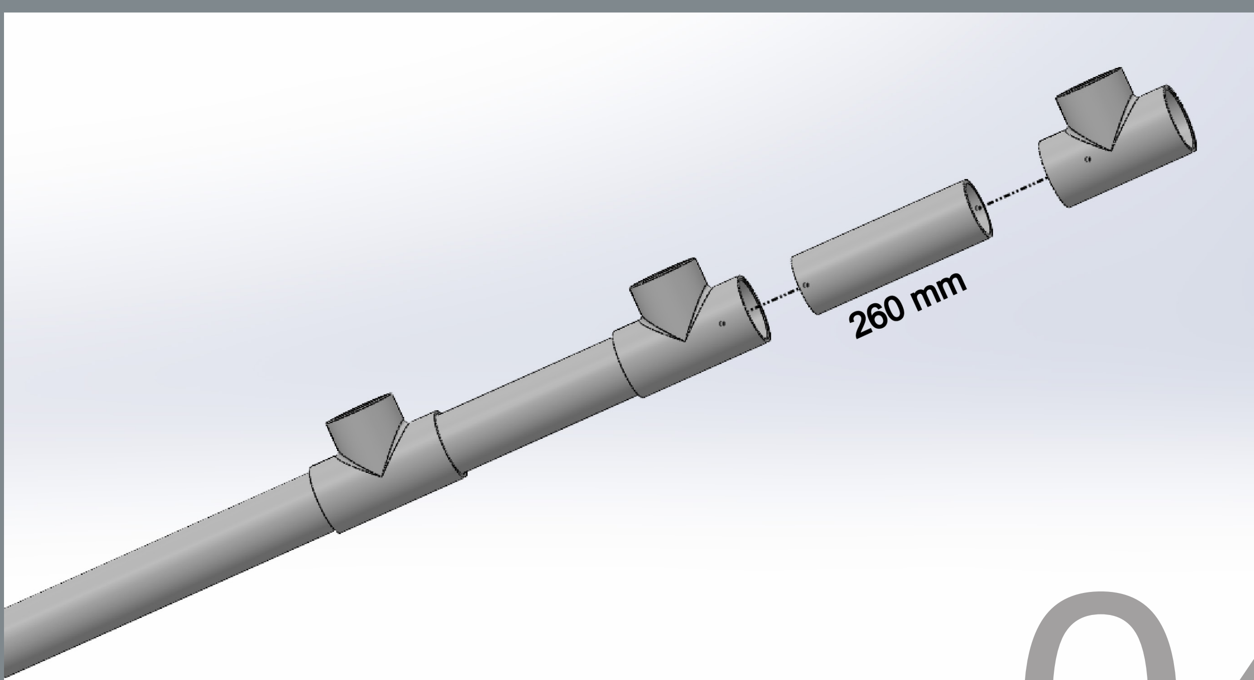


02

SUPPORT FRAME: RIGHT LEG ASSEMBLIES

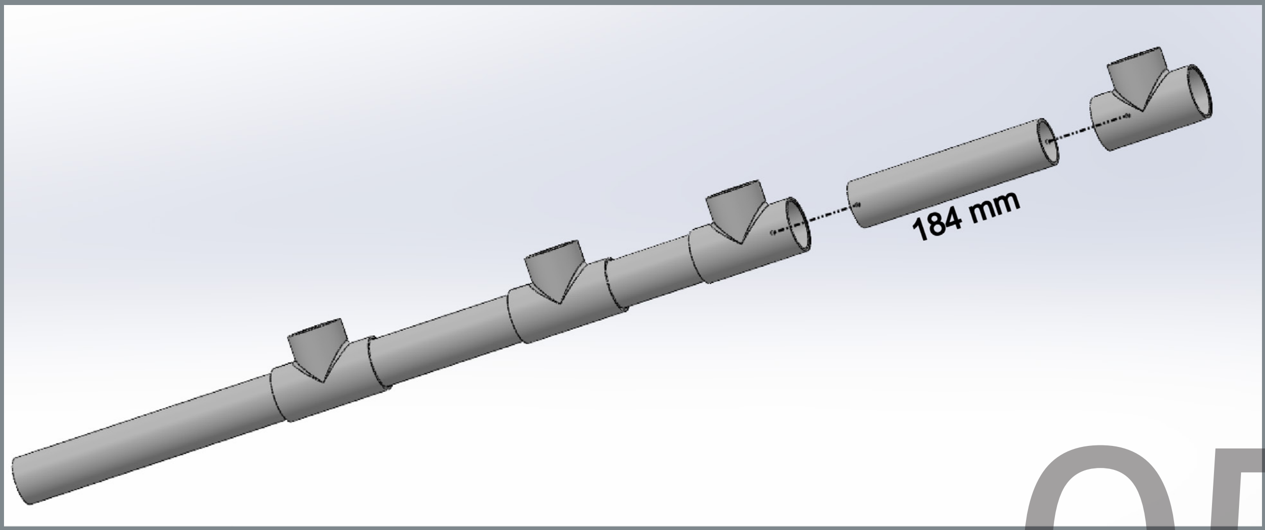


03

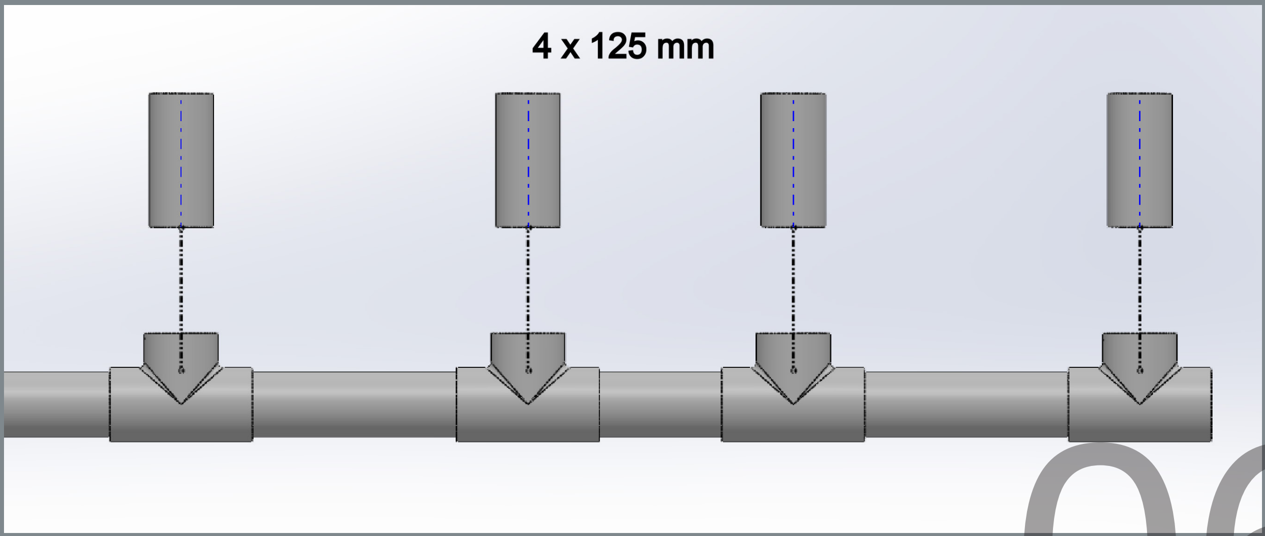


04

SUPPORT FRAME: RIGHT LEG ASSEMBLIES

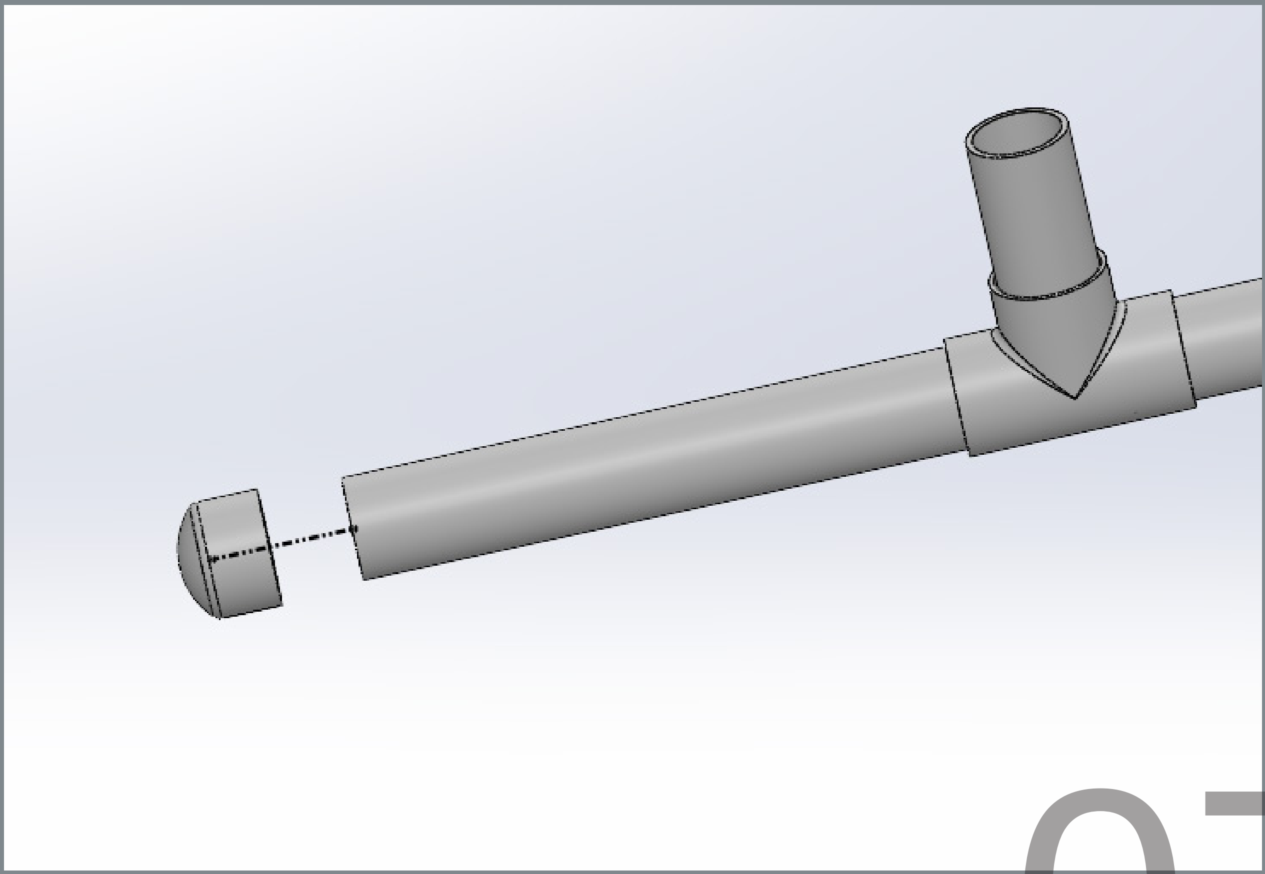


05



06

SUPPORT FRAME: RIGHT LEG ASSEMBLIES

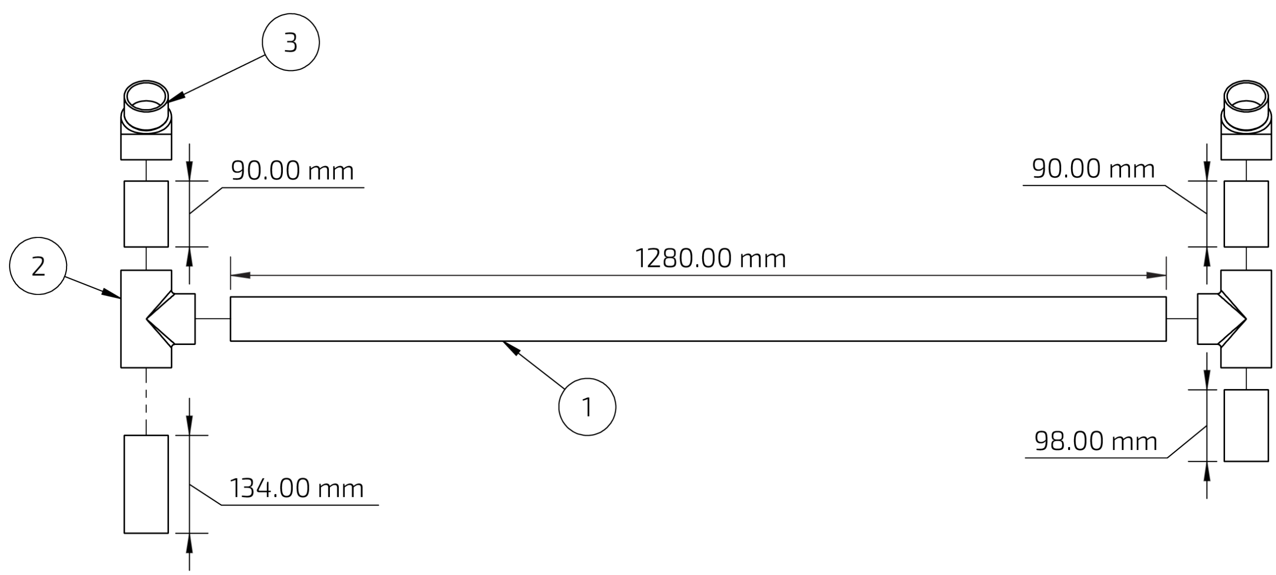


07

Hydroponic System: Top Brace Assembly

FOLLOW THE BELOW INSTRUCTIONS and diagrams to assemble the top brace structure of the hydroponic system. We recommend cutting all PVC pipe components to the approximate sizes drawn below. Please remember to use pipe cement to seal all permanent pipe to fitting connections.

ITEM NO.	PART	DESCRIPTION	QTY.
1	32mm Dia PVC	Standard-Wall Unthreaded Rigid PVC Pipe for Water	5
2	32mm Dia T Fitting	Standard-Wall PVC Pipe Fitting for Water	2
3	32mm Female to Male 45 Degree Fitting	Standard-Wall PVC Pipe Fitting for Water	2



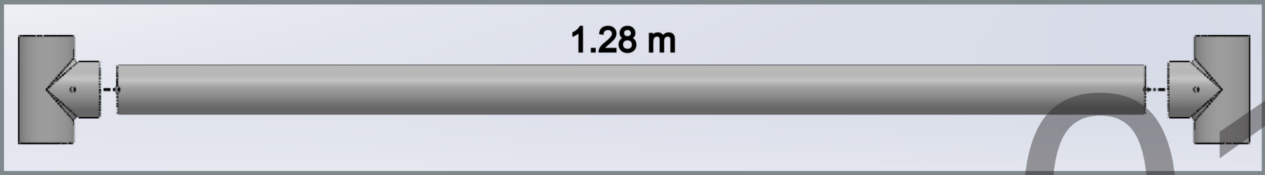
	NAME	DATE
DRAWN	RM	4/25/23
COMMENTS:		

TITLE: Top Brace Assembly

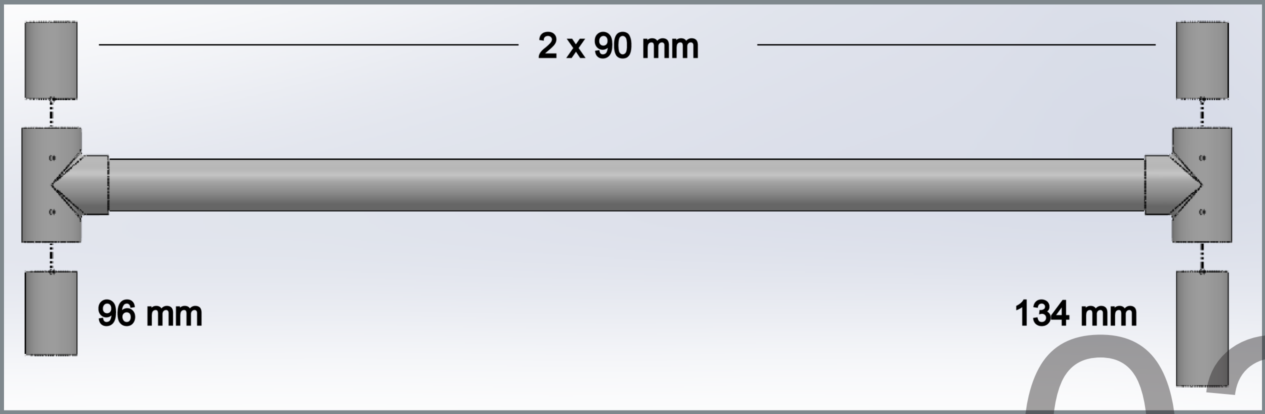
SIZE	DWG. NO.	REV
A	3	A

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

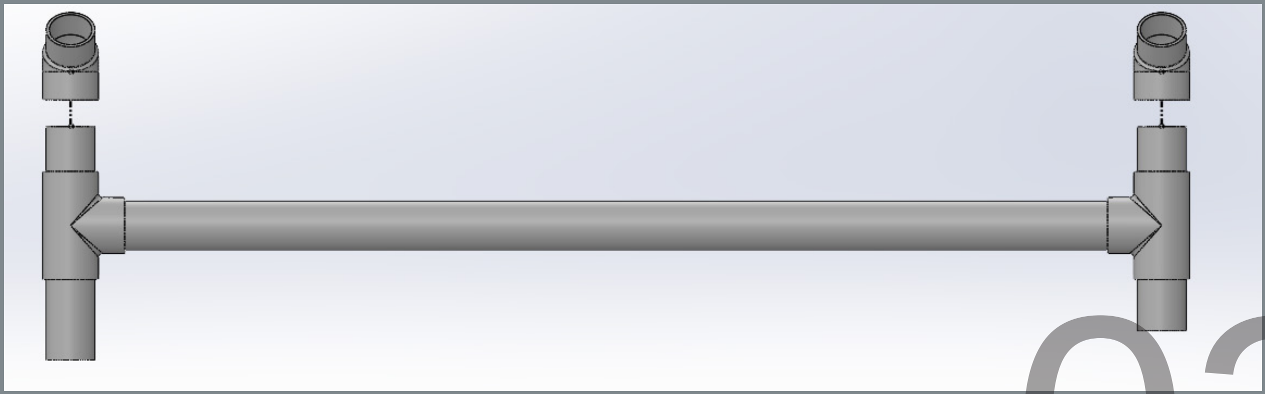
SUPPORT FRAME: TOP BRACE ASSEMBLY



01



02

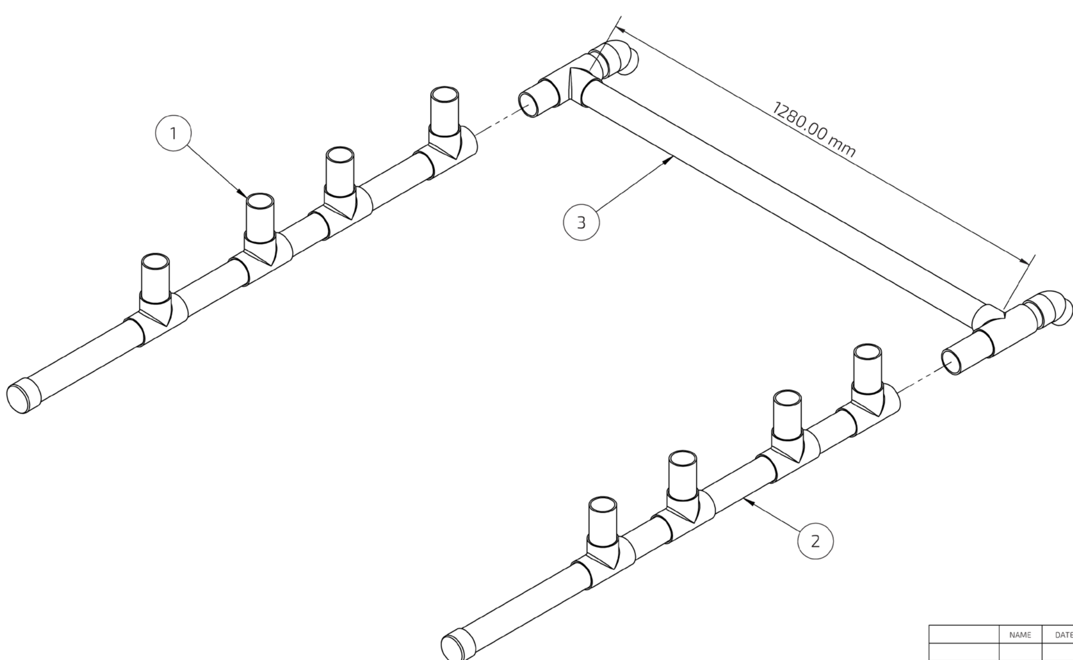


03

Hydroponic System: Half Frame Assembly

FOLLOW THE BELOW INSTRUCTIONS and diagrams to assemble the half frame structure of the hydroponic system. For this, please attach the left leg structure to the 96mm end, and the right leg structure to the 134mm end. Note that TWO of these assemblies must be created. We recommend cutting all PVC pipe components to the approximate sizes drawn below. Please remember to use pipe cement to seal all permanent pipe to fitting connections.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Left Support Leg		1
2	Right Support Leg		1
3	Top support Brace Assembly		1



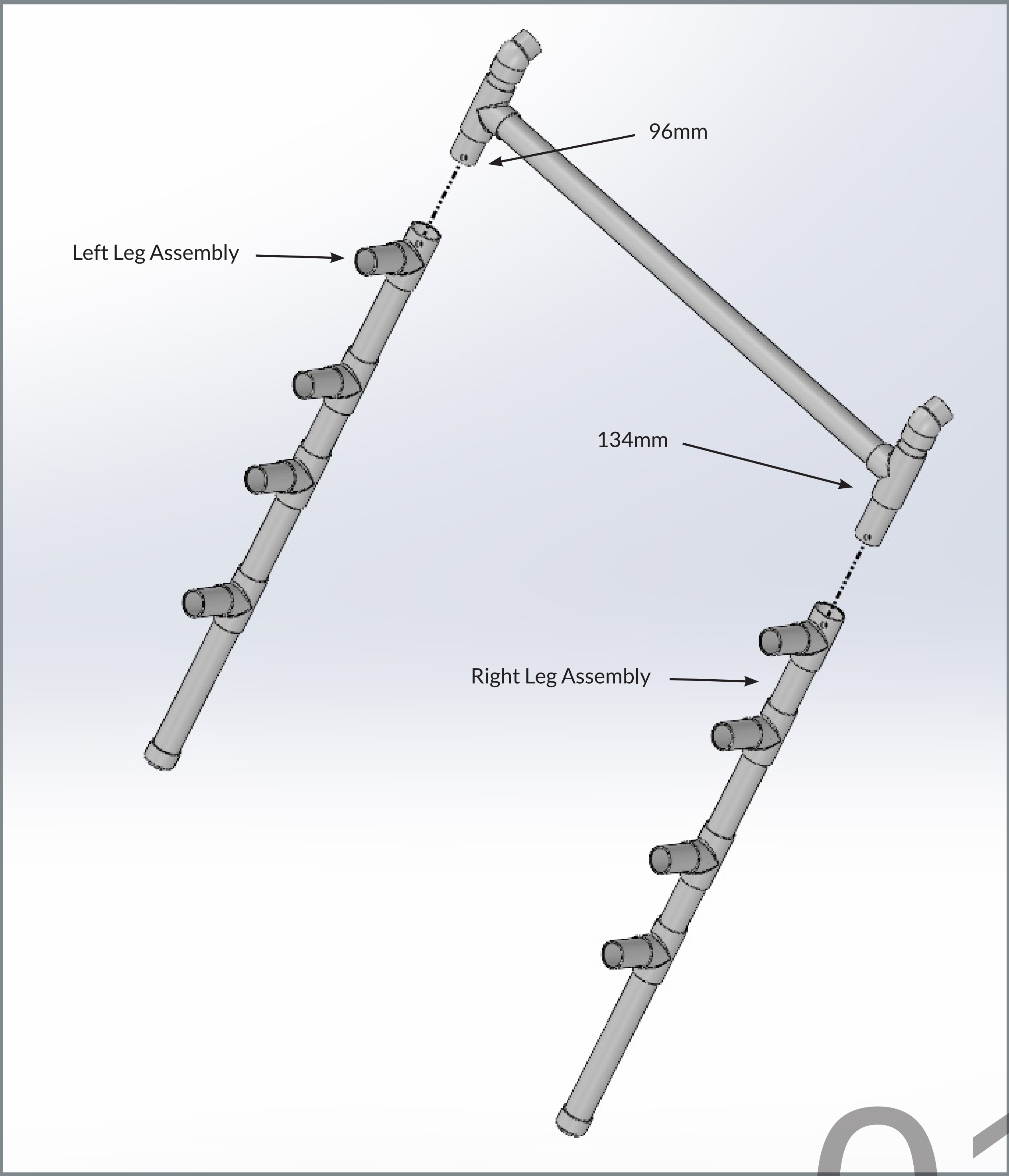
	NAME	DATE
DRAWN	RM	4/25/23
COMMENTS:		

TITLE: Half Frame Assembly

SIZE: B | DWG. NO. 4 | REV A

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

HALF FRAME ASSEMBLIES

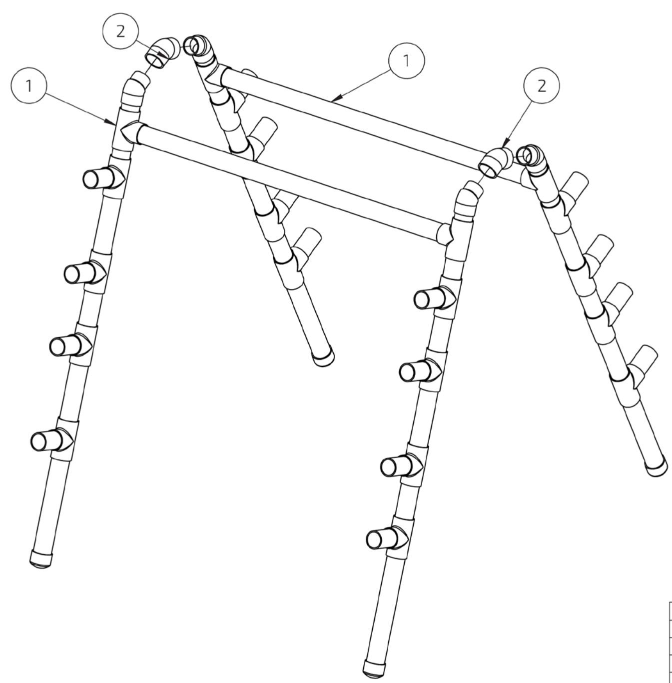


01

Hydroponic System: Full Frame Assembly

FOLLOW THE BELOW INSTRUCTIONS and diagrams to assemble the full frame of the hydroponic system's structure. We recommend cutting all PVC pipe components to the approximate sizes drawn below. Please remember to use pipe cement to seal all permanent pipe to fitting connections.

ITEM NO.	PART	DESCRIPTION	QTY.
1	Half-Frame Assembly		2
2	32mm DIA 45 Degree Fitting	Standard-Wall PVC Pipe Fitting for Water	2



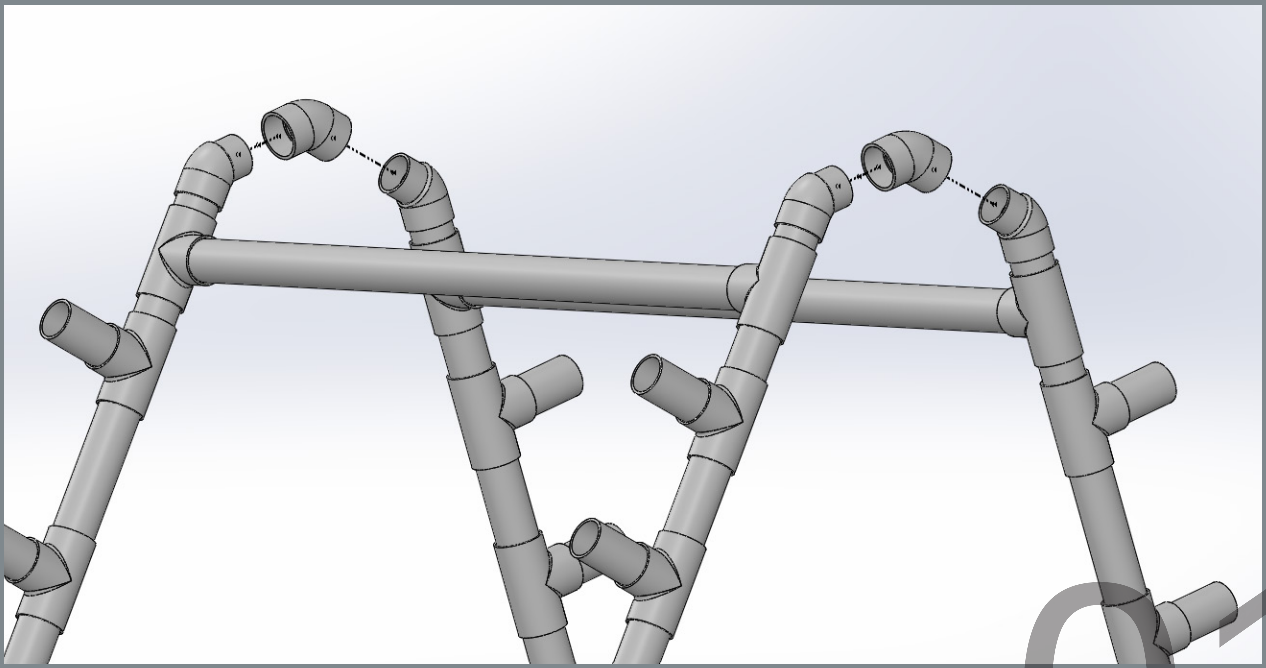
	NAME	DATE
DRAWN	RM	4/25/23
COMMENTS:		

TITLE: Freestanding Frame

SIZE B | DWG. NO. 5 | REV A

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1

FULL FRAME ASSEMBLY

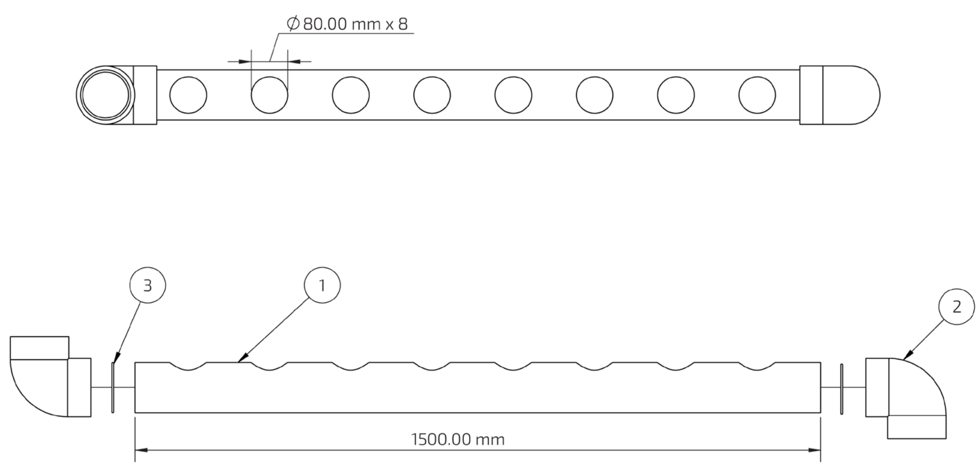


01

Hydroponic System: Growing Channel

FOLLOW THE BELOW INSTRUCTIONS and diagrams to assemble the growing channels of the hydroponic system's structure. We recommend cutting all PVC pipe components to the approximate sizes drawn below. Note that SIX of these assemblies need to be created. Additionally, two more channels must be made that will have one 90 degree fitting and a reducer pump fitting. This combines for a total of EIGHT growing channels. Please remember to use rubber gaskets to impermanently seal pipe to fitting connections.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	110mm DIA PVC	Standard-Wall Unthreaded Rigid PVC Pipe for Water	1
2	110mm DIA PVC 90 Degree Fitting	Standard-Wall PVC Pipe Fitting for Water	2
3	Rubber Gasket	Oil-Resistant Buna-N O-Ring	2



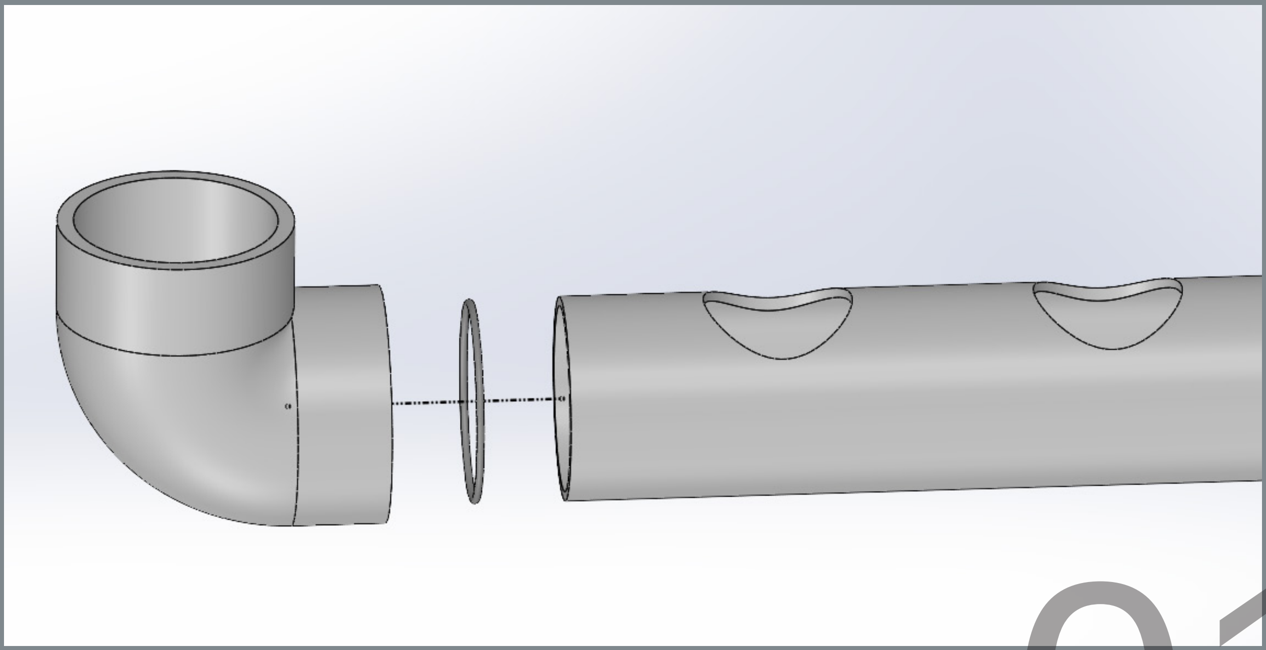
	NAME	DATE
DRAWN	RM	4/25/23
COMMENTS:		

TITLE: Growing Channel

SIZE: B | DWG. NO. 6 | REV A

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

GROWING CHANNEL ASSEMBLIES

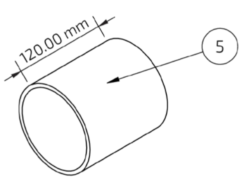


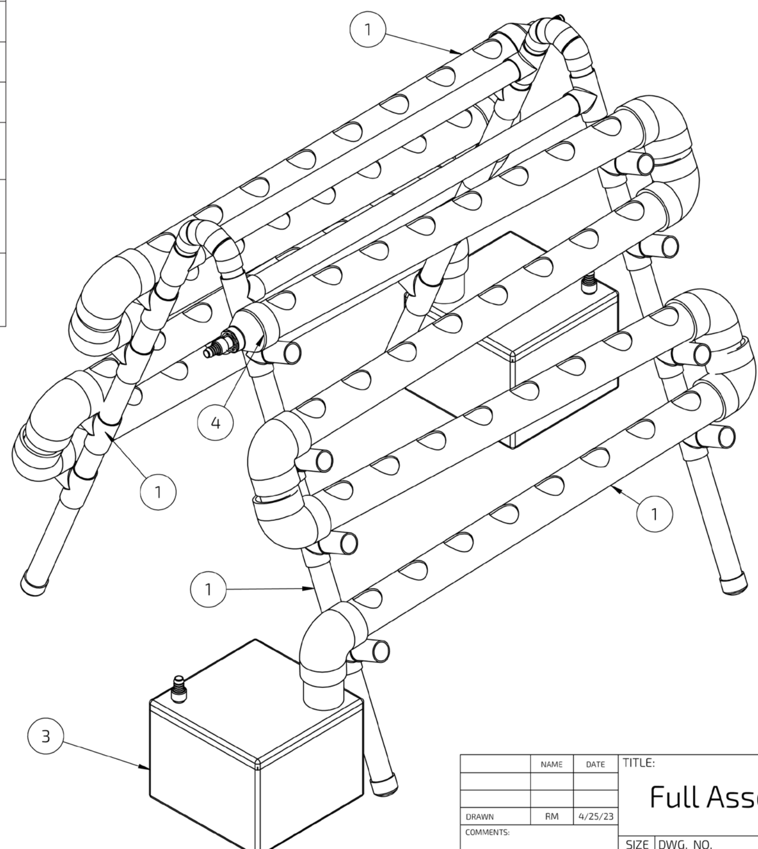
01

Hydroponic System: Complete Assembly

FOLLOW THE BELOW INSTRUCTIONS to complete the assembly of the hydroponic system. With all of the growing channel components connected and installed, they should rest firmly on the finished structure. Add zip ties where needed to better secure the growing channels to the frame structure. After all of the pipe cement has dried, we recommend checking the entire assembly for structural stability before use.

ITEM NO.	PART	DESCRIPTION	QTY.
1	Free-Standing Frame		1
2	Growing Chamber		8
3	Water Tank		2
4	Reducing Adapter for water pump		2
5	110 mm DIA PVC	Connection pipe between Growing Chamber levels	6
6	Rubber Gasket	Not Shown	6





	NAME	DATE
DRAWN	RM	4/25/23
COMMENTS:		

TITLE: Full Assembly

SIZE B | DWG. NO. 7 | REV A

SCALE: 1:10 | WEIGHT: | SHEET 1 OF 1

Next Steps After Assembly

WITH THE ASSEMBLY COMPLETE, you are ready to start planting! The upcoming sections provide insight into how you can make the most of your hydroponic system. We will be reviewing everything from general crop cycling, to growing conditions, crop selection, and more. Additionally, we encourage users to learn more about our greenhouse to complete their growing ecosystem.

FROM SEED TO SPROUT: CHOOSING, PREPARING, FAND GROWING THE PLANTS FOR USE IN THE SYSTEM

CROP CYCLING

As our hydroponics operation is designed to be in an indoor greenhouse, our plants will be in a mostly temperature and climate controlled environment. However, as there will not be an HVAC system in our design, the temperature could still fluctuate depending on the season in Israel. For this reason, we suggest a technique called crop cycling. In this technique, different crops are chosen and cycled, or changed, throughout the year depending on the climate at that time. For instance, plants that are not as sensitive to high heat and low humidity should be chosen for a climate like Israel's in the summer. Plants that are more resistant to cold weather and do well in moderate humidity levels should be chosen for winter months.

When choosing what crops you want to grow, you should take into consideration the average high and low temperatures of your region, along with how long those plants will take to reach harvest time. You should also factor in the average humidity in your region as the seasons change. We have chosen two crops below that would work well in a desert climate. Feel free to substitute what crops as needed for your own region you are growing in.

CUCUMBERS FOR WARM WEATHER MONTHS [15]

Cucumbers grown hydroponically do best in high temperatures, between 75 Fahrenheit (24 Celsius) to 85 Fahrenheit (29 Celsius). This makes them an ideal crop for summer months in Israel.

Another attractive feature of cucumbers as a hydroponic crop is that they grow best in high light conditions. On a rooftop garden in an environment that is frequently sunny, cucumbers would be an excellent choice.

LETTUCE FOR COOL WEATHER MONTHS

One of the best cool weather crops to begin your hydroponic journey with is lettuce. Lettuce is a popular choice for most home growers using an NFT system, and has plenty of information available on its cultivation. Additionally, there is a high demand for lettuce in the restaurant and home chef industry[16]. For this reason, lettuce presents an economical crop, as you could potentially sell any extra lettuce heads you have to restaurants, or at the farmer's market. Lettuce is also eaten in a variety of global cultures, and can be palatable to almost anyone.

Lettuce seeds for hydroponic systems are easy to find online and purchase for a low cost[17]. Butterhead lettuce seeds range from $5-$9 for packs of 1000 seeds on Amazon in the United States, while romaine lettuce seeds for packs of 3000 go for $5-$7 in the United States Amazon. At Walmarts in the United States, a head of romaine lettuce[18] can go for $1.88, while a head of butterhead lettuce[19] can go for $2.98. If you grow 1000 heads of butterhead lettuce that you bought as seeds for $5 in our hydroponic system, and sold them for $1 each, you could make a 99.5% profit, excluding overhead costs. As the pricing of seeds may vary by country, we encourage you to choose plants that are best suited for your needs.

GERMINATION PROCESS AND PREPARING SPROUTS FOR PUTTING IN TO NFT SYSTEM

Germination [20]

In a hydroponic system, crops are ideally started from a seed germinated without any use of soil. Alternate growing materials commonly used are rockwool, coco peat, and coco coir. We suggest rockwool plugs, as these are pH neutral. However, as they are a silica material, caution must be taken when handling. Be careful not to breathe in fibers when germinating your seeds, and wear gloves.

Once you have sourced the rockwool plugs, they should be placed into a large plastic tray that has been filled with pH neutral, clean water. The plugs should be left for as much time as it takes for them to become moist and absorb all of the water. If they still feel dry, more water should be added. Once sufficiently soaked, the rockwool plugs should be moved into a dry, clean plastic tray.

From there, holes should be poked into the rockwool with the back of a wooden spoon to a depth of 6mm. 2-3 seeds of your choice should be placed into the holes at this point, then covered with a small piece of rockwool. The tray should then be covered with the plastic dome to retain moisture. These should be left for approximately 72 hours, or whenever shoots start emerging from the seeds.

After shoots have emerged from the seeds, the largest and healthiest looking sprout should be chosen from its respective hole. The unhealthy shoots can be discarded. There should be one shoot per rockwool hole. From here on, the plants should be exposed to sunlight in the greenhouse for two to three weeks. At the end of each day, the plants' roots should be checked for growth. Once the roots are growing out of the bottom of the rockwool cube, the plants can be transplanted into the growing unit system.

Placing Into Net Cups [21]

The plant contained in its original rockwool plug can be transported directly into a net cup. The net cup should then be placed into an available growing hole in the hydroponics growing system. Choose a net cup size that is suitable for your rockwool plug and plant size. If you think your plant needs to be in a larger net cup, then fill the excess space around the plug with expanded clay pebbles to keep the plant stabilized.

DETERMINING THE IDEAL ENVIRONMENTAL CONDITIONS FOR CROPS

pH [24]

The ideal pH range for plants in a hydroponics system sits around neutral (between 6.5-7.5 on the pH scale). This pH range can be measured with a pH probe. If the pH dips below 6.5, the water is becoming too acidic. This could be due to inherent acidity of the water source you are using, or because the plants are excreting acidic wastes[22] into the water that build up over time. If the pH starts to rise above 7.5, the water is becoming too basic. This is usually due to added nutrients like vitamins slowly being leached from the water by the roots of the plants[23].

pH can be adjusted with pH up or pH down solutions, which are specifically formulated for hydroponic systems. These solutions can usually be purchased online. You could also make the water more acidic when necessary by adding natural substances like lemon juice, citric acid, or vinegar. To make the water more basic, you can also use baking soda dissolved in the water.

Temperature [25]

The ideal air temperature range for hydroponic plants is between 18 to 26 degrees Celsius. The temperature can be altered through space heaters to make it warmer. Windows can also be opened in the greenhouse if the temperature becomes too high.

The ideal water temperature for a hydroponics operation is the same as the ideal air temperature. Water temperature can be controlled by painting all pipes and reservoirs white, in order to reflect sunlight. Heating pads can also be applied to raise the temperature of the water.

Humidity [26]

The ideal relative air humidity to begin growth is between 60 to 70%. As the plants grow bigger, and begin to flower, we suggest reducing humidity. By reducing humidity, the flowers are less likely to rot. As the plants grow, a humidity level of 40 to 60% is best.

Sunlight Exposure & Wind

It is best for most plants grown in a hydroponic setting to have eight hours of full sunlight per day. Plants ideally need some wind or air flow to grow properly and become strong. However, excessive winds will damage plants and their ability to grow to fruition. Our greenhouse design protects plants through the use of polycarbonate sheets, which will help to reduce direct wind gusts. Plants that need the most sunlight should be on the top rows of the hydroponics system, while plants that prefer shade should be on the bottom rows.

Nutrient Availability

The ideal nutrient solutions to use will change slightly with plant type. Please see the extensive section below (Nutrient Solutions and Necessary Chemicals) for a comprehensive guide to this sometimes complicated aspect of hydroponic farming.

Suggested Crops & Growing Conditions

WE SUGGEST USING THE TABLE BELOW to decide which crops are most ideal to use within your system. Depending on the sophistication of your project, you may consider choosing the best crop for your operation based on the provided growing conditions.

Suggested Crops and Growing Conditions Table

Crop Variety	Ideal pH [1] Level	Daily Light (Hours)	Ideal EC Level (mS/cm)	Ideal Air Temperature for Growth (°C)	Time to Harvest (Weeks)	Number of Harvests (Per Plant)
Lettuce [2, 3]	5.5-6	10-14	1.2-1.8	15-18	4	Single (head) or multiple (leaves)
Mint [4, 5]	6-7	14-16	2.2-2.6	18-21	13	Multiple (leaves)
Cucumber [6, 7]	5-5.5	12-14	1.7-2.0	23-29	6	Multiple (fruit)
Basil [8, 9]	5.5-6	16	1.0-1.6	18-21	4	Multiple (leaves)
Fennel [10] (Florence)	6.4-6.8	10-12	1.0-1.4	15-18	6-8	Single (bulb)
Strawberries [11]	6	14-16	1.0-1.4	18-21	8-12	Multiple (fruit)
Tomatoes [12, 13]	6-6.5	10-18 (varies)	2.0-2.4	21-26	14	Multiple (fruit)
Chives [14, 15]	6-6.5	14-18	2.0-2.4	18-21	8	Multiple (stalks)
Radish [16, 17]	6-7	8-10	1.8-2.0	10-18	7	Once (bulb)
Spinach [18]	6-7	12	1.8-2.3	15-18	7-8	Once (leaves)

NUTRIENT SOLUTIONS AND NECESSARY CHEMICALS

Necessary Nutrients [27]

The nutrients plants need depends upon their growing stage. Plants accumulate most of their nutrients during the flowering and ripening stage. After the plant has come to full fruition, adding more fertilizer is not recommended.

Nutrient solutions for growing crops hydroponically are formulated with three components in mind. Firstly, plants require primary macronutrients. The primary macronutrients consist of nitrogen, phosphorus, and potassium. Plants also require secondary macronutrients. These consist of magnesium, sulfur, and calcium. Finally, plants require a smaller quantity of micronutrients. These are boron, chlorine, manganese, iron, nickel, copper, zinc and molybdenum. These macro- and micronutrients come as chemical compounds, generally in the form of salts. For example, nitrogen comes as nitrate salt, which is then dissolved into the water.

You can either buy the different components separately and mix your own solution, or buy pre-made hydroponic nutrient solutions. It may be more economical to buy pre-made solutions, as nutrients like molybdenum can be expensive. In either case, we recommend using a liquid solution, as this will be easier to add to the water. In order to get a broad reading on the concentration of nutrients in the water, you can use an electrical conductivity or nutrient probe. If the water is too concentrated, plants will become dehydrated as the water inside of them flows back into the reservoirs through osmosis[28]. Conversely, if the water has no nutrients, it will drain any vitamins and minerals in the plants back into the water.

The exact nutrients needed differ on the type of plant you are growing. You must research the nutrient needs of each plant type specifically to ensure they will grow at peak capacity.

It appears most economical to buy pre-made solutions, as some of these chemicals are only available in bulk and are quite expensive (for example, molybdenum).

Water Quality *[29, 30]*

In order to preserve the cleanliness and quality of your produce, water quality is important. If the water you are using is contaminated with wastes or harmful chemicals, these will leach into the plants that you are growing. The contaminated produce could harm someone who eats it. Likewise, having unnecessary chemicals in the water or nutrients in varying quantities can affect plant growth and production. For these reasons, we suggest that you start with either rainwater or distilled water in your tanks. From there, add your nutrient solutions in the necessary calculated amounts. This is the best way to ensure your water is clean and free from contaminating components.

Alternatively, if you only have access to tap water, you should first use water testing strips to determine what quantities of chemicals already exist in the water. Certain chemicals used to purify drinking water can be harmful in large enough quantities to plants, such as bleach or chlorine. Water testing strips are easily purchased online from hydroponic stores or from hardware stores. You could also purchase an electrical conductivity or nutrient probe, although these are more expensive than testing strips.

If only pond, well, stream, or lake water is available to you, you must first purify this water. Fresh water from natural sources contains potentially pathogenic bacteria and other microorganisms. For instance, E. coli is a type of bacteria that can cause serious health issues to humans if ingested. E. coli is often found in freshwater ponds and wells[29]. In order to purify your water, we suggest you use hydrogen peroxide or chlorine. With either of these methods, you should use the suggested amount of either chemical per volume of water on their respective labels.

HARVESTING PRODUCE

Depending on what crops you choose to grow, you may harvest them in different methods. Some plants can be harvested many times, such as cucumbers or tomatoes. In these cases, pick the produce off of the plant and keep the rest of the plant within the hydroponic system as it will continue to produce more fruit or vegetables. For other vegetables like lettuce, the entire plant will be picked when it reaches maturity, and the roots removed.

System Maintenance

In this section we discuss how to upkeep and maintain the hydroponic-greenhouse system. Within this section it is assumed our design was fully recreated without deviation however, the information is still generalized.

DISASSEMBLY [11]

Throughout the hydroponic system, leaks, clogs and algae may form. When this occurs, the system must be disassembled for either repairs or replacement. The first step in disassembly is to shut the water pump off and flush out the system. When this is finished, the growing channels may be removed from the frame. If zip ties or other fasteners were used, these connections will need to be severed. After the growing channels are detached, the U-PVC fittings may be separated from the U-PVC piping. From this point any clogs or problems should be accessible. When reassembling the system follow the instructions within the handbook again.

Cleaners such as hydrogen peroxide or bleach may be used to kill the algae growth however, these chemicals may harm the crops as well. If the use of these chemicals are desired, the disassembled hydroponic system should first be fully removed from the greenhouse. The crops should then be removed from the growing channels and stored in a safe environment. After the hydroponic system is cleaned with the chemicals, the growing channels should then be washed with clean water. This ensures that no lingering chemicals can damage the crops when they are moved back into the hydroponic system.

ROOT HEALTH [7]

The two major issues that threaten root health within an NFT system are root rot and overgrown roots. Root rot is often caused by lack of oxygen to a plant, in hydroponics this a sign of overwatering. If the nutrient solution level is too high within the growing channels, there will not be enough oxygen for the plants to absorb. The treatment for root rot depends on how early it is noticed. If noticed before the root rot fully sets, this most likely means that the flow rate of your water pump is too high and needs to be decreased. If this is not a possibility for your system, an aerator should be added into the nutrient solution tank. An aerator will ensure the crops receive more oxygen, however an aerator is not a complete solution. Even with the crops receiving more oxygen, too much nutrient solution within the growing channels will still hurt the crops. However, in more extreme cases you may have to remove the crops from your system. Any crops that have fully set root rot need to be discarded, the rest washed with clean water. Be sure to gently, yet completely wash all the roots of the crops. Before placing the crops back into the system, soak the root bed in a sterilizing agent. The addition of root builders and microbial inoculants to the agent will support strong root growth, and help prevent root rot in the future.

For overgrown roots, the roots simply need to be trimmed. Remove any overgrown crops from the growing channels, and using clippers, trim the roots down. This should be done conservatively as removing too much may damage or kill the crops. When the roots are trimmed, be sure to wash them with clean water, as to not contaminate the other crops when placed back into the growing channels.

References

1. Instructables. (2017). PVC Hydroponics Unit. Instructables. https://www.instructables.com/PVC-Hydroponics-Unit/
2. Jagdish. (2023, January 26). How to Build a Hydroponic Unit with PVC Pipes: DIY in Simple Steps. Agri Farming. https://www.agrifarming.in/how-to-build-a-hydroponic-unit-with-pvc-pipes-diy-in-simple-steps#:~:text=The%20ultimate%20result%20should%20be%20a%203%201%2F2,reserv
3. Polyvinyl Chloride - Chemical Safety Facts. (2022, October 14). Chemical Safety Facts. https://www.chemicalsafetyfacts.org/chemicals/polyvinyl-chloride/
4. Polyvinyl Chloride (PVC) Plastic: Uses, Properties, Benefits & Toxicity. (n.d.). https://omnexus.specialchem.com/selection-guide/polyvinyl-chloride-pvc-plastic
5. PVC and Organic Gardening: Is PVC Safe to Use? (2022, October 5). Accessible Gardens. https://accessiblegardens.org/pvc-and-organic-gardening-is-pvc-safe-to-use/
6. Denisa. (2023). Best Hydroponic Growing Medium for Hydroponic Systems. PonicsArea. https://ponicsarea.com/best-hydroponic-growing-medium/#:~:text=10%20Best%20Hydroponic%20Growing%20Media%20Compared%201%201.,material%20that%20has%20no%20negative%20environmental%20impact.%20
7. Jamie. (2022, February 10). NFT Hydroponics: Basics, Setup, Pros/Cons, FAQ. WhyFarmIt. https://whyfarmit.com/nft-hydroponics/
8. Admin. (2020). How Hygrometers Work. Hygrometer.net. https://hygrometer.net/hygrometers-work/
9. The Editors of Encyclopaedia Britannica. (1998, July 20). Psychrometer | instrument. Encyclopedia Britannica. https://www.britannica.com/technology/psychrometer
10. Sohail, U. (2017). This Incredible Rooftop Farm In Israel Grows Thousands Of Organic Vegetables Throughout The Year. Wonderful Engineering. https://wonderfulengineering.com/this-incredible-rooftop-farm-in-israel-grows-thousands-of-organic-vegetables-throughout-the-year/
11. Greenhouse Building Materials: Should I Choose Glass, Polycarbonate, or Poly Film? (2022, February 25). Dengarden. https://dengarden.com/landscaping/greenhouse-glass-guide
12. Polycarbonate (PC) - Properties, Uses, & Structure - Guide. (n.d.). https://omnexus.specialchem.com/selection-guide/polycarbonate-pc-plastic
13. Tammy. (2018, September 3). Double Polyfilm Greenhouse - Grow Your Own Food Anywhere. Grow Your Own Food Anywhere. https://www.blog.advancegreenhouses.com/double-polyfilm-greenhouse/#:~:text=Double%20polyfilm%20greenhouses%20consist%20of%202%20layers%20of,you%20up%20to%2040%25%20of%20your%20energy%20costs.
14. Team, C. (2020, July 15). How To Pick A Tarp For Your Greenhouse DIY Project. CanvasandCanopy.com. https://canvasandcanopy.com/greenhouse-tarp/
15. Rusnak, P. (2019, November 14). Everything You Need to Know About Hydroponic Cucumber Production - Greenhouse Grower. Greenhouse Grower. https://www.greenhousegrower.com/production/everything-you-need-to-know-about-hydroponic-cucumber-production/
16. Market Minute: Record high lettuce market as demand exceeds supply | Produce News. (n.d.). https://theproducenews.com/headlines/market-minute-record-high-lettuce-market-demand-exceeds-supply

17. Dupuis, A., & Technology, E. G. (2023). Hydroponic Lettuce: Everything You Need to Know | Eden Green. Eden Green. https://www.edengreen.com/blog-collection/hydroponic-butterhead-lettuce
18. Romaine Lettuce. (n.d.). walmart.com. https://www.walmart.com/c/kp/romaine-lettuce
19. Butterhead Lettuce. (n.d.). walmart.com. https://www.walmart.com/ip/Butter-Lettuce/44391110
20. Stephens, O. (2022). How To Germinate Seeds For Hydroponics: Step-By-Step. The Hydroponics Planet. https://thehydroponicsplanet.com/how-to-germinate-seeds-for-hydroponics-step-by-step/
21. Valencia, J. (2023, March 20). How to Choose the Best Net Pots for your Hydroponics System. The Greenery. https://www.greeneryretail.com/post/how-to-choose-the-best-net-pots-for-your-hydroponics-system
22. Why Does Soil pH Change? | Soils - Part 4: Soil pH - passel. (n.d.). https://passel2.unl.edu/view/lesson/d2b-52174b1a7/6#:~:text=Native%20vegetation
23. What is pH and Why Does it Rise? A Complete and Updated Guide. (2020, September 7). Happy Hydro. https://www.happyhydro.com/blogs/news/what-is-ph-and-why-does-it-rise#:~:text=Hydroponic%20setups%20are%20likely%20to,its%20acidity%20to%20become%20alkaline
24. Soil pH and the Availability of Plant Nutrients | Nutrient Stewardship. (n.d.). https://nutrientstewardship.org/implementation/soil-ph-and-the-availability-of-plant-nutrients/#:~:text=It%20has%20been%20determined%20that,compatible%20to%20plant%20root%20growth
25. Admin, N. (2021, July 27). Best Temperature for Hydroponics. North Slope Chillers. https://northslopechillers.com/blog/best-temperature-for-hydroponics/#:~:text=Experts%20agree%20that%20the%20best,-roots%20and%20optimal%20nutrient%20absorption
26. Team, A. N. (2022). How To Build Your Own Hydroponics Grow Room – Dialing In Your Temperature and Humidity (part 3). Advanced Nutrients. https://www.advancednutrients.com/articles/grow-room-temperature-humidity/
27. Trees.com Staff. (2022, December 20). Hydroponic Nutrient Solution - The Essential Guide - Trees.com. Trees.com. https://www.trees.com/gardening-and-landscaping/hydroponic-nutrient-guide
28. Smart Garden Guide & Smart Garden Guide. (2019, February 6). Hydroponic Nutrient Solution (Easy Guide) - Smart Garden Guide. Smart Garden Guide. https://smartgardenguide.com/hydroponic-nutrient-solution-easy-guide-2/
29. E. Coli - Health Implications in Recreational and Drinking Water. (n.d.). The Water Project. https://thewaterproject.org/water-scarcity/health-implications-of-e-coli
30. Water Supply | We Grow Hydroponics. (n.d.). https://wegrowhydro.com/water-supply/

REFERENCE LIST FOR “SUGGESTED CROPS AND GROWING CONDITIONS TABLE”

1. Electrical Conductivity and pH Guide for Hydroponics - Oklahoma State University. (2017, April 1). https://extension.okstate.edu/fact-sheets/electrical-conductivity-and-ph-guide-for-hydroponics.html
2. Dupuis, A., & Technology, E. G. (2023). Hydroponic Lettuce: Everything You Need to Know | Eden Green. Eden Green. https://www.edengreen.com/blog-collection/hydroponic-butterhead-lettuce#:~:text=Lettuce%20seedlings%20should%20get%20about,hours%20of%20light%20per%20day
3. Lettuce | NC State Extension Publications. (n.d.). https://content.ces.ncsu.edu/lettuce#:~:text=Lettuce%20is%20adapted%20to%20cool,provided%20that%20nights%20are%20cool
4. Mint Hydroponic Growing Guide. (n.d.). Foody Vertical Gardens. https://foodyverticalgarden.com/blogs/resources/mint-hydroponic-growing-guide#:~:text=Once%20your%20mint%20plants%20are,level%20of%206.0%20to%207.0
5. Dupuis, A. (2022). A Grower's Guide to Hydroponic Mint | Eden Green. Eden Green. https://www.edengreen.com/blog-collection/hydroponic-mint-guide#:~:text=Mint%20needs%2014%2D16%20hours,an%20EC%20of%202.2%2D2.6
6. Hydroponic Cucumbers | Greenhouse Cucumbers | Cropking. (n.d.). https://cropking.com/blog/hobby-greenhouse-product
7. Davis, D. (2021). How To Grow Hydroponic Cucumbers. Hydrobuilder Learning Center. https://hydrobuilder.com/learn/hydroponic-cucumbers/#:~:text=They%20grow%20best%20in%20temperatures,about%20ten%20degrees%20at%20night.&text=The%20more%20light%20you%20can,hours%20of%20light%20each%20day
8. Hoffman, E. (2022). 5 Tips For Growing Hydroponic Basil At Home. The Green Garden Life. https://thegreengardenlife.com/growing-hydroponic-basil-at-home/#:~:text=Tip%202%3A%20Provide%20The%20Ideal%20Environmental%20Factors&text=The%20ideal%20temperature%20for%20hydroponic,place%20to%20grow%20hydroponic%20basil
9. Virginia. (2022). How To Grow Basil Hydroponically and Keep It Healthy. The Culinary Herb Garden. https://howtoculinaryherbgarden.com/grow-basil-hydroponically/#:~:text=Basil%20is%20a%20wonderful%20candidate,days%20using%20a%20hydroponic%20system
10. Jagdish. (2019). Growing Fennel Hydroponically - A Full Guide | Gardening Tips. Gardening Tips. https://gardeningtips.in/growing-fennel-hydroponically-a-full-guide
11. Stevens, D. (2023). Growing Hydroponic Strawberries. IGWorks. https://igworks.com/blogs/growing-guides/growing-hydroponic-strawberries-in-your-iharvest
12. Greg. (2023, January 29). How to Grow Hydroponic Tomatoes | Rural Living Today. Rural Living Today. https://rurallivingtoday.com/hydroponics/how-to-grow-hydroponic-tomatoes/#:~:text=How%20Much%20Light%20Do%20Hydroponic,hours%20of%20light%20per%20day
13. Leaffin. (2019). A Beginners Guide to Growing Tomatoes Hydroponically in Home. Leaffin. https://www.leaffin.com/hydroponic-tomatoes/
14. Bradley, A. (2019). How to grow chives at home. www.realestate.com.au. https://www.realestate.com.au/lifestyle/how-to-grow-chives/
15. Simply Hydroponics – Hydro Chives. (n.d.). https://www.simplyhydro.com/hydro_chives/
16. Chris. (2021, December 13). List of pH & EC Levels for 65+ Hydroponic Vegetables & Herbs. Happy Hydro Farm. https://happyhydrofarm.com/ph-ec-hydroponic-vegetable/
17. Davis, D. (2021b). How To Grow Hydroponic Radish. Hydrobuilder Learning Center. https://hydrobuilder.com/learn/hydroponic-radish/
18. Dupuis, A., & Technology, E. G. (2023b). Hydroponic Spinach: Everything You Need to Know | Eden Green. Eden Green. https://www.edengreen.com/blog-collection/hydroponic-spinach#:~:text=How%20Much%20Light%20Is%20Needed,HID%20lighting%20will%20work%20too

HAIFA HYDRO 2023

AN ASSEMBLY MANUAL PREPARED BY KELLY HEFFERNAN, RAYDEN MORLEY, SEAN NUZIO, AND NATANEL PINKHASOV IN COLLABORATION WITH THE MITYAALIM FOUNDATION, THE BRAUDE COLLEGE OF ENGINEERING, HAIFA UNIVERSITY, GIVAT YOAV, LIVINGREEN, AND WORCESTER POLYTECHNIC INSTITUTE.