STOCKHOLM JUNIOR WATER PRIZE 2021

DESIGN AND CONSTRUCTION OF AN IRRIGATION SYSTEM POWERED BY RENEWABLE ENERGY

SPAIN

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Abstract:

The principal objective of this project is to design, develop, and if it's possible, make an automatic irrigation system that works from renewable energies. For this reason, the necessary energy would be provided by a solar panel. The project is divided into three parts:
The first one consists on developing a study of the land and drawing up a map of the orchard
The second one consists on making all the necessary calculations to carry out the project.
And finally the third one consists on building the irrigation system physically, from the data obtained from the first and the second part.

Having into account the aforementioned objectives, this project aims to design an irrigation system for a vegetable patch and construct it, considering that it collects rainwater and has a submerged pump. To construct this system, which is the final objective of the work, it must be taken into account that the installation budget is affordable.

The practical performance has been divided into the assembly of the irrigation and the installation of the local power plant, which would be the solar panel.

Keywords: Automatic, irrigation system, renewable energies, solar panel.

TABLE OF CONTENTS

Acknowledgment

Doing this project has allowed me to learn a lot about a topic that interests me and of which I had little knowledge. It has been very satisfying and exciting for me to go through this learning process, which has been long, difficult, and, needless to say, sometimes even a little cumbersome.

1. INTRODUCTION

1.1 Origin of the project

Last summer, before the beginning of the first high school year, I began thinking about the topic of my research project. The topic had to be interesting for me, because I would have to devote a good part of my time, and on the other hand it had to be useful, not only for me but also for the future. And in the middle of this assessment, I found myself going to irrigate my grandfather's orchard. We had to pump the water from a well into 200-liter tanks, fill a watering can and irrigate plant by plant. After several days of rehearsing this procedure, I realized that it was a job that I liked, but I found it very hard, and from there the idea of doing a research project arose. The following days, when I replicated the process, it was clear to me that this project would allow me to improve the functionality of the orchard; and in addition, to take care of the environment being that the necessary energy should come from renewable energies.

1.1 Objectives

The main objective of this project is to design and develop an irrigation system that works with renewable energies. Precisely the energy needed for the functioning of the irrigation system will be provided by a solar panel.

This objective can be divided into three parts:

- **Irrigation design:** This objective includes the land study, make a plan, design the irrigation system, the elaboration of the calculations the irrigation water needs, and the selection of the necessary materials according to my budget.
- **Design of the solar panel system:** This objective includes the elaboration of all the electrical calculations for the installation of the solar panel, design and develop the block diagram of the electrical system, and finally, the selection of the necessary materials according to budgets for their construction.
- **Irrigation construction:** This objective includes its assembly and the solar panel.

Sustainable development goals.

This research project was carried out in a town located 23 KM away from the city of Barcelona and which uses rainwater by means of a pump powered by a solar panel. This project achieves some objectives and goals of the sustainable development goals. I will detail these objectives below.

- **Goal 7: Ensure access to affordable, reliable, sustainable and modern energy**

The use of sustainable energies contributes to reducing climate change, but this requires energy efficiency, which uses clean and safe renewable energies. The work presented, translates these clean energies into the use of a solar panel. This goal belongs to *(7.2 By 2030, increase substantially the share of renewable energy in the global energy mix)* which equally tells us that to advance the country and reduce CFC emissions, energy efficiency is needed, and albeit modestly, with this project I can contribute.

- **Goal 11: Make cities inclusive, safe, resilient and sustainable.**

The use of rainwater through the use of a pump contributes, even with a grain of sand to an efficient use of resources, the mitigation of climate change and adaptation to it, therefore, it achieve the goal. (*11.B By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.)*

- **Goal 12: Ensure sustainable consumption and production patterns.**

This project is within this goal because sustainable consumption and production are to do more and better with less, and the purpose of the same work, is to take advantage of solar energy and rainwater in a rational way from drip irrigation and the possibility of integrating a humidity sensor to avoid watering if the sun already contains a sufficient amount of water. This use is to obtain food, and therefore a direct consumption is made (KM 0) so no packaging waste is generated. Milestones are met *12.2 By 2030, achieve the sustainable management and efficient use of natural resources, 12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses, 12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse*

It would also meet achievement *12.4 in the farming production chemicals fertilizers aren't used, there are substituted using natural fertilizers, herbicides and insecticides. 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment.*

- **Goal 13: Take urgent action to combat climate change and its impacts.**

The installation of the irrigation system is one of these measures proposed by Objective 13 to combat climate change and its effects, the achievement I have reach doing this project is the goal *13.3 Improve educations, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning because one of the purposes is the result of raising awareness to mitigate climate change and help reduce its effects.*

1.3 Project organization

This project is divided into two essential parts.

The first one consists on developing the theoretical frame that is determined by the study of all the necessary concepts to bring about and adequately understand all the necessary steps for the project development.

The second part is based on the technological process. Its objective consists on perform an comparative analysis of all the possible alternatives referred on:

- Control systems
- Power systems
- Various types of pumping (the well already has a submerged pump.)
- Finally the various irrigation systems to carry out the project.

One time examined all the alternatives, the most appropriate ones will be selected to prepare the project design. Once I have the design done, I will proceed to explain the planning of the construction of the irrigation system. Afterwards, the process of purchasing the materials and the assembly of the system can begin. Finally, I will present the results obtained and carry out an objective evaluation.

1.4 Methodology

Once I had the content of the project, I contacted an industrial engineer to determine if it was feasible to carry it out. After approval of the feasibility, I was able to embark on the project.

1. The first step was to realize a study of the garden; specifically, measuring the entire terrain and drawing up a plan with the Autosketch program.
2. Next, I proceeded to make the irrigation calculations (flow and irrigation water needs).
3. Once time I had all the calculus developed, I proceed with the elaboration of the theoretical frame:
    a. In order to carry out the project, I proceeded to do a search for the information and a study on all the possible alternatives to execute it.
    b. Study of control systems: PLC, PC, wiring.
    c. Study of power systems: wind turbine, solar panel, wind engine.
    d. Study of the type of irrigation system: drip, exudation, sequential, simultaneous, flood.

   e. Once this study was completed, I proceeded to select the most suitable components for the project and develop the design.
4. Once the design of the irrigation system was drawn up, I proceeded to look for the commercial technical documentation, catalogs and budgets. During this process, I got in contact with different supplier companies to consult different budgets and obtain various points of view that would help me enrich the project.
5. When I had the materials, I proceeded to build the project.
6. Once the irrigation system was built, I made its evaluation through a checklist.

2. CALCULATIONS

To construct this system, the irrigation water needs must be calculated. This calculus will be applied to the irrigation programmer, once the irrigation system is installed. The calculus will determine the amount of water that has to be applied to the crops.
Irrigation scheduling can be executed based on the approximate water needs of the crops according to the time of year and the farmer's experience.Although this experience is very important, some different calculation methods help to carry out a much more precise programming in order to save water and energy. The method adopted for this project is the hydrological balance.

2.1 Hydraulic calculations

The hydraulic calculations have been elaborated by means of an excel. [1]

The first column of the spreadsheet comprises the months of the year; the second is the total precipitation of the month in (mm) and the third is the result of dividing the monthly precipitation by the days of each month (column J). The monthly precipitation data given in mm/month are extracted from the Agrometeorological Network of Catalonia (XAC), managed by the Meteorological Service of Catalonia (SMC).

The system formed by the soil and the crop has water inlets and outlets. The water content varies over time based on these inputs and outputs.
If the water inlets are higher than the outlets, the soil will become damp; while if they are smaller, it will dry up; therefore, the water balance (HA) in an irrigated system will be:

$$\Delta H = Nn + Pef - Etc$$

Where:
Nn: Clean irrigation needs
Pef: effective precipitation
Etc: Crop Evapotranspiration

[1] See excel in Annex 1

The main objective of irrigation is to maintain soil humidity in a constant way (AH = 0) and that it remains at a humidity level close to the capacity of the land. Considering this fact, we would consider the net irrigation needs as follows:

$$0 = Nn + Pef - ETc$$

$$Nn = ETc - Pef \text{ (column c)}$$

The final amount of water to be incorporated into the irrigation system (total irrigation water needs NTR) must be higher than the clean water needs, because it must be taken into account that in the efficiency of irrigation application, not all the water applied may be used by plants, since it can be lost by runoff or drainage. Like that, the total irrigation needs (NTR) will be calculated, using the following equation:

$$NTR = Nn/Ef \text{ (column M)}$$

Where Ef is the irrigation application efficiency. (is a constant extracted from the document *Pau, J., 2020. DT04. Gestió Eficient De L'Aigua De Reg (I). 1st ed. Generalitat de Catalunya. Departament d'agricultura ramaderia i pesca.)*

Sistema de reg	Eficiència mitjana durant tot el període de reg	Eficiència en els moments punta de reg
Superfície	0,55-0,84	0,70-0,87
Aspersió	0,67-0,90	0,55-0,90
Degoteig	0,74-0,95	0,74-0,95

Ef

From these values I have taken the interval of 0.74-0.95, because the selected irrigation system is by drip. And I have used an Ef = 0.8, which is the mean. In the column (F) we find the calculations of crop evapotranspiration (ETc). This calculation is determined by a formula proposed by the Food and Agriculture Organization of the United Nations (FAO).

$$ETc = ETo \times Kc$$

ET0 (Reference Evapotranspiration) is a measure of the capacity of an environment to evaporate water through a vegetation cover;this capacity is conditioned by solar radiation, air temperature, ambient humidity and wind speed.Currently, the Meteorological Service of the Generalitat de Catalunya provides this information through the network of automatic meteorological stations.The ET0 data corresponding to the orchard of this project located in the municipality of Caldes de Montbui (located in the province of Barcelona) I have looked for them in the meteorological station of Caldes de Montbui (Torre Marimon); specifically, I have consulted those of the last year.

The crop coefficient (Kc) is a factor that does not contain an associated physical dimension, corrects the ET0, and finally obtains an estimate of the evapotranspiration of a given crop. The Kc depends on the type of crop and the area where it is placed. Due to the complexity of determining Kc, FAO published a specific monograph on this topic. The Kc used in the excel are used for the vast majority of crops, because Caldes de Montbui does not have local Kc, I have extracted them from the document: Tarruella, X., 2020. DT04. Gestión Eficiente De La Agua De Riego (I). 1st ed. Barcelona: Diputación de Barcelona.

The Kc (a) of the table belongs to favorable meteorological conditions and the Kc (b) to the unfavorable ones. A calculation table has been made from the favorable Kc and another with the unfavorable Kc.

Fase Conreu	Mes	Kc (a)	Kc (b)
Fase 1	Gen	0,35	0,5
Fase 1	Feb	0,35	0,5
Fase 1	Mar	0,35	0,5
Fase 1	Abr	0,67	0,81
Fase 2	Mai	0,67	0,81
Fase 3	Jun	1,01	1,16
Fase 3	Jul	1,01	1,16
Fase 4	Ago	0,89	1,02
Fase 5	Set	0,78	0,88
Fase 1	Oct	0,35	0,5
Fase 1	Nov	0,35	0,5
Fase 1	Des	0,35	0,5

Kc

2.2 Electrical calculations

The electrical calculations have been prepared using an excel.[2]

The electrical calculations will serve to determine the electrical characteristics of the components of the electrical system; this way we can determine which components to look for in the market.

Once the irrigation needs in L / day have been calculated, we proceed to calculate the operating time of the pump. Dividing the volume of water (v) per day by its flow (QP), we will obtain the time (t) (in minutes) that must be in operation.

$$t = \frac{v}{qP}$$

With this value, all the corresponding electrical calculations can be carried out, which will determine which materials are selected for mounting the solar panel. To perform the calculations, we focused on the concept of energy.

Energy is the ability of a mechanism or any electrical device to carry out work. The principle of conservation of energy says that "energy is neither created nor destroyed, it is transformed"; in the case of electrical energy, this transformation is manifested by obtaining

[2] See excel in Annex 2

light, heat, cold, movement, or other useful work performed by any device connected to a closed electrical circuit.

Electrical power is the rate at which energy is consumed. Power (P) equals energy (E) divided by time (t). Power (P) is expressed in watts (W), energy (E) in joules (J), and time (t) in seconds.

$$P = \frac{E}{t}$$

From this formula it will be possible to calculate the necessary energy of the pump; Taking into account the power (W) and the time (h) of use of the various equipment, the total daily energy demand in Wh / day can be established. Therefore, the energy is equal to a power multiplied for the time of application.

$$E = t \times P$$

To the value of the planned daily consumption (Wh / day), the particular efficiencies of the elements that comprise it will be applied: regulator, battery and inverter; so that the result, which we call necessary energy, is the dirty energy that must be produced in the modules to effectively satisfy the expected clean consumptions. This value will always be higher than the clean energy that you want to supply to the consumptions.

The battery power is calculated from the required energy of the pump (EP). First, dividing the required energy of the pump (EP) by the performance of the regulator (RO), the usable energy of the battery (EBA), in watt hours, will be calculated.

$$EBa = \frac{EP}{rO}$$

Dividing the usable energy of the battery (EBA) by the product of its performance (rB) for the use of the battery (aB), the necessary energy of the battery is obtained.

$$EB = \frac{EBa}{(rB \times aB)}$$

To find out what capacity (QB) the battery should have, divide the usable energy of the battery (EBA) by the working voltage of the battery (UB). The capacity will be obtained in Ampere hours (Ah).

$$QB = \frac{EBa}{UB}$$

Once the battery power (EB) has been calculated, the board power (SE) can be calculated, which will be obtained by dividing the battery power by the inverter performance (RO).

$$ES = \frac{EB}{rR}$$

As previously said, the power equals the energy between time. To calculate the power of the solar panel, a new concept of time will be introduced, the Solar Peak Hours (HPS), which are the value that expresses the hours of sunlight per day with a fixed intensity of 1,000 W / m2. Peak solar hours have been extracted from the *Solar Radiation Atlas of Catalonia.* From this atlas the daily global solar irradiation of each month is extracted. And by means of a conversion factor it goes to HPS. Therefore, the power (PS) of the plate will be obtained by dividing the solar panel energy (SE) by the solar peak hours (HPS). The power will be obtained in Watts (W).

$$PS = \frac{ES}{HPS}$$

Dividing the power of the solar panel (PS) by the performance of the plate (rS) will calculate the power to catch the sun (PSOL), in Watts (W).

$$Psol = \frac{PS}{rS}$$

The surface of the plate (SS) (m2) will be obtained by dividing the power taken from the sun (PSOL) (W) by the power that the sun gives at ground level (Ps-t), which is 1,000 W / m2.

$$SS = \frac{Psol}{Ps - t}$$

Finally, the amount of electricity that passes through the section of a conductor in the unit of time will be calculated; in this case the section that goes from the plate to the battery. Plate - battery current (IS). It will be calculated by dividing the power taken from the sun (PSOL) by the working voltage of the battery (UB). It will be obtained in Amps (A).

$$IS = \frac{PS}{UB}$$

3. PROJECT (TECHNOLOGICAL PROCESS)

3.1 The requirement (the objective).

The objective of this project is to design and physically develop an irrigation system that works from renewable energies. Precisely, the energy necessary for the operation of the irrigation will be provided by a solar panel. To carry out this project, a study of the terrain must be carried out, and a generation of ideas must be detailed to choose the most suitable components for the project. Next, the design will be explained.

3.2 Terrain study

The study of the land will tell us what the arable area is and the amount of water available to install the irrigation system. Keep in mind that the garden already has a well (its power source comes from groundwater) with a pump and a water outlet. From this study I have determined:

- Total area of the orchard: 272.17 m2
- Arable area: 125m2
- Well depth: 11.36m
- Well capacity: 15.5 m3
- Pump flow: 24 l / min

3.3 Design

3 .3.1 Irrigation system design[3]

The design of the irrigation system installation is determined by the location of the well, which is the water outlet from the garden. To obtain or enter water into the irrigation system we have a submerged pump Espa, which is the one that will pump the water to the surface.

Once the water reaches the surface through the well outlet, it will be channeled through a Ø16 polyethylene pipe that will form the distribution network that will conduct the water to the different sectors of the system.

The orchard has been divided into three various sectors. These are at present provided by the disposition of the cultivation plots from the beginning of the orchard. Each sector is commanded by an irrigation valve that decides the flow of water to it. Once the water reaches each sector, each of these pipes will feed a network of independent irrigation pipes for each table (I have tried that the separation between them is about 0.7 m):

- The first plot measures 4.32 m. 5 irrigation pipes will be placed longitudinally on the table. 0.72 m apart from each other.
- The second measure 6m. 7 irrigation pipes separated by 0.75 m will be installed longitudinally.
- The third measurement is 4.08 m. 5 irrigation pipes 0.68 m apart will be established longitudinally.

The irrigation network to be installed will be built with PE 100, PN 16, SDR 11 series polyethylene pipe, according to UNE-EN 12201-2. Each pipe has some drippers (small standard holes in the pipe) every 40 cm, which will be the ones that will supply water to the crops. The entire irrigation system will be controlled by a programmer that will allow it to be activated automatically as previously indicated.

3.3.2 Design of the solar panel installation.[4]

The energy necessary for the operation of the irrigation system will come from a photovoltaic solar panel. This will generate enough electrical energy to operate the irrigation programmer and the pump, which will allow watering the entire growing area.

The electrical installation will be built in the garden shed; the solar panel will be placed on the roof, with its corresponding support; and inside the barrack the service booth will be adapted where we will find the regulator, the inverter, the controller and the battery.

- **Solar panel:**

To cover the energy demand of the pump and the irrigation controller, an AmeriSolar solar panel will be installed - 280W 0 + 3% - 60Ce - 30v polycrystalline. The solar panel will be located on the roof of the shed where the tools are kept and will be located on the south side, so it will be placed in the part of the land where the sun shines the most. The panel will be placed on an open inclined roof support. It will be facing south, as it is the optimal orientation for the northern hemisphere.

[3] See diagram in Annex 3
[4] See blocks diagram Annex 4

- **Battery:**

As solar energy is a type of discontinuous energy; In other words, we cannot always have it because there are periods of no insolation and that every day we must water, a battery will be installed that will store the solar energy in order to use it when its necessary. In this way, the electricity supply will be guaranteed continuously, even if the solar conditions are not adequate. The battery is connected between the inverter and the regulator. It would be installed inside the shed, where a service booth would be built.

- **Regulator:**

The charge regulator has the function of controlling that the battery charging and discharging process is carried out so that the accumulator is always within the correct operating conditions, so it will be placed between the plate and the battery . This will be located inside the service booth, fixed to the wall.

- **Inverter:**

The inverter is the element that will be in charge of converting the direct current generated by the solar panels and the one stored in the battery into alternating current so that the pump can work. It will be located inside the service booth.

- **Controller:**

The controller is a device that is responsible for governing the photovoltaic solar installation. The controller of choice is the Venus GX, which provides an intuitive control and monitoring system. It consists of a start-up system that allows you to configure it for periods of time without having noise. It also does a monthly start-up test.

3.4 Installation process

To install the irrigation system I have followed the following steps:

- Measure the general irrigation piping according to the measurements specified in the irrigation system design plan.

- Once the tubes have been measured and marked, they should be cut with a utility knife. The tubes are hard to cut, because they are made of a very hard plastic that dominates a lot and has a lot of strength.

- Make the holes in the main pipe to place the taps that will join the general irrigation pipe with the irrigation pipes that will supply the water to the plants.

- Once the holes are made, the taps are placed. They have to be snapped on. It is very difficult to get them in, since they have to be turned over the hole and you have to use a lot of force; they must screw well so that they do not lose water. And then you have to put the end caps on the main pipes.

- Once all the taps and the three end plugs are in place, the main pipes must be joined using the valves, the tees and the elbow.

- It begins by joining sector 1 with the pipe that joins with sector 3. The valve, the T and the valve of sector 2 are placed.

The procedure to join the valves and the T in the pipe is the same: the collar is removed and it is put inside the tube, which is inserted inside the valve or the T. It is necessary to watch that the rubber inside does not move and that the tube does not exceed the blue connection.

- Once attached, the pipe that comes out of the well is placed and feeds the entire irrigation system. A T is placed that will distribute the water to sector 2, and it is joined with the previously placed T, which joins the pipe at the well outlet with the general pipe that distributes the water towards sectors 1 and 3.

- Finally, all that remains is to place the general pipeline of sector 2. First, place the valve that will decide the passage of water to sector 2. Next, put a T and the pipe that will bypass the well to be able to irrigate the entire arable area .
- Finally, the whole general installation is wedged with pegs.

- Once the general pipes have been installed, the irrigation pipes in each sector are measured and cut

- When all the tubes have been cut, they are placed on the taps previously installed to the main pipes. With your finger you have to open the tube and insert it into the tap and tighten with the thread so that it does not lose water.

- Once all the irrigation pipes are in place, a knot is made at the end and a piece of cut pipe is placed so that the water is not lost.

- Finally, we proceed to join the hose from the pump outlet with the pipe that connects it to the irrigation system.

Once the entire system is assembled, to make it operational, the water passage must be opened by sectors, and wait for the flow to inflate the irrigation pipes. At the beginning the tubes are screwed a lot and make folds that block the water, which cannot reach the end. To solve it, the water flow must be stopped, check tube by tube, and undo all the bends that there are.

Once all the sectors have been reviewed and verified that they work, it is necessary to install the irrigation controller. When I went to install it, I observed out that the controller was not compatible with the orchard well pump. The programmer was designed to be used with a compatible pump and/or a domestic tap, which must always be open, and the programmer regulates the flow of water (it works like a solenoid valve.). But the installed pump does not work like a household tap because it needs electrical power, and cannot always be connected to the mains and therefore be in operation. To rectify this problem and have the irrigation system programmed to water at a specific time, we opted to place a timer plug.

3.5 Result.

After intense work, I have managed to fulfill its primary objective: to build the irrigation system in my grandfather's garden to make his life easier when watering. The installation of the irrigation system captured two intense days. At first, I wanted to do it in one day, but I didn't think it would involve such a high volume of work.

As can be seen in the following photographs, the garden is completely watered; these images illustrate very well that the main objective of the work has been fulfilled, and that the irrigation system works perfectly.

Improvement proposal

The improvement proposal consists of placing a three-inlet valve between the pump outlet and the irrigation system connection. Of the three valve inlets, one would be for the pump outlet, the other for the connection of the irrigation system, the object of this work, and, finally, the third would be to connect a hose that would allow watering fruit trees and flowers. That is not in the arable area, fill some external tanks, and also be able to water the garden with the hose if the irrigation system breaks down.

Also to improve these project, and digitalize it, I would like to apply a humidity sensor to the soil. These sensor Stops or turns on the irrigation system according to the real water needs of the soil. It has Wireless communication, and no need to dig Avoid overwatering, continually measure soil moisture level, and determine when to allow watering. It has an automatic calibration: detects soil type and adjusts all calculations accordingly. Also has a frost detection: it is the only one that prevents irrigation from being activated when the temperature approaches 0 degrees. With these new for applimentation into the irrigation system. It will be possible to make a more reasonable use of water, with greater control of its spending. In this way, only the necessary water will be applied to the crops.

4. CONCLUSIONS

With this work, all the necessary elements that make up the installation of the irrigation system powered by a photovoltaic solar panel have been defined, designed, and built.

During the execution of the project, it has been concluded that the construction of an irrigation system for a domestic garden from a well fed by rainwater is feasible. And it has been shown that the energy needed to run the well pump can come from a solar panel.

Despite all the work achieved in the calculations and the design of the solar panel installation, it has been established that its installation is not economically viable due to the high cost of the photovoltaic solar panel, the battery and the inverter; although I suggested changing the lithium battery for an AGM (lead), they told me it was not possible due to its short useful life. So the installation works with conventional electrical energy.

Once the installation of the irrigation system has been completed, it has been possible to verify that all the calculations and the design carried out are adapted to the purpose of the work: to irrigate the entire arable surface of the orchard in a given time and flow rate. And it is the system we employ every day to irrigate the garden.

Bibliography

2020. *Evapotranspiración Del Cultivo Guías Para La Determinación De Los Requerimientos De Agua De Los Cultivos*.

2020. *Fitxa Tècnica 06. Eina Recomanacions Reg Ruralcat*. 1st ed. Generalitat de catalunya. Departament d'agricultura ramaderia i pesca.

Allen, R., 2004. *Crop Evapotranspiration*. Rome: Food and Agriculture Organization of the United Nations.

ACCIONA: Sustainable Infrastructures and Renewable Energy. (2020). Retrieved 2020, from https://www.acciona.com/

Catalunya, I., 2020. *Instal·Lacions Solars Fotovoltaiques*. [online] Ioc.xtec.cat. Available:<https://ioc.xtec.cat/materials/FP/Materials/0801_IEA/IEA_0801_M06/web/html/WebContent/u1/a3/continguts.html> [Accessed 2020].

Microaspersión. (2020). Retrieved 2020, from https://www.materialesriegos.com/Materiales-de-Riegos/Goteros-Microaspersion/Microaspersion

Mitjà i Sarvisé, A., 1996. *Atlas De Radiació Solar A Catalunya*. Cataluña: Generalitat de Catalunya. Departament d'indústria Comerç i Turisme.

Pau, J., 2020. *DT04. Gestió Eficient De L'Aigua De Reg (I)*. 1st ed. Generalitat de Catalunya. Departament d'agricultura ramaderia i pesca.

Tarruella, X., 2009. *Criteris De Sostenibilitat Als Horts Municipals*. Barcelona: Diputació de Barcelona.

Tarruella, X., 2020. DT04. Gestió Eficient De L'Aigua De Reg (I). 1st ed. Barcelona: Diputació de Barcelona.

Tecnical.cat. 2020. *Tecnical Automatització I Electrònica Industrial Manresa Igualada (Barcelona) Ripoll (Girona) Lleida*. [online] Available at: <https://www.tecnical.cat/> [Accessed 2020].

Xarxa-i.CAT - Ruralcat. (2020). Retrieved October 2020, from https://ruralcat.gencat.cat/xarxa-i.cat

ANNEX 1

WEATHER STATION — Caldes de Montbui (Vallés Oriental)

Period	Month	P	ETo	daily ETo	n. days
2019	JANUARY	30,2	34,03	1,10	31
	FEBRUARY	36,6	51,17	1,83	28
	MARCH	61,9	86,21	2,78	31
	APRIL	61,7	81,25	2,71	30
	MAY	56,4	116,25	3,75	31
	JUNE	39,8	166,74	5,56	30
	JULY	33,1	163,2	5,26	31
	AUGUST	27,2	150,6	4,86	31
	SEPTEMBER	75,2	104,23	3,47	30
	OCTOBER	88,4	64,28	2,07	31
	NOVEMBER	67,8	39,22	1,31	30
	DECEMBER	28,7	26,84	0,87	31
	MAXIMUM	**607,0**	**1084,0**		

Data extracted from the Xarxa Agrometeorològica de Catalunya (XAC), managed by the Servei Meteorològic de Catalunya (SMC)

P: precipitation according to weather station data, mm per month and m2
ETo: Evapotranspiration of the reference crop (weather station data); mm per month and m2

ANNEX 2

WATER NEEDS CALCULATIONS, VEGETABLE GARDEN CALDES DE MONTBUI

Kc favorable

Given project variables:

Fc Pef	0,75	
Ef	0,8	
Plots area	191,25	m2
No. Plots	1	
Total plot area	191,25	m2

Month	Precipitation (P)		ETo	Kc	ETc= ETo x Kc ETc	Pef=P x FcPef Effective Precipitation (Pef)		Nn= ETc - Pef Irrigation cleaning needed (Nn)		NTR=Nn/Ef Total irrigation needs (NTR) per m2		Total Irrigation Needs (NTR) per Ha		Irrigation per plot		num days / month
	mm/month	mm/day	monthly		monthly	mm/month	mm/day	mm/month	mm/day	L/month	L/day	m3/month	m3/day	L/month	L/day	
JANUARY	30,20	0,97	34,03	0,35	11,91	22,65	0,73	-10,74	-0,35	-13,42	-0,43	-134,24	-4,33	-2.567,41	-82,82	31
FEBRUARY	36,60	1,31	51,17	0,35	17,91	27,45	0,98	-9,54	-0,34	-11,93	-0,43	-119,26	-4,26	-2.280,78	-81,46	28
MARCH	61,90	2,00	86,21	0,35	30,17	46,43	1,50	-16,25	-0,52	-20,31	-0,66	-203,14	-6,55	-3.885,12	-125,33	31
APRIL	61,70	2,06	81,25	0,67	54,44	46,28	1,54	8,16	0,27	10,20	0,34	102,03	3,40	1.951,35	65,04	30
MAY	56,40	1,82	116,25	0,67	77,89	42,30	1,36	35,59	1,15	44,48	1,43	444,84	14,35	8.507,64	274,44	31
JUNE	39,80	1,33	166,74	1,01	168,41	29,85	1,00	138,56	4,62	173,20	5,77	1.731,97	57,73	33.123,88	1.104,13	30
JULY	33,10	1,07	163,20	1,01	164,83	24,83	0,80	140,01	4,52	175,01	5,65	1.750,09	56,45	33.470,42	1.079,69	31
AUGUST	27,20	0,88	150,60	0,89	134,03	20,40	0,66	113,63	3,67	142,04	4,58	1.420,43	45,82	27.165,63	876,31	31
SEPTEMBER	75,20	2,51	104,23	0,78	81,30	56,40	1,88	24,90	0,83	31,12	1,04	311,24	10,37	5.952,51	198,42	30
OCTOBER	88,40	2,85	64,28	0,35	22,50	66,30	2,14	-43,80	-1,41	-54,75	-1,77	-547,53	-17,66	-10.471,42	-337,79	31
NOVEMBER	67,80	2,26	39,22	0,35	13,73	50,85	1,70	-37,12	-1,24	-46,40	-1,55	-464,04	-15,47	-8.874,72	-295,82	30
DECEMBER	28,70	0,93	26,84	0,35	9,39	21,53	0,69	-12,13	-0,39	-15,16	-0,49	-151,64	-4,89	-2.900,07	-93,55	31
MAXIMUM	88,40	2,85	166,74	1,01	168,41	66,30	2,14	140,01	4,62	175,01	5,77	1.750,09	57,73	33.470,42	1.104,13	

ANNEX 3

CALDES DE MONTBUI VWGWTABLE GARDEN IRRIGATION ELECTRICAL CALCULATIONS

Magnitude	Symbol	Value	Units	Obs.
Pump power	PP	736	W	
Pump flow	qB	24	L/min	
Inverter efficiency	rO	93%		
Battery efficiency	rB	95%		
Pump working voltage	UP	220	V	AC
Battery working voltage	UB	12	V	DC
Use of the battery	aB	80%		
Regulator efficiency	rR	100%		
Plate efficiency	rS	17%		
Solar power to the ground	Ps-t	1.000	W/m^2	

Battery current - inverter
IB=PP/(rO·UB)
65,95 A

	Power (W)	
Battery	PB=IB·UB	791,3978495
Inverter	PP/rO	791
Regulator	input max PS	100
	output PB	791,3978495

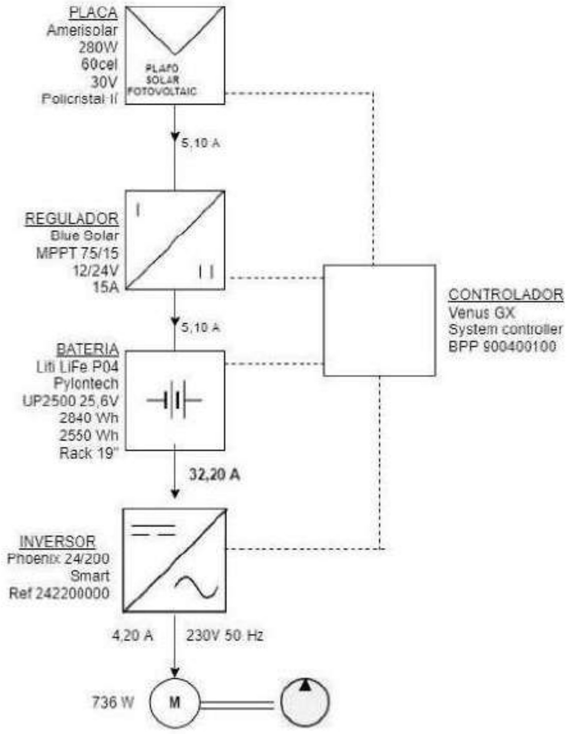
		t=V/qP	EP= t x PP		EBa=EP/rO	EB=EBa/(rB·aB)	QB= EBa/UB	ES=EB/rR		PS=ES/HPS	Psol=PS/rS	SS=Psol/Ps-t	IS=PS/UB
	IRRIGATION PER PLOT (V)	Pump run time (t)	Pump energy required (EP)		Battery energy (EB) in Wh		Battery Capacity (QB)	Solar panel Power (ES)	Peak Solar Hours (HPS)	Solar panel power (PS)	Power to draw from the sun (Psol)	Solar panel area (SS)	Solar Panel - battery current
	L/dia	min	W x min	Wh	aprofitable	necessària	Ah	Wh	h	W	W	m^2	A
January	-82,82	-3,45	-2.539,81	-42,33	-45,52	-47,91	-3,99	-47,91	1,80	-26,62	-156,57	-0,16	-2,22
February	-81,46	-3,39	-2.497,99	-41,63	-44,77	-47,12	-3,93	-47,12	2,63	-17,92	-105,40	-0,11	-1,49
March	-125,33	-5,22	-3.843,35	-64,06	-68,88	-72,50	-6,04	-72,50	3,61	-20,08	-118,14	-0,12	-1,67
April	65,04	2,71	1.994,71	33,25	35,75	37,63	3,14	37,63	4,86	7,74	45,54	0,05	0,65
May	274,44	11,43	8.416,16	140,27	150,83	158,77	13,23	158,77	5,83	27,23	160,19	0,16	2,27
June	1.104,13	46,01	33.859,96	564,33	606,81	638,75	53,23	638,75	6,39	99,96	588,00	0,59	8,33
July	1.079,69	44,99	33.110,53	551,84	593,38	624,61	52,06	624,61	6,25	99,94	587,87	0,59	8,33
August	876,31	36,51	26.873,52	447,89	481,60	506,95	42,25	506,95	5,55	91,34	537,31	0,54	7,61
September	198,42	8,27	6.084,79	101,41	109,05	114,79	9,57	114,79	4,37	26,27	154,51	0,15	2,19
October	-337,79	-14,07	-10.358,82	-172,65	-185,64	-195,41	-16,28	-195,41	3,19	-61,26	-360,34	-0,36	-5,10
November	-295,82	-12,33	-9.071,93	-151,20	-162,58	-171,14	-14,26	-171,14	2,08	-82,28	-483,98	-0,48	-6,86
December	-93,55	-3,90	-2.868,88	-47,81	-51,41	-54,12	-4,51	-54,12	1,61	-33,61	-197,73	-0,20	-2,80
MAXIMUM	1104,1	46,01	33.859,96	564,33	606,81	638,75	53,23	638,75	6,39	99,96	588,00	0,59	8,33

ANNEX 4

Disseny i construcció d'un sistema de reg alimentat per energies renovables.

Anejo 4

Instal·lació solar fotovoltaica - Diagrama de blocs



74

Disseny i construcció d'un sistema de reg alimentat per energies renovables.

Anejo 3