iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** VI **Month of publication:** June 2023

DOI: https://doi.org/10.22214/ijraset.2023.54465

Improvement Proposal based on the Optimization of Environmental Variables for the Production of an Aquaponic System (Greenhouse) at the Campus "Los Robles", Fundación Universitaria de Popayán, Colombia

Edwin Rivera[1], Margie V. Quijano[2], Richard M. Imbachi[3], Sebastián Sánchez[4], Yazmín A. Alban[5], Yhoan V. Flor[6]
[1, 2, 3, 4, 5, 6] *Faculty of Engineering - Architecture Fundación Universitaria de Popayán, Cauca, Colombia*

Abstract: The research focuses on the analysis of environmental variables and the operation of a greenhouse used for the production of fish and plants under aquaponic technology. It is important to mention the existence of studies on these techniques, although they do not represent and provide the totality of knowledge on the processes that occur in them, from their design and materiality. This work intends to make a contribution to sustainable production in aquaponic systems (greenhouse), studying the variables that most affect the development of plants and fish. The research was carried out in the aquaponic prototype of the "Los Robles" campus of the Fundación Universitaria de Popayán, Colombia. Initially, the effect of the physical and environmental parameters of the greenhouse was analyzed, such as design, production area, structure, climate and environment, which are variables that influence the productive performance of the greenhouses (fish and plants installed). With the results obtained from the analysis of environmental variables, improvements are proposed to optimize the production system. This proposal aims to contribute to food security and the social and productive reactivation of the communities in the region.
Keywords: Environment, Aquaponics System, Environmental Variables, greenhouse.

I. INTRODUCTION.

The Fundación Universitaria de Popayán [1] has a greenhouse aquaponic system, located in its campus "Los Robles", it is used as an R+D laboratory for technology validation. Research projects are continuously developed in areas related to the technology, becoming the basis of the biotechnology Spin-Off "Acuaponía Digital para Todos" [2]. This initiative has received national and international awards, one of them is the award for "Innovation for sustainable lifestyles Colombia-2020" [3], conducted by the University of the Andes [4] and the PNUMA Program of the ONU [5]. The project integrates prototypes of measurement and control of variables in automation and industry 4.0 [6], searching to increase yields productivity and profitability of its plants and fish harvests [7].

Aquaponics system, integrates hydroponics [8] and aquaculture [8] for the joint development of plants and fish, with the purpose of supporting food sustainability in the world, also for ornamental and research uses. In a hydroponic system, aquaculture provides necessary nutrients to plants for their growth and development. These systems contribute to water efficiency and mitigate pollution, because no fertilizers are used, as is the case with traditional agriculture [9]. Consequently, this type of production system [10] represents access to new clean production strategies [9] for rural and urban families worldwide. Aquaponic systems consider key aspects such as water recirculation (taking advantage of the symbiosis [11] between fish and plants), and coverage by a greenhouse to provide optimal environmental conditions for its operation. It is also important to consider the architectural and spatial design and, in general, the equipment.

In this research, the effect of the environmental and physical parameters of the aquaponic system was analyzed, considering aspects of design, materiality, equipment, area, structure, climate, lighting, orientation, ventilation, and relevant physical variables. The aquaponic system used was developed considering the crops and fish to be adapted to the conditions of a multivariable and multifactorial system: water / heat / air / radiation / relative humidity / temperature / atmospheric pressure / time / flow / Ph / volume / electric current / oxygen saturation / nitrates / nitrites / ammonium and algae, vital characteristics in the microenvironments.

This provides information that objectively shows the relationship between the parameters of analysis and productive performance, demonstrating that they are indispensable variables in the profitability of production.

The objective of this article is to characterize and analyze the relevant environmental variables for the optimal productive operation of the aquaponic system at the "Los Robles" campus, Fundación Universitaria de Popayán, Colombia. For this purpose, the fundamental physical variables present in the aquaponic system and environment were initially identified, then the parameters of the essential physical variables that a monitoring process should have in the aquaponic system were determined, and finally, thermodynamic simulations of the analyzed variables were carried out using Energy 2D software.

II. METHODOLOGY

Inductive method [12] was used to develop the research in a social innovation environment [13]. Environmental factors were monitored: wind speed, soil temperature, water temperature, air temperature, relative humidity, and elements that influence the design of a greenhouse. The analysis of the structure and materials [14] of the greenhouse was carried out, which complemented the type of physical improvements used in each of the microclimates generated inside the greenhouse. The characteristics of the variables analyzed are presented below:

1) *Air velocity [15]:* it is important in the aquaponic system environment, due to the air flow that allows heat transfer by convection, influencing the correct development of the plants [15]. The greenhouse was considered as an open system [16], however, to avoid the infection of pests, the access door is always closed. The greenhouse has several levels on the floor, producing different heights in the roof cover, generating three microenvironments or subsystems. A Uni-Trend UT362 Anemometer was used, with measuring ranges between 2m/s and 10m/s.
2) *Temperature:* allows heat transfer by convection, directly affecting the functions of photosynthesis, respiration, cell membrane permeability, water and nutrient absorption, transpiration, enzyme activities, etc. Vital biological reactions cannot take place if the temperature is below 0 °C, or above 50 °C [17]. The lower limit corresponds to the freezing point of water and the upper limit to protein denaturation. The optimum temperature varies according to the species, it is between 10° - 25 °C [17]. This variable was measured in water (fish pond, floating beds, sedimentation tank, distribution tank, NFT system), in the covers, in the air subsystems, and in the soil. An infrared mercury thermometer GM320 (measuring range from -50°C to 380°C, accuracy of 1.5%, resolution of 0.1°C or 0.1°F and an average distance of 12:1 with a power supply of 2 AAA 1.5V batteries), and a Thermo hygrometer htc2 were used for this purpose.
3) *Relative Humidity (RH) [18]:* ambient humidity affects plant metabolism, if the value is high, gas exchange is limited, transpiration and nutrient absorption are reduced, and if the value is low, the plant's stomata close, and the rate of photosynthesis is reduced [18]. RH provides stability and recuperation to plants when the ambient temperature increases, allowing the cultivation of some vegetables or fruits that are suitable for low temperatures such as strawberries (example of product cultivated in the greenhouse).
4) *Greenhouse cover [19]:* usually, the material used is made of plastic film, but polycarbonate (thermoplastic polymer with good impact resistance) is also used. For the system under study, a bamboo construction [19] (known in the region as *guadua*) was used, in the form of a chapel, covered with plastic, and a lateral gabled ventilation, with areas of 5 m^2, a height in the center of 4.5m and 2m on the sides. The front lateral enclosure and the roof were made of plastic, the *guadua* beams measured 10 linear meters, a radius of 13 cm, their joints were in ties with perforations and fastenings with ¼ inch screws.

Some variables that were evaluated in the greenhouse cover (roof) are presented in Table I.

Table I.

Evaluated Greenhouse cover variables.

Light Transfer %	Heat Transmission ($W/m^2°C$)	Density (g/cm^3)	Anti-drip	Anti-dust
75 - 83	4 - 4,8	1,2	SI	SI

Light transfer %: percentage of sunlight entering the greenhouse (diffuse solar radiation). Heat Transmission: ($W/m^2°C$), heat transfer inside the greenhouse. Density (g/cm^3), of high-density polyethylene. Anti-drip: characteristic of high-density polyethylene.
Anti-dust: characteristic of high-density polyethylene. The types of direct, diffuse and reflected solar radiation [20] are a determining factor in the production of plants and fish, and analyzing in different months, this factor was identified as influencing the crops developed in the aquaponic system.

5) *Soil [21]:* where the greenhouse is installed is a clay soil, which causes a problem due to its high level of filtration because of its low permeability and high-water retention. The structure of the soil is important in the capture of energy and heat transfer by conduction [21], relevant elements that allow the plant to carry out its photosynthetic process and transfer heat at times when the environment requires it.

Finally, the application "Energy 2D V 3.0.3" [22] was used to simulate the recorded data, simulating the air temperature in the 3 defined microenvironments and water temperature.

III. RESULTS

A. Initial Concept

After establishing the objectives and determining the fundamental aspects to be improved in the aquaponic system (under a greenhouse type structure, such as the one installed in the Los Robles campus, see Figure 1). This research started with the registration and recognition of the aquaponic environment, and of the structure that isolates and protects this system. For this, the implementation of tools for the organization of processes and reading of environmental variables contained in this aquaponic system was necessary.

Fig. 1 Aquaponic greenhouse “Los Robles” campus.

It is important to identify the design characteristics and components of the greenhouse's initial model, due to the direct influence on the environmental conditions inside the greenhouse. Structural material such as *guadua angustifolia* [23], high density polyethylene type plastic material for external coating, external water collection tank made of 100% virgin polyethylene with U.V. additive approved by the U.S. FDA to store food and drinks (Figure 2).

Fig. 2 Greenhouse structure and materials

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue VI Jun 2023- Available at www.ijraset.com

The structure and materials implemented in the aquaponic greenhouse were selected for their cost-benefit ratio, but without a future study on the viability of the materials, and without considering the extreme environmental conditions present in the aquaponic system. Thus, there were failures in the efficiency of the system. The main materials that make up the greenhouse are: guadua, plastic, bolts, and concrete foundations. Despite its performance is acceptable and achieves some of the minimum efficiency standards due to the characteristics of the materials, the architectural design does not fulfill the standards to ensure sustainability conditions and optimal crop productivity.

B. Site Distribution

Figure 3 shows the aquaponic system layout plan.

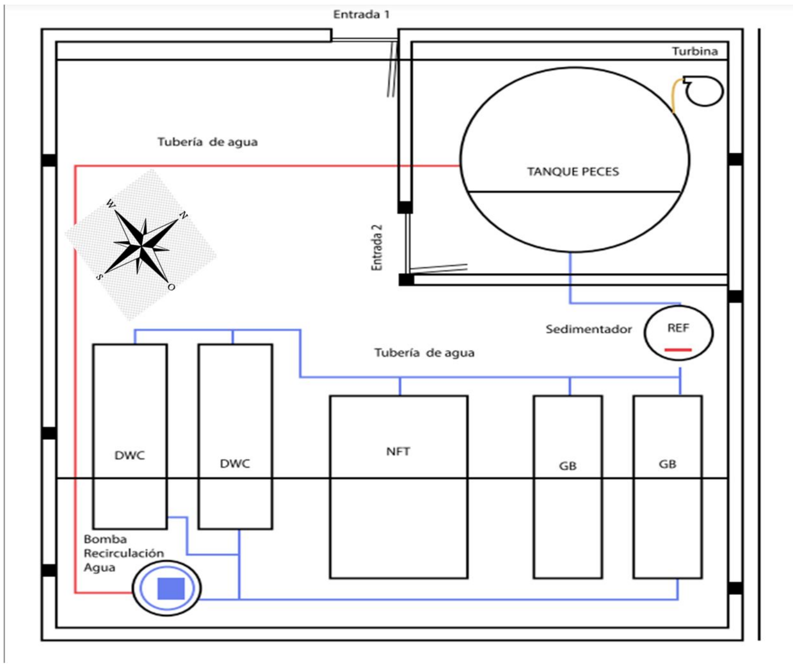


Fig. 3 Initial layout plans of the aquaponic greenhouse, Los Robles campus.

The plant layout of the aquaculture and fish production systems are key elements for the efficiency of the aquaponic greenhouse, the fish pond and equipment implemented for its operation were located in the northern part to facilitate their feeding and to take advantage of the flow of water through gravity towards the sedimenter. According to the established circulation network, there are the "gravel beds" (GB) which are a bed type structure covered with plastic and filled with small stones, the structure is elevated from the ground at 40 cm. Likewise, there is the NFT production technique [24] (nutrient film technique), organized in a pyramidal structure, which considers an efficient irrigation to its sections or pipes to supply the necessary nutrients, and in addition, the distance between its sections is considered for the light input, and the water drainage with a short inclination.

The hydraulic circuit in the greenhouse ends with the water supply to the "floating beds", which are a technique based on a floating material (extruded polystyrene) that supports the plants, and allows them to obtain nutrients from the water through the root, but without contact with the stems, branches, leaves and fruits of the plant.

The system presents 3 integrated production techniques in aquaponics, it is composed of a network of pipes that transports the water with the nutrients to the input that each of the installed systems has, and the subsequent output at the other side of these systems, through a slow flow, which finishes with the arrival at the storage pond, where the water is oxygenated to be pumped back to the fish pond and give continuity to the aquaponic process.

The monitoring process of environmental variables of the aquaponic system was developed under the methodology and analysis of microenvironments. Following the identification of the plant layout and hydroponic production characteristics, the microenvironments were differentiated, which allowed obtaining data efficiently, since 3 types of production are installed: floating beds, bed with substrate (stone), and the NFT system (Nutrient Film Technique). Different variables were identified in the cultivation and production of the plants, and the variation of environmental conditions due to the structural design, manufacturing materials and bioclimatic variables of the area. Figure 4 illustrates the three types of microenvironments identified.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue VI Jun 2023- Available at www.ijraset.com

The one in yellow contains the fish tank, the one in green contains the gravel beds, and the one in red contains the NFT structures and floating beds. The three subsystems form a single thermodynamic system, which at the beginning of the research was considered as a closed and multivariate system, due to the number of variables that interact in each zone, and it was also considered as a multifactorial system because changes in the variables of one region affected the behavior of the other areas.

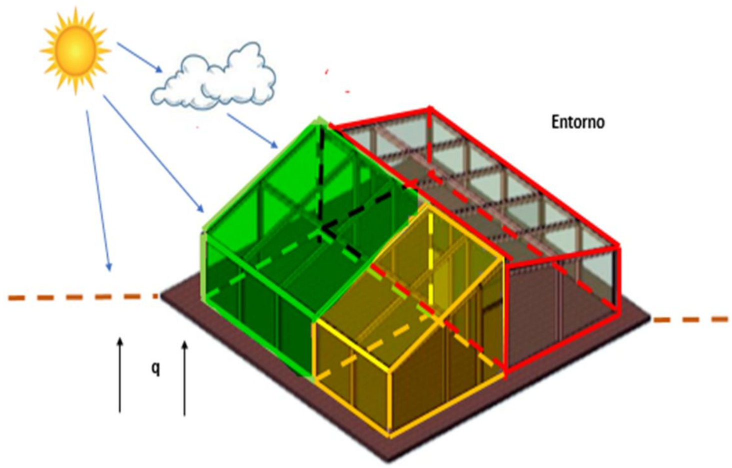


Fig. 4. Aquaponic system thermodynamic description, "Los Robles" campus.

From thermodynamics, the three types of solar radiation interact: direct, diffuse and reflected. In the interior of the greenhouse, solar radiation enters as diffuse radiation as it crosses the high-density polyethylene structure. In heat transfer, the phenomena of conduction, convection and radiation are involved. Conduction occurs when the radiation interacts with the coverings, modifying their internal energy. Similarly, the radiation incident on the soil is distributed 30% on the surface and 70% inside the soil. Convection occurs in the variation of the internal energy of the air that is part of the environment, of the air inside the system, and of the variation of heat in the internal hydraulic network. Radiation occurs in the interaction between the amount of atmospheric heat and the energy incident on the surface of the roofs.

A sampling of the variables with the highest impact on the environment and the components with the greatest interaction in the aquaponic system was proposed. Factors such as humidity, environment temperature, water temperature, and construction materials were considered. Thus, this data recording allowed a complete diagnosis, at different times of the day, over several months, in a discontinuous form. This analysis highlights the importance of monitoring the aquaponic environment at night, when there is no natural light, with environmental conditions opposite to those of the day.

Table II shows the temperature data for the night and early morning hours, recorded in the microenvironments, showing that microenvironment N° 3 presented the greatest temperature reduction, registering a decrease of 6.6 °C, while microenvironment N° 2 showed a decrease of 6.4 °C, and N° 1 registered a decrease of 4 °C.

Table II.
Temperature in system microenvironments.

TIME	MICROENVIRONMENT #1(Fish Pond)	MICROENVIRONMENT #2 (Gravel beds)	MICROENVIRONMENT #3 (Distribution Tank)
8:30 p. m.	18	19,2	19,5
9:20 p. m.	17,5	15,3	16,4
10:00 p. m.	18	15,9	16
11:00 p. m.	18	15	15,2

12:15 a. m.	16	14,2	14,3
1:00 a. m.	16	14,3	14,2
2:00 a. m.	16	14,2	14,3
3:00 a. m.	16	14,1	14
4:00 a. m.	14	13,3	13,3
5:00 a. m.	14	13	13
6:00 a. m.	14	12,8	12,9

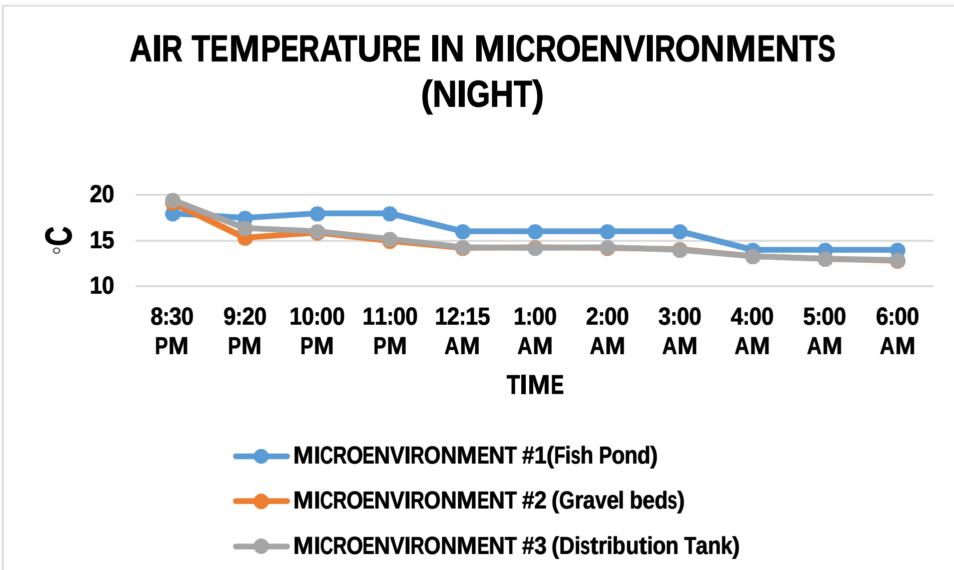


Fig. 5. Air temperature of the microenvironments of the aquaponic system, "Los Robles" campus

Table III shows the relationship between temperature and humidity in environment N° 1 (fish tank) and N° 2 (hydroponic beds) during the night and early morning.

Table III.
Temperature - Relative Humidity in Pond and Floating Beds (Night)

Temperature - Relative Humidity in Pond and Floating Beds (Night)				
TIME	FISH POND		FLOATING BEDS	
	°C	Relative Humidity	°C	Relative Humidity
8:00 p. m.	21	78,0	21	79,1
9:00 p. m.	17,7	94,5	17,7	94,1
10:00 p. m.	17	96,3	16,9	96,4

11:00 p. m.	16,8	97,1	16,7	97,2
12:00 a. m.	16,6	97,1	16,5	97,9
1:00 a. m.	16,5	97,3	16,4	98,1
2:00 a. m.	16,8	97,1	16,3	98,3
3:00 a. m.	16,8	97,1	16	98,5
4:00 a. m.	16,9	97,5	16,3	98,3
5:00 a. m.	16,9	97,5	16,5	97,8

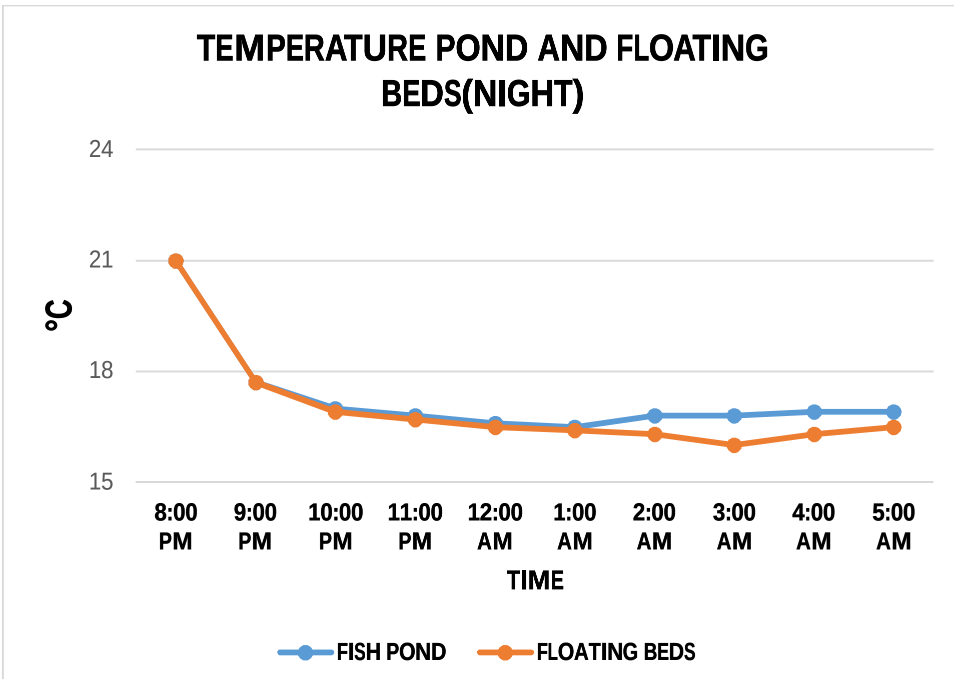


Fig. 6. Relative humidity in pond and floating beds of the aquaponic system, "Los Robles" campus.

Relative humidity is important in the hydration process of plants, especially when there is a low temperature.

C. Simulation

The adequate use of construction materials affects the thermodynamic behavior of the system: the soil or surface that covers the greenhouse is a determining factor in the capture of energy by the components or materials that cover it (gravel, blankets, concrete or soil). The heat transfer from the soil to the environment at night returns a percentage close to 70% [25] of the heat received during the day from direct or diffuse solar radiation [26].

The mentioned factors were related through simulations using the Energy 2D (SE2D) software [22]. This is a free and open-source simulation tool for design, analysis and heat transfer in thermodynamic systems. To perform the simulations in day and night scenarios, the objects in the graphical interface required by SE2D were configured with the technical parameters of each greenhouse material, and with the data of physical variables recorded during the development of the research. It is important to indicate the critical points of temperature, the lowest levels were located between 5:30 am to 6:30 am with 12.9° C. and the highest point between 12 am to 1:30 pm with a temperature of 39.5 C. Figure 7 illustrates the simulation configuration for the night.

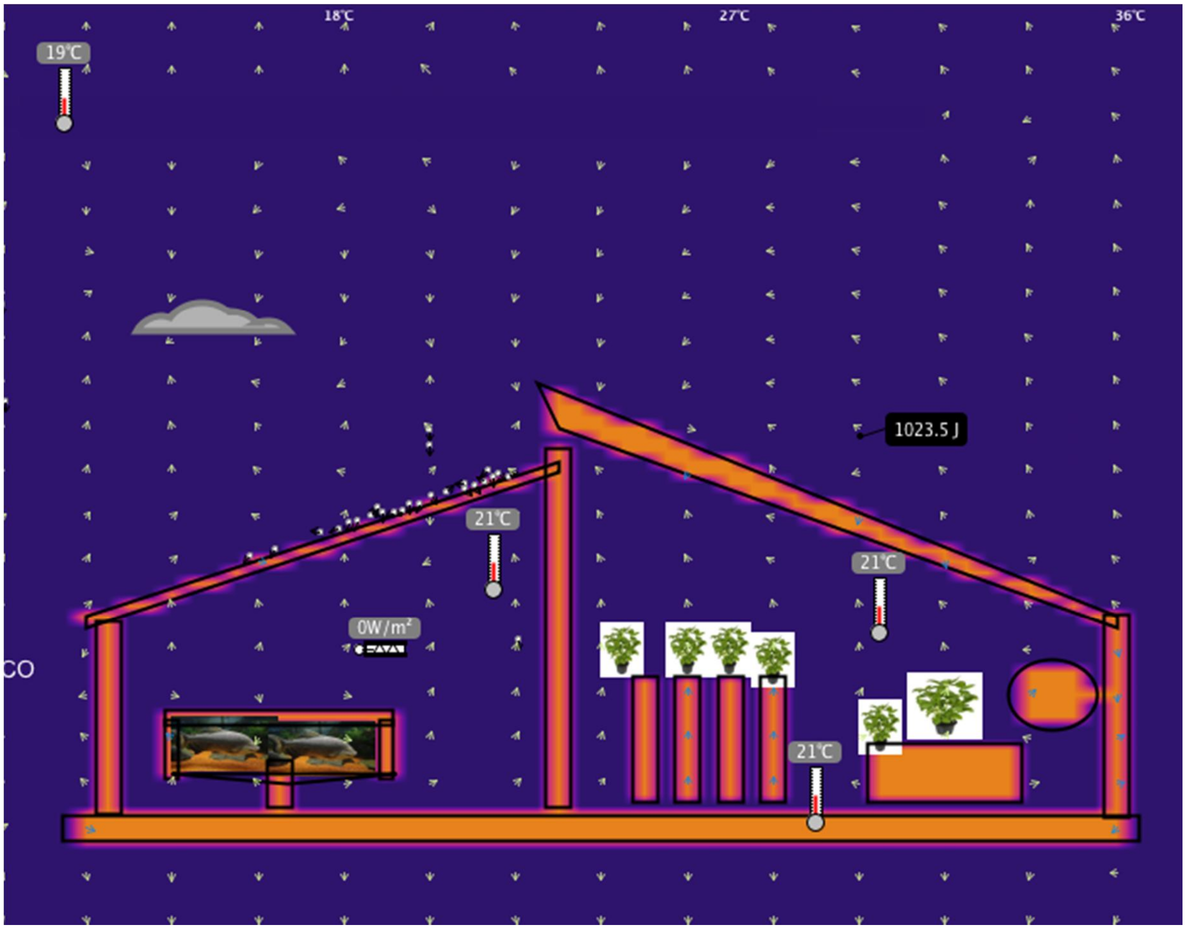


Fig. 7 Thermal simulation night in an aquaponic system

As shown in Figure 7, nighttime temperatures change according to heat transfer. While the outside of the greenhouse recorded temperatures of 19° C, the inside recorded a higher temperature of 21° C. The 2° C differential that the aquaponic greenhouse registers generates optimal conditions for the plants and fish in the system.

Figure 8 relates the temperature behavior in the three microenvironments, the associated temperatures in the distribution tank will tend to be constant compared to the data from the other contexts, the water of the main tank acts as a heat exchanger and thermal regulator, transporting heat by convection between the different subsystems. Temperatures in the other subsystems are reduced by the loss of thermal energy from the environment.

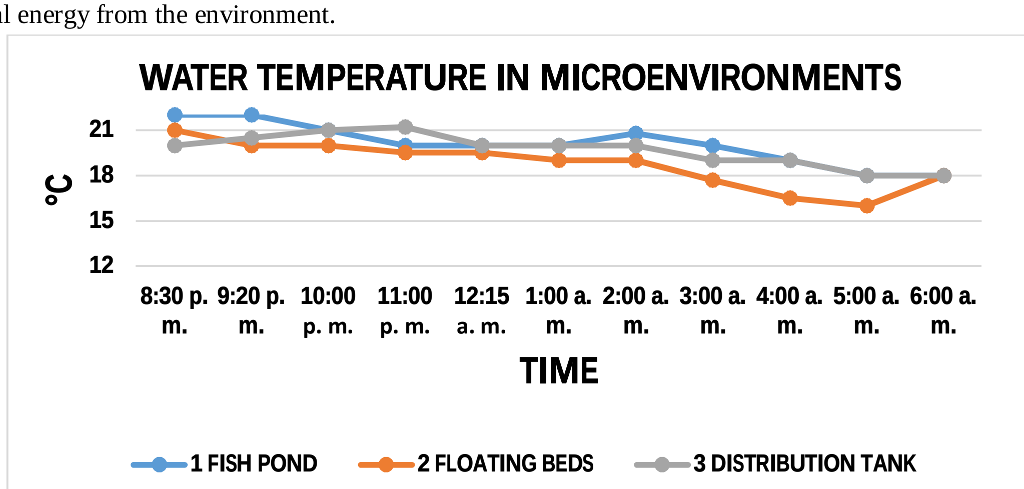


Fig. 8 Simulation of water temperature, with initial ambient temperature of 22°C of the aquaponic system (8pm - 6am)

Figure 9 shows the data obtained from the simulation for an ambient temperature of 19°C at 8 pm, which decreases until 6 am, inducing changes inside the microenvironments.

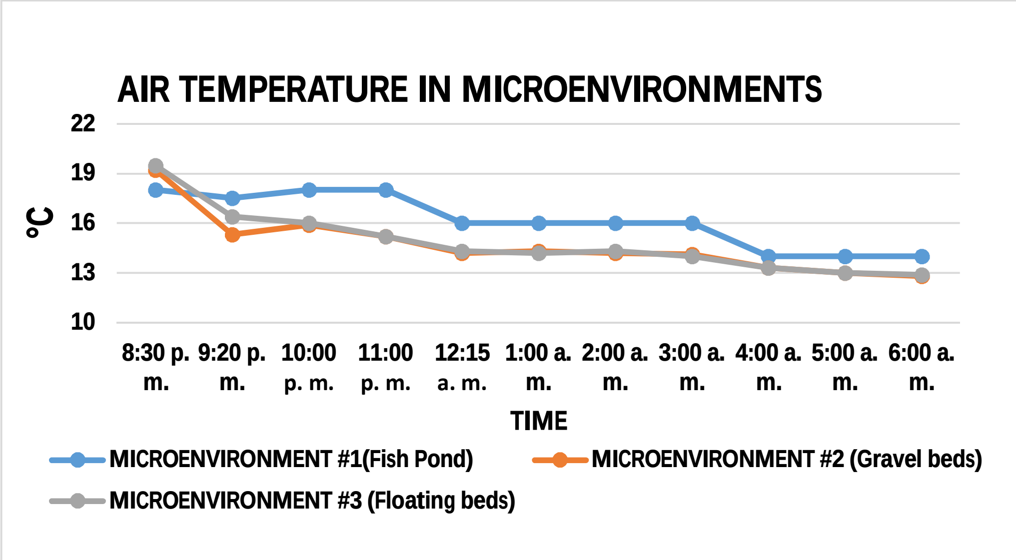


Fig. 9. Simulation of air temperature, with initial ambient temperature of 19°C at 8pm, decreasing until 6am, in the aquaponic system

The temperature curves of the gravel beds and the floating beds have similar downward trends, unlike the fish pond curve which loses less energy.

In Figure 10, the simulations are presented during the day in the same time period of nighttime data collection, taking into account the materiality conditions of the aquaponic system, each object in the graphical interface of the SE2D was configured according to the specific environmental conditions of the area.

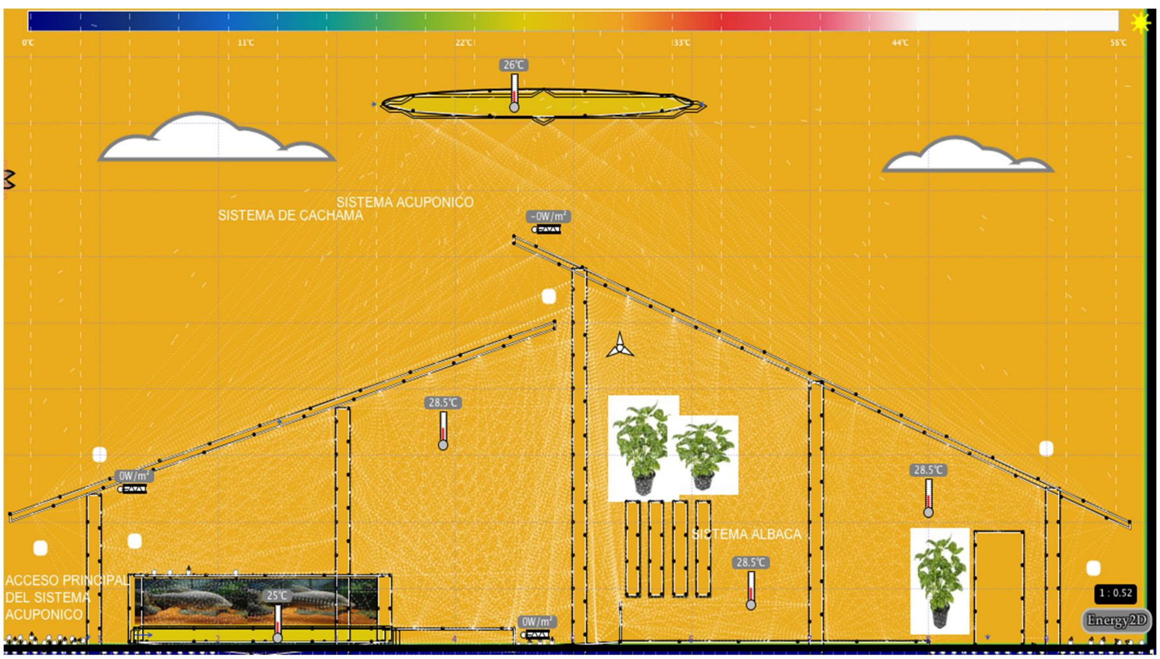


Fig. 10. Aquaponic system's diurnal thermal simulation

In Figure 11, a similar behavior is observed between the microenvironments of the fish tank and the gravel beds, in two hours they achieved temperatures of approximately 35 °C in the air, a condition that reduces the plants' production capacity.

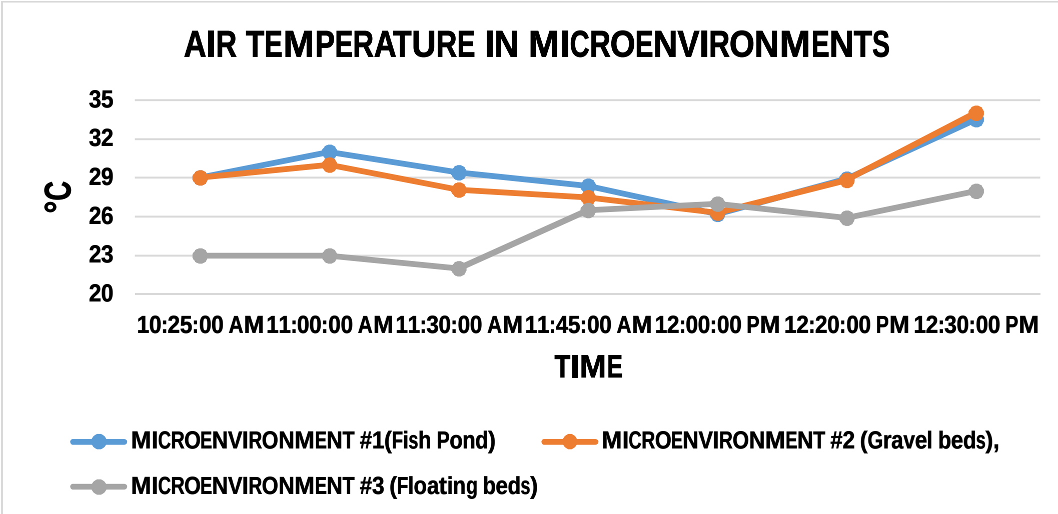


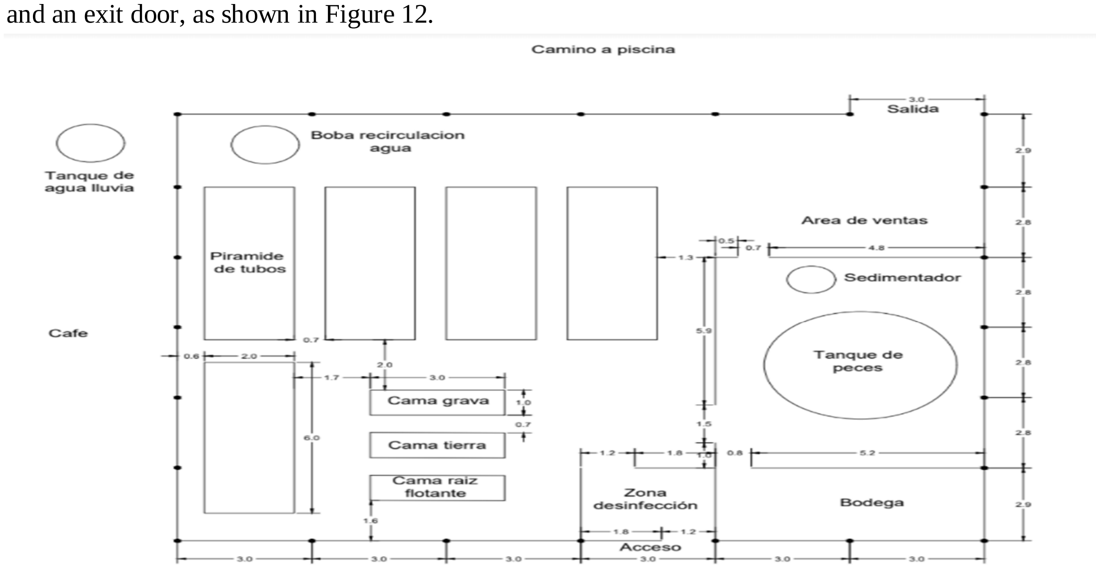
Fig. 11. Simulation of air temperature, with initial ambient temperature of 26°C in the aquaponic system in the daytime between 10 am and 12:30 pm

The temperature behavior for the daytime differs from the nighttime heat transfer. The daytime temperature is caused by solar radiation, and when it enters the aquaponic system through diffuse solar radiation, it increases the internal temperature. Figure 10 shows that the system's outside temperature is 26°C, different from the inside temperature, which ranges between 28.5° C and 56°C. High temperatures inside the system are a problem, generating stress and affecting the optimal development of plants and fish. To mitigate this emergency, some measures were adopted and are explained below

For the greenhouse where the study was carried out, an uncovered soil with the capacity to germinate seeds and native herbs was implemented in the first stage. These conditions caused dust contamination in the environment during the hours with the highest temperature increase, with effects on the relative humidity, coating of plants, fruits, substrates, equipment and water turbidity.

D. Improvement Proposal

The proposed site has the necessary spaces for the circulation of people with mobility disabilities. It also has a disinfection area, an entrance door, and an exit door, as shown in Figure 12.



Road to pool, Water recirculation pump, rainwater tank, coffee, pyramid of pipes, gravel bed, soil bed, floating root bed, exit, sales area, sedimentator, fish tank, storage, disinfection area, entrance.

Fig. 12 Updated aquaponic system layout plan.

A white tarp covering the soil was installed to increase the use of incident radiation, seeking the best use by the plants by receiving direct and reflected radiation from the tarp inside the greenhouse (Figure 13). This improvement action avoids reducing the pathogen load [27] of the soil, preventing the propagation of pests and diseases, as well as reducing dust and environmental pollution, effective measures that make the aquaponic greenhouse more efficient and sustainable.

Fig. 13 Coated aquaponic environments.

After the proposed improvements were made to optimize the functioning of the aquaponic greenhouse, the walls were modified with anti-affect mesh, taking advantage of the natural ventilation systems of the environment, improving pond oxygenation, humidity and pest control. This helps to increase the production and development of plants and fish. The average maximum temperatures reached with the modifications were 34°C during the day and 12°C at night.

The adequate development of plants and fish is linked to optimal management conditions. For example, for conventional plantations, it is essential to have variables such as fertile soil, favorable climate and crop management. Therefore, integrating indoor or greenhouse cultivation offers great advantages compared to traditional agriculture, since it allows better control over the environment, irrigation, and pests. Therefore, greenhouse cultivation is an efficient, sustainable and sustainable technology that provides a solution to food security and offers productivity advantages.

Aquaponic production is a circular process that uses the resources generated by fish farming to grow plants (Figure 14). In other words, it transforms the organic waste resulting from fish feeding and excretion into nutrients to fertilize the seedlings, which means constant periods of organic fertilization free of charge. In aquaponics, this circular flow is essential for food production.

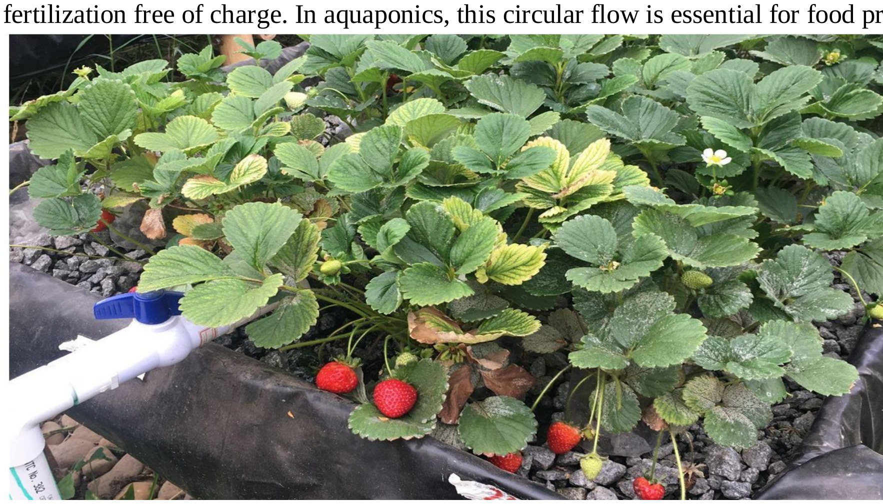


Fig. 14. Aquaponic strawberry production, "Los Robles" campus.

IV. CONCLUSIONS

The country's agricultural production is confronted with major challenges and emergencies, which affect its operational profitability and capacity to be sustainable. This has been generated for multiple reasons, among them the constant increase in prices of construction materials, agricultural fertilizers, agrochemicals, and animal feed. In addition, climate change is generating abrupt variations in temperature and precipitation, which are reflected in heavy rains, floods or long summers (for Colombia, an example of this is the El Niño and La Niña phenomena).

Under this scenario, it is important to seek technological alternatives that promote efficient, sustainable and environmentally friendly production. The proposal in this research is an aquaponic system (in greenhouses), which reduces water consumption, minimizes environmental pollution (by not using agrochemicals), the pathogen load of the soil is not affected, and increases production in relation to the area of the crop. For the correct functioning of aquaponic systems (which integrate fish and plant production), it is essential to guarantee a controlled environment that offers optimal conditions for plant and fish production. An additional advantage of these systems is the reduction of water and energy consumption.

The research was carried out at the "Los Robles" campus of the Fundación Universitaria de Popayán. The physical variables that influence the optimal functioning of the aquaponic greenhouse are: temperature (T), relative humidity (RH), air flow, water flow, solar radiation (direct, diffuse and reflected). The optimal limits for temperature, which allow the development and performance of fish and plants in the aquaponic system are: Water temperature in fish pond (22-24)°C for tilapia, Air temperature in microenvironment #2 (25-35)°C, Water temperature (21-22)°C. Air temperature in microenvironment 3 (24-32)°C, water temperature (21_22)°C, and for relative humidity RH (56-68)% in the day and RH (80-98)% at night.

The design and distribution of the structure that encloses and protects the aquaponic system is an important factor; if it does not have the necessary requirements, growth rates in fish and plants are reduced. With the implementation of a white tarpaulin on the floor, it was possible to reduce the production time of vegetables up to 21 days in lettuce. In addition, the change of the plastic walls for an anti-fungus mesh allowed improving the temperature conditions in microenvironments 1 and 3, which initially reached temperatures between (28-55)°C day, (-2 to 9)°C night, and after the improvement, the average maximum temperatures reached were 34°C during the day and 12°C at night.

The integration of two food production areas in the same space, represents for the environment the need to maintain controlled a series of parameters, a clear example of these, are the air currents needed within the aquaponic greenhouse to maintain an adequate temperature for the environment, or in the case of fish that need proper oxygenation in the pond. These variables make the aquaponic process sustainable, contributing to an efficient production, contributing to the family and business economy, but with greater importance for global food security and sustainable development.

Finally, it is important to mention the design and distribution of the structure that encloses and protects the aquaponic system; if it does not meet the necessary requirements, the growth rates of fish and plants will be reduced. Therefore, the contribution of information for the optimal and general development of an aquaponic system must advance and perfect the control of environmental and structural variables that compose it.

V. ACKNOWLEDGMENTS

Our gratitude to God for giving us health and wisdom to complete this article; to the Faculty of Engineering and Architecture of the Popayán University Foundation; to the Seedbed for Research in Business Entrepreneurship; especially to our tutor mg. Richard Marcelo Imbachi Chavez for his dedication and support; to our parents, relatives and friends for supporting us and believing in us.
¡Infinite thanks!

REFERENCES

[1] «"Fundacion Universitaria De Popayan",» [En línea]. Available: https://www.fup.edu.co.
[2] «"Acuaponia Digital Para Todos",» [En línea]. Available: https://acuaponia-digital-para-todos.mailchimpsites.com.
[3] «"Concurso Regional de Innovación para los Estilos de Vida Sostenibles",» 8/ 04/ 2022. [En línea]. Available: https://online-event/lanzamiento-del-concurso-regional-de-innovacion-para-los-estilos-de-vida-0.
[4] «"Universidad De Los Andes - Colombia",» [En línea]. Available: https://uniandes.edu.co.
[5] «"Programa de la ONU para el Medio Ambiente",» [En línea]. Available: https://www.unep.org/es/sobre-onu-medio-ambiente.
[6] O. I. Rodriguez Gutierrez , "Diseño e Implementacion de un Microsistema de Cultivo Acuaponico Automatizado", Villavicencio, 2016.
[7] N. Millares Dorado, L. Perez Jar, B. J. Ceballos, E. R. Flores Gutierrez y M. Isla Molleda, «" Un Metodo Alternativo Para Incrementar la Productividad en el Cultivo Acuicola-Agricola en Proyectos Comunitarios con Enfoque de Genero: La Acuaponia",» Revista Cubana De Investigaciones Pesqueras - AQUADOCS, vol. 34, nº 2, pp. 84-89, 2017.

[8] A. M. Gonzales Bermudez, "Diseño, Construccion y Analicis de Funcionamiento Inicial de un Sistema de Acuaponia que Combina un Estanque Ornamental con un Jardin Vertical Exterior", Sevilla, 2017.
[9] G. Ortega, " Agroecologia vs. Agricultura Convencional", Asuncion: BASE - Investigaciones Sociales, 2009.
[10] M. F. Garcia Zertuche, A. Sandoval Rangel, V. Robledo Torres, A. Benavides Mendoza y M. Cabrera De La Fuente, «"Rentabilidad y Rendimiento Agronómico de Lechuga Acuapónica",» Revista Mexicana de Ciencias Agricolas, nº 26, 2021.
[11] M. R. De Felipe Anton, "Biotecnologias Limpias en Agricultura: Fijacion Biologica de Nitrogeno. Estructura-Funcion de la Simbiosis Rhizobium-Leguminosa", Madrid: Real Academia de Farmacia (España), 2009.
[12] F. Andrade Zamora, O. J. Alejo Machado y C. R. Armendariz Zambrano, «"Metodo Inductivo y Su Refutacion Deductista",» Conrado, vol. 14, nº 63, 2018.
[13] J. Hernandez Ascanio, P. Tirado Valencia y A. Ariza Montes , «El Concepto de Innovacion Social: Ámbitos, Definiciones y Alcances Teoricos,» CIRIEC, nº 88, pp. 165-199, 2016.
[14] T. Ingold, «"Los Materiales Contra la Materialidad",» IDAES, vol. 7, nº 11, 2013.
[15] J. D. Mecón Rodriguez, "Tendencias Tecnologicas en la Implementacion de Sistemas de Monitoreo en Sistemas Acuaponicos", Colombia , 2020.
[16] R. De La Rosa Rodriguez, A. Lara Herrera, J. Lozano Gutierrez, L. E. Padilla Bernal, J. J. Avelar Mejia y R. Castañeda Miranda, «" Rendimiento y Calidad de Tomate en Sistemas Hidroponicos Abierto y Cerrado",» Revista Mexicana de Ciencias Agricolas, nº 17, pp. 3439-3452, 2016.
[17] J. Leal Iga, "Modelado para control predictivo de la temperatura en invernaderos", Mexico, 2008.
[18] L. Huertas, «"El Control Ambiental en Invernaderos: Humedad Relativa",» Marzo 2008. [En línea]. Available:https://www.mapa.gob.es/ministerio/pags/biblioteca/revistas/pdf_Hort/Hort_2008_205_52_54.pdf
[19] J. Hernandez y J. Parra, "Evolucion de las Estructuras de Invernadero, 2006.
[20] R. H. Lira Saldivar, "Agricultura Protegida Vertical", Mexico, 2022.
[21] B. Rios Rios, E. Torres Flores y J. E. Celis Escudero, "Monitoreo automatizado de la temperatura y la humedad del suelo de un invernadero para la producción de tomate", Universidad Nacional de San Martín. Fondo Editorial, 2019.
[22] «De Ingenierias,» 26 Febrero 2022. [En línea]. Available: https://deingenierias.com/software/energy-2d/.
[23] L. E. Moreno M, E. E. Trujillo y L. R. Osorio, «"Estudio de las características físicas de haces de fibra de guadua angustifolia",» Scientia et Technica, vol. 1, nº 34, 2007.
[24] R. G. Aquino Guerreño, N. Lopez Silvero y M. A. Jara Rodriguez, "Hidroponía NFT Automatizada", Facultad Politécnica - Universidad Nacional del Este, 2019.
[25] IDEAM,» [En línea]. Available: http://www.ideam.gov.co/web/tiempo-y-clima/la-radiacion-solar-y-su-paso-por-la-atmosfera.
[26] M. Pareja Aparicio, "Radiacion Solar y su Aprovechamiento Energetico, Barcelona: Marcombo S.A-, 2010.
[27] J. Mora Rodriguez, H. M. Ramos y P. A. Lopéz Jimenez, «"Eventos de intrusión patógena en sistemas de distribución de agua potable",» SciELO Analytics, vol. 4, nº 3, 2013.