A Solar-Powered Aquaponics with IoT-Based Monitoring and Data Gathering at the Technological University of the Philippines-Taguig

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ABSTRACT

The agriculture sector is one of the main driving forces of the economy, yet it is gravely affected by the growing number of industrializations and climate change, resulting in low productivity and food scarcity. This is why innovative farming methods are introduced to farmers to help them slowly adapt and mitigate these problems. Numerous studies regarding aquaponics have been conducted to enhance the quality of food production, but only some of them use renewable energy as source of electricity. This paper discusses how the system, powered by solar energy and has a monitoring website using the Internet of Things (IoT), can help in improving agricultural growth and food security, create entrepreneurial opportunities, and combat the effects of climate change. The growth of the lettuce from the system was compared to the existing aquaponics study from the De La Salle University (DLSU), which resulted in the researchers' system being ahead by having a 60.89% growth rate in just a week of monitoring. The findings also indicate that insufficient light exposure may result in leggy lettuce and suggest that thorough monitoring of the pH level must be practiced since it plays a vital role in the growth of both lettuce and tilapia.

Keywords: Aquaponics; Solar Power; Internet of Things (IoT); Renewable Energy; Agriculture; Photovoltaics

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ABSTRACT

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I. THE PROBLEM AND ITS BACKGROUND

This chapter introduces the background of the study, together with the statement of the problem, objectives and the scopes and delimitations. The frameworks used are also included, with the significance of the study and definition of terms used in the research.

1.1. Background of the Study

The agriculture sector is the most crucial sector in the Philippines. According to a Sector Assessment by the Asian Development Bank in 2012, the sector is important for inclusive growth, mainly because it has been the key driver of the economy in the rural areas where the majority of the Philippine population lives but where poverty incidence remains high[4]. However, farmers are still using the conventional method of farming, even in the midst of rampant land conversion and industrialization by huge enterprises. According to the Department of Agrarian Reform (DAR), between 1988 and 2016, when the Comprehensive Agrarian Reform Law (CARL) took effect, agricultural land with a total of 97,592.5 hectares was approved for conversion for nonagricultural purposes. During these 28 years, the approved conversion applications of land are 80.6 percent in Luzon, 7.8 percent in the Visayas, and 11.6 percent in Mindanao. Included in the converted lands are the Calabarzon and Central Luzon, which produce large volumes of palay and other crops[10]. Hence, the conversion of prime agricultural lands undermines food security. That is why, according to the Philippine Statistics Authority (PSA), the value of production in agriculture and fisheries decreased by 0.3% during the first quarter of 2022[61]. Meanwhile, from 2001-2021, the average annual share of agriculture, forestry, and fishery (AFF) grew at only around 1.1 percent annually. In contrast, the population growth rate during the same period is around 1.4 percent[1]. This indicates that the Philippines' agricultural sector is not producing enough food to sustain a high population growth rate, and thus, the farm productivity is low.

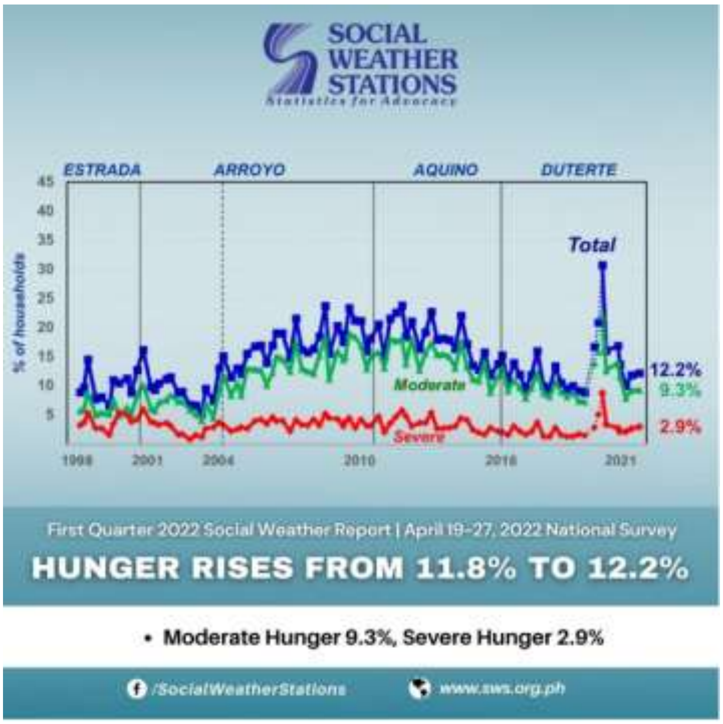


Figure 1. Social Weather Stations Survey: Hunger rises from 11.8% to 12.2% in the first quarter of 2022. [73]

Moreover, one of the adverse effects of low farm productivity is hunger. According to a recent survey of the Social Weather Stations (SWS) as shown in Figure 1., 12.2% of Filipino families, or about 3.1 million of the 109.6 million Filipinos, have experienced being hungry or not having to eat at least once from January to March of 2022[73]. With that, the Department of Agriculture (DA) launched the "Plant, Plant, Plant Program" to counter the growing number of concerns about food security, especially during the height of the pandemic. On May 26, 2020, it introduced a modern and innovative way of farming called aquaponics—where aquaculture (fish farming) and hydroponics (soil-less farming) integrate to imitate the ecosystem of the traditional way, its natural processes, and by using fish waste as food for bacteria, turn it into fertilizer for the plants that will then be filtered and purified right back to the fish tank[59][60]. As food demand grows higher, the conventional way of agricultural farming barely meets the desired requirements because of high fertilizer costs, problems with water irrigation, and land area for farming, thus, aquaponics could be the new way of combating food scarcity. This method, unlike the regular, is inexpensive, cost-effective, very efficient, and free from various issues related to long-established techniques in agriculture. As per the "Plant, Plant, Plant Program" of DA, in only a square meter of its aquaponics unit, in a month or two, it can produce an estimated 50 to 75 catfish and harvest 54 heads of lettuce. This type of farming has grown and gained popularity worldwide as it can yield two products (seafood and plants) in one production setup. Within this system, it provides easy ways of growing foods, thus putting less pressure on commercial producers. Furthermore, with the worsening effects of climate change, especially in arid areas, aquaponics can be a potential key method in transforming agriculture and enhancing food security [15].

1.2. Statement of the Problem

This research aims to give a response to alternative food production with the innovative touch of engineering fundamentals. Thus, to thoroughly navigate the researcher's objectives, here are the following questions that need to be addressed within this paper:

1. How can a Solar-Powered Aquaponics with IoT-Based Monitoring and Data Gathering system improve agricultural growth and food scarcity?
2. How will Aquaponics with IoT-Based Monitoring and Data Gathering powered by solar power create new livelihood for farmers and other entrepreneurs?
3. What will the IoT-based Monitoring and Data Gathering provide to the process of growing nutrient-dense crops faster in Aquaponics?
4. Why is the Aquaponics setup a solution in combating the effects of climate change and land conversion in the agriculture sector?

1.3. General and Specific Objectives

1.3.1. General Objectives

1. To design and develop a Solar-Powered Aquaponics with Total Dissolved Solids (TDS) Sensor, Digital Temperature and Humidity (DHT22) Sensor, Direct-to-Digital Temperature (DS18B20) Sensor, pH Sensor and Monitoring Module (ESP32 Module) for the Agricultural Project of the Technological University of the Philippines - Taguig Campus.

1.3.2. Specific Objectives

1. To design an aquaponics system that utilizes a TDS sensor for measuring the levels of salt, nutrients, and other concentrates in the water, pH sensor for measuring the acidity and basicity of the water, a DHT22 Sensor for monitoring the amount of humidity and temperature inside the system, a DS18B20 Sensor for monitoring the temperature of the water, and a Monitoring Module (ESP32 Module)
2. To develop a monitoring website, and program the sensors and modules needed for that is connected to the devices for monitoring and gathering data.
3. To develop an effective aquaponics system with components run by solar power for controlling the growth factors of the chosen species.

1.4. Significance of the Study

Aquaponics is a system where wastes produced by marine organisms benefit plants that are found on other parts of the components. From an easier perspective, the existence of both organisms is mutually beneficial to each other. The ecosystem is built and controlled by engineering principles. Aquaponics has no problem when it comes to lack of arable land and water scarcity, for it may contain numerous plants within a limited space and also be a habitat for various fishes. The said system serves a lot of uses, some of which are: it extends water use; plants recover dissolved nutrients from the water; and it also reduces discharge from the environment. To specify, here are the evident impacts of this study on many institutions.

1.4.1. Students

The potential benefits include increased awareness of an alternative method of planting and growing crops. It also allows researchers to investigate how fish, plants, and microbes interact in a live ecosystem, conduct water quality testing, and assess and track the growth rates of fish or crops for various academic studies. It will inspire engineering students to come up with new ideas for greening the ecosystem and providing a safe haven for marine life. Furthermore, it demonstrates how solar power aids in crop production efficiency.[19][20]

1.4.2. The University

The study will be advantageous to the university since it will provide nutritious, fresh food in a more hygienic form of gardening, actively support the eradication of hunger, and assist in serving as the university's learning center. And along with engineering, science, chemistry, business principles, and marketing, it teaches students practical skills such as problem-solving abilities, analysis of data, and proper planning. [19][20]

1.4.3. Farmers

The aquaponics system will provide farmers with ideas on how to develop a sustainable, cost-effective planting method that contributes to the prevention of diseases; and nurtures a foundation for a much healthier lifestyle. In addition, a solar-powered one will mean less expense on their behalf in the long run as it supplies the power needed to improve the whole system and its products. [19][20]

1.5. Scope and Delimitations

1.5.1. Scope

The general aim of this research is to build a solar-powered enclosed aquaponics unit inside the Technological University of the Philippines - Taguig Campus and study the yield of the setup. The following are the capabilities of the desired aquaponics to maintain the balance in the imitation of the natural ecosystem that the conventional way of farming has:

1. Utilizes an off grid solar panel to energize the whole aquaponics system;
2. It can detect the salt level, amount of nutrients, and concentration of the water with the use of a TDS sensor;
3. With pH sensor, it can check the acidity and basicity of the water;
4. Keeps track of the water temperature with the DS18B20 sensor;
5. Using DHT22 sensor, the temperature and humidity of the enclosed system can be monitored;
6. The whole condition of the aquaponics system can be monitored through a website made solely for the system by using ESP32 Module.

1.5.2. Delimitations

In order for the researchers to achieve the general and specific objectives of this study on time and be able to answer the statement of the problems, this project study shall be limited only to:

1. Planting Loose-Leaf Lettuce (Lactuca Sativa) seedlings as this would only take 40-45 days to maturity since transfer [85][85]. It also requires a pH level of 5.8 to 6.2, which is ideal for most fish. It thrives in water with a temperature of 70° to 74° Fahrenheit (20° to 23° Celsius). Additionally, the optimal water temperature for the plants, bacteria, and fish to coexist in one system is 22° to 31° Celsius[65]. It requires 7 inches of spacing between other lettuce to encourage maximum growth, prevent overcrowding, and ensure each plant receives enough light.[81][85]
2. Culturing Tilapia (Oreochromis niloticus) which requires 71-86°F (22-30°C) and a water pH Level of 6.5 to 9. Moreover, according to Rossana Sallenave, the optimal pH level to sustain an ideal living condition for the fish, plant, and healthy bacteria is a pH level of 6.0 to 7.0[65]. An adult tilapia, which takes about 6 months, of about 45 to 50 grams requires 20% to 25% protein content. In every 3 gallons of water is one pound of tilapia, this is the rule of the thumb. Tilapia are omnivore fish species that eat plants and animal-based feed. Included in its diet are algae, soybean meal, corn, fish food, animal feed such as blood meal, meat and bone meal, and fish meal.[81]
3. The system will be assembled on a 1.5 meter by 1.9 meter plot of land infront of the Italian Building at the Technological University of the Philippines-Taguig.
4. This Solar-Powered Aquaponics with IoT-Based Monitoring and Data Gathering at the Technological University of the Philippines-Taguig shall be studied for 28 weeks starting from May 17, 2022.

1.6. SWOT Analysis

Figure 2. Strengths, Weaknesses, Opportunities, and Threats of a Solar-Powered Aquaponics with an IoT-Based Monitoring.[22]

1.6.1. Strengths

Aquaponics aids agriculture by increasing farm productivity. Farmers could monitor their farms and respond quickly if there is a problem within the system. Aside from that, using aquaponics will assist producers in starting their businesses. Aquaponics organic products, such as lettuce and fish, are nutritious. As a result, more consumers will be interested in purchasing aquaponics produce.[22]

1.6.2. Weaknesses

The entire aquaponics mechanism requires a lot of attention. The system is difficult because the charging system must be operational at all times to avoid crop production malfunctions. Several crops are also excluded due to technical constraints. This study only looks at leafy plants, specifically loose-leaf lettuce.[22]

1.6.3. Opportunities

People are encouraged to consume vegetables grown in aquaponics systems because the use of chemicals is drastically reduced. As a result, the available supply of nutritious food will grow faster. The platform for aquaculture research is item niche markets. Human activities such as remediation contribute to eutrophication. Aquaponics is more profitable than traditional agriculture and aquaculture methods.[22]

1.6.4. Threats

As shown in Figure 2, these are the potential threats to the system, including possible health problems that may lead to fish loss; unexpected failure that may occur due to system imbalance; natural disasters that might affect the entire construction process; and lack of funds, which could make it difficult to provide the right components. Identifying the causes of these incidents can help the researchers in preventing these problems to happen.[22]

II. REVIEW OF RELATED LITERATURE AND STUDIES

2.1. Related Foreign Studies

2.1.1. Development of an Aquaponic System using a Solar Powered Control Pump[53]

The number of non-renewable resources decreases as it starts to run out while the demand keeps rising. But because electricity has become a necessary part of everyone's daily life, the problem of electricity production will be a challenge for future generations. The cited literature aims to use a solar panel to power the flow of water and air pumps of the aquaponics system instead of grid power. The goal is to make it independent of grid power, using renewable energy as a power source. The researcher's study is to develop an aquaponics system powered by a solar panel. The only difference is that in addition to the water and air pumps used in the cited literature, there will be a TDS Sensor, DHT22 Sensor, and DS18B20 Sensor used in the study. Although not implemented in the final output of the cited literature, it talks about an optimal solution to maximize capturing the sun's energy by tracking the sun's movement and attaching a motor that will allow the solar panel to face the sun at all times.

2.1.2. Solar Aquaponics – The Future of Growing. Portable Farms® Aquaponics Systems[21]

As published in Portable Farms (2020), in an aquaponic, putting together water, plants, and fish happens. It is considered the lifeblood of heat and light. In addition, the continuous aeration pumps and the circulation are required to provide the tank with the necessary oxygen are a part of it. Following that, controlled environment agriculture (CEA) is encouraged to be used to improve what the aquaponic system already produces. The two examples of it are the heat for the fish tanks and the grow lights for the plants. Growing lights answer the rule of thumb, which means that plants need to have full-spectrum lighting. On the other hand, heat for the fish tanks maintains the water in the tank at the right temperature, which aids in increasing your output. Both of them require a precise quantity of power, which might be expensive to support, in order to supply the proper light to grow plants more quickly and healthily and the right amount of heat to maintain the tank's water temperature. And to solve that, solar energy provides some of the required electricity and offers a much more cost-effective way to upgrade an aquaponics system. For instance, a 200-watt solar power system with two deep-cycle batteries, a 20-amp maximum power point, and a single fish tank system with grow lights should be able to support the system with proper construction and insulation even in challenging conditions.

2.1.3. Small-scale aquaponic food production. Integrated fish and plant farming.[30]

It covers the nitrogen cycle and nitrification, the relevance of bacteria, and the concept of balancing an aquaponic unit. The paper goes into great detail about the three categories of living organisms that comprise the aquaponic ecosystem (bacteria, plants, and fish). It also covers management tactics, troubleshooting approaches, and related issues, with an emphasis on local and sustainable aquaponic input sources. It is relevant to the study of the researchers because it demonstrates the crucial parameters to take into account when starting a small-scale aquaponics and the variables to consider while setting up the system. A method of integrated agricultural intensification, aquaponics, solves the requirements of water scarcity projects. Improved agricultural methods are required globally to alleviate rural poverty and promote food security.

2.1.4. Solar Powered Aquaponics: Modeling Real World Solutions through Engineering Technology[83]

This paper describes the technologies used to implement a senior capstone project which focuses on sustainable development. The overall goal of the senior capstone project was to bring together students from different disciplines to address a problem related to sustainability which was the design of an aquaponics system using renewable energy sources.[83]

2.1.5 Equipment and Intelligent Control System in Aquaponics: A Review[27]

Aquaponics is a concept of an ecological planting and breeding mode, promoted due to the population growth and rising food safety issues. To create an ecologically balanced relationship, farmed crops, fish, and microbes form a mutually beneficial symbiosis and peaceful coexistence. In the cited literature, it focuses in systematically analyzing and summarizing the planting and breeding equipment involved in aquaponics and the monitoring and control of planting and breeding environment. Meanwhile, in the researcher's paper, the focus is to develop an efficient solar powered aquaponics system. The goal is to have a higher yield of crops as compared to traditional planting. To achieve precise optimization and regulation of water resources, nutrient resources, and the planting and breeding environment in the aquaponics system the cited literature and the researcher's study both uses various sensors. The only difference between the two is that the study uses solar panel to power the whole aquaponics system. [27]

2.1.6 Aquaponics [24]

Compared to the conventional farming practices, aquaponics is considered to be better substitute. It possesses some incredibly remarkable qualities that can surpass the traditional farming practices in the foreseeable future. Noticeably, aquaponics utilizes 90% less water than conventional farming

In an aquaponics system, plants can grow all year round. This system allows for usage in any environment and in any weather, thus it also recycles the system's water. In addition, aquaculture provides a farmer with two sources of revenue, which are the fish and fruits and veggies. The primary goal of the system is to create an Aquaponics monitoring system powered by the Internet of

Things which record and shows data such as pH level, continuously updating data on temperature, humidity, and water level a user's system. Constant monitoring of the water inside the Aquarium tank setup is possible for the growth and survival of fish and vegetation associated with them entire system. The utilization of Wi-Fi contributed to establish a connection with the system's data server on the web system parameter values, such as the pH value, were the database's entries for temperature and humidity provided providing data to the web server so that users can access the information in JavaScript Object Notation format, as well as also in graphical format With the use of the Internet values of Items in the Aquaponics Monitoring system information and the system's parameters can be displayed ongoing on the web server.

2.1.7 Challenges of Sustainable and Commercial Aquaponics [33]

Aquaponics combines the elements of recirculating aquaculture and hydroponics, where the water from the fish tanks is used for plant growth, as it flows back to the tank where the process repeats. It is an integrated multidisciplinary system with its role in food security gradually becoming relevant because of the global population now exceeding 7.2 billion. The still rising population is expected to reach 9.6 billion in the next 35 years where more than 75% living in urban areas. The cited literature is intended to illustrate existing aquaponics difficulties and provide ideas for future research. The design and use of aquaponics systems relies on environmental, mechanical, and civil engineering design concepts, as well as aquatic and plant-related biology, biochemistry, and biotechnology. Aquaponics is also reacting to a variety of ecological and social concerns, emphasizing the significance of focusing on efficient and sustainable agricultural production methods. It seems that aquaponics is a promising solution for sustainable aquaculture and hydroponic practice given the fact that aquaponics follows nutrient and water reusing principles. Nonetheless, further research and developments are needed as demonstrated by the challenges described in the cited literature. With the aim to establish fully controlled and standardized aquaponic systems that will be easy to handle and economically viable these challenges need to be resolved.

2.1.8 Optimal Utilization of Renewable Energy in Aquaponic Systems [40]

This paper has focused its study on the management of energy consumption of an aquaponics system. The researchers used various Hybridized Renewable Energy Systems to power the aquaponics system and developed a way to manage the energy use and consumption, which is relevant to the current study as it can provide information as to how the researchers can manage the power source of the system in the most optimal way. Since the researchers are also using a renewable source to power the aquaponics system, the researchers can use the study as a reference as to how to fully maximize the off-grid solar panel system for the aquaponics. The difference is that the researchers will not be needing the Decision Support System in the said study, as the researchers are fully off-grid and will only be utilizing one energy source, instead the researchers will be making use of IoT monitoring system for the Aquaponics to provide information and control in the use of appliances and power consumption.

2.1.9 Literature Review on Aquaponics as Commercial Food Production and suggestions for improvements to the Matthaei Aquaponics system.[52]

The University of Michigan has experimented with aquaponics in its Matthaei Botanical Gardens through the desire to commercialize the practices of its sustainable agricultural methods and suggest improvements to easily harness its aim. Within the study, Merchant, C. (2021) used different literature reviews and put them together to create suggestions for improving the possibility of aquaponics being commercialized. The experiment pinpointed several factors, such as water quality control and nutrient management. It is also essential to understand the correlation of both external and internal environments of aquaponics. In addition, for the system to be commercially successful, public awareness and knowledge about aquaponics must increase because, in business, the public interest is a major key to gaining possible consumers, as well as producers. With these results, the researchers of this study can further develop the quality of making solar-powered aquaponics with an IoT-Based monitoring system.

2.1.10 An International Survey of Aquaponics Practitioners. [44]

Aquaponics is experiencing a period of rapid growth where participants are innovators and early adopters of technology, and it is being practiced in at least 43 countries around the world and on every continent. The cited literature is the first large-scale survey of practitioners of aquaponics, and the findings may serve as a baseline for future research, policy, advocacy, and outreach about this growing form of agriculture. Based on the survey most of the respondents were from the US, a large part of the reason is that the survey originates in the US and is only offered in English. The respondents for the survey are hobbyists, educators, non-profit organizations, commercial operators, and consultants. The average system took up 15 square meter of space and contains 500 gallons of water. Primarily, aquaponics is a niche backyard activity currently. The findings of the cited literature indicate that experimentation in crop production is active and ongoing. To improve the aquaponics community, further research, optimization, and communication of the best crop production methods are needed. The respondents were open to using sustainable alternatives to the conventional water, energy, and feed sources used in the aquaponics system. The average respondent agrees that growing his/her food was a personal priority as it ensures that the food will be safe and clean. The reported most popular raised edible crops are leafy greens, herbs, and tomatoes. Aquaponics varies in size and type of production system, and towards environmentally sustainable methods of production, the cited literature found a high adoption rate among respondents. The results from the survey will expand the researcher's understanding of aquaponics producers and the demographics, motivations, and production systems.

2.2. Related Local Studies

2.2.1 A System Study on La Estrella Aquaponics. [12]

"A System Study on La Estrella Aquaponics" is a study that aims to solve the problem of La Estrella Farm, Philippines by reducing the monthly cost and meeting the target maximum production rate at the minimum cost. It is relevant as La Estrella Farm is one of the main partners of the Philippine Aquaponic. The researchers give tutorials, ideas, and help to other enthusiasts of aquaponics. The researchers can use this study to provide an idea of how to create a system in aquaponics. It is also relevant to the researcher's current study as it helps to have an idea of how to create aquaponics that produces increased crop rates by utilizing the materials at a lower minimum spend. The study used different sensors and a website that is connected to the devices used for monitoring and controlling the growth factors inside the system while the system of La Estrella Aquaponics was monitored and controlled by a caretaker. The La Estrella Farm used a water tester for checking the quality of the water inside the fish tank and to check the pH level while it also used a sensor for checking the pH level. The farm also used different quarters for the cycle of plant growth.

2.2.2. Designing an Aquaponics System Integrated with a Solar-Powered Arduino Aquatic Feeders for Village Farmers. [13]

This study aims to solve the problem of water consumption in the agricultural sectors where 80% of the total Philippine water consumption comes from the agriculture areas. It is relevant to the researcher's study as it is like the researcher's aquaponics system, which uses Arduino and solar panels for recirculating the aquaponics system. The study uses different sensors and a website that is connected to the devices for monitoring and controlling the growth factors inside the system, like the temperature of the water, the humidity, pH level, and the temperature inside the system, while the related study only uses an incorporated Arduino uno sensor for fish feeding.

2.2.3 Development of a solar-powered smart aquaponics system through internet of things (IoT). [31]

This literature entitled "Development of a Solar-powered Smart Aquaponics System through the Internet of Things (IoT)" aims to develop an Arduino-based urban suitable smart aquaponics system. The cited literature provided three different aquaponic setups to determine the system's efficiency. On the other hand, the researchers intend to develop an off-grid solar-powered sustainable smart aquaponics equipped with sensors and microcontrollers. The researchers used this study to understand more about different aquaponic setups with the same components as theirs. The difference between the two studies is the components used and the choice of sensors; the researchers intend to use the Total dissolved liquids (TDS) sensor to monitor the water quality of the aquaponic system. Unlike the app mentioned in the study, the researchers will develop an interactive website that will record and store data from the microcontrollers; this aims to provide the user remote access to the aquaponic system wherever and whenever possible. This literature used a variety of crops with three (3) different aquaponic setups to further examine the system's efficiency, a feat that the researchers will not be able to do as the researchers aim to use a specific kind of crop.

2.2.4 Yield Evaluation of Brassica Rapa, Lactuca Sativa, and Brassica Integrifolia Using Image Processing in an Aquaponics with Temperature-Controlled Greenhouse [82]

Even though aquaponics is improving and gaining popularity locally and internationally, lacking in constant monitoring (e.g., temperature for the plants) is one of its problems. Tolentino et al. (2020) of the Technological University of the Philippines - Manila (TUPM) developed an aquaponics system placed in a closed greenhouse to control the temperature with image processing to evaluate and assess the yield of their plants (i.e., pak choi, mustard greens, and lettuce) and compare it to the traditional farming, which is soil-based. If the data acquired is not promising, the smart system has a correcting device that triggers the grow lights, aerator, evaporative cooler, and fans to adjust and correct the needed requirements of the plants. Unlike what the researchers are aiming to achieve in this study, this existing paper used monitoring to observe the condition of the plants through processing images.

2.3 Definition of Terms

These are words used in this paper that is uniquely defined or uncommon for others to read.[1][2][5][6][25][23][29][34][45][47][50][58][64][86]

1. AC - alternating current, an electric current that reverses its direction at regularly recurring intervals
2. Acidity of water - the quality, state, or degree of being acid, pH level of less than 7
3. Aerator - an apparatus for aerating something
4. Amp - Ampere, the unit for measuring electric current.
5. Anthropogenic - of, relating to, or resulting from the influence of human beings on nature
6. Aquaculture - the cultivation of aquatic organisms (such as fish or shellfish) especially for food
7. Aquaponics - a system of growing plants in the water that has been used to cultivate aquatic organisms.
8. Aquatic Feeders - a device or pipe for supplying water (as in a boiler or tank)
9. Arable land - fit for or used for the growing of crops
10. Arduino - refers to an open-source electronics platform or board and the software used to program it.
11. Basicity of water - the quality, state, or degree of being base, pH level of greater than 7.
12. Beneficial symbiosis - the living together in more or less intimate association or close union of two dissimilar organisms that benefits both organisms.
13. Biochemistry - the scientific study of the chemistry of living things.
14. Biofilter - a filter bed in which sewage is subjected to the action of microorganisms that assist in decomposing it.

15. Biotechnology - the use of living cells and bacteria in industrial and scientific processes.
16. Brassica Integrifolia - Leaf Mustard, an annual plant that reaches up to 30 cm high when fully matured. It is cultivated for its edible leaves.
17. Brassica Rapa - Turnip, used as a root vegetable. It's a biannual plant with a swollen, wide and tuberous root.
18. Capstone - the high point; crowning achievement
19. CEA - controlled environment agriculture, an advanced and intensive form of hydroponically-based agriculture where plants grow within a controlled environment to optimize horticultural practices.
20. Comprehensive Agrarian Reform Law - shall cover, regardless of tenurial arrangement and commodity produced, all public and private agricultural lands, as provided in Proclamation No. 131 and Executive Order No. 229, including other lands of the public domain suitable for agriculture.
21. DC - direct current, an electric current flowing in one direction only and substantially constant in value.
22. Decision Support System - a computerized program used to support determinations, judgments, and courses of action in an organization or a business.
23. Deep-cycle batteries - a lead battery designed to provide sustained power over a long period and run reliably until it is 80% discharged or more, at which point it needs to be recharged.
24. Department of Agrarian Reform - an executive department of the Philippine government responsible for the redistribution of agrarian land in the Philippines.
25. DHT22 Sensor - Digital Temperature, And Humidity Sensor, a basic ultralow-cost digital temperature and humidity sensor.
26. DS18B20 Sensor - Temperature Sensor Module is a digital temperature sensor suitable for the cold storage, granaries, storage tanks,

telecommunications room, electric power room, cable trough, and other temperature measurement and control areas.

27. Environmental catastrophe - defined as a catastrophic event regarding the natural environment that is due to human activity.
28. Eutrophication - the process of too many plants growing on the surface of a river, lake, etc., often because chemicals that are used to help crops grow have been carried there by rain.
29. Evaporative cooler - a device that cools air through the evaporation of water.
30. Full-spectrum lighting - light that covers the electromagnetic spectrum from infrared to near-ultraviolet, or all wavelengths that are useful to plant or animal life; in particular, sunlight is considered full spectrum, even though the solar spectral distribution reaching Earth changes with time of day, latitude, and atmospheric conditions.

31. Hybridized Renewable Energy Systems - composed of one renewable and one conventional energy source or more than one renewable with or without conventional energy sources, that works in stand-alone or grid-connected mode.
32. Hydroponics - the process of growing plants in water or sand, rather than in soil.
33. Image Processing - a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it.
34. Industrialization - the process of developing industries in a country or an area
35. Internet of Things (IoT) - the connection of devices within everyday objects via the internet, enabling them to share data
36. Inverter - a device for converting direct current into alternating current
37. IoT-based Monitoring - allows objects to be sensed or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems and resulting in improved efficiency, accuracy and economic benefit with the added merits of minimum human intervention.
38. Grid Power - power that comes from an electric grid.
39. Grow lights - an electric light to help plants grow.
40. JavaScript Object Notation - JSON, a text format for storing and transporting data.
41. Lactuca Sativa - lettuce, a well-known plant worldwide due to its use in the preparation of salad, soup, and vegetable curries.
42. Land conversion - defined as the act or method of modifying the current physical use of a parcel of agricultural land for either a non-agricultural purpose or the same agricultural use but other than soil cultivation as well as growing of crops and trees as approved by DAR.

43. Microcontroller - a compact integrated circuit designed to govern a specific operation in an embedded system.
44. Miniature Relay Module - a separate hardware device used for remote device switching. With it you can remotely control devices over a network or the Internet. Devices can be remotely powered on or off with commands coming from ClockWatch Enterprise delivered over a local or wide area network.
45. Monitoring Module - a modern management platform, providing application-aware infrastructure monitoring and analysis for improved time to value.
46. Monocrystalline - solar cells made from silicon crystallized into a single crystal.
47. Multidisciplinary - combining or involving more than one discipline or field of study.
48. Natural ecosystem - a community of living and non-living entities and occurs freely in nature.
49. Nitrification - the oxidation (as by bacteria) of ammonium salts to nitrites and the further oxidation of nitrites to nitrates.
50. Non-renewable resources - a natural substance that is not replenished with the speed at which it is consumed. It is a finite resource.
51. Off-grid - not connected to or served by publicly or privately managed utilities (such as electricity, gas, or water).
52. Off-grid Solar Panel - a system that is not connected to the electricity grid and therefore requires battery storage.
53. pH sensor - a scientific device used to accurately measure acidity and alkalinity in water and other liquid substances.
54. Renewable resources - a type of substance that can be used repeatedly and does not run out because it is naturally replaced.
55. Social Weather Stations - SWS, a social research institution in the Philippines founded in August 1985.

56. Solar-Powered Aquaponics - aquaponics that is powered by energy produced by a solar panel.
57. TDS sensor - Total Dissolved Solids, used for measuring TDS value of the water, to reflect the cleanliness of the water.
58. Temperature-Controlled Greenhouse - an enclosed greenhouse where the temperature inside can be controlled with the use of devices such as grow lights, aerator, evaporative cooler, fans, and etc.
59. Water Solenoid Valve - an electro-mechanical valve that is commonly employed to control the flow of liquid or gas.

2.4 Conceptual Framework

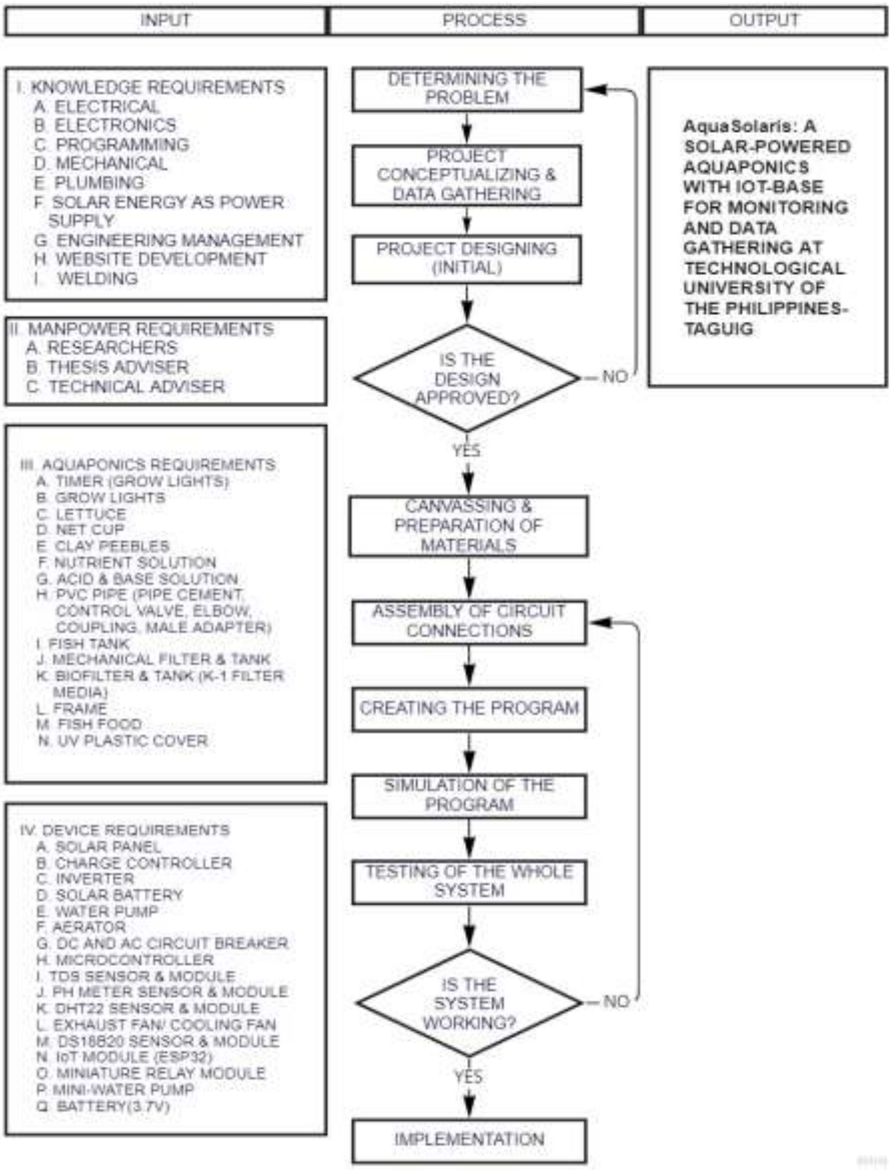


Figure 3. Conceptual Framework of a Solar-Powered Aquaponics with an IoT-Based Monitoring.

Figure 3 shows the conceptual framework of the study wherein the input consists of the following: knowledge, manpower, aquaponics, and devices. It also includes a detailed list of the necessary tools per requirement.

The process will start by determining the problem, then conceptualizing the project and data gathering, followed by project designing. As soon as the researchers finish the initial design, it will be subject to approval. If the proposal is accepted, researchers will continue canvassing and preparing materials. Simultaneously, the researchers will begin setting up the circuit connection. After that, the next activity would be to create the program and then simulate it. Assuming the circuit connection as well as the program run perfectly, testing the whole system would be the penultimate step before proceeding with the implementation. The output would be a study on the overall performance of the system of Solar-Powered Aquaponics with IoT-Based Monitoring and Data Gathering at the Technological University of the Philippines Taguig.

III. RESEARCH METHODOLOGY

This chapter focuses on the technical aspect of the research. It expands on the different variables that need to be considered in designing and assembling the whole system. The project cost, different tests that will be done on specific parts of the system, evaluation of the study, and the project schedule that the researchers adhered to were specified.

3.1 Project Concept

The project consists of two systems, the aquaponics system, and the control & monitoring system. In the aquaponics system, the water pump, aerator, grow lights, and microcontrollers are powered by a solar panel. The hours of daylight in Taguig City are 12:55 hours, almost 13 hours. Thereby, making sure that the solar panel gets enough sunlight to power the whole system. Meanwhile, the control & monitoring system uses a TDS and pH sensor to measure the levels of salt, nutrients, acidity, basicity, and other concentrates in the water. A DS18B20 and DHT22 sensor for monitoring the temperature of the water, and the amount of humidity and temperature inside the system. The IoT module (ESP32 Module) is responsible for sending and receiving system data through wireless networks.

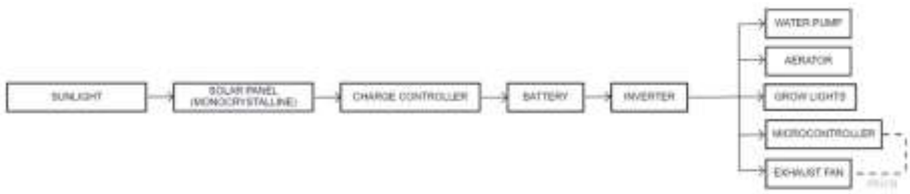


Figure 4. Block Diagram of the System of a Solar-Powered Aquaponics

Solar energy is the source of the system, as shown in Figure 4. The current and voltage from the panel will go to the charge controller to regulate it. This controller will keep the battery and inverter from overheating. The loads namely water pump, aerator, grow lights, microcontroller, and exhaust fan, will be fed as the electricity passes through the inverter, which will convert DC to AC. In addition, the exhaust fan will only turn on/off if the microcontroller read a certain set point.

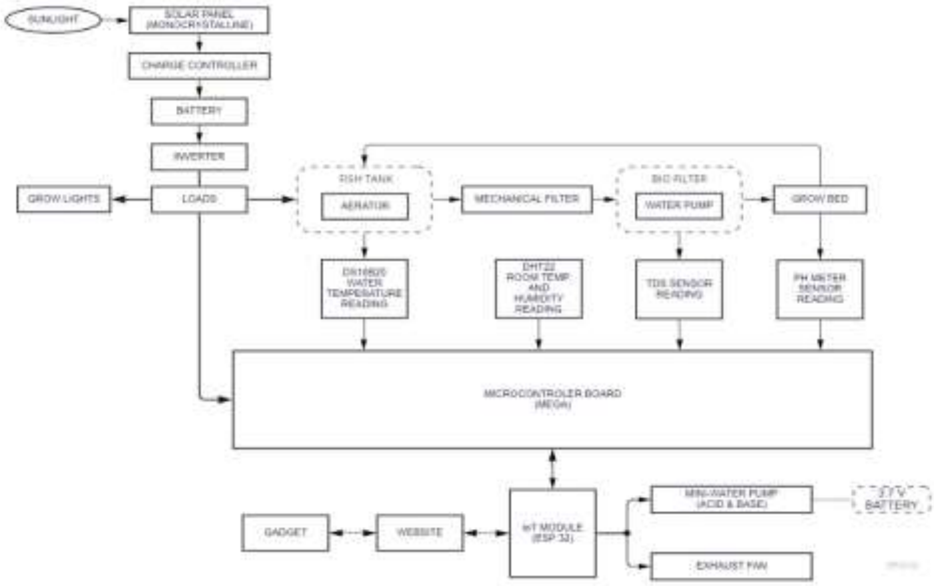


Figure 5. Block Diagram of the System of a Solar-Powered Aquaponics with an IoT-Based Monitoring.

Figure 5 is the overall flow of processes acting in the aquaponic system. The solar panels harvest electrical energy from the sunlight and deliver power to the loads. The loads are divided into three, namely the grow lights, the microcontrollers, and the heavy loads such as pumps and aerators.

The activities in the aquaponics system are shown in Figure 5, the water circulates from the fish tank to the filters and proceeds to the grow bed through the water pump. The water quality is monitored using different sensors that are placed on different parts of the system, DS18B20 water temperature sensor monitors the temperature in the fish tank, TDS sensor monitors the filter tanks and pH meter sensor monitors the pH levels in the grow bed, ultimately, DHT22 humidity and room temperature sensor monitors the conditions inside the closed aquaponic system. all sensors are gathered and stored in the microcontroller board and if the value drops below the threshold, the output motors activate, all the while the monitoring system monitors the whole processes from a website/application through ESP32 IoT module.

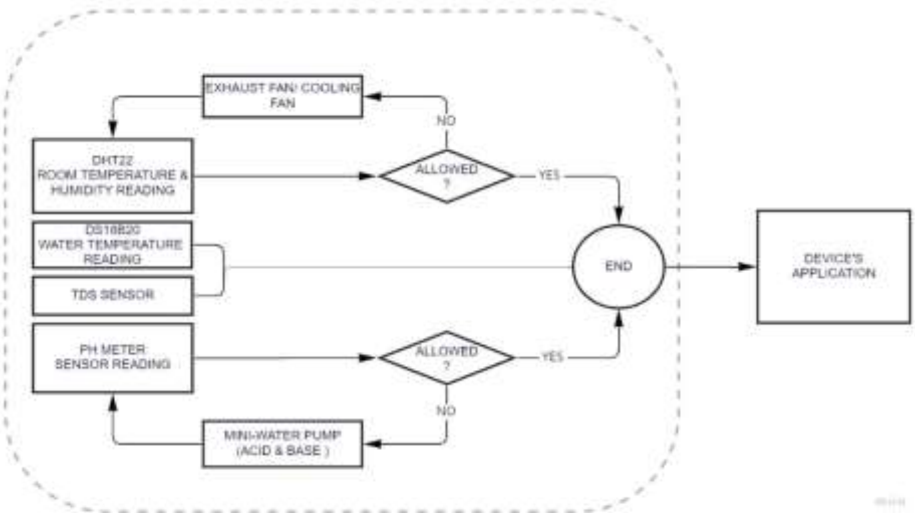


Figure 6. Flow Chart of the System of the input and output Aquaponics with an IoT-Based Monitoring.

There are four input readings, as shown in Figure 6: the DHT22 sensor, the pH meter sensor, TDS sensor and the DS18B20 sensor. If the temperature input of DHT22 is not allowed to the set range of the system, the system will automatically control it by turning ON the exhaust fan or cooling fan. The peristaltic dosing pump acts when the desired value of pH level is insufficient; if the temperature and pH level is permitted, the monitoring will continue. The water temperature and nutrient density cannot be controlled automatically but will be monitored. The read data gathered by the system will be sent to the device's application via the wireless network.

3.2 Project Design and Assembly

In this section, the researchers will discuss the overall design of the Solar-Powered Aquaponics with an IoT-Based Monitoring. The researchers have also identified the variables and different factors that need to be considered throughout the designing and assembly process of the whole system.

3.2.1 Design Procedures

Table 1. Dimensions of the Aquaponics System

MATERIAL	DIMENSION
Aquaponic System	Height (*from the ground to the tip of solar panel*) = 94.9 inches
	Length = 49.46 inches
	Width = 57.6 inches
Fish tank (1000 Liters)	Height = 45.3 inches
	Length = 47.2 inches
	Width = 39.4 inches
4 x 5 Grow bed	Depth = 12 inches
	Length = 47.2 inches
	Width = 39.4 inches
	Diameter (*plant hole*) = 3 inches
	Distance per plant hole = 7 inches
	Distance from fish tank = 12 inches
Filter tanks (200 liters)	Height = 34.5 inches
	Diameter = 23.5 inches
Solar panel	Tilt angle = 11.78 degree
Grow lights	Length = 48 inches
	Width = 2 inches
Pipes	Diameter (*from fish tank to filters*) = ¾ inches PVC pipe
	Diameter (*from filters to grow bed to fish tank*) = ½ inches PVC pipe

The researchers will be using a Deep-Water Culture (DWC) type of Aquaponics, it is one of the three common methods of aquaponics. The DWC is also known as the raft method or floating system method of aquaponics that utilizes nutrient rich water as the medium for the plants, supported by a styrofoam and net cups. [66][81]

The Table 1 shows the dimensions of the materials needed to build the aquaponic system. The measurements are as follows: from the ground to the tip of the solar panel, 94.9 inches in height, 49.46 inches in length, and 57.6 inches in width. The fish tank that will be used has a water volume of 1000 liters, a height of 45.3 inches, a length of 47.2 inches, and a width of 39.4 inches and can hold up to 50 adult Tilapia, because it is the rule of thumb that only 1 tilapia for every 19 liters of water, as shown below. [35][81]

TILAPIA FISH

1 ADULT TILAPIA = 45 TO 50 GRAMS
1 FISH REQUIRED 5 GALLONS
5 GALLONS = 18.9271 LITERS

$$\text{NO. OF TILAPIA} = \frac{\text{1000 LITERS OF IBC TANK}}{\text{18.9271 LITERS}}$$

NO. OF TILAPIA = 52.83

NO. OF TILAPIA = 50

K-1 FILTER

1 L OF K-1 MEDIA FILTER = 1 LB OF FISH
1 ADULT TILAPIA = 50 GRAMS
453.592 GRAMS = 1 lb

50 GRAMS X 50 FISH = 2500 GRAMS
2500 GRAMS/ 453.592 GRAMS = 5.51 lb

1 L OF K-1 MEDIA FILTER x 5.51 lb = 5.51 LITERS
5.51 LITERS x 0.8 LITER OF 250 GRAMS K-1 FILTER PER PACK = 7 PACKS

Equation 1. Calculation of the Total Fish and K-1 Filter Required

Moreover, the 200-liter filter tanks have a diameter of 23.5 inches and a height of 34.5 inches. The grow beds will have an area of 47.2 inches long by 39.4 inches wide and a depth of 12 inches, with 20 plant holes of 3 inches in diameter and a distance of 7 inches from each, to be placed 12 inches above the fish tank to provide aeration. Furthermore, as shown in the Table 1, the pipes from the fish tank to the filters should be ¾-inch PVC pipe, and the pipes from the filters to the grow bed back to the fish tank should be half inch PVC pipe. Lastly, to provide sufficient lighting for plants when needed, the grow lights shall have a total length of 48 inches with a 2-inch width.

Throughout the designing process, the researchers considered various factors that may affect the system and the overall yield of the aquaponics. Factors such as the average sun peak hours in Taguig, hours of sunlight from sunrise to sunset in Taguig, and the cardinal direction of the location were used to calculate the positioning of the solar panels to be used in the aquaponics system.[80]

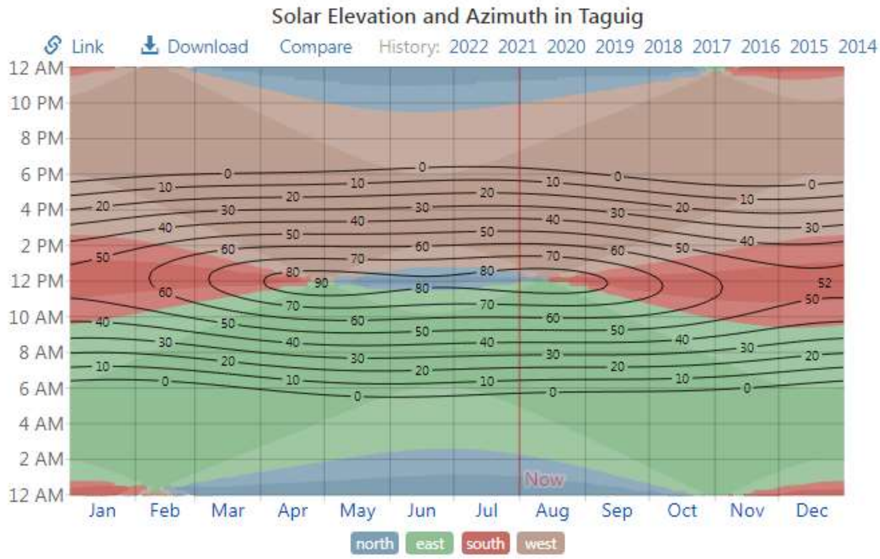


Figure 7. Solar Elevation and Azimuth in Taguig City from 2014-2022

According to Weather Spark, a company founded in 2014 by Dr. James Diebel, who holds a master's and a Ph.D. in Aeronautics and Astronautics from Stanford University, on Figure 7, Taguig has a 4-hour and 30-minute sun peak hours from 10 a.m. to 2:30 p.m. to the South. And as shown in the computation below, this variable is critical in calculating the optimal tilt and position of the solar panels.:[57][80]

LATITUDE X 0.812 = ANGULAR INCLINATION FROM HORIZONTAL FACING SOUTH

14.513687875 X 0.812 = 11.7851

Equation 2. Calculation of the Total Angular Inclination

As a result, the solar panels will be elevated at an angle of 11.7851 degrees and placed in front of the Italian Building at the Technological University of the Philippines—Taguig. The latitudinal location of the Technological University of the Philippines - Taguig is 14.513687875, while the longitudinal location is 121.039647945, according to Google Maps as shown in Figure 8. The latitudinal location is then multiplied by 0.812, the correction rate for fixed-mount solar panels based on the annual average for the country. As a result, the angular inclination of the solar panels to be used from the horizontal axis facing south is 11.7851 degrees.[80]

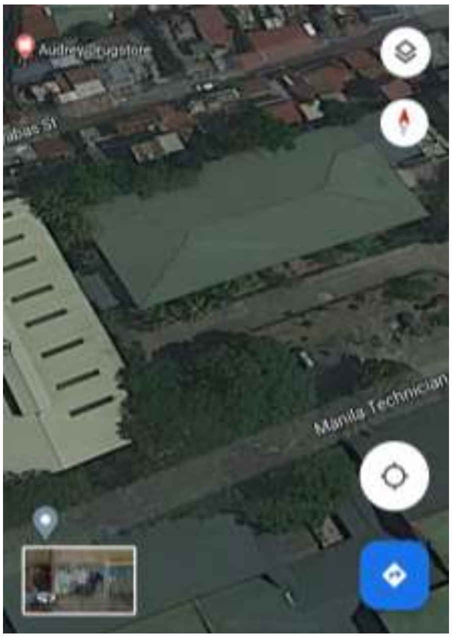


Figure 8. Location of Italian Building, Technological University of the Philippines – Taguig based on Google Maps

Table 2. Average per Day Elevation and Azimuth Angle of the Sun in Taguig City from 1999-present[80]

hh:mm	Elevation a	Azimuth angle
0:00	-80.96	170.71
0:15	-79.76	151.35
0:30	-77.63	137.49
0:45	-74.96	128.29
1:00	-71.99	122.17
1:15	-68.85	117.99
1:30	-65.6	115.07
1:45	-62.28	112.99
2:00	-58.93	111.49
2:15	-55.54	110.41
2:30	-52.13	109.65
2:45	-48.71	109.14
3:00	-45.28	108.81
3:15	-41.84	108.64
3:30	-38.4	108.61
3:45	-34.97	108.68
4:00	-31.54	108.86
4:15	-28.11	109.12
4:30	-24.69	109.47
4:45	-21.28	109.89
5:00	-17.88	110.39
5:15	-14.49	110.95
5:30	-11.13	111.6
5:45	-7.78	112.31
6:00	-4.35	113.1
6:15	-0.38	113.98
6:30	2.56	114.93
6:45	5.72	115.98
7:00	8.92	117.13
7:15	12.11	118.38
7:30	15.26	119.74
7:45	18.38	121.24
8:00	21.45	122.87
8:15	24.46	124.67
8:30	27.4	126.63
8:45	30.27	128.8
9:00	33.05	131.17
9:15	35.73	133.79
9:30	38.28	136.67
9:45	40.7	139.84
10:00	42.95	143.32
10:15	45.02	147.14
10:30	46.88	151.3
10:45	48.49	155.81
11:00	49.84	160.65
11:15	50.89	165.78
11:30	51.61	171.16
11:45	52	176.68

hh:mm	Elevation angle	Azimuth angle
12:00	52.03	182.27
12:15	51.71	187.82
12:30	51.05	193.22
12:45	50.06	198.41
13:00	48.77	203.31
13:15	47.2	207.88
13:30	45.38	212.11
13:45	43.35	215.99
14:00	41.13	219.53
14:15	38.74	222.76
14:30	36.21	225.69
14:45	33.56	228.35
15:00	30.8	230.77
15:15	27.95	232.97
15:30	25.02	234.98
15:45	22.02	236.8
16:00	18.96	238.47
16:15	15.85	239.99
16:30	12.7	241.38
16:45	9.52	242.65
17:00	6.32	243.81
17:15	3.15	244.88
17:30	0.16	245.85
17:45	-3.6	246.74
18:00	-7.15	247.54
18:15	-10.5	248.27
18:30	-13.86	248.93
18:45	-17.24	249.51
19:00	-20.64	250.02
19:15	-24.05	250.46
19:30	-27.47	250.82
19:45	-30.89	251.1
20:00	-34.32	251.29
20:15	-37.76	251.38
20:30	-41.2	251.37
20:45	-44.63	251.23
21:00	-48.06	250.93
21:15	-51.49	250.46
21:30	-54.9	249.75
21:45	-58.29	248.74
22:00	-61.66	247.33
22:15	-64.98	245.37
22:30	-68.24	242.63
22:45	-71.41	238.73
23:00	-74.42	233.05
23:15	-77.16	224.54
23:30	-79.41	211.67
23:45	-80.82	193.27
24:00:00	-80.97	171.44

Meanwhile, the solar panels' azimuth angle should be the mean of the highlighted values in Table 2. The azimuth angle was used by the researchers from 10 a.m. to 2:30 p.m. It is 4 hours and 30 minutes because it is the sun-peak hours of the day in Taguig City. The researchers should perform the following calculation to obtain the mean azimuth angle:

$$\frac{143.32+147.14+151.3+155.81+160.65+165.78+171.16+176.68+182.27+187.82+193.22+198.41+203.31+207.88+212.11+215.99+219.53+222.76+225.69}{19} = 186.559$$

Equation 3. Calculation of the Mean of the Azimuth Angle

The researchers added up all the azimuth angle values from 10 a.m. to 2:30 p.m., then divided them by the number of values. As a result, the azimuth angle for the actual position is 186.359 degrees.

Next, the researchers determined the required flow rate for the aquaponics system. The flow of water must be at an appropriate rate so that the nutrients can be absorbed first before it flows out of the grow bed and back to the fish tank. The researchers calculated the volume of the grow bed that has a dimension of 39.4 inches (width) by 47.2 inches (length) by 12 inches (height).[35]

$$\text{FLOW RATE} = L \times W \times H \quad (\text{NO. OF GROW BED})$$

$$L = 47.2 \text{ inch}$$

$$W = 39.4 \text{ inch}$$

$$H = 12 \text{ inch}$$

$$\#\text{ OF GROW BED} = 1$$

$$\text{FLOW RATE} = ((47.2)(39.4)(12))\text{inches} \times 1$$

$$\text{FLOW RATE} = 22316.16 \text{ in}^3$$

$$\text{FLOW RATE} = 365.7 \ (\text{L / hr})$$

Equation 4. Calculation of the Flow Rate

Next, multiply the product of these three dimensions by the number of grow beds, to obtain the flow rate needed. Hence, the aquaponics system needs a 365 liter per hour of flow rate.[35]

Aerator is a device that emits airstones for water quality, airstones is the amount of oxygen or the bubbles that the aerator produces.

$$\text{RATE OF OXYGEN DIFFUSION } \frac{(lbO_2)}{(hr)} = 0.07\frac{(ft^3)}{(min)} \times 0.075\frac{(lbmin)}{(ft^3)} \times 0.23\frac{(lbO_2)}{(lbair)} \times 0.01\frac{(lb)}{(ft)} \times 1\,(ft) \times 0.5\frac{air}{(lbmin)} \times 60\frac{(min)}{(hr)}$$

$$\text{RATE OF OXYGEN DIFFUSION } \frac{(lbO_2)}{(hr)} = 0.001863\frac{(lbO_2)}{(hr)} \quad (\text{REQUIRED } O_2 \text{ FOR THE SYSTEM})$$

2% of fish body consumption of 1 adult fish(50 grams) = 1 gram

1 gram x 50 fish = 50 grams   50 grams = 0.110231 lb

$$\#\text{ OF AIRSTONES} = \frac{0.110231(lbO_2/hr)}{0.00036225(lbO_2/hr)} = 304 \ (\text{Airstones})$$

Equation 5. Calculation of the Rating of Aerator

To calculate the airstones the proponents must calculate the rate of oxygen diffusion by acquiring the dimensions of the desired aerator, in the Equation 5 the volume of the aerator is in cu.ft per minute, it needs to be converted to pound oxygen per hour, to do so, the cu.ft is multiplied to pound minute per cu.ft, then pound oxygen per pound air, to pound per foot, the units cancelled and the product is multiplied in the specifications of the grow bed. Ultimately, the product above is divided to the required oxygen for the system.[78]

Table 3. Load Analysis of the Solar-Powered Aquaponics

EQUIPMENT	POWER (W)	QTY.	TOTAL POWER (W)	DURATION (hrs)	POWER CONSUMPTION (Wh)
AERATOR	18	1	18	12	216
WATER PUMP	25	1	25	6	150
EXHAUST FAN	25	1	25	5	125
GROW LIGHTS	26	1	26	6	156
MICROCONTROLLER	10	1	10	24	240

TOTAL:	887	Wh/day
	0.887	KWh

Since the researchers identified the various loads and specifications, Table 3 shows the total expected load of the entire system. The power rating of each component was multiplied by the corresponding quantity, resulting in the Total Power, as shown in the table above. The Total Power was then multiplied by the duration, or how long each component would operate in a day, to calculate the total power consumption per watthour. Finally, the researchers add up the total power consumption to obtain the watthour per day or kilowatt-hour per day rating.

Now, to get the PV Power or the overall efficiency of the Solar Panels that would supply to the Total Expected Load, the researchers used the calculation below:

SUN PEAK HOURS AT TAGUIG IS 4.50 hrs/day

$$\text{PV POWER} = \frac{\text{DAILY CONSUMPTION(kWh)}}{\text{SUN PEAK HOURS(h)}} \times 1.3 = \frac{887}{4.5} \times 1.3 = 256.24 \text{ W}$$

$$\text{NO. OF PV PANELS} = \frac{\text{PV POWER (W)}}{\text{PV PANEL RATING(W)}} = \frac{256.24}{550} = 1$$

Equation 6. Calculation of the Rating of PV Panels[43]

According to Leonics, an ASEAN-leading microgrid company, the daily consumption or total expected load must be divided by the sun peak hours, which are 4 hours and 30 minutes per day, and then multiplied by 1.3 to calculate the energy lost in the system [43]. As a result, the researchers estimated a PV power of 0.25624 kW, or 256.24 Watts.

To calculate the number of PV panels, divide the PV power by the PV panel rating. The 256.24 Watts must then be divided by the 500 watts rating of the researchers' canvassed solar panel. As a result, the solar-powered aquaponics will require a 0.5, or roughly one PV panels.

Next, the researchers calculated the Battery Bank, or the total batteries needed. The researchers used the computation below:

GUIDELINES ON SYSTEM VOLTAGE
12 V - SMALL INSTALLATIONS (<1200 W)
24 V - MEDIUM INSTALLATION (1200 W - 2400 W)
48 V - LARGE INSTALLATION (>2400 W)

D.O.D: 80% efficiency of battery; 90% Depth of Discharge

$$\text{BATTERY BANK CAPACITY} = \frac{\text{NIGHT CONSUMPTION}}{\text{(D.O.D} \times \text{EFF} \times \text{SYSTEM VOLTAGE)}} = \frac{887 \text{ Whr}}{(0.5 \times 0.80 \times 12\text{V})} = 104.79 \text{ Whr}$$

$$\text{NO. OF STRINGS} = \frac{\text{BATTERY CAPACITY}}{\text{BATTERY RATING}} = \frac{104.79 \text{ Whr}}{208 \text{ Ah}} = 1 \text{ (PARALLEL CONNECTIONS)}$$

$$\text{NO. OF SERIES} = \frac{\text{SYSTEM VOLTAGE}}{\text{V8}} = \frac{12}{12} = 1 \text{ (SERIES CONNECTIONS)}$$

Equation 7. Calculation of the Rating of Batteries

The researchers calculated the battery bank capacity by multiplying the total expected load by the total days of autonomy, which, according to Beckers[7] , is three days. The depth of discharge, or inefficiency of sealed lead acid batteries, is then divided by the efficiency rating of the battery studied by the researchers; and the system voltage of small installation, which is 12 volts. As a result, the capacity of the battery bank is 184.79 W/hr.

The number of strings was then calculated by dividing the battery capacity by the battery capacity rating of the battery canvassed by the researchers. As a result, the number of string/s of a single parallel connection is one (1).

Finally, the number of series was calculated by dividing the small installation's system voltage, which is 12 volts, by the voltage rating of the canvassed battery. As a result, the 1 Series Connection result.

Now, the researchers computed the minimum wattage rating of an inverter needed to supply the running loads. The researchers used the computation below:

Table 4. Inverter Rating of the Solar-Powered Aquaponics

EQUIPMENT	POWER (W)	QTY.	RUNNING (W)	
AERATOR	18	1	36	*2 because it is motor
WATER PUMP	25	1	50	*2
EXHAUST FAN	25	1	50	*2
GROW LIGHTS	26	1	33.8	*1.3
MICROCONTROLLER	10	1	13	*1.3
		TOTAL:	182.8	For safety, the inverter should be considered 25-30% bigger size.
				The inverter size should be about 228.5 W or greater.

According to Leonics, an ASEAN leading microgrid company, the inverter should be 25-30% larger in size than the computed total running load for safety reasons. [43]. As a result, the researchers added up the total running load of 182.8 Watts and multiplied it by 1.25 or 0.25 to get a value of approximately 228.5 Watts or higher. The researchers were able to make use of a 1-kilowatt inverter.

The included inverter is a Hybrid Inverter, which is a combination of a Solar Charge Controller and an Inverter because the researchers canvassed a Solar Panel Kit.

Next, the researchers calculated the Solar Charger Controller and the Connections of PV Panels. The researchers used the calculations below:

SOLAR PV CONNECTION (SERIES & STRINGS):

$$\text{NO. OF SERIES} = \frac{V_{max}}{V_{oc}} = \frac{41.6}{49.8} = 1$$

$$\text{NO. OF STRINGS} = \frac{\text{NO. OF PV PANELS}}{\text{NO. OF SERIES}} = \frac{1}{1} = 1 \quad \text{(PARALLEL CONNECTION)}$$

$$I_{cc} = I_{sc} \times \text{NO. OF STRINGS} \times 1.25 = 14.02A \times 1 \times 1.25 = 17.525$$

(Less than the Icc(Rated) of the Solar Charge Controller)

Equation 8. Calculation of the Connection of Solar Charge Controller and PV Panels[7]

The researchers calculated the number of series connections by dividing the maximum voltage of the solar charge controller by the open circuit voltage of the PV panel, the researchers found a total of two series connections. The researchers then calculated the number of strings by dividing the number of PV Panels by the number of Series, yielding a value of one (1) Parallel Connection. Lastly, the Charging Current (14.02 A) is calculated by multiplying the Short Circuit Current, the Number of Strings, and the 1.25 safety factor. As a result, the value of 17.525 Amps of charging current is less than the solar charge controller's charging current rating of 40 Amps. [7]

Moreover, the researchers calculated the Direct Current and Alternating Current to determine the required rating of Protective Device. The researchers used the calculation below:

$$I_{dc} = I_{sc} \times \text{\# OF STRINGS OF PV PANELS} \times 1.25 = 14.02 \times 1 \times 1.25 = 17.525 \quad \text{[illegible] 2P DC CB (FROM PV PANELS TO SCC)}$$

$$I_{dc} = I_{cc} = \text{[illegible] 2P DC CB (FROM CHARGE CONTROLLER TO BATTERY)}$$

$$I_{dc} = \frac{P_{rated}}{\text{SYSTEM VOLTAGE}} = \frac{\text{[illegible]}}{12} = \text{[illegible]} \quad \text{[illegible] 2P DC CB (FROM BATTERY TO INVERTER)}$$

$$I_{ac} = \frac{P_{rated}}{V_{rated}} = \frac{1100}{220V} = 5 \quad \text{[illegible] 2P AC CB (FROM INVERTER TO A LOAD)}$$

Equation 9. Calculation of the Rating of the Required Protective Device[7]

The Direct Current from the Solar Charger Controller to Battery is equal to the Short Circuit Current of PV Panels multiplied by the number of strings and the 125% of the Circuit Breaker Size of the ampacity of the cable and wire, according to the National Electrical Code. Hence, the calculated value of Direct Current of 20 Amp, and thus, the Protective Device to be used shall have a rating of 50 AT. [7]

Furthermore, the Direct Current from the Battery to Inverter is equal to the Power Rating of the Solar Charge Controller divided by the System Voltage. Thus, the calculated value of 45.83 Amps, therefore, the researchers shall use a 50 AT Protective Device.[7]

Lastly, the Alternating Current from the Inverter to Load is equal to Power Rating of the Solar Charge Controller divided by the Nominal Voltage System in the Philippines or the Voltage Grid, which is 220 Volts. Hence, the calculated value of 5 Amp, and thus, the researchers shall use a 10 AT of Protective Device.[7]

3.2.2 Assembly Procedures

When building the aquaponics system, the area should first be cleared out of any debris or garbage. Before building the outer form of the aquaponics system, it is important to know that the assembly procedure is followed.

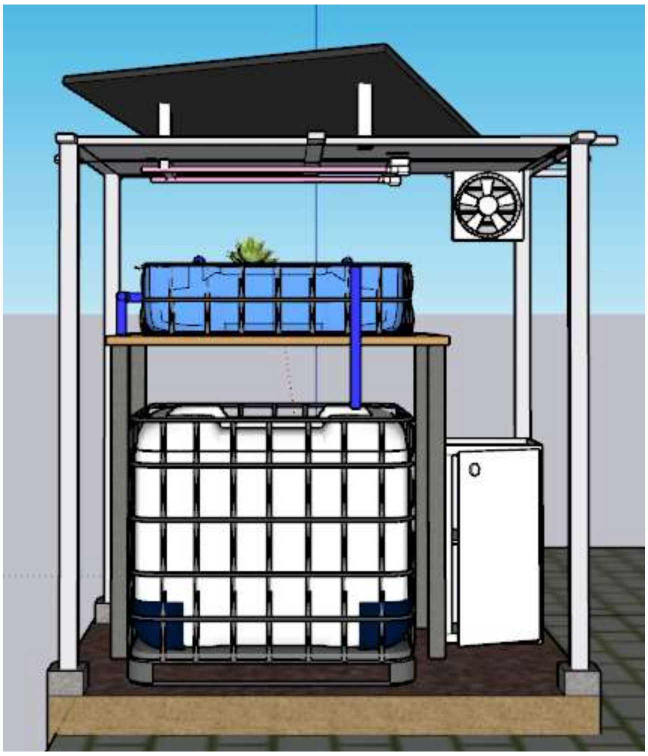


Figure 9. Front View of the Design for the Aquaponics

The whole aquaponics system has a height of 94.9 inches from the ground to the tip of solar panel, length of 49.46 inches and width of 57.6 inches as shown in Figure 9. The steel bar used as the pillar for the aquaponics system is 2.97 meters in height and 1.5 mm in diameter. These steel bars are then placed at the four corners of the 2.85 square meters area for the aquaponics system. The researchers will then wield the top and connect the pillars with a beam. Two additional beams will also be wielded at the middle to form a cross.

The material used for the fish tank is an IBC tank with the dimensions 45.3 x 47.2 x 39.4 inches. It is then placed 12 inches under the grow bed, that has the dimensions 12 x 47.2 x 39.4 inches. The grow bed has 4 rows and 5 columns which totals to 20 plant holes. Each plant whole has a diameter of 3 inches and 7 inches apart from each other. The grow bed is placed 57.3 inches above ground using a platform built specifically for it.

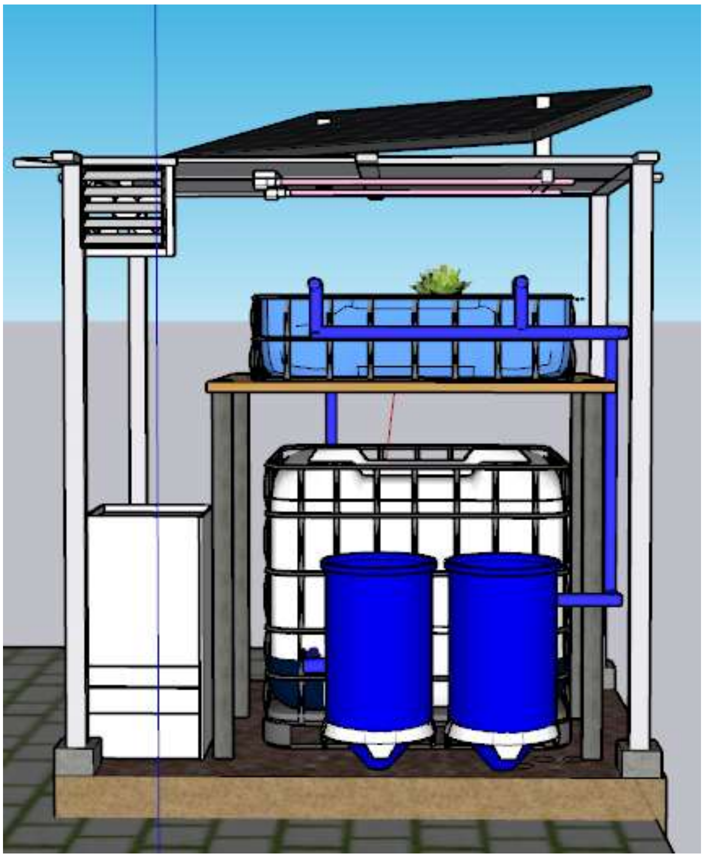


Figure 10. Back View of the Design for the Aquaponics

After that, behind the fish tank under the grow bed, two filter tanks are placed. It has a height of 34.5 inches and 23.5 inches in diameter as shown in Figure 10. The two filter tanks are 12 inches apart from each other and from the fish tank. A cabinet with a height of 35 inches and 12 inches in length and width will be placed on the right side of the grow bed beside the filter tanks. Inside the cabinet will be the inverter, charge controller, microcontroller, and the timer.

The next step when these are in place, connecting them with pipes will take place. The pipes are distributed to 4 different containers, a 3/4" diameter pipe are used to direct water from the fish tank going to the two filter tanks, and a 1/2" diameter pipe is used to carry pumped water up to the grow bed and also to drain water from the grow bed down to the fish tank. The exhaust fan will then be attached at the ceiling of the aquaponics system, just above the cabinet.

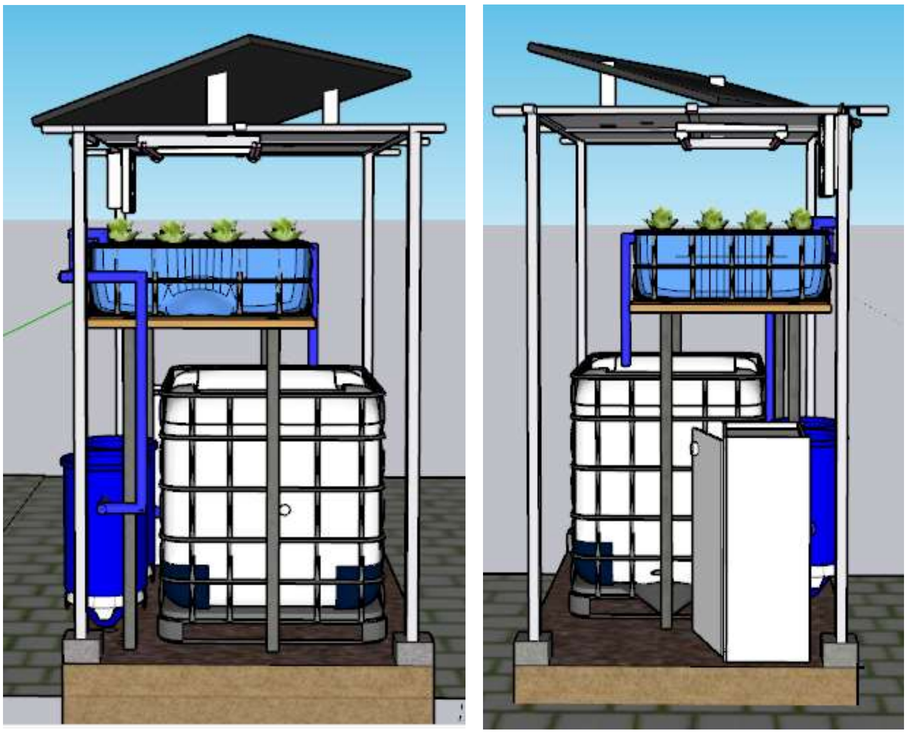


Figure 11. Side View of the Design for the Aquaponics

A grow light will also be placed at the ceiling above the grow bed as shown in Figure 11. What follows this is placing the different sensors into their corresponding places. The pH sensor is installed on the grow bed. DHT22 sensor will be placed on top of the cabinet. The DS18B20 sensor at the fish tank, just enough so that the electronics will not get wet. The aerator will also be placed in the fish tank. the water pump is placed in the biofilter tank.

3.3 Project Cost

3.3.1 Bill of Materials

Table 5. Costing of Materials for the Aquaponics

MATERIAL COST:	GOLDSUN LUMBER AND CONSTRUCTION SUPPLY				
AQUAPONICS					
No.	Item	Unit	Qty.	Price	Total
1	Grow Lights (4ft., 36W LED)	pcs.	1	430	₱ 430.00
2	Net Pot	pcs.	25	20	₱ 500.00
3	Clay Pebles	pack	2	268	₱ 536.00
4	Acid & Base Adjuster	pack	2	400	₱ 800.00
5	Nutrient Solution	litres	2	550	₱ 1,100.00
6	3/4" dia. Control Valve	pcs.	5	65	₱ 325.00
	1/2" dia. Control Valve		5	85	₱ 425.00
7	PVC Cement	pcs.	1	100	₱ 100.00
8	3/4" PVC Pipe	pcs.	2	100	₱ 200.00
	1/2" PVC Pipe		6	80	₱ 480.00
9	3/4" PVC Elbow	lengths	8	15	₱ 120.00
	1/2" PVC Elbow		2	20	₱ 40.00
10	3/4" PVC Coupling	pcs.	4	6	₱ 24.00
	1" PVC Coupling		3	9	₱ 27.00
11	1/2" PVC Male Adapter	pcs.	5	20	₱ 100.00
	3/4" PVC Male Adapter		4	15	₱ 60.00
12	Female Adapter	pcs.	10	20	₱ 200.00
13	3/4" GI Pipe S20	lengths	2	365	₱ 730.00
14	Vulcaseal	pcs.	3	360	₱ 1,080.00
15	Coco Lumber 2x2x10	pcs.	2	100	₱ 200.00
16	3 Gang Universal Adapter	pcs.	2	78	₱ 156.00
17	Hinges	packs	1	37	₱ 37.00
18	Cable Tie	packs	1	205	₱ 205.00
19	Duct Tape	roll	6	180	₱ 1,080.00
20	Flap Disc	pcs.	1	50	₱ 50.00
21	Plastic Moulding 3/4	pcs.	5	90	₱ 450.00
22	Sandpaper	pcs.	4	40	₱ 160.00
23	Drill bit	pcs.	1	85	₱ 85.00
24	THHN wire #12	lengths	10	30	₱ 300.00
25	2 Gang Outlet	set	2	130	₱ 260.00

25	2 Gang Outlet	set	2	130	₱ 260.00
26	3 Gang Outlet	set	2	170	₱ 340.00
27	Single Switch	set	2	90	₱ 180.00
28	Junction Box with Cover	pcs.	2	35	₱ 70.00
29	Rubber Plug	pcs.	3	55	₱ 165.00
30	Polycarbonate Sheet	pcs.	1	1000	₱ 1,000.00
31	Level Hose	lengths	10	20	₱ 200.00
32	Cutting disc	pcs.	10	50	₱ 500.00
33	Check Valve 3/4	pcs.	1	260	₱ 260.00
34	Glass Clip	pcs.	4	150	₱ 600.00
35	PVTWIN-4MM	lengths	5	120	₱ 600.00
36	Paint Brush 1/2	pcs.	10	30	₱ 300.00
37	Paint Brush 1 1/2	pcs.	1	70	₱ 70.00
38	Reducer/Thinner	litres	3	50	₱ 150.00
39	Primer	litres	3	270	₱ 810.00
40	Cement	pcs.	2	230	₱ 460.00
41	Welding Rod 1/2 kg	kg	2	90	₱ 180.00
42	Teflon	pcs	10	20	₱ 200.00
43	Angle Bar	pcs	4	180	₱ 720.00
44	Flat Bar	pcs	3	160	₱ 480.00
45	Silicone	pcs	1	165	₱ 165.00
46	Water Proof Sandpaper	pcs	4	18.5	₱ 74.00
47	Black Screw 2"	pcs	126	2	₱ 252.00
48	Varnish	pcs	1	60	₱ 60.00
49	Flexible 1/2	lengths	3	15	₱ 45.00
50	Blind Rivets	pcs	20	1	₱ 20.00

50	Blind Rivets	pcs	20	1	₱ 20.00
51	Styroboard	pcs	1	128	₱ 128.00
52	Solignum Clear	litres	1	320	₱ 320.00
53	Enamel Paint	litres	1	70	₱ 70.00
54	Plywood	pcs	1	1395	₱ 1,395.00
55	1.5mm GI Tubular	lengths	6	768	₱ 4,608.00
56	Air Stone	pcs.	3	40	₱ 120.00
57	Mechanical Filter	packs	3	320	₱ 960.00
58	Biofilter (K-1)	packs	3	800	₱ 2,400.00
59	Fish Food	packs	1	1450	₱ 1,450.00
60	Timer	pcs.	3	289	₱ 867.00
61	IBC Tank	pcs.	1	6000	₱ 6,000.00
62	UV Plastic	lengths	5	171	₱ 855.00
63	Twist Lock	pcs.	2	150	₱ 300.00
64	Water Tank Barrel	pcs.	2	1300	₱ 2,600.00
TOTAL:					₱ 40,234.00

The Table 5 above shows the list of materials used in the researcher's aquaponics system. The prices are gathered by the researchers through canvassing online. There are 64 items on the list amounting to Php 40, 234.

Table 6. Costing of Materials for the Aquaponics

MATERIAL COST:	DEECO				
DEVICE					
No.	Item	Unit	Qty.	Price	Total
1	Monocrystalline Solar Panels (1ps. 500w) with battery (12v,200ah, 2.4kwh storage Sealed Lead Acid) & Inverter (1kw)	Set	1	45000	₱ 45,000.00
2	Water Pump	pcs.	1	1500	₱ 1,500.00
3	Aerator (18w)	pcs.	1	1200	₱ 1,200.00
4	Arduino Mega	pcs.	1	1500	₱ 1,500.00
5	TDS Sensor & Module	pcs.	1	875	₱ 875.00
6	pH Meter Sensor	pcs.	1	1605	₱ 1,605.00
7	DHT22 Sensor & Module	pcs.	1	139	₱ 139.00
8	Exhaust/Cooling Fan (20w)	pcs.	1	1665	₱ 1,665.00
10	DS18B20 Sensor & Module	pcs.	1	100	₱ 100.00
11	IoT Module (ESP8266)	pcs.	1	100	₱ 100.00
12	Relay Module (4 channels)	pcs.	1	191	₱ 191.00
13	Peristaltic Dosing Valve	pcs.	2	2907	₱ 5,814.00
14	DC Circuit Breaker (32AT-2P)	pcs.	2	230	₱ 460.00
15	AC Circuit Breaker (10AT 2P)	pcs.	1	130	₱ 130.00
16	MC4 30A	pcs.	2	60	₱ 120.00
				TOTAL:	₱ 59,689.00

TOTAL	₱ 103,023.00

The Table 6 above shows the list of devices used in the aquaponics system of the researchers. These devices not only include the solar panel but also the different sensors used in the study. Altogether, there are 16 devices used in the aquaponics system which totals a sum of Php 59,689.

The researchers decided to add a floating budget of Php 3,100 which can be used when the budget is short. In total, the whole aquaponics system costs Php 103,023. The 14 researchers involved in this study will then divide the total cost which is Php 7,835.93 each.

3.4 Project Testing and Evaluation

3.4.1 Functionality Test

3.4.1.1 Solar Panel

The functionality of the solar panel will be tested using a multimeter that is set on DC voltage while being exposed at the sun. The process will be followed by connecting the negative lead and positive lead of a multimeter to the negative and positive wire of the panel, respectively.

3.4.1.2 Battery Bank

The battery's capabilities will be tested by connecting the multimeter's negative lead and positive lead to the negative and positive terminals of the battery, respectively.

3.4.1.3 Solar Charge Controller

To test the functionality of the solar charge controller, the researchers must check the LED display to see if it's working and showing the solar panel and battery readings. Another way is to read the power output using a multimeter. If the readings of the multimeter are very low or there is no voltage output at all, the controller probably has a functionality problem.

3.4.1.4 Inverter

The inverter's functionality will be tested by connecting it to the battery and at a limited controlled power (for testing only). A multimeter will be used to identify the readings of the inverter's output and see if it works fine according to its standards.

3.4.1.5 Aerator

The functionality of the aerator will be tested if the device can air to make enough tiny bubbles that floats from the end of the aerator to the surface of the water and explodes when reaching it.

3.4.1.6 Water Pump

To test the functionality and reliability of the water pump, the device should be checked if the size of the pump is enough to push the water from the fish tank up to the top part of the pipe and push the flow of the water up to the bed of plants.

3.4.1.7 Exhaust Fan

The functionality of the exhaust fan will be evaluated to see if it maintains the necessary ventilation for aquaponics grow rooms, which can exchange, circulate, and mix air to regulate humidity, temperature, and carbon dioxide levels.

3.4.1.8 Microcontroller

The microcontroller functionality test will be evaluated whether the sketch acquired to the desire system maintains the monitoring and controlling of the aquaponic system.

3.4.1.9 ESP32 Module

The ES832 functionality will be evaluated to see whether it maintains the actual data compared in sending data via air to the desired gadgets.

3.4.1.10 DHT22 Module & sensor

The DHT22 testing will determine whether the temperature and humidity of the indoor aquaponic system suffice the requirement of the system.

3.4.1.11 TDS Module & Sensor

The TDS meter will be tested by determining its effectiveness in monitoring the nutrient concentration of the solution in the system.

3.4.1.12 pH Meter Sensor

The pH meter will be tested by determining its capability and accuracy in monitoring the acid and base of the solution in the system.

3.4.1.13 DS18B20 Module & Sensor

The DS18B20 will measure the water temperature of the system. The functionality test will be evaluated whether the measured data suffice the requirement of water temperature of both the fish and plants.

3.4.1.14 Monitoring Website

The Website will be tested for its functionality by determining whether it effectively monitors the systems required by aquaponics, such as the pH value, temperature, humidity level, and water level using the appropriate sensors.

3.4.2 Reliability Test

3.4.2.1 Battery Bank

The electricity produced by the solar panel will be stored in the battery. It is important that there will be no loss of energy while it is stored inside. So, it is a must to make sure the reliability of the battery. Because the electricity stored inside the battery will keep the whole system working while the solar panel cannot produce electricity at night.

3.4.2.2 Solar Charge Controller

The solar charge controller's job is to prevent the inverter and battery from overheating. The reliability must be guaranteed as the workability of the whole system depends on it.

3.4.2.3 Aerator

The reliability of the aerator is important as it makes the water to move and get stirred. Also, aeration plays a big role in keeping the fish healthy because enough aeration allows the fishes to breathe properly.

3.4.2.4 Water Pump

A reliability test for the water pump is important because it plays a big role as it is assigned in distributing the water and the nutrient for the plants.

3.4.2.5 Exhaust Fan

As plants require carbon dioxide (CO_2) for growth and photosynthetic processes, thus the exhaust fan will be put to the test to see if it can reliably supply aquaponics with the required quantities of CO_2 and ensure a fresh supply of air into the grow room.

3.4.3 Benefit-Cost Analysis

Table 7. Benefit & Costing of the Aquaponics System

Cost	Year				
	1	2	3	4	5
Hardware Components	₱ 90,001.00	PHP 0	PHP 0	PHP 0	PHP 0
Labor	₱ 68,200.00	PHP 0	PHP 0	PHP 0	PHP 0
Maintenance	₱ 5,000.00	₱ 5,000.00	₱ 5,000.00	₱ 5,000.00	₱ 5,000.00
Total Cost	₱ 163,201.00	₱ 5,000.00	₱ 5,000.00	₱ 5,000.00	₱ 5,000.00

Benefits	Year				
	1	2	3	4	5
Electricity Conservation	₱ 9,567.27	₱ 9,567.27	₱ 9,567.27	₱ 9,567.27	₱ 9,567.27
Harvest	₱ 28,800.00	₱ 28,800.00	₱ 28,800.00	₱ 28,800.00	₱ 28,800.00
Water Conservation	₱ 1,425.72	₱ 1,425.72	₱ 1,425.72	₱ 1,425.72	₱ 1,425.72
Fertilizer Conservation	₱ 900.00	₱ 900.00	₱ 900.00	₱ 900.00	₱ 900.00
Total Cost	₱ 40,692.99	₱ 40,692.99	₱ 40,692.99	₱ 40,692.99	₱ 40,692.99

Table 8. Costing Breakdown of the Aquaponics System

Components	Wh
grow lights	156
exhaust fan	125
water pump	150
aerator	216
arduino mega	240
TOTAL:	887

	Unit	Amt	Qty per Month	Total per Month	per Year
Water	m^3	36.24	2	72.48	869.76
Maintenance Fee	-	1.50	1	1.50	18
Environmental Charge	-	32.10	1	32.10	385.2
VAT (12%)	-	-	-	12.73	152.755
				TOTAL:	1425.72

	Unit	Amt	Qty	Possible Yield per Month	Total per Year
Ave. Cost of Lettuce	kg	₱ 50.00	20	₱ 400.00	₱ 4,800.00
Ave. Cost of Tilapia	kg	₱ 133.00	50	₱ 2,000.00	₱ 24,400.00

	In liters
Tank	1000
Water Required per Fish	19
Total Fishes in tank	52.6

Rate per kwh based on Meralco	5.4737

kWh	kwh/month	kwh/yr
0.887	145.66	1747.86

Annual Bill	9567.27

Tables 7 and 8 shows the benefits and costs of the study. The costs consist of Hardware components, Labor, and maintenance. The costs of hardware and labor stacked at year one (1) since the project only requires a year to build, and the continuing costs like maintenance persist as long as the project stands. On the other hand, benefits consist of electrical conservation[51], harvest, water conservation[49], and fertilizer conservation. Harvest benefits are determined by the average price of the specific harvest (lettuce and tilapia) in the market[62][77][79]. The conservation benefits are the costs saved in the system instead of relying on distributors.

Table 9. Benefit Cost Analysis of the Aquaponics System

BENEFIT-COST ANALYSIS

Given:	Formula = B/C
B = To be determined	
C = 103,023	
n = 6 years	
i = 6.4% or 0.064	

Time Value of Money: Present Value		
Years (n)	i = 6.4%	i = 10%
0	1.0000	1.0000
1	0.9398	0.9091
2	0.8833	0.8264
3	0.8302	0.7513
4	0.7802	0.6830
5	0.7333	0.6209

FORMULAS	
PV	(1 + i)^n -1 / i (1+i)^n
DIV	1(1+i)^n
PWF	(1+i)^n -1/ i*(1+i)^n
PDV	AMT/(1+i)^n or (AMT)(PWF)
FV	(1*(1+i)^n)

Time Value of Money: Present Value and Future Value				
Op Years	AMT	n	PWF	PDV
1	₱ 40,692.99	2	0.8833	₱ 35,944.82
2	₱ 40,692.99	3	0.8302	₱ 33,782.73
3	₱ 40,692.99	4	0.7802	₱ 31,750.68
4	₱ 40,692.99	5	0.7333	₱ 29,840.87
5	₱ 40,692.99	6	0.6892	₱ 28,045.93
			TOTAL (B)	₱ 159,365.03

B/C	159,365.03/103,023	1.55	> 1

Table 9 above presents the benefit-cost analysis, which is the systematic enumeration of all benefits and costs in the study. In Table 9, the Op years stand for the operational years of the project. The AMT is the benefit calculated per year. Meanwhile, the PWF is the present worth factor. Lastly, the PDV is the AMT x PWF, which is the present-day value of the benefit after inflation. According to Philippine Star, the current inflation rate as of July is 6.4% or 0.064.[63] The benefit-cost ratio is determined by dividing the benefits over costs, and the quotient must be greater than one (1) to be an acceptable investment.

3.4.4 Acceptability Evaluation

The researchers' project study is a Solar-Powered Aquaponics with an IoT-Based Monitoring and Data Gathering; which is an innovative system culturing Lettuce without the use of soil; and a pond which will have Tilapia in it. The system will be powered by the electricity gained by the solar panel, the water will then circulate to the connecting components which will benefit the living organisms found in Aquaponics. Thus, the water will be supervised and monitored with the use of Internet of Things (IoT) which will let the researchers monitor the temperature, humidity etc. of the water circulating around the system.

3.4.4.1 Demographics:

1. Age: Which age bracket includes your age?
   a. 18-20
   b. 21-29
   c. 30-39
   d. 40-49
   e. 50-59
   f. 60 or older
2. Gender: What is your gender?
   a. Male
   b. Female
   c. Others (Specify):
3. Marital Status: What is your current marital status?
   a. Single
   b. Married
   c. Widowed
   d. Divorced
   e. Separated

3.4.4.2 Customer Satisfaction Survey (CSAT)

According to Qualtrics, Customer Satisfaction Survey (CSAT) is a key performance indicator and is usually used to determine the satisfaction of the customers with a certain product or services**.** Moreover, it focuses on evaluating the interaction and reaction of the customer or respondent towards the device at the present time.[17][18]

Table 10. Scale and Interpretation of the CSAT Theory

Scale	Interpretation
5	Very Satisfied
4	Satisfied
3	Neither satisfied nor unsatisfied
2	Unsatisfied
1	Very Unsatisfied

The researchers will use a five-point Likert scale, as Table 10 shows, to determine the satisfaction of the respondents to the overall design, functionality, and performance of the aquaponics system. As indicated in the table, 5 will be the highest and will be interpreted as “Very Satisfied”, 4 for “Satisfied”, 3 for “Neither satisfied nor unsatisfied”, 2 for “Unsatisfied”, and 1 for “Very Unsatisfied”. With that, below are the following questions that the researchers will use:

1. How satisfied are you with the concept of a Solar-Powered Aquaponics with an IoT-Based Monitoring and Data Gathering?
2. How satisfied are you with the overall design of the system?
3. How satisfied are you with the quality of materials used in assembling the system?
4. Rate your satisfaction with the system in resolving agricultural deficiencies and food scarcity.
5. How satisfied are you with the data gathering and monitoring of the website intended solely for the system?
6. Rate your satisfaction with the functionalities of the sensors for monitoring the aquaponics system.
7. Did our Solar-Powered Aquaponics with an IoT-Based Monitoring and Data Gathering meet your expectations?
    a. Yes
    b. No
8. Do you think this project study will be of help to alleviate the current crisis in our agriculture?
    a. Yes
    b. No
9. Do you think that this project study is reliable in terms of the different sensors and devices used to monitor the overall system?
    a. Yes
    b. No
10. Would you recommend the Solar-Powered Aquaponics with an IoT-Based Monitoring and Data Gathering as a solution for agricultural low productivity and food scarcity?
    a. Yes
    b. No

To calculate the CSAT Score, the total number of responses of questions 1 to 6 with 4 (Satisfied) and 5 (Very Satisfied) as it is the two highest values, hence, it would indicate a more accurate predictor of customer satisfaction. The formula is shown below:

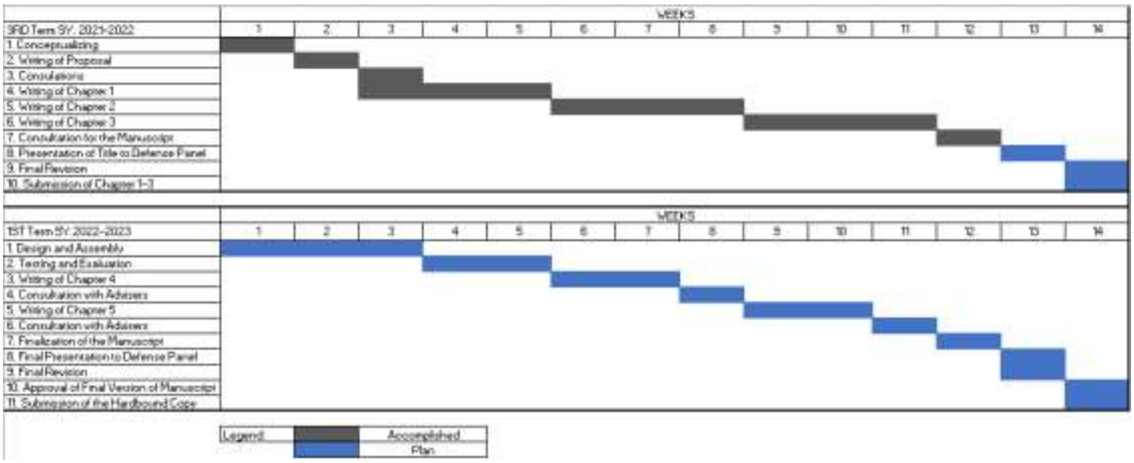
$$\frac{Number\ of\ Satisfied\ Respondents\ (4\ and\ 5)}{Number\ of\ Survey\ Responses} \times 100$$
$$= \%\ of\ Satisfied\ Respondents.$$

Equation 10. Calculation of the Percentage of Satisfied Respondents

3.5 Project Schedule

3.5.1 Gantt Chart

Table 11. Gantt Chart



In the first week of the third term of the school year 2021-2022, the researchers started conceptualizing the study. In the second week, the proposal was written and was shown for consultation the following week. The proposed study by the researchers was approved by two faculty members in the electrical and allied departments. The writing of the first chapter also began in the same week as the consultation and only ended in the fifth week after the start of the third term. From the sixth to eighth week will be the writing of chapter two. Followed by the writing of chapter three on weeks nine to eleven. In the twelfth week, the researchers will consult the professor handling their research paper and make sure that the researchers are ready for the title defense, the following week. The final revision will take place before the first three chapters of the thesis will be submitted in the last week of the term.

Starting on the first term of the school year 2022-2023, the first three weeks will be covered by the design and assembly of the project. The following two weeks will be the testing and evaluation of the system. The next six weeks will be writing chapters 4 and 5 with the consultation with advisers every two weeks. On the twelfth week will be the finalization of the manuscript, followed by final revision after the final presentation to the defense panel next week. The last week will be the approval of the final version of the manuscript and the submission of the hardbound copy.

3.5.2 PERT & CPM

3.5.2.1 PERT

Table 12. Activity Letter, Description, and the Immediate Predecessors

ACTIVITY	DESCRIPTION	IMMEDIATE PREDECESSORS
A	CONCEPTUALIZING	-
B	WRITING OF PROPOSAL	A
C	CONSULTATIONS	B
D	WRITING OF CHAPTER 1	B
E	WRITING OF CHAPTER 2	D
F	WRITING OF CHAPTER 3	E
G	CONSULTATION FOR THE MANUSCRIPT	D, E, F
H	PRESENTATION OF TITLE TO DEFENSE PANEL	G
I	FINAL REVISION	H
J	SUBMISSION OF CHAPTER 1-3	H
K	DESIGN AND ASSEMBLY	J
L	TESTING AND EVALUATION	K
M	WRITING OF CHAPTER 4	K, L
N	CONSULTATION WITH ADVISERS	M
O	WRITING OF CHAPTER 5	M
P	CONSULTATION WITH ADVISERS	O
Q	FINALIZATION OF THE MANUSCRIPT	P
R	FINAL PRESENTATION TO DEFENSE PANEL	Q
S	FINAL REVISION	R
T	APPROVAL OF FINAL VERSION OF MANUSCRIPT	S
U	SUBMISSION OF THE HARDBOUND COPY	S

After conceptualizing for a week, the researchers came up with 21 activities that needs to be done in order for the study to be completed. Based on the Table shown above, except for the first activity which is the conceptualizing of the concept of the study, the other activities can only be done after the required activities are finished. For example, writing the proposal can only be done after the conceptualizing is finished. On the same note, writing of the proposal needs to be done first in order to proceed with consultations and writing of Chapter 1. The other activities follow the same rule up to the final two activities, which can be done simultaneously, but only after the nineteenth activity is completed.

Table 13. The Computed Expected Activity Time (in weeks)

ACTIVITY	DESCRIPTION	IMMEDIATE PREDECESSORS	a	m	b	EXPECTED ACTIVITY TIME IN WEEKS VALUE
A	CONCEPTUALIZING	-	0	1	2	1
B	WRITING OF PROPOSAL	A	0	1	2	1
C	CONSULTATIONS	B	0	1	2	1
D	WRITING OF CHAPTER 1	B	2	3	4	3
E	WRITING OF CHAPTER 2	D	2	3	4	3
F	WRITING OF CHAPTER 3	E	2	3	4	3
G	CONSULTATION FOR THE MANUSCRIPT	D, E, F	0	1	2	1
H	PRESENTATION OF TITLE TO DEFENSE PANEL	G	0	1	2	1
I	FINAL REVISION	H	0	1	2	1
J	SUBMISSION OF CHAPTER 1-3	H	0	1	2	1
K	DESIGN AND ASSEMBLY	J	2	3	4	3
L	TESTING AND EVALUATION	K	1	2	3	2
M	WRITING OF CHAPTER 4	K, L	1	2	3	2
N	CONSULTATION WITH ADVISERS	M	0	1	2	1
O	WRITING OF CHAPTER 5	M	1	2	3	2
P	CONSULTATION WITH ADVISERS	O	0	1	2	1
Q	FINALIZATION OF THE MANUSCRIPT	P	0	1	2	1
R	FINAL PRESENTATION TO DEFENSE PANEL	Q	0	1	2	1
S	FINAL REVISION	R	0	1	2	1
T	APPROVAL OF FINAL VERSION OF MANUSCRIPT	S	0	1	2	1
U	SUBMISSION OF THE HARDBOUND COPY	S	0	1	2	1

The expected time in weeks is the period of time allotted by the researchers to complete the corresponding activities. So far, each activity has been done in accordance with this Table 13 and the researchers aim to keep this up until the thesis is finished. The researchers assumed the minimum time (a), maximum time (b), and most likely time (m) based on their previous experiences and considering the other academic schedules presently. Now, using the formula, as shown below, these three were then used to get the expected time in weeks as indicated in the table.

$$\frac{(a + (4 \times m) + b)}{6}$$

Where:

a = Optimistic Time

m = Most Probable Time

b = Pessimistic Time

Equation 11. Calculation of the Expected Activity Time

Table 14. The Computed Earliest Start Time (EST) and Earliest Finish Time (EFT) & Latest Start Time (LST) and Latest Finish Time (LFT)

ACTIVITY	DESCRIPTION	IMMEDIATE PREDECESSORS	a	m	b	EXPECTED ACTIVITY TIME IN WEEKS VALUE	EST	EFT	LST	LFT
A	CONCEPTUALIZING	-	0	1	2	1	0	1	0	1
B	WRITING OF PROPOSAL	A	0	1	2	1	1	2	1	2
C	CONSULTATIONS	B	0	1	2	1	2	3	2	3
D	WRITING OF CHAPTER 1	B	2	3	4	3	2	5	2	5
E	WRITING OF CHAPTER 2	D	2	3	4	3	5	8	5	8
F	WRITING OF CHAPTER 3	E	2	3	4	3	8	11	8	11
G	CONSULTATION FOR THE MANUSCRIPT	D, E, F	0	1	2	1	11	12	11	12
H	PRESENTATION OF TITLE TO DEFENSE PANEL	G	0	1	2	1	12	13	12	13
I	FINAL REVISION	H	0	1	2	1	13	14	13	14
J	SUBMISSION OF CHAPTER 1-3	H	0	1	2	1	13	14	13	14
K	DESIGN AND ASSEMBLY	J	2	3	4	3	14	17	14	17
L	TESTING AND EVALUATION	K	1	2	3	2	17	19	17	19
M	WRITING OF CHAPTER 4	K, L	1	2	3	2	19	21	19	21
N	CONSULTATION WITH ADVISERS	M	0	1	2	1	21	22	21	22
O	WRITING OF CHAPTER 5	M	1	2	3	2	22	24	22	24
P	CONSULTATION WITH ADVISERS	O	0	1	2	1	24	25	24	25
Q	FINALIZATION OF THE MANUSCRIPT	P	0	1	2	1	25	26	25	26
R	FINAL PRESENTATION TO DEFENSE PANEL	Q	0	1	2	1	26	27	26	27
S	FINAL REVISION	R	0	1	2	1	27	28	27	28
T	APPROVAL OF FINAL VERSION OF MANUSCRIPT	S	0	1	2	1	28	29	28	29
U	SUBMISSION OF THE HARDBOUND COPY	S	0	1	2	1	28	29	28	29

As shown in Table 14, the earliest start time (EST) is the earliest finish time (EFT) from the predecessor activity, with the exception of the first activity or activities that do not have a predecessor, their EST will always be zero. On the other hand, the EFT can be obtained by adding the EST to the expected time in weeks to finish the activity. It is computed using the Forward Pass, or starting from Activity A to Activity U.

Different from how the EST and EFT are obtained, to get the LST and LFT must first start from the end. The EFT from the last activity will be the LFT of the same activity. To get the LST, the LFT is subtracted from the expected time to finish the activity. It is a bit similar to how the EST and EFT are obtained but it is done in reverse or backward and instead of addition, it uses subtraction that is why this method of calculation is called a backward pass. While the method used in getting the EST and EFT is forward pass.

Table 15. The Computed Standard Deviation, Variance, and Z-Score

a	m	b	EXPECTED ACTIVITY TIME IN WEEKS VALUE	EST	EFT	LST	LFT	SLACK	CRITICAL	STD. DEVIATION	VARIANCE
0	1	2	1	0	1	0	1	0	YES	0.33	0.11
0	1	2	1	1	2	1	2	0	YES	0.33	0.11
0	1	2	1	2	3	2	3	0	YES	0.33	0.11
2	3	4	3	2	5	2	5	0	YES	0.33	0.11
2	3	4	3	5	8	5	8	0	YES	0.33	0.11
2	3	4	3	8	11	8	11	0	YES	0.33	0.11
0	1	2	1	11	12	11	12	0	YES	0.33	0.11
0	1	2	1	12	13	12	13	0	YES	0.33	0.11
0	1	2	1	13	14	13	14	0	YES	0.33	0.11
0	1	2	1	13	14	13	14	0	YES	0.33	0.11
2	3	4	3	14	17	14	17	0	YES	0.33	0.11
1	2	3	2	17	19	17	19	0	YES	0.33	0.11
1	2	3	2	19	21	19	21	0	YES	0.33	0.11
0	1	2	1	21	22	21	22	0	YES	0.33	0.11
1	2	3	2	22	24	22	24	0	YES	0.33	0.11
0	1	2	1	24	25	24	25	0	YES	0.33	0.11
0	1	2	1	25	26	25	26	0	YES	0.33	0.11
0	1	2	1	26	27	26	27	0	YES	0.33	0.11
0	1	2	1	27	28	27	28	0	YES	0.33	0.11
0	1	2	1	28	29	28	29	0	YES	0.33	0.11
0	1	2	1	28	29	28	29	0	YES	0.33	0.11
											2.33
											1.53

$$Z = \frac{T-29}{1.53} = \frac{31-29}{1.53} = 1.31 \quad 0.9049 \times 100\% \quad 90.50\%$$

The standard deviation is needed to get the variance. To obtain the standard deviation is by dividing the difference between the Pessimistic time (b) and Optimistic time (a) into 6. The variance is the standard deviation squared. The next step will be to get the probability of completing the study. In order to do that, the formula used will be the difference between the expected completion time and the expected completion time in the critical path divided by the variance of the critical path. The answer, which is 1.31, will then be plotted on the Z-score to get the corresponding probability of 90.50%. This means that the probability of completing the project in 29 weeks is 90%.

3.5.5.2 CPM

Table 16. Time-Cost Trade-Offs

ACTIVITY	DESCRIPTION	EXPECTED TIME (in weeks)	EARLIEST START TIME(in weeks)	EST INPUT	LATEST START (in weeks)	LST INPUT	TOTAL RESOURCES REQUIRED
A	CONCEPTUALIZING	1	0	1	0	1	₱ -
B	WRITING OF PROPOSAL	1	1	1	1	2	₱ -
C	CONSULTATIONS	1	2	2	2	3	₱ 520.00
D	WRITING OF CHAPTER 1	3	2	2	2	3	₱ -
E	WRITING OF CHAPTER 2	3	5	5	5	6	₱ -
F	WRITING OF CHAPTER 3	3	8	8	8	9	₱ 600.00
G	CONSULTATION FOR THE MANUSCRIPT	1	11	11	11	12	₱ -
H	PRESENTATION OF TITLE TO DEFENSE PANEL	1	12	12	12	13	₱ 3,500.00
I	FINAL REVISION	1	13	13	13	14	₱ -
J	SUBMISSION OF CHAPTER 1-3	1	13	13	13	14	₱ 1,500.00
K	DESIGN AND ASSEMBLY	3	14	14	14	15	₱ 90,001.00
L	TESTING AND EVALUATION	2	17	17	17	18	₱ 1,500.00
M	WRITING OF CHAPTER 4	2	19	19	19	20	₱ -
N	CONSULTATION WITH ADVISERS	1	21	21	21	22	₱ 1,500.00
O	WRITING OF CHAPTER 5	2	22	22	22	23	₱ -
P	CONSULTATION WITH ADVISERS	1	24	24	24	25	₱ 1,500.00
Q	FINALIZATION OF THE MANUSCRIPT	1	25	25	25	26	₱ 1,500.00
R	FINAL PRESENTATION TO DEFENSE PANEL	1	26	26	26	27	₱ 5,500.00
S	FINAL REVISION	1	27	27	27	28	₱ -
T	APPROVAL OF FINAL VERSION OF MANUSCRIPT	1	28	28	28	28	₱ 2,000.00
U	SUBMISSION OF THE HARDBOUND COPY	1	28	28	28	28	₱ 4,000.00
	TOTAL DAYS					TOTAL	₱ 113,621.00

Table 16 lists the activities and expected completion time throughout the study. The activities are itemized in the description column and the expected activity time in weeks in the column beside. Expected activity time is the duration of each activity, and the earliest start time is the earliest possible time in weeks where the activity can start. On the contrary, the latest start time is the latest possible time in weeks where the activity can start. The total resources column lists the calculated expenses of each activity.

Table 17. Earliest Start Time Costing

FOR EARLIEST START TIME

ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	0													
B	0													
C		520												
D		0	0	0										
E					0	0	0							
F								200	200	200				
G											0			
H												3,500		
I													0	
J													1500	
K														30000.33
L														
M														
N														
O														
P														
Q														
R														
S														
T														
U														
WEEKLY COST	0	520	0	0	0	0	0	200	200	200	0	3500	1500	30000.33
CUMMULATIVE PROJECT COST	520	520	520	520	520	520	520	720	920	1120	920	4620	6120	36120.33

ACTIVITY	15	16	17	18	19	20	21	22	23	24	25	26	27	28
A														
B														
C														
D														
E														
F														
G														
H														
I														
J														
K	30000.33	30000.33												
L			750	750										
M					0	0								
N							1500							
O								0	0					
P										1500				
Q											1500			
R												5500		
S													0	
T														2000
U														4000
WEEKLY COST	30000.33	30000.33	750	750	0	0	1500	0	0	1500	1500	5500	0	6000
CUMMULATIVE PROJECT COST	66120.67	96121	96871	97621	97621	97621	99121	99121	99121	100621	102121	107621	107621	113621

Table 18. Latest Start Time Costing

FOR LATEST START TIME

ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
A	0																											
B		0																										
C			720																									
D			0	0	0																							
E						0	0	0																				
F									200	200	200																	
G												0																
H													3500															
I														0														
J														1500														
K															[illegible]	[illegible]	[illegible]											
L																		750	750									
M																				0	0							
N																						[illegible]						
O																							0	0				
P																									1500			
Q																										1500		
R																											[illegible]	
S																												0
T																												[illegible]
U																												[illegible]
WEEKLY COST	0	0	720	0	0	0	0	0	200	200	200	0	3500	[illegible]	[illegible]	[illegible]	[illegible]	750	750	0	0	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]
CUMMULATIVE PROJECT COST	0	0	720	720	720	720	720	720	720	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The Table 17 shows the earliest start time costing every week. This is the money spent every week at the earliest start time for fourteen weeks. The Table 18, on the other hand, represents the money spent at the latest start time costing, which is the money spent at the latest start time.

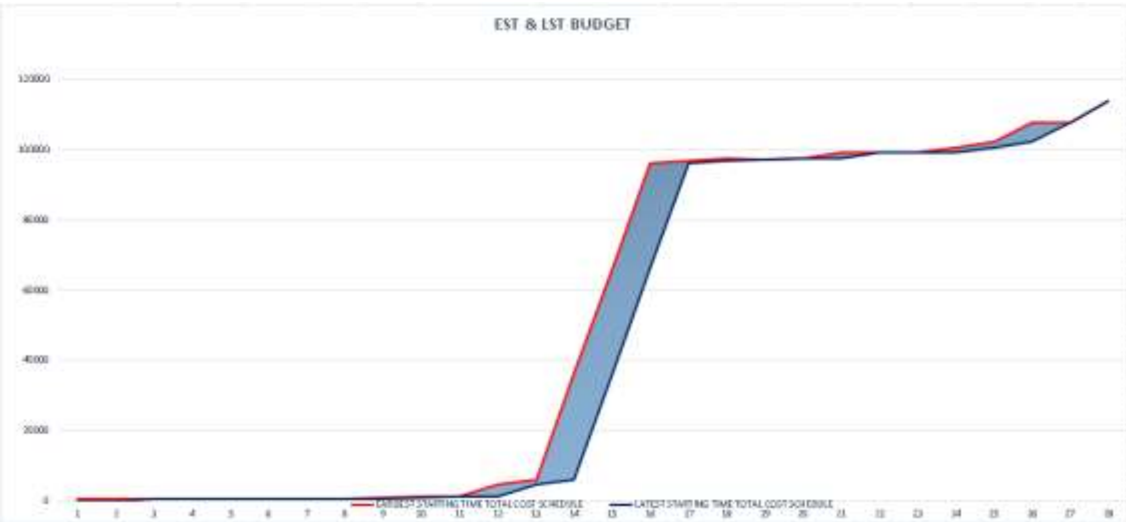


Figure 12. Graph of the Earliest and Latest Start Time Costing

As shown in Figure 12, the range between the EST costing and LST costing is the feasible budget for total project costs. This means that only the money within that range can be used in the project.

IV. RESULTS AND DISCUSSIONS

This chapter discusses the results gathered by the researchers during the testing phase of the study from 19th to 23rd, and 27th to 29th of December 2022. It includes the different parameters being monitored, charging capacity, pH level, growth of both fish and lettuce, codes, and the survey questionnaires being answered.

4.1 Data Parameters

4.1.1 Room Temperature

Table 19. Five-hour trends of room temperature for eight (8) days of the aquaponics system.

ROOM TEMPERATURE						
DATE	10:00 am	11:00 am	12:00 pm	1:00 pm	2:00 pm	AVERAGE
12/19/2022	30.75	31.25	28.92	27.84	27.91	29 °C
12/20/2022	32.92	33.28	33.8	31	29.7	32 °C
12/21/2022	31.76	30.28	33	32.23	31.54	32 °C
12/22/2022	31.71	32.05	31.98	33.04	31.99	32 °C
12/23/2022	32.6	32	31.88	31.88	32.01	32 °C
12/27/2022	29.92	29.86	29.9	29.82	28.22	30 °C
12/28/2022	33	33.1	33.34	30.88	31.92	32 °C
12/29/2022	33.7	32.88	30.5	33	31.92	32 °C

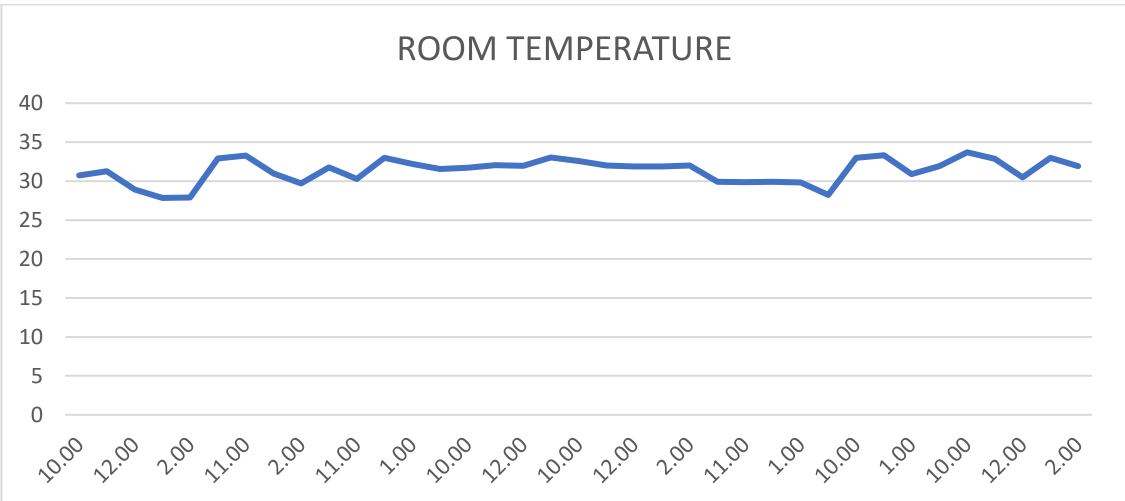


Figure 13. Five-hour trends of room temperature for eight (8) days of the aquaponics system.

Table 19 and Figure 13 above shows the five-hour trends of the room temperature of the aquaponics system. Monitoring the climatic condition of the inside of the enclosed area is a crucial part for the growth of the lettuce. The data gathering period was from 19th to 23rd, 26th, 28th, and 29th of December 2022. The lowest average temperature from the covered days of observation is from the 19th of December 2022, which is 29 °C. On the other hand, all the other days got an average of 32 °C except on the 26th of December 2022 with 30 °C mean. Overall, the average temperatures of each day met the desired setpoint of the aquaponics set-up.

4.1.2 Humidity

Table 20. Five-hour trends of humidity for eight (8) days of the aquaponics system.

HUMIDITY						
DATE	10:00 am	11:00 am	12:00 pm	1:00 pm	2:00 pm	AVERAGE
12/19/2022	63.06	62.425	54.78	81.6	76.2	68%
12/20/2022	52.76	59.5	60.92	69.14	60.92	61%
12/21/2022	49.78	50.06	47.98	49.41	51.08	50%
12/22/2022	49.01	47.91	48.03	49.45	50.12	49%
12/23/2022	47.9	50.9	48.02	41.42	48.52	47%
12/27/2022	61.31	62.28	65.68	67.22	70.66	65%
12/28/2022	56.08	56.16	51.58	61.24	69.36	59%
12/29/2022	54.12	58.79	63.98	65.16	70.1	62%

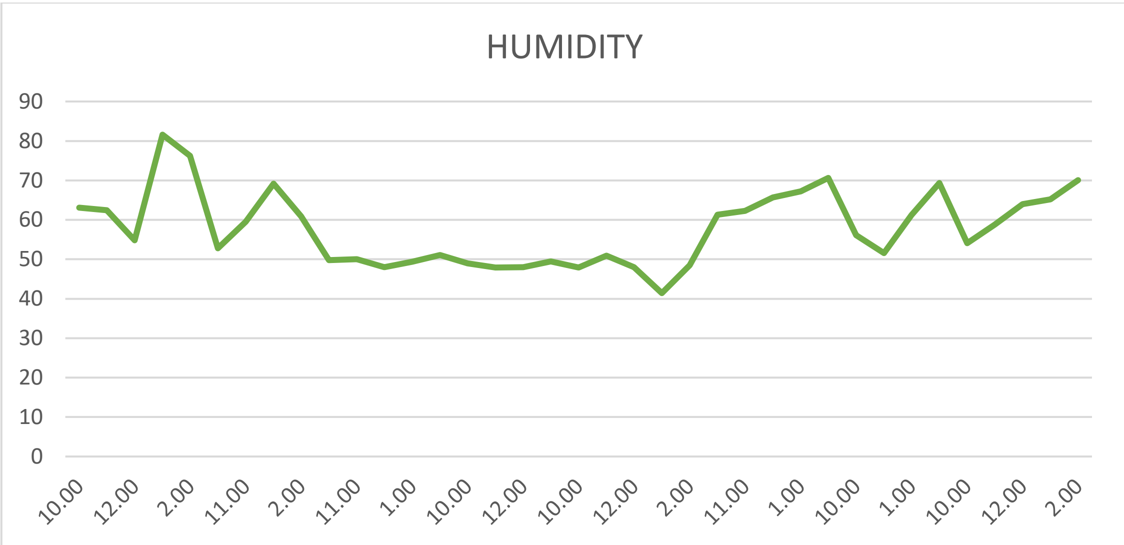


Figure 14. Five-hour trends of humidity for eight (8) days of the aquaponics system.

Humidity is related to the temperature inside the enclosed aquaponics. According to Louisville, KY, Weather Forecast Office, warm air can possess more water vapor (moisture) than cold air, so with the same amount of absolute/specific humidity, air will have a higher relative humidity if the air is cooler, and a lower relative humidity if the air is warmer [55]. With that, as indicated in Figure 14, December 19 has the highest average among the other days with a recorded humidity of 68%. While the lowest recorded humidity was 47% on December 23.

4.1.3 Water Temperature

Table 21. Five-hour trends of water temperature for eight (8) days of the aquaponics system.

WATER TEMPERATURE						
DATE	10:00 am	11:00 am	12:00 pm	1:00 pm	2:00 pm	AVERAGE
12/19/2022	26.69	27.06	26.94	27.012	26.99	27 °C
12/20/2022	26.928	26.928	27.036	27.25	27.052	27 °C
12/21/2022	26.991	27.203	27.01	26.76	26.96	27 °C
12/22/2022	26.778	27.091	26.18	26.03	27.19	27 °C
12/23/2022	26.5	26.5	26.1	26.95	27.02	27 °C
12/27/2022	26.121	26.154	26.178	26.286	26.324	26 °C
12/28/2022	26.86	26.13	26.38	26.666	26.678	27 °C
12/29/2022	26.548	26.654	26.56	26.386	26.738	27 °C

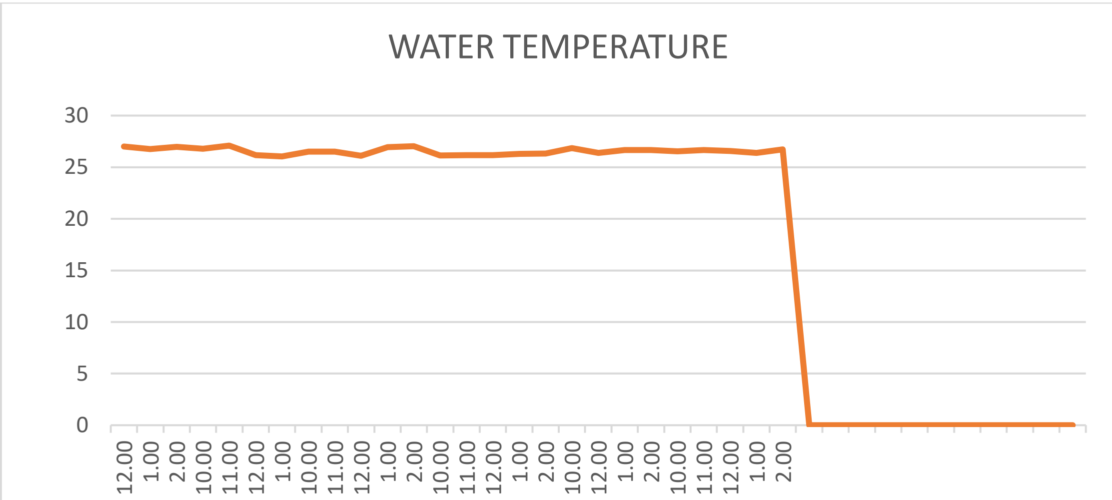


Figure 15. Five-hour trends of water temperature for eight (8) days of the aquaponics system.

Water plays an important role in aquaponics. Therefore, the temperature of the water, specifically in the fish tank, must be monitored. In the five-hour schedule of gathering water temperature data, most of the days got the same average temperature of water, which is 27 °C. In addition, 26 °C is the mean of all the temperatures observed on the 26th of December 2022. With the aquaponics being located to an area where sunlight is directly affecting the water temperature, hence, it summarizes how some of the recorded temperatures are fluctuating from time to time.

4.1.4 Water & Room Temperature Calibrating Comparison

Table 22. Room Temperature Comparison

Alcohol-based Thermometer	Temperature Sensor (DHT22)	% Slope	r^2	Slope	Intercept	Remarks
30	30.69	102%	0.9603	0.55	13.95	PASSED
30.9	31	100.32%				PASSED
30.9	31.10	100.65%				PASSED
31.8	31.10	97.80%				PASSED
32.5	32.10	98.77%				PASSED
33.7	32.60	96.74%				PASSED

Table 23. Water Temperature Comparison

Alcohol-based Thermometer	**Temperature Sensor (DHT22)**	**% Slope**	r^2	**Slope**	**Intercept**	**Remarks**
26	26.94	103.62%	0.88	0.1562	22.97	PASSED
26	27	103.85%				PASSED
26	27	103.85%				PASSED
26	27.19	104.58%				PASSED
28	27.31	97.54%				PASSED
28	27.38	97.79%				PASSED

Certified True and Correct By:

Jonathan Daved D. Dela Cruz, LPT, RChT
Faculty, Chemistry and Science Education,
Science Coordinator, Basic Arts and
Sciences Department
Technological University of the Philippines – Taguig

The data in Table 22 shows the six (6) different readings of the room temperature of the aquaponics system with each having 10-minute intervals of observations. The researchers used to compare the results gathered using an alcohol-based thermometer and the DHT22 sensor. The percentage in correlations of the results are close. The regression result is 0.9603 that has a slope and intercept of (0.55, 13.95).

On the other hand, the comparison of the results in water temperature observed by using, again, alcohol-based thermometer, and DS18B200, was shown in Table 23. They are observed in 10-minute time intervals. The marginal differences are so little that they all almost have the same outcomes. The percentage in terms of the correlation of the two instruments all ranges from more than a hundred percent and have a regression result which is 0.88 that has a slope and intercept of (0.1562, 22.97).

In this case, both of the comparisons have passed the 85 to 105 percent result of regression, so the remarks of the researchers are passed.

4.1.5 Total Dissolved Solids (TDS)

Table 24. Five-hour trends of total dissolved solids for eight (8) days of the aquaponics system.

TOTAL DISSOLVED SOLIDS (TDS)						
DATE	10:00 am	11:00 am	12:00 pm	1:00 pm	2:00 pm	AVERAGE
12/19/2022	209.9	207.05	283.162	272.754	281.01	251 ppm
12/20/2022	284.226	242.582	240.052	258.257	240.052	253 ppm
12/21/2022	305.101	298.945	305.023	301.145	286.086	299 ppm
12/22/2022	369.69	390.012	310.15	378.05	390.952	368 ppm
12/23/2022	479.17	460.23	401.95	485.91	398.21	445 ppm
12/27/2022	483.93	488.88	593.176	479.854	598.684	529 ppm
12/28/2022	560.388	510.846	498.93	482.864	461.818	503 ppm
12/29/2022	478.89	478.582	460.17	452.382	454.6	465 ppm

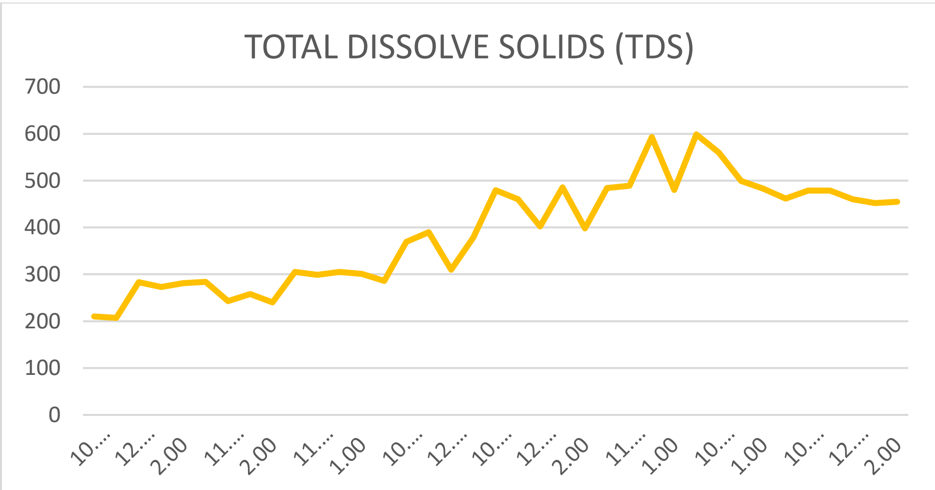


Figure 16. Five-hour trends of total dissolved solids for eight (8) days of the aquaponics system.

Fish deposits waste such as their feces. Also, they are being fed by foods solely for their type. The purpose of detecting the total dissolved solids is to distinguish how many solids were in the water. The average being observed is increasing day by day. The first day of the TDS data gathering, which is19th of December 2022, got the lowest average of 251 ppm. On the other hand, 529 ppm was the highest recorded TDS average, and it was from 28th of December 2022.

4.2 Charging Capacity

Table 25. Five-hour trends of charging capacity for eight (8) days of the aquaponics system.

DATE	10:00 am	11:00 am	12:00 pm	1:00 pm	2:00 pm
12/19/2022	19	24	29	35	37
12/20/2022	20	22	26	29	34
12/21/2022	24	34	43	49	51
12/22/2022	20	23	28	37	43
12/23/2022	30	34	43	50	56
12/27/2022	34	39	44	48	52
12/28/2022	41	46	50	55	63
12/29/2022	26	38	47	57	65

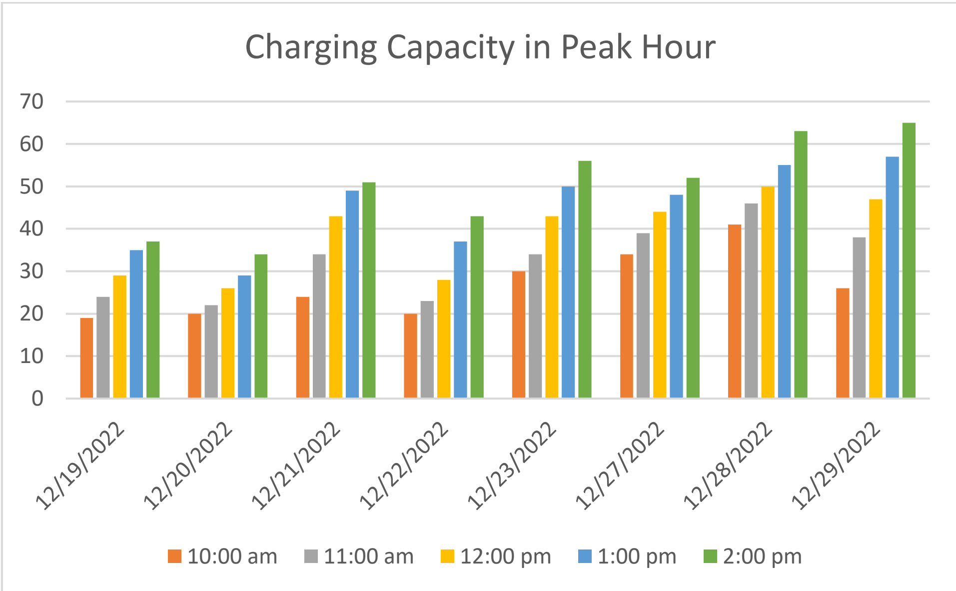


Figure 17. Five-hour trends of charging capacity for eight (8) days of the aquaponics system.

Table 26. Four trends of charging capacity average for eight (8) days of the aquaponics system.

DATE	1	2	3	4	AVERAGE
12/19/2022	5	5	6	2	4.5
12/20/2022	2	4	3	5	3.5
12/21/2022	10	9	6	2	6.8
12/22/2022	3	5	9	6	5.8
12/23/2022	4	9	7	6	6.5
12/27/2022	5	5	4	4	4.5
12/28/2022	5	4	5	8	5.5
12/29/2022	12	9	10	8	9.8
			Average Ah per day		5.8

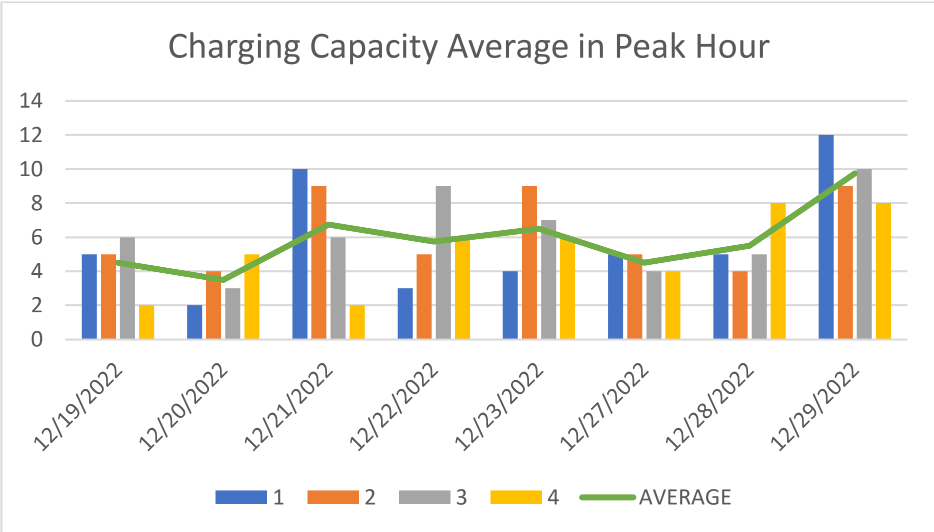


Figure 18. Four-hour trends of charging capacity average for eight (8) days of the aquaponics system.

The researchers started gathering the data of the Charging Capacity on December 19 - 29, 2022, except for December 24 - 26, 2022. The given values were recorded during the peak hours of the sun which is from 10 a.m. to 2 p.m. During the gathering of data, the highest average Ampere per hour recorded is 9.8 with the lowest being 3.5. The average Ampere per hour during peak hours per day is 5.8.

The reason for it being so low is the weather. There was not enough sunlight getting through that day because of the cloudy weather. And because the solar panel can only produce energy when there is enough sunlight. The efficiency of the solar panel was reduced thus having a low average Ampere per hour. Meanwhile, on December 29, 2022, the solar panel was properly exposed to sunlight during the sun's peak hours. Hence, it was able to produce 9.8 Ampere per hour.

Therefore, the solar panel will be more efficient if it is in a position where there is enough sunlight for it to produce energy.

4.3 PV Voltage and Charging Current

Table 27. Three-hour trends of PV voltage and charging current for three (3) days of the aquaponics system.

DATE	PARAMETER	11:00 am	12:00 pm	1:00 pm
01/05/2023	PV VOLTAGE	39.4	37.1	39.3
	CHARGING CURRENT	4.18	1.74	9.76
01/06/2023	PV VOLTAGE	38.8	38.3	38.5
	CHARGING CURRENT	5.61	4.42	5.97
01/07/2023	PV VOLTAGE	41.4	39.7	38.4
	CHARGING CURRENT	4.81	3.46	6.12

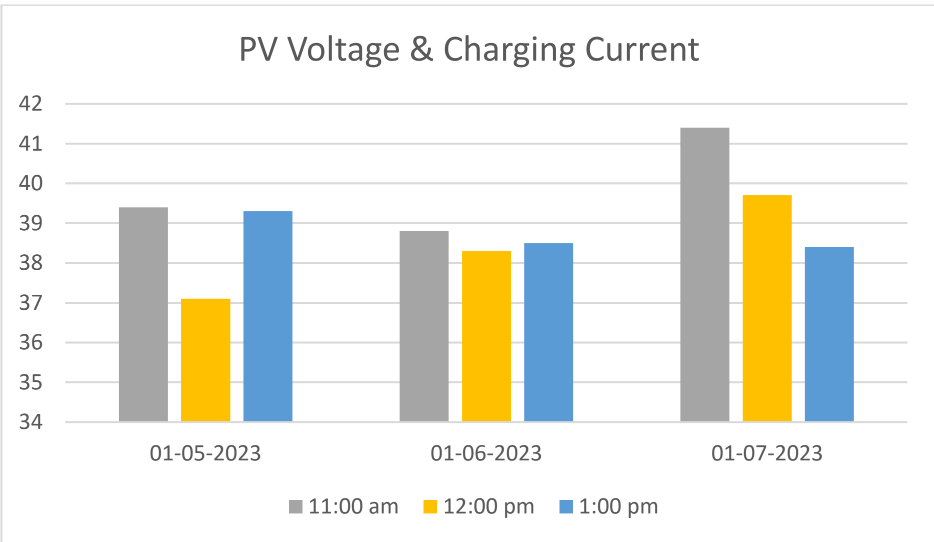


Figure 19. Three-hour trends of PV voltage and charging current for three (3) days of the aquaponics system.

The researchers started gathering the data on the PV voltage and charging current on January 5 - 7, 2023. The given values were recorded during the sun peak hours which are from 11 a.m. to 1 p.m. Throughout the duration of the data gathering, the highest PV voltage recorded was 41.4 V which was on January 7, 2023, at 11 am. The highest charging current on the other hand was 9.76 A on January 5, 2023, at 1 pm. The lowest recorded PV voltage and charging current was on January 5, 2023, at 12 pm.

The only reason why there are differences between these two parameters is the amount of sunlight absorbed by the PV panel. During cloudy weather, although the voltage will be still high the charging current will be much lower.

4.4 pH Level

According to Sigma Aldrich Labware Notes, a company that manufactures instruments that is calibrated to measure any laboratory sampling, the %Slope should be between 85% and 105%. On the other hand, r^2 is the regression, which shows the relationship between the x and y variable. If the value of r^2 is closer to 1, it means that there is a relationship between the x and y variable.

The data in Table 28 and 29 shows the three (3) different readings in three different buffer solutions. The researchers compared the results collected by the two sensors to verify whether the sensor used by the researchers is valid. In Table 28, the Hanna Instrument percentage in correlations of the results are very close. The regression result is 0.999 that has a slope and intercept of 0.969 and 0.026 respectively. In Table 29, the DF Robot percentage in correlations of the results are very close. The regression result is 0.998 that has a slope and intercept of 1.111, -0.8078 respectively.

The results of both sensors have passed the 85 to 105 percent result of regression, so the remarks of the researchers are passed.

Table 28. Measured pH Level on different buffer solution using Hanna Instrument.

Hanna Instrument pH Level Sensor Calibration						
Buffer Solution	Measured pH	% Slope	r^2	Slope	Intercept	REMARKS
6.86	6.68	97.37	0.999	0.969	0.026	PASSED
9.18	8.92	97.16				
4.01	3.91	97.5				

Table 29. Measured pH Level on different buffer solution using DF Robot.

DF Robot pH Level Sensor Calibration						
Buffer Solution	Measured pH	% Slope	r^2	Slope	Intercept	REMARKS
6.86	6.65	96.93	0.998	1.111	-0.8078	PASSED
9.18	9.48	96.63				
4.01	3.72	92.76				

Hanna Instrument pH Level Sensor Calibration						
Buffer Solution	Measured pH	% Slope	r^2	Slope	Intercept	REMARKS
6.86	6.68	97.37	0.999	0.969	0.026	PASSED
9.18	8.92	97.16				
4.01	3.91	97.50				

pH level of water from the fish tank read by Hanna Instrument: 5.60

DF Robot pH Level Sensor Calibration						
Buffer Solution	Measured pH	% Slope	r^2	Slope	Intercept	REMARKS
6.86	6.65	96.93	0.998	1.111	-0.8078	PASSED
9.18	9.48	96.63				
4.01	3.72	92.76				

pH level of water from the fish tank read by DF Robot Sensor: 6.48

PHOTO DOCUMENTATION:

Certified True and Correct By:

Mr. C[illegible]pher [illegible]s, MSc, RChT 1/11/23
Section Head, BET Ch[illegible]mical Technology
Chemical Technology Department, TUP-T

4.5 Growth of the Fish (Tilapia)

Table 30. Average length of the fish for eight (8) days of the aquaponics system.

DAY	LENGTH
1	0.80315
2	0.809712
3	0.809712
4	0.814961
5	0.826772
6	0.892389
7	0.939633
8	0.954069

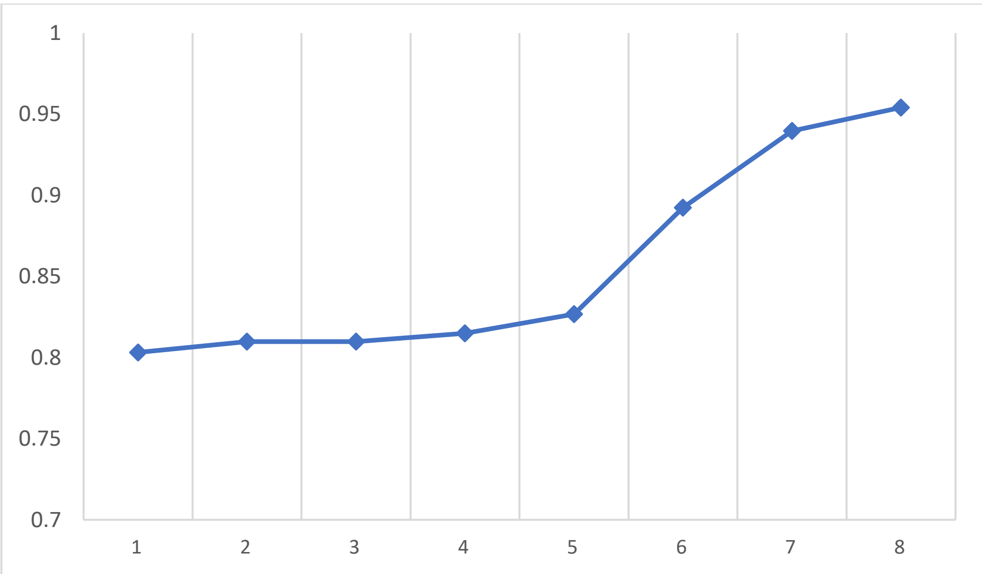


Figure 20. Average length of the fish for eight (8) days of the aquaponics system.

$$\frac{(\text{length})\ (\text{side girth})\ (\text{top girth})}{900}$$

Equation 12. Estimated Weight of the Fat-bodied Fish

Table 31. Average weight of the fish for eight (8) days of the aquaponics system.

DAY	WEIGHT
1	2.01E-05
2	2.1E-05
3	2.44E-05
4	3.11E-05
5	3.67E-05
6	5.72E-05
7	7.5E-05
8	7.76E-05

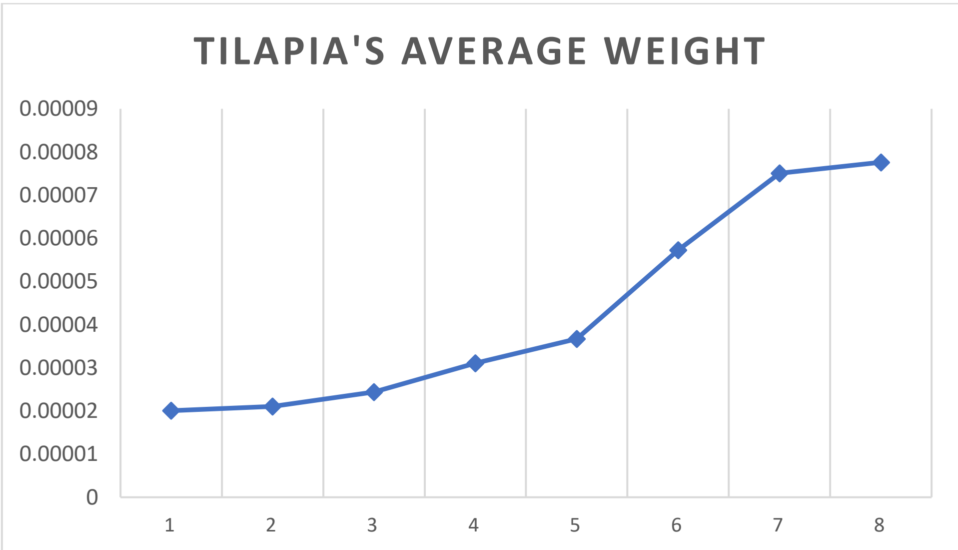


Figure 21. Average weight of the fish for eight (8) days of the aquaponics system.

In an aquaponics system, good production happens by having good growth, specifically for principal supply of nutrients of the plants—the tilapia. The researchers began with 150 pieces of three-week-old tilapia fingerlings for the system. Initially, the number of fish was supposedly only 50 pieces. Slight changes were made, like in the number of species, since growing fish at that early stage has a high chance of demise for several reasons. And so, for preventive measures, adding more fish was made to meet the nutritional requirements of the lettuce plant. Thus, 30 out of 50 freshwater tilapias were selected to be observed in the water tank.

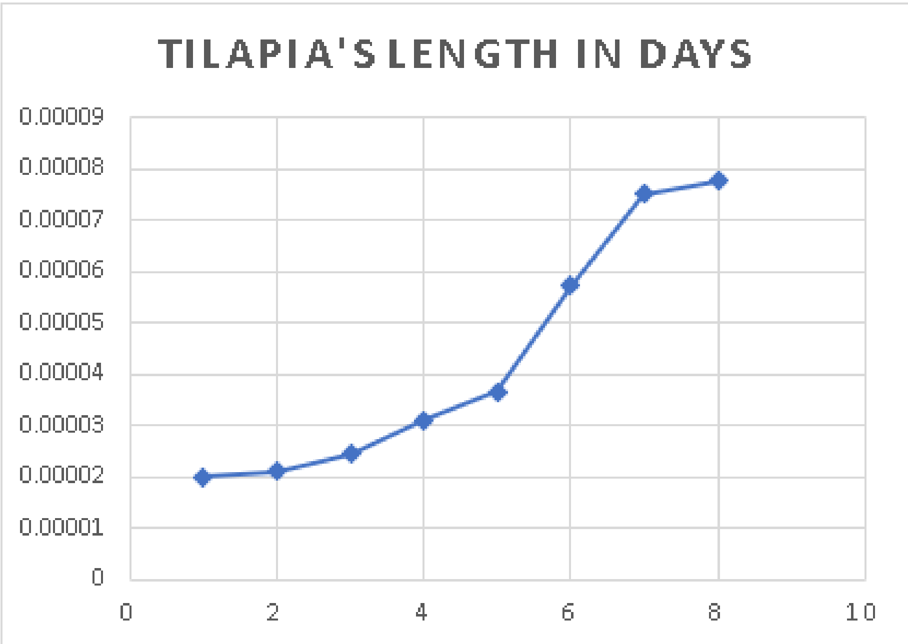


Figure 22. Average length of the fish for eight (8) days of the aquaponics system.

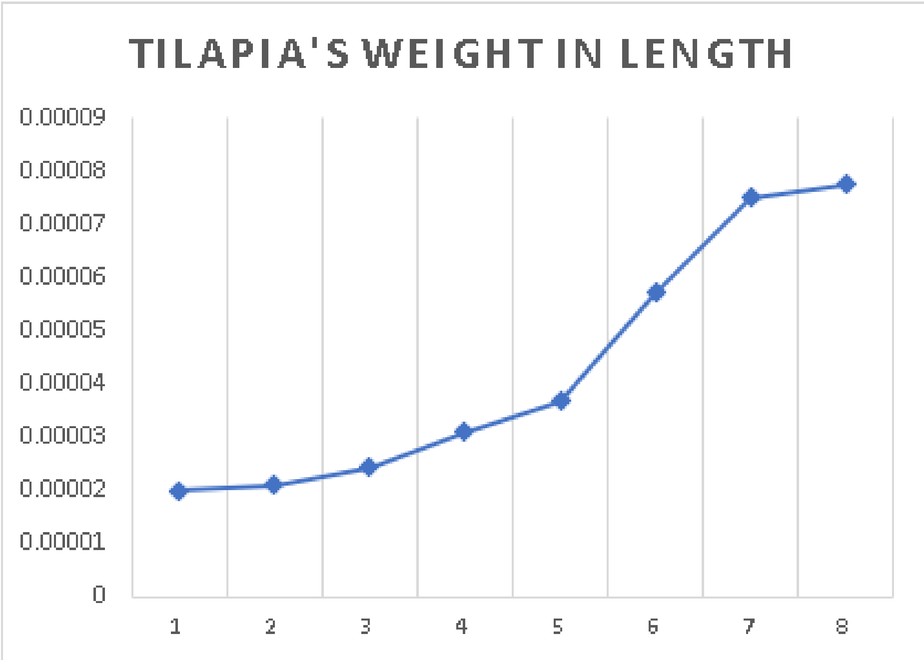


Figure 23. Average weight of the fish for eight (8) days of the aquaponics system.

$$\frac{\text{Number of dying animals in a month} * 100}{\text{Number of fish in the collection at the same time}}$$

$$\frac{22*100}{150} \quad 14.66667$$

Equation 13. Mortality Rate of the Fish

The results above are the observations concerning the development of tilapia, whether its growth changes rapidly or gradually. In the initial measurement for the average length shown on Graph 10, the result is 0.80 inches. On the other hand, its weight is 0.00002 g, shown in Graph 11. After days of rearing, it grew to 0.95 inches in length and 0.000077 g in weight. And at the final monitoring, it was determined that the difference between the initial mean length and weight is 0.15 in. and 0.000057 g. In addition, the weight gain of the tilapia in this study was quite reasonable given the time of observation, which may be a result of enhanced management techniques, high-quality feed, and the right temperature throughout the system.

Moreover, 22 out of 150 tilapias died between the first day of their entry into the system and the last day of monitoring. According to its growth and mortality rates, tilapia is growing sufficiently and dying off at a relatively low percentage, which is 14.67 %. It happened due to a lack of oxygen when some parts of the water system, including the water pump, weren't yet operational. Also, two of them were already dead before being put in the tank. Most of it died because of the constant water alteration to meet their needs in a nutrient-rich environment.

4.6 Growth of the Lettuce

Table 32. The lengths and widths of all twenty (20) lettuce for eight (8) days of the aquaponics system.

DATE	MEASUREMENT	1	2	3	4	5	6	7	8	9	10
12/19/ 2022	LENGTH	1.9	3.1	2.1	3	2.9	1.5	2.5	2.375	2.5	2.3
	WIDTH	3.25	3.3	2.5	1.9	1.5	1.9	2	3.5	2.375	2.2
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	2.65	1.625	1.75	2.5	1.9	2.5	1.875	2.5	2.25	2.15
	WIDTH	1.9	2.2	2.3	3.25	1.875	2.1	2.8	2.625	2.2	2.1
12/20/ 2022	**MEASUREMENT**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	LENGTH	2.2	3.1	2.5	3.2	3	1.8	2.7	2.55	2.7	2.3
	WIDTH	3.5	3.5	3	2	1.625	2.2	2.1	3.9	2.5	2.2
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	2.9	1.75	2	2.7	2	2.7	2	2.65	2.5	2.15
	WIDTH	2.1	2.3	2.3	3.6	2	2.5	3	3.25	2.2	2.25
12/21/ 2022	**MEASUREMENT**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	LENGTH	1.9	3.4	3	2.4	3.2	2	2.6	2.1	2.85	2.3
	WIDTH	4.2	2.8	3.5	3.6	1.7	1.9	2.7	4.5	2.75	2.2
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	2.3	1.75	2.1	2.7	2	2.7	2	3.5	2.5	2.2
	WIDTH	3.2	2.95	2.6	4.3	2.15	3	3.5	3.7	2.7	2.7

12/22/2022	**MEASUREMENT**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	LENGTH	2.4	3.625	3.25	3	3.5	2	2.5		2.9	
	WIDTH	3.5	2.5	3	4.1	3.1	2.125	3		3.4	
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	2.9	1.9	3.5	2.75	2.125	3	2.5	3.6	2.95	2.5
	WIDTH	3.625	2.75	3	3.5	2.5	3.125	3.7	4.1	3.125	3.125
12/23/2022	**MEASUREMENT**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	LENGTH	3.25	4	3.7	3.75	3.85	1.85	2.5	3	3	
	WIDTH	4	6	6.25	6	3.15	2.65	3.5	3.5	4	2.75
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	3.5	1.5	4.25	3	2.5	3.5	3	3.75	3.25	3.15
	WIDTH	4.5	3	4.5	3.5	2.75	3	4.15	5.5	5	3.65
12/27/2022	**MEASUREMENT**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	LENGTH	3.1	3.15	3.5	3	2.625	2.2	2.8	2.5	3.5	2.45
	WIDTH	7.45	6.9	6.9	6.2	5.85	3.3	6.1	4.5	5.1	2.8
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	4.25	2.1	2.75	3.25	2.75	3.25	1.55	2.825	1.5	3.7
	WIDTH	6	4.1	6	4.2	3.75	4.5	4.25	7.1	5.7	4.5

12/28/2022	**MEASUREMENT**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	LENGTH	3.5	7.5	3.125	3.625	2.5	1.5	3	3.5	4	3.5
	WIDTH	13	8.5	10.5	11	7.5	5.5	9.5	7	6	5
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	6	2.5	3.125	2.5	3.1	3.5	5	6.5	4.1	6
	WIDTH	8	5	9	10	5	5	9.6	12	8.1	6.25
12/29/2022	**MEASUREMENT**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	LENGTH	6.5	8	5	6	5	2	2.5	3	2	3
	WIDTH	11.5	10	12	12	12	6.5	11	9	8	8
	MEASUREMENT	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
	LENGTH	6.8	3	3	4	4.5	3.825	5	5	4	5.5
	WIDTH	10.25	7	10	11.5	7.5	9.5	9.825	14	10	8.5

Table 33. The average length, width, and area of the lettuce.

AVERAGE LENGTH WIDTH & AREA (PER DAY)				
NUMBER OF DAYS	MONITORED DAYS	LENGTH (INCHES)	WIDTH (INCHES)	AREA (inch)^2
1	12/19/22	2.29375	2.38875	5.479195313
2	12/20/22	2.47	2.60125	6.4250875
3	12/21/22	2.475	3.0325	7.5054375
4	12/22/22	2.82	3.13875	8.851275
5	12/23/22	3.1375	4.0675	12.76178125
6	12/27/22	2.8375	5.26	14.92525
7	12/28/22	3.90375	8.0725	31.51302188
8	12/29/22	4.38125	9.90375	43.39080469

Table 34. The growth rate of the lettuce

GROWTH RATE	
D1-D2	0.172633413
D2-D3	0.16814557
D3-D4	0.179314997
D4-D5	0.441801464
D5-D6	0.169527177
D6-D7	1.111389885
D7-D8	0.376916656
AVE RATE	0.374247023

$$p = \frac{D1 - D2}{D7 - D8} \times 100 = \frac{0.172633413}{0.376916656} \times 100$$

$$p = 46.13\%$$

$$\%\ development = p(x) - 100\%\ of\ y$$

$$\%\ development = 46.13 - 100\%$$

$$\%\ development = 53.87$$

Equation 14. The percentage development of the lettuce.

On Table 32, the data shows a complete observation on the lettuce from the day it was transferred to the grow bed until the 8th day of data gathering. There are 20 lettuces on the grow bed, and each was observed individually according to its length and width. On the first four days of observation, the lettuce grew unexpectedly fast and healthy, with lengths varying from 1.8 inches to 2.9 inches and expanding it to a maximum of 3.625 inches. Furthermore, it continuously grew in its healthy state up until the end of observation; according to the table that the figure shows, the lettuce stood with 8 inches as the longest length and 14 inches for width, which is an impressive growth in for a short span of time.

The average growth rate of the lettuce on Table 33 was solved by getting the average measurements of length, width, and area per day, as shown on Table 33. From the day it was first monitored up to the end of the data gathering in Day 8, the percentage in the development of the lettuce was 53.87%.

In emphasis to the efficacy of the system, the researchers compared it to an existing conventional aquaponic system study at the De La Salle University in Manila. The accumulated average growth rate for a week of the said study was 0.146%. Meanwhile, the average growth rate of the system for eight days was 0.374%. It means that the compared study was just 39.11% of the lettuce growth of the system. To put it simply, the researchers' system was 60.89% ahead in terms of lettuce development.

To sum it up, the lettuce on the advanced system grows faster and more consistently in size. With these observations alone, the researchers concluded that the researchers' system is more efficient to use because it can keep the lettuce in a more stable and healthy state.

4.7 Minipump

Table 35. The average solution secretion of the minipump

Trial Number	1	2	3	4	5	6	7	8	9	10
Readings (mL)	6	6.8	6.6	6.2	6.8	6.2	6.2	6.2	6	7.2
								Average	**6.42**	

The two (2) minipumps used in this project are the same, both having constant time intervals and duration of secretion. The researchers assume that the secretion of the two minipumps will be more or less equal. The pumps will only activate if the system reads a pH level below 6 or over 7.

Based on the data recorded in Table 35 during testing, in 10 trials, the minimum amount of pH solution being discharged by the minipump is 6 mL, while the highest volume is 7.2 mL. The average volume of pH solution pumped out of the minipump is 6.42 mL. The duration of each pump lasts for 3 seconds and will continue to do so until the pH level becomes stable. The pH level will only be considered stable if it enters the range of 6-7.

4.8 Codes

4.8.1 Compiled Codes for Arduino Mega and Sensors

The following sketches are the codes needed for the Arduino Mega and Sensors. Those that are introduced with a "//" are the explanations for the function or purpose of the following codes.

```
#include <DHT.h>
#include <OneWire.h>
#include <DallasTemperature.h>
#include "GravityTDS.h"
#include <LiquidCrystal_I2C.h>

#define Type DHT22
#define DHT_SENSOR 2
#define ONE_WIRE_BUS 3
#define FAN 4
#define ACID_PUMP 6
#define BASE_PUMP 7
#define PH_SENSOR A0
#define TDS_SENSOR A7

GravityTDS gravityTds;
DHT dht(DHT_SENSOR, Type);
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature ds18b20(&oneWire);
LiquidCrystal_I2C lcd(0x27, 20, 4); // set the LCD address to 0x27 for a 20 chars and 4 
line display
```

```
float humidity;
float tempC_dht;
float tempF_dht;
float tdsValue = 0;
float temperature = 25;       // current temperature for compensation
float ph_level = 0;
float calibration_value = 16.60;
unsigned long int avgval;
int buffer_arr[10], temp;

void setup() {
  Serial.begin(9600);
  dht.begin();
  ds18b20.begin();

  gravityTds.setPin(TDS_SENSOR);
  gravityTds.setAref(5.0);  //reference voltage on ADC, default 5.0V on Arduino UNO
  gravityTds.setAdcRange(1024);  //1024 for 10bit ADC;4096 for 12bit ADC
  gravityTds.begin();  //initialization
  pinMode(FAN, OUTPUT);
  pinMode(ACID_PUMP, OUTPUT);
  pinMode(BASE_PUMP, OUTPUT);

  lcd.init();
  lcd.clear();
  lcd.backlight(); // Backlight on.
  lcd.setCursor(7, 1);  // Set cursor to character 2 on line 0
  lcd.print("Hello!");
  delay(1000);
```

```
  lcd.setCursor(2, 1);  // Move cursor to character 2 on line 1
  lcd.print("Initializing");
  delay(500);

  lcd.setCursor(2, 1);  // Move cursor to character 2 on line 1
  lcd.print("Initializing.");
  delay(500);

  lcd.setCursor(2, 1);  // Move cursor to character 2 on line 1
  lcd.print("Initializing..");
  delay(500);

  lcd.setCursor(2, 1);  // Move cursor to character 2 on line 1
  lcd.print("Initializing...");
  delay(500);

  lcd.setCursor(2, 1);  // Move cursor to character 2 on line 1
  lcd.print("Initializing....");
  delay(500);
}

int acidPos = 0;    // variable to store the servo position
int basePos = 0;    // variable to store the servo position

void loop() {
  // Air temp
  humidity = dht.readHumidity();
  tempC_dht = dht.readTemperature();

  // Water temp
```

```
  ds18b20.requestTemperatures();

  // TDS
  gravityTds.setTemperature(ds18b20.getTempCByIndex(0));  // set the temperature and
execute temperature compensation
  gravityTds.update();  //sample and calculate
  tdsValue = gravityTds.getTdsValue();  // then get the value

  // ph Level
  for (int i = 0; i < 10; i++)
  {
    buffer_arr[i] = analogRead(PH_SENSOR);
    delay(30);
  }
  for (int i = 0; i < 9; i++)
  {
    for (int j = i + 1; j < 10; j++)
    {
      if (buffer_arr[i] > buffer_arr[j])
      {
        temp = buffer_arr[i];
        buffer_arr[i] = buffer_arr[j];
        buffer_arr[j] = temp;
      }
    }
  }
  avgval = 0;
  for (int i = 2; i < 8; i++)
    avgval += buffer_arr[i];
  float volt = (float)avgval * 5.0 / 1024 / 6;
```

```
ph_level = -5.70 * volt + calibration_value;

lcd.setCursor(0, 0);  // Move cursor to character 0 on line 0
lcd.print("Room temp: " + String(tempC_dht) + " C");

lcd.setCursor(0, 1);
lcd.print("Humidity: " + String(humidity) + " %");

lcd.setCursor(0, 2);
lcd.print("Water temp: " + String(ds18b20.getTempCByIndex(0)) + " C");

lcd.setCursor(0, 3);
lcd.print("TDS: " + String(tdsValue) + " ppm");

delay(2000);

lcd.clear();

lcd.setCursor(0, 0);
lcd.print("ph Level: " + String(ph_level));

delay(2000);

if (tempC_dht > 31) {
  digitalWrite(FAN, LOW);
  // Serial.println("Fan is ON");
}  else {
  digitalWrite(FAN, HIGH);
  // Serial.println("Fan is OFF");
}
```

```
  if (ph_level < 6) {
  // if (true)  {
    digitalWrite(BASE_PUMP, HIGH); //turns the LED on
    // Serial.println("MOTOR is ON");
    delay(3000); // CHANGED IF YOU WANT LONGER MOTOR DURATION
    digitalWrite(BASE_PUMP, LOW);
    // Serial.println("MOTOR is OFF");
    delay(500);
  }

  if (ph_level > 7) {
  // if (true)  {
    digitalWrite(ACID_PUMP, HIGH); //turns the LED on
    // Serial.println("MOTOR is ON");
    delay(3000); // CHANGED IF YOU WANT LONGER MOTOR DURATION
    digitalWrite(ACID_PUMP, LOW);
    // Serial.println("MOTOR is OFF");
    delay(500);
  }

  Serial.println(String(tempC_dht) + " " +
                String(humidity) + " " +
                String(ph_level) + " " +
                String(ds18b20.getTempCByIndex(0)) + " " +
                String(tdsValue));
}
```

4.8.2 Compiled Codes for ESP32 and Website

The following sketches are the codes needed for the ESP32 and Website. Those that are introduced with a "//" are the explanations for the function or purpose of the following codes. With these, anyone can have an access to the website wherever and whenever, as long the system is connected to the internet.

```
#include <WiFi.h>
#include <HTTPClient.h>
#include <SoftwareSerial.h>

#define WIFI_SSID "PLDT" // WIFI SSID here
#define WIFI_PASSWORD "Aquasolaris" // WIFI password here
#define LED_WIFI 2
#define                                          SERVER_ADD_READINGS
"https://aquaponicsiotsystem.000webhostapp.com/addReadings.php"

SoftwareSerial serial1(16, 17); // RX, TX

char emptyStr[] = "";
char dataFromMega[200];//String data; //holds incoming string
unsigned long lastTime = 0;
unsigned long timerDelay = 5; // Set timer to 5 seconds (5000)

void setup() {
  Serial.begin(115200);
  serial1.begin(9600);
  pinMode(LED_WIFI, OUTPUT);
  Serial.println("****************************");
```

```
  Serial.println("GROUP");
  Serial.println("***************************");
  delay(1000);
  Serial.print("Connecting to ");
  Serial.print(WIFI_SSID);
  Serial.print(" with password ");
  Serial.println(WIFI_PASSWORD);
  WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
  while (WiFi.status() != WL_CONNECTED) {
    digitalWrite(LED_WIFI, HIGH);
    delay(100);
    digitalWrite(LED_WIFI, LOW);
    delay(100);
    Serial.print(".");
  }
  Serial.println("");
  Serial.print("Connected to WiFi network with IP Address: ");
  Serial.println(WiFi.localIP());
  while (!serial1) {
    ; // wait for serial port to connect. Needed for native USB port only
  }
}

void loop() {
  String str = "";
  String strs[20];
  int StringCount = 0;

  String temp_dht22 = "";
  String humidity = "";
```

```
  String ph_level = "";
  String temp_ds18b20 = "";
  String tds = "";

  if (serial1.available() > 0) {
    byte x = serial1.readBytesUntil('\n', dataFromMega, 200);//data = Serial.readString();
//read string
    dataFromMega[x] = '\0'; //adding null caharcater
    Serial.print("Data: ");
    Serial.println(dataFromMega);
    if (strcmp(emptyStr, dataFromMega) == 0)
    {
      Serial.println("Wala");
    }
    else
    {
      str = dataFromMega;
    }
  }

  // Split the string into substrings
  while (str.length() > 0)
  {
    int index = str.indexOf(' ');
    if (index == -1) // No space found
    {
      strs[StringCount++] = str;
      break;
    }
    else
```

```
    {
      strs[StringCount++] = str.substring(0, index);
      str = str.substring(index + 1);
    }
  }

  temp_dht22 = strs[0];
  humidity = strs[1];
  ph_level = strs[2];
  temp_ds18b20 = strs[3];
  tds = strs[4];

  Serial.println("Room Temperature: " + temp_dht22);
  Serial.println("Humidity: " + humidity);
  Serial.println("pH Level: " + ph_level);
  Serial.println("Water Temperature: " + temp_ds18b20);
  Serial.println("Total Dissolved Solids: " + tds);

  postReadings(temp_dht22, humidity, ph_level, temp_ds18b20, tds);
  delay(5000);
}

void postReadings(String air_temperature, String humidity, String pH_level, String
water_temperature, String total_dissolved_solid) {
  if ((millis() - lastTime) > timerDelay) {
    //Check WiFi connection status
    if (WiFi.status() == WL_CONNECTED) {
      WiFiClient client;
      HTTPClient http;
```

String data = "air_temperature=" + air_temperature + "&humidity=" + humidity +
"&pH_level=" + pH_level + "&water_temperature=" + water_temperature +
"&total_dissolved_solid=" + total_dissolved_solid;

http.begin(client, SERVER_ADD_READINGS); // Connect to host where MySQL databse is hosted

http.addHeader("Content-Type", "application/x-www-form-urlencoded"); // Specify content-type header

int httpCode = http.POST(data); // Send POST request to php file and store server response code in variable named httpCode

// Serial.println("Values are");

// Serial.println("air_temperature: " + air_temperature);

// Serial.println("humidity: " + humidity);

// Serial.println("pH_level " + pH_level);

// Serial.println("water_temperature: " + water_temperature);

// Serial.println("total_dissolved_solid: " + total_dissolved_solid);

// if connection eatablished then do this

if (httpCode == 200) {

Serial.println("Values uploaded successfully.");

Serial.print("HTTP Response code: ");

Serial.println(httpCode);

String webpage = http.getString(); // Get html webpage output and store it in a string

Serial.println(webpage + "\n");

digitalWrite(LED_WIFI, HIGH);

delay(1000);

digitalWrite(LED_WIFI, LOW);

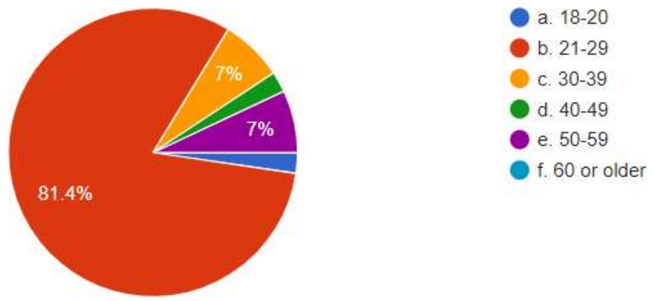
delay(1000);

```
      }
      else { // if failed to connect then return and restart
        Serial.print("HTTP Response code: ");
        Serial.println(httpCode);
        Serial.println("Failed to upload values. \n");
        String webpage = http.getString();    // Get html webpage output and store it in a
string
        Serial.println(webpage + "\n");
        http.end();
        return;
      }
      // Free resources
      http.end();
    }
    else {
      Serial.println("WiFi Disconnected");
    }
    lastTime = millis();
  }
  Serial.println();
}
```

4.9 Acceptability Evaluation

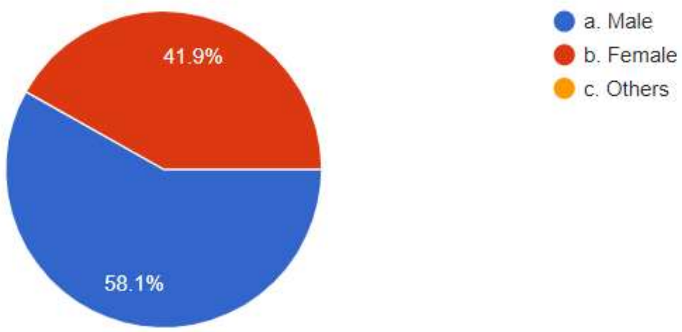
1. Which age bracket includes your age?

43 responses



2. What is your gender?

43 responses



3. What is your current marital status?

43 responses

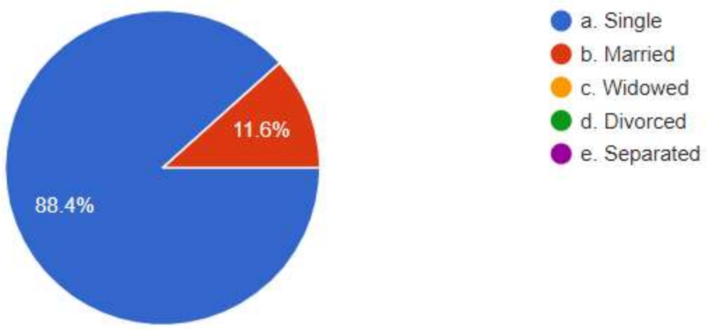
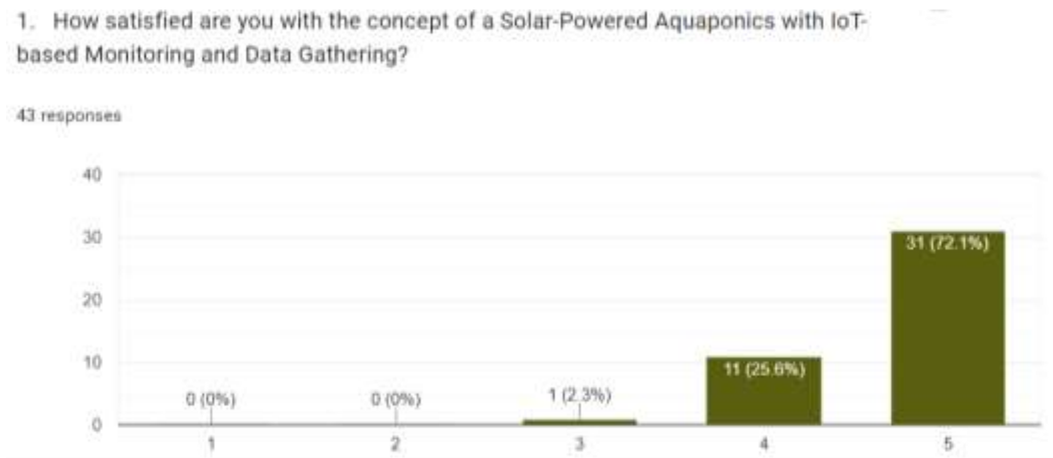


Figure 24. Demographics of the Respondents

The proponents conducted the survey through the use of google forms, a IoT-based software developed by Google for conducting surveys, where majority of the respondents were aged 21-29 years old, having a survey turnout of 93.3% as shown in Figure 24. Further, 25 out of the 43 respondents were male, while 18 were female; and there were 5 married and 38 single respondents.



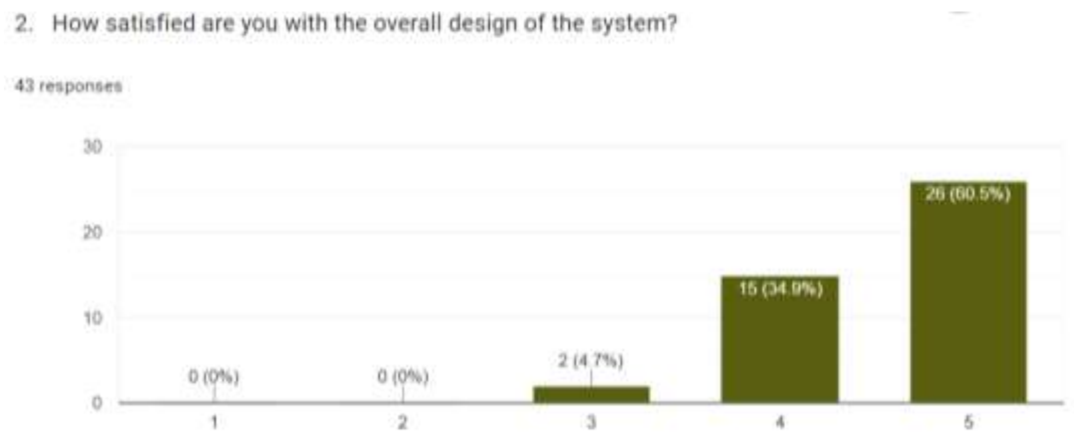


Figure 25. Questions 1 and 2

According to the bar graph above, 25.6 percent of respondents are satisfied with the system concept, while 2.3% of respondents are unsatisfied with it. 72.1% of respondents rate the system concept as very satisfied. 60.5% of respondents are extremely satisfied with the system's overall design, compared to 34.9% who are satisfied and 4.7% who are unsatisfied.

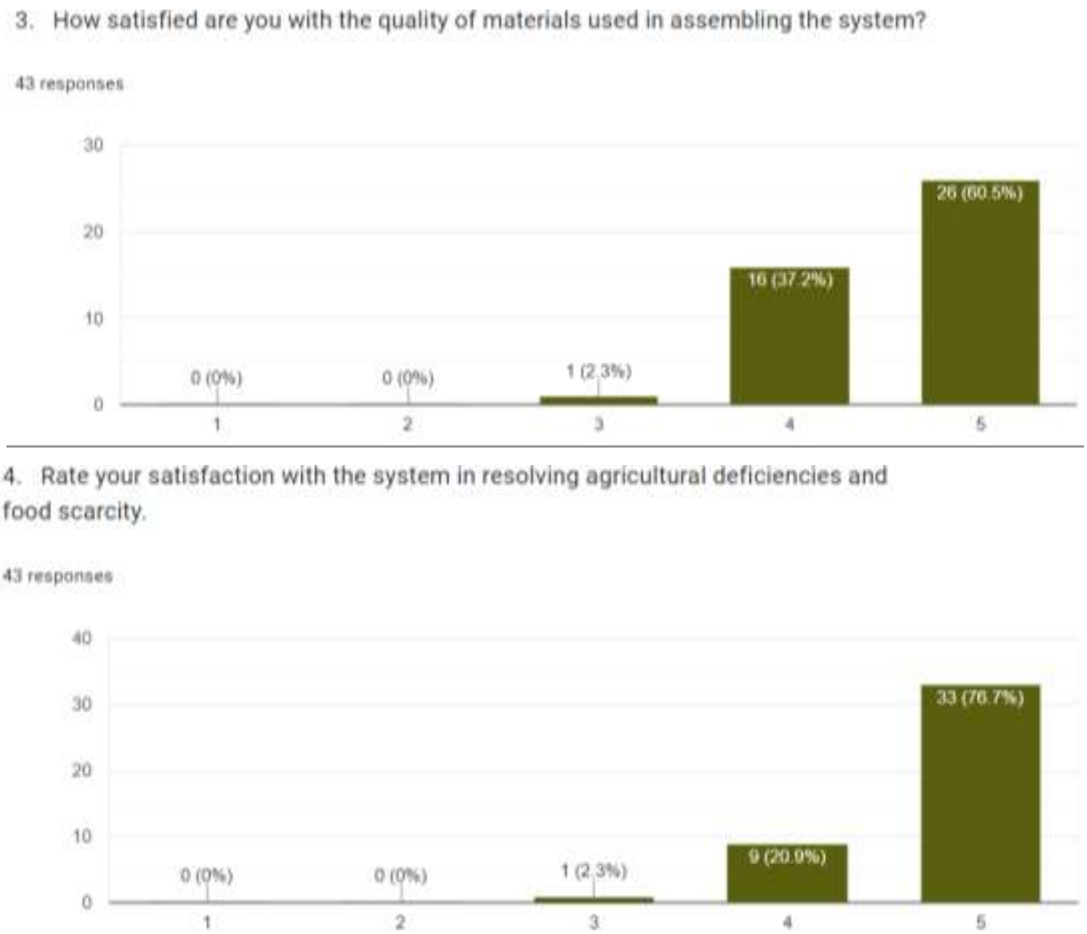


Figure 26. Questions 3 and 4

According to the graph above, in terms of the quality of materials used to assemble the system, 60.5% of respondents are very satisfied, 37.2% are satisfied, and 2.3% are unsatisfied. In terms of the system's effectiveness in addressing agricultural deficiencies and food scarcity, 76.7% of respondents are very satisfied, 20.9% are satisfied, and 2.3% are dissatisfied.

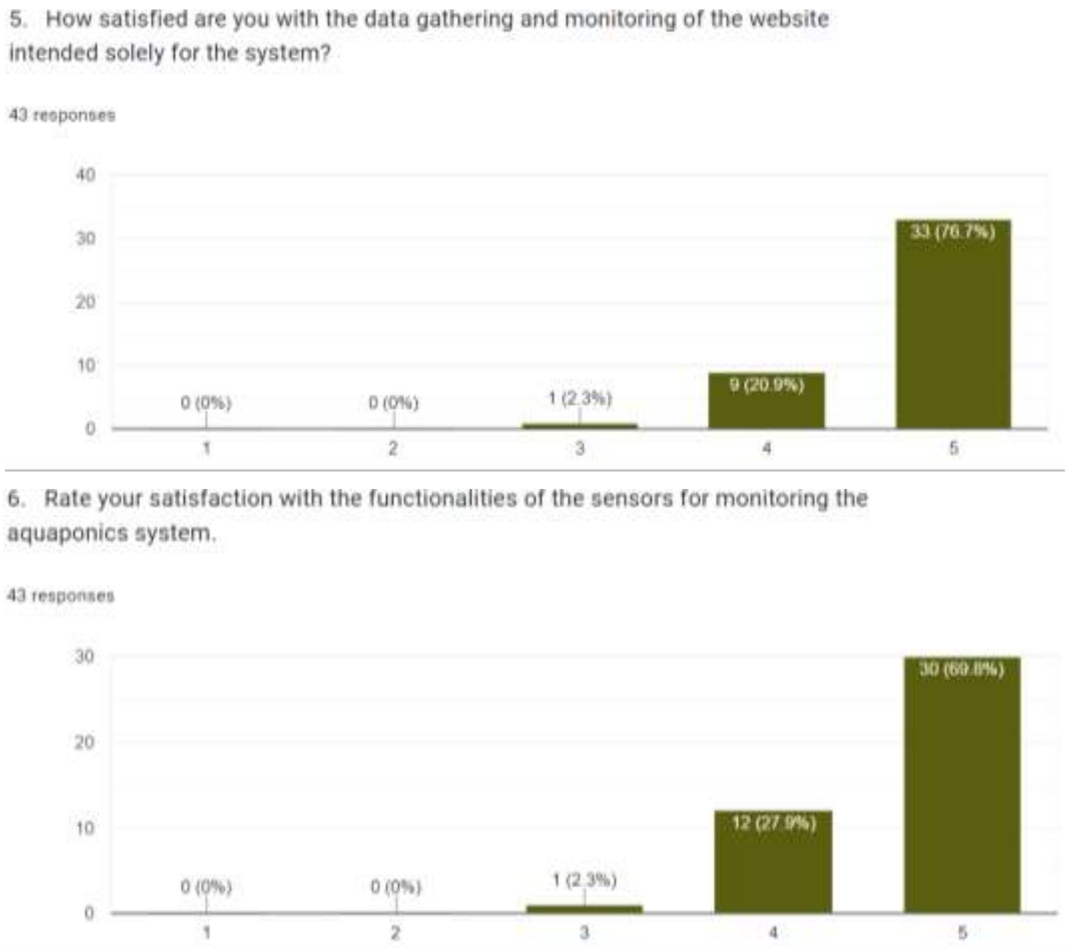
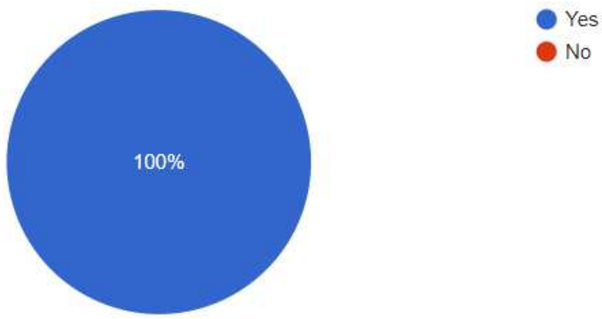


Figure 27. Questions 5 and 6

Furthermore, in terms of data gathering and monitoring of the website intended solely for the system, 76.7% of respondents are very satisfied, 20.9% are satisfied, and 2.3% are dissatisfied. In terms of the functionalities of the sensors for monitoring the aquaponics system, 69.8% of respondents are very satisfied, 27.9% are satisfied, and 2.3% are dissatisfied as shown above.

7. Did our Solar-Powered Aquaponics with IoT-based Monitoring and Data Gathering meet your expectations?

43 responses



8. Do you think this project study will be of help to alleviate the current crisis in our agriculture?

43 responses

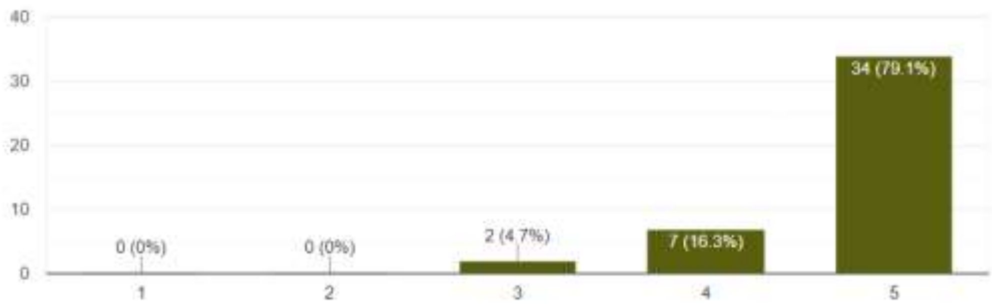
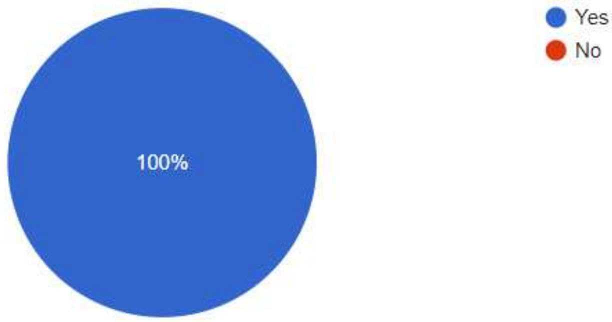


Figure 28. Questions 7 and 8

Additionally, according to all respondents, the project study exceeded their expectations. Majority of them agree and believe that the study will help to alleviate the current agricultural crisis, which equates to 79.1% of the respondents being very satisfied.

9. Do you think that this project study is reliable in terms of the different sensors and devices used to monitor the overall system?

43 responses



10. Would you recommend the Solar-Powered Aquaponics with IoT-based Monitoring and Data Gathering as a solution for agricultural low productivity and food scarcity?

43 responses

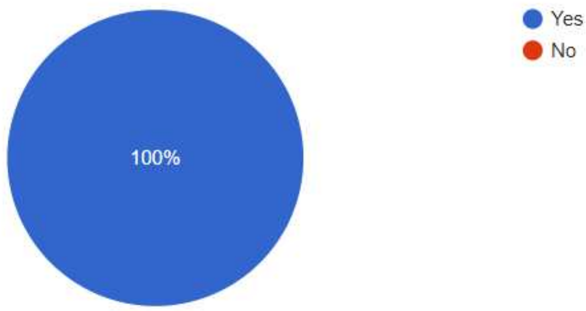


Figure 29. Questions 9 and 10

According to the Figure 29 above, 100% of respondents believe the project study is trustworthy in terms of the various sensors and devices used to monitor the overall system. Furthermore, 100% of respondents agree that Solar-powered Aquaponics with an IoT-Based Monitoring and Gathering is recommended as a solution for low agricultural productivity and food scarcity.

Table 36. CSAT Results

	4	5	No. of Survey Responses	CSAT Results
Q1	11	31	43	97.67
Q2	15	26	43	95.35
Q3	16	26	43	97.67
Q4	9	33	43	97.67
Q5	9	33	43	97.67
Q6	12	30	43	97.67
Q7	[redacted]			
Q8	7	34	43	95.35
Q9	[redacted]			
Q10				

The table above shows the Computation of the CSAT Score using the formula indicated in Equation 10, Questions 1 to 6 and Question 8 were made to measure the Customer Satisfaction of the system. According to the computation, the percentage of satisfied customers were 97.67% for questions 1, 3, 4, 5, and 6; while question 2 and 8 has a CSAT Score of 95.35%. This just shows that majority of the respondents are satisfied with the concept, functionality, and design of this project study.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

To sum up everything that has so far been discussed in this paper, the proponents were able to set up and develop a system that can monitor the pH Level, Room Temperature, Humidity, TDS, and Water Temperature. With that, the researchers were able to diagnose and troubleshoot the system, especially the pH level that the proponents were able to control to achieve the desired pH level of the study. Although the monitoring website was limited to being a local host website, it still helped greatly on monitoring and data gathering of the crucial parameters. Thus, it made the process of making a nutrient-rich environment relatively easy for the proponents due to the enhanced monitoring and data gathering system.

The whole process of setting up the system requires a great amount of manpower and skills. Thus, offering the various job opportunities for various skills. While the products offers great income; a huge investment for great long-term income.

The controlled environment and the system were able to present an observable and significant difference for growing the loose-leaf lettuce and tilapia. Aside from this, the Solar PV System was able to provide enough power supply to the system under the right weather conditions, and in the right location with enough sunlight. However, the loose-leaf lettuce did show signs of legginess due to insufficient light, especially during the day because of the shady area of the location, and inclement weather during the rainy season in the country. Nonetheless, the system showed great potential in growing healthy lettuce, which can be improved by controlling further variables other than the pH level.

5.2 Recommendations

For the improvement of the study and the system, after the testing phase and result interpretation, the proponents would like to recommend to future researchers the following:

1. Control the other crucial variables other than the pH level;
2. Utilize other existing applications or websites that will be able to further improve the monitoring, control and data gathering of the system and will be able to do so remotely;
3. Attach an automatic feeding system that shall feed the fishes with a certain amount of feeds at a certain point of time to accurately measure the growth rate;
4. Attach a function that would recognize a fault in the system, especially if a certain parameter with a desired range have been compromised, and would notify the user;
5. Use tuna boxes or grape boxes as grow beds instead of an upcycled material;
6. Study the effects of placing a lettuce near or far from the water entrances of the grow bed;
7. Attach a secondary power supply in case the main solar PV supply will not be able to sustain the system, especially during inclement weather with a cloudy sky;
8. Consider planting a different crop (i.e. bok choy, water cabbage, spinach and water spinach) that has similar growth variables.

DECLERATIONS

Ethical Approval
Not Applicable

Competing Interests
Not Applicable

Author's Contributions
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Sean Joven G. Incomio: Conceptualization, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Visualization, Supervision, Funding acquisition

Serjay O. Abad: Conceptualization, Resources, Writing - Original Draft, Visualization, Funding acquisition

Engr. Edwin Roldan: Supervision, Project administration

Funding

Not Applicable

Availability of data and materials

Data and Materials shall be provided upon request.

REFERENCES:

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