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# CPS, Sustainability and Efficiency in an Aquaponic Greenhouse

J. Galvão[1,2], P. Santos[1], L. Aires[3,4], F. Neves[5]

[1] Department of Electrical Engineering/ESTG, Polytechnic of Leiria, 2411-901 Leiria (Portugal)
Phone:+00351 244820300, e-mail: **jrgalvao@ipleiria.pt, 2182024@my.ipleiria.pt, luis.aires@ipleiria.pt, fneves@ipleiria.pt**

[3]LSRE-LCM - Laboratory of Separation and Reaction Engineering – Laboratory of Catalysis and Materials, Escola Superior de Tecnologia e Gestão, Instituto Politécnico de Leiria, 2411-901 Leiria, Portugal
[4]ALiCE - Associate Laboratory in Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto (Portugal)
[2] R&D Unit, Institute for Systems Engineering and Computers /INESC Coimbra (Portugal)
[5]Department of Computer Science, Polytechnic of Leiria, 2411-901 Leiria (Portugal)

**Abstract.** Nowadays the humanity needs to produce food in greater quantity and quality, in order to satisfy citizens and markets, supported by advanced technologies such as cyber-physical system (CPS) or intelligent systems where software and electronic devices and receivers of physical variables are mechanisms that control the management of multiple actions inherent to plant growth. Electronic devices and receivers of physical variables are mechanisms that involve a network of IoT components and control multiple actions inherent to plant growth in agricultural greenhouses, which in short, are intensive food production systems. In this context, this paper presents a case study that uses a monitoring and management system that considers environmental parameters measured inside a greenhouse, allowing the manager to assess the working status of an aquaponic systems, and detect critical conditions that require quick decisions in real time. It is intended to develop technology that can be used in greenhouses, close to consumer centres or cities, to mitigate the impact of transport, lowering $CO_2$ emissions resulting from the distribution channels between the producers and consumers.

**Key words.** Cyber-physical system, aquaponic system, energy efficiency, environmental monitoring system.

## 1. Introduction

Energy costs and productivity are two interconnected factors in economic activity sectors [1]. Agriculture is a relevant and fundamental area for the community and many countries depend on this sector [2]. Recently, more flexible and better-performing plant production technologies have been used, such as hydroponics and aquaponics under greenhouse conditions [3].

Greenhouses are used to control or modify the various environmental factors that affect plant growth, mainly air temperature, relative humidity, rain, wind, hail and snow [4]. Hence, greenhouses allow greater production and a greater diversity of crops cultivated throughout the year, not requiring specific periods for crop plantation due to environmental factors.

Greenhouses require energy to provide a suitable environment for agricultural production. Using solar energy in solar greenhouses is a sustainable solution to this problem [5].

In this study, it is intended to understand and analyse the energy consumption of a case study - greenhouse for the production of vegetables by an aquaponic system, located at Campus 2 of the Polytechnic of Leiria - in order to design a photovoltaic system that will make the activity more sustainable. Inherent to this objective, is also, intended to study and implement technological systems that can lead to the improvement of the energy efficiency and productivity of this plant production process, through the collection, monitoring and control of environmental parameters with remote platform support [6].

## 2. Greenhouse Systems for Sustainable Operation

### *A1. Greenhouse Characterization*

The greenhouse in the present study was carried out has 150 $m^2$ of total area (15m length and 10m width). In the greenhouse, aquaponics cultivation techniques and occasionally small-scale hydroponics are used in specific scientific studies. Inside, there are 3 aquaponic lines, each with a fish tank, a frustoconical filter with sedimentation, a biofilter, a DWC hydroponic bed and a SUMP containment tank (Fig. 1). The water flows by gravity from the fish tank to the frustoconical filter, where large solids are filtered, which are cleaned automatically and periodically with the aid of a motor and a water pump. The water is subsequently pumped into a biofilter, which contains bio balls that allows the growth of nitrifying microorganisms among others, which help to mineralize in nutrients making them bioavailable to plants. From the biofilter, the water flows to the hydroponics bed and at the end the water is collected in the SUMP reservoir. The water is then returned to the fish tank via a water pump. The system works as closed cycle, with small water losses.

Fig. 1. Aquaponic lines in the greenhouse.

In terms of climate control of the greenhouse, the current system is precarious, consisting of two long side windows with non-automated vertical openings, which allow passive air circulation.

*A2. Consumption Analysis*

Initially, Chauvin Arnoux energy analyser, model CA 8334B [7], installed in the switchboard of the greenhouse, which has a three-phase system, for a period of 21 days, from 7 May 2019 to 27 May 2019 with a sampling period of 15 minutes, to analyse the consumption of the installation (Fig. 2).

Through the collection of data, a load diagram was created (graphic representation of the load as a function of time) which shows the energy consumption in each hour, thus being able to analyse the variation and peaks of energy consumption in the installation (Fig. 3).

An important fact is that the greenhouse loads are practically all single-phase and most loads are in continuous operation.

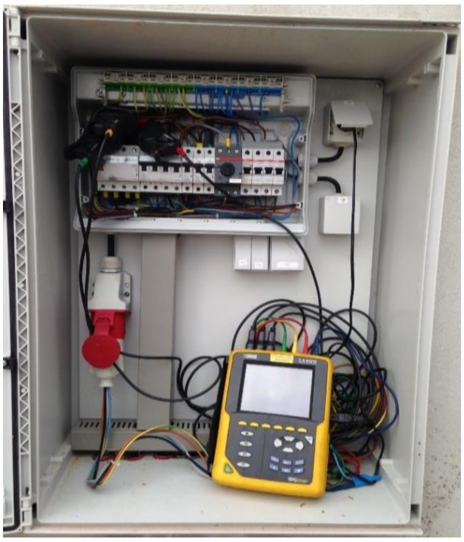

Fig. 2. Energy analyser in the in the electric panel of the greenhouse.

After analysing the temperatures of the measurement days and comparing them with the electrical consumptions, it was possible to verify that when the consumptions increased to their peaks, with low ambient temperatures or cloudy the weather. Thus, the electrical consumption peaks are consistent with the ambient temperatures and therefore with the expected period of operation of the heaters for heating the water.

It was decided to re-install the energy analyser in the electric panel of the greenhouse to collect more data on consumption, during a period of 13 days.

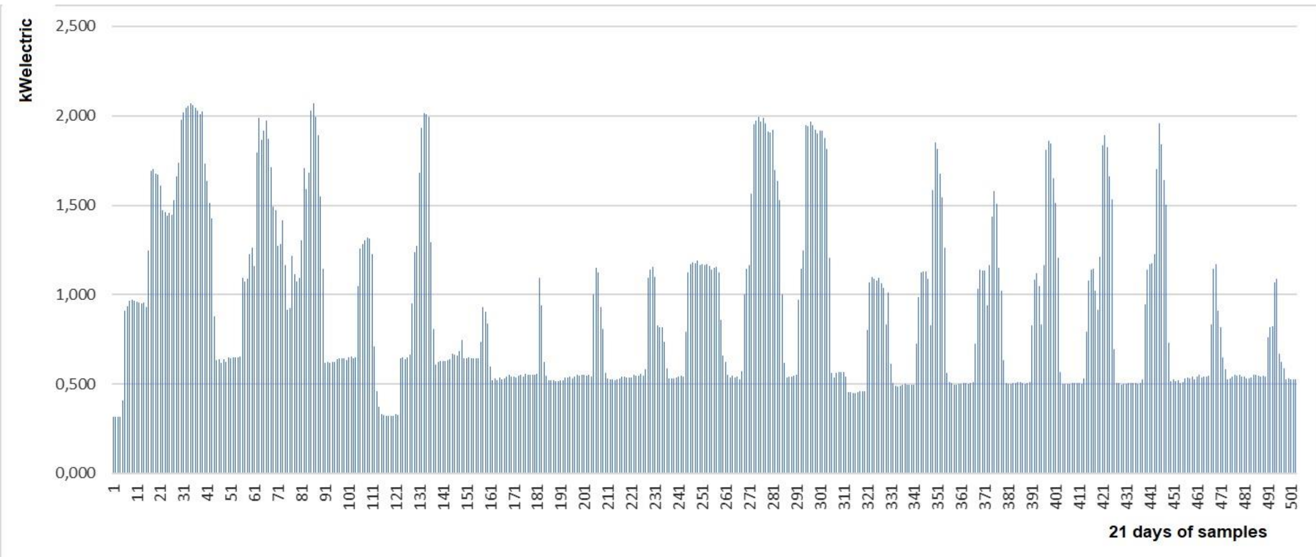


Fig. 3. May 2019 load diagram and 21 samples days.

The fact that the windows must be opened and closed manually creates major constraints in maintaining ideal climatic conditions.

The current system also resorts to the use of a green shading screen, placed and fixed internally to reduce excess radiation and, as far as possible, the indoor air temperature in the hottest periods of the year.

From 12 February 2020 to 25 February 2020 with a sampling period of 1 minute, to carry out an analysis consumption of the installation in another season of the year.

Through the collection of data, a load diagram was created (Fig. 4), to observe the differences between the consumption of the data collected previously.

Through the analysis between the consumptions collected initially and the final consumptions, the peak power is slightly lower, 1.82kW, but the consumptions are higher.

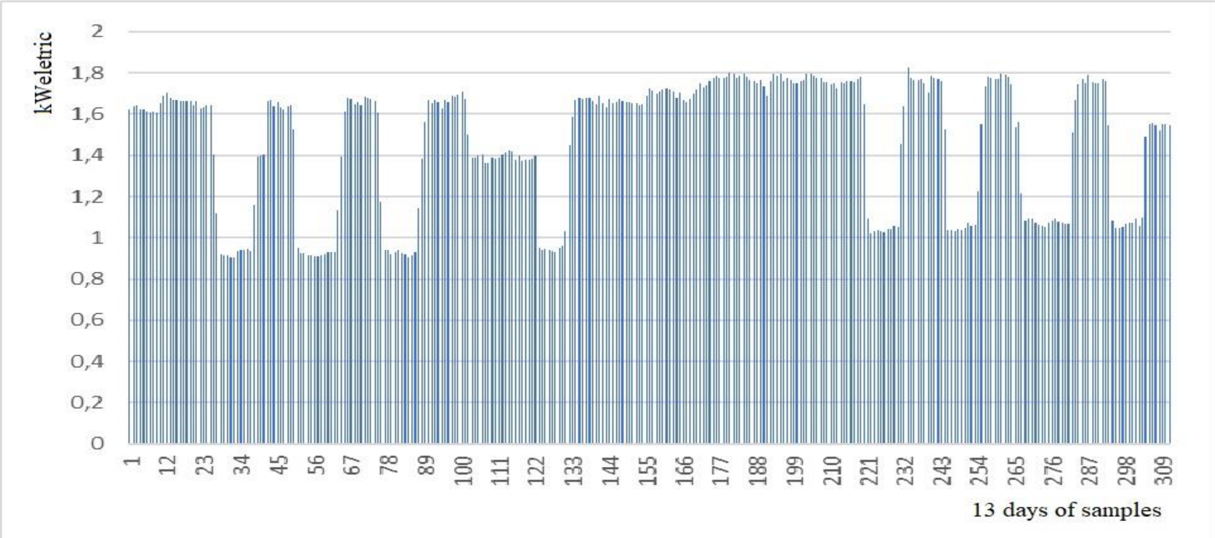


Fig. 4. Load diagram in February 2020 during 13 days of samples.

This is due to the greater number of loads in operation, namely, because aquaponic lines 1 and 2 were put into full operation.

## 3. Methodology, Model Developed and Results

This research has several parts that in the final context intends to be a model of greater automation and sensing of this type of intensive agricultural, activity in a controlled environment of a greenhouse and to raise the levels of sustainability by a local production of electricity by photovoltaic technology [8,9].

Next, the process of producing electricity is highlighted, followed by the process of collecting, monitoring and remotely viewing some parameters of the greenhouse to facilitate its management and increase its efficiency.

*A3. Photovoltaic System*

The values of the load diagram were used for the dimensioning of the system of renewable electricity production. The design of the photovoltaic production system for this greenhouse was carried out and two scenarios were designed by using PVsyst software and Sunny Design [10,11].

In a self-consumption scenario, the investment is lower, it is possible to reduce the electric bill and sell the excess energy produced to the grid.

The scenario in an isolated network regime presents high costs and if applied to this case study, it wouldnt show great benefits. The self-consumption photovoltaic system consists of the production of electrical energy to supply the needs of the consumer and the excess electrical energy can be injected into the electrical grid.

The dimensioned self-consumption system consists of 2 strings with 8 photovoltaic modules each with Suntech 240Wp photovoltaic module, Sunny Boy 3600TL inverter with 3.68kW output power.

The sizing of the photovoltaic system for isolated grid was also carried out. In this solution there is no purchase of energy from the grid for certain situations in which the system cannot produce enough energy to respond to the load but can feed the loads through the batteries.

In the configuration of the photovoltaic group, the 280Wp Suntech photovoltaic module were installed 63 photovoltaic modules were installed but considering the load to be supplied. The inverter sized for the system was the 5kW Sunny Boy, and to support the photovoltaic group, 3 inverters were needed, which allows it to function properly. For each inverter, 2 strings were placed, where each string has 10 and 11 photovoltaic modules respectively.

For the dimensioning of the batteries, 2 Sunny Island inverters were needed; this inverter ensures a frequency equal to that of the electrical grid and is compatible with it. With these inverters, inverters such as the Sunny Boy can be used for an isolated photovoltaic system, which is the case with the system dimensioned in the greenhouse. Sunny Island 8.0H was used in the design of the system that guarantees the use of batteries when necessary.

The batteries used in the LG Chem RESU 13 system have a capacity of 252Ah, a voltage of 48V and a power of 13.1kW. To guarantee the greenhouse autonomy time for three days, 3438Ah is needed. So, 14 batteries were needed, the division of the batteries to be connected to the Sunny Island inverter was carried out in the same way, 7 batteries connected to each inverter.

*A4. System Monitoring and Visualization*

The part of the model developed that monitor environmental parameters in the greenhouse under study is essential to assess the functioning of aquaponic systems and to detect critical conditions that require urgent action (Fig. 5). For this, sensors that collect these variables and microcontrollers are needed, which will allow this data to be made available and viewed remotely over the Internet.

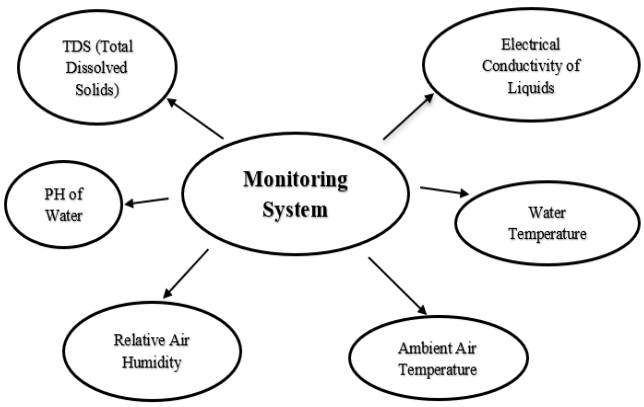


Fig. 5. Model developed for the monitoring system.

The block diagram (Fig. 6) consists of the processes developed in the project and the connections between the several microcontrollers and sensors can be observed.

The ESP32 NodeMCU receives the parameter data from the sensors, where the data is processed and sent via wi-fi to the Raspberry Pi microcomputer (Fig. 7), where the data is saved in order to have a history of the parameters.

Data can also be viewed remotely through a computer dashboard or mobile application on a smartphone.

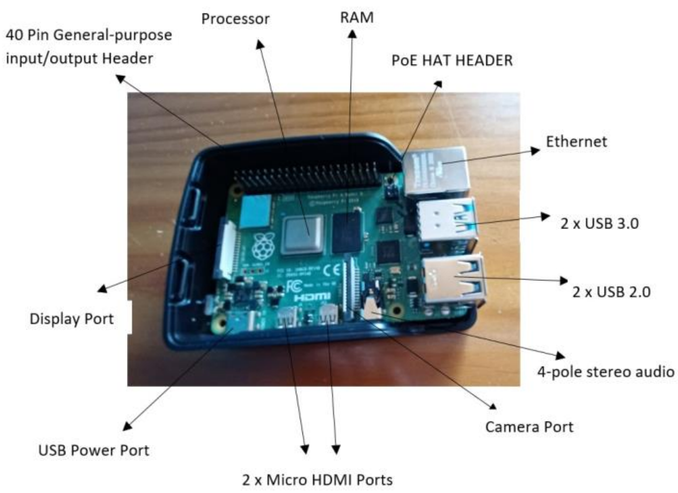


Fig. 7. Raspberry Pi microcomputer main components.

To visualize the values of the sensor readings, a dashboard was created with the monitoring of each sensor, for this it was necessary to develop a flow for each sensor. For example, the ambient temperature stream, which consists of receiving the ambient temperature via the MQTT protocol and providing the value for sampling via a graph and a text field.

The interface consists of a dashboard (Fig. 8), a Blynk mobile application [12] and a MariaDB database [13]. Blynk is a mobile application that allows us to create a graphical interface and customize it according to what we want to control remotely, with multiple devices connected (Fig. 9).

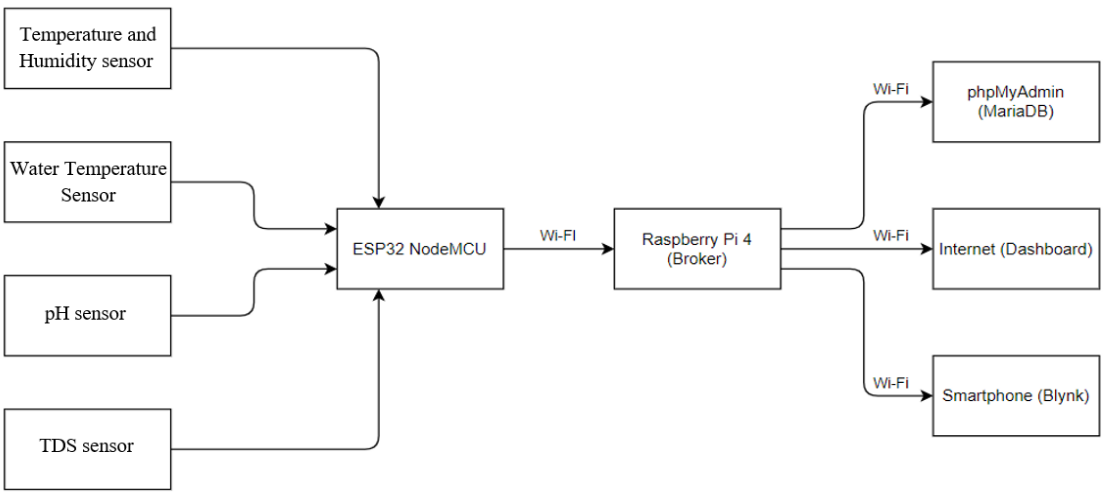


Fig. 6. System block diagram

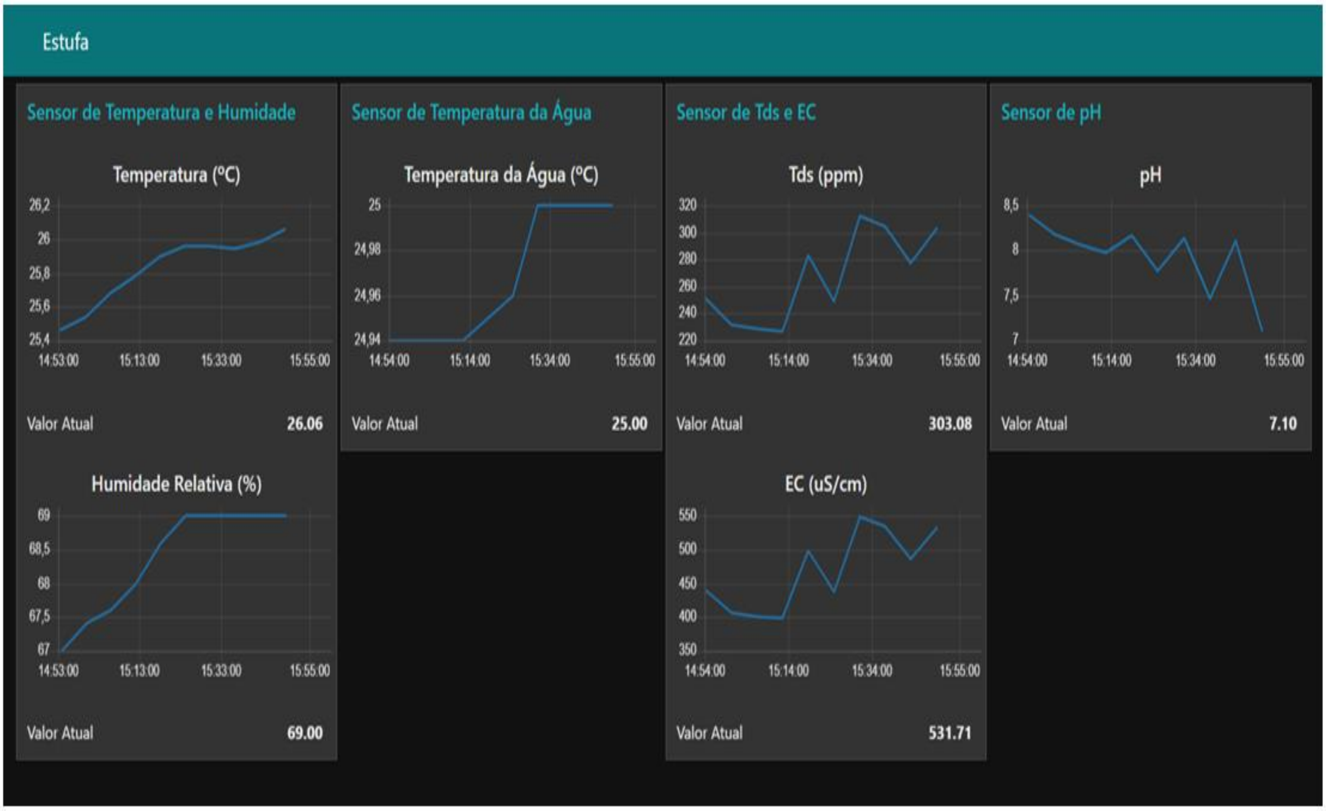


Fig. 8. Greenhouse dashboard with the values of variables collected by the equipment.


Fig. 9. Blynk graphical interface on smartphone.

*A5. Results*

The tests carried out demonstrate that the monitoring system performs the collection and visualization of the parameters of ambient temperature, relative humidity, temperature, pH, Tds and EC of the water through the internet in a dashboard, providing its visualization in a mobile application and placement these values in a database.

The result of the software simulation shows that the photovoltaic system has an energy production of 5530 kWh/year, with a performance index of 83.16%. The solar fraction of the system is 30.21%, that is, close to 30% of the energy that powers the greenhouse comes from the photovoltaic system, with the rest being purchased from the grid.

## 3. Conclusion

Almost all equipment is in continuous operation in the greenhouse, the values of the load diagram were used for the dimensioning of the system of renewable electricity production. The design of the photovoltaic production system for this greenhouse was carried out and two scenarios were designed.

In a self-consumption scenario, the investment is lower, it is possible to reduce the electric bill and sell the excess energy produced to the grid.

The scenario in an isolated network regime presents high costs and if applied to this case study, it wouldnt show great benefits.

The real-time monitoring of some data is a relevant part of this study, in particular the physical variables inherent to the environmental mode of operation of the greenhouse, such as: air temperature, relative humidity of the air, water temperature, electrical conductivity of nutrient solution, originating from liquid biomass from fish (barbels and catfish), TDS (Total Dissolved Solids) and pH, considered as the main parameters to detect critical conditions and where anomalies may come from in the nutrient distribution process.

The sensors used in this project have useful life and good performance characteristics. The real-time monitoring system can greatly reduce costs and environmental impacts with transportation, by reducing system supervision trips, while contributing to enhance plant production.

In the future, it will be necessary to use sensors with greater durability that can guarantee better continuity and reliability of the operation.

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