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RESIDENTIAL AUTOMATED IRRIGATION SYSTEM

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Abstract. *Projects and technologies related to irrigation have been sought more frequently due to the continued need for irrigation of gardens, lawns and plantations. This project aims to develop an automated irrigation system, efficient, and low-cost operational, decreasing the use of energy and water, for residential gardens. The system has a mesh of sensors that measures soil moisture, verifies the presence of rain, the time programmed to irrigate and temperature, so that from these parameters the Arduino turn on / turn off a pump, resulting in irrigation. For this, the techniques of fluid mechanics were used, considering the fluid along the water hoses, tubes, pipes, controlling the flow, and the amount of water needed. The project was satisfactory, achieved the objectives, generating water saving, energy and labor reduction.*

Keywords: Automated system, i*rrigatio*n, arduino, internal flow.

1. INTRODUCTION

The planet Earth consists of 70% of the water on its entire surface, 97% of which is made up of saltwater, found in oceans and seas, and considered unfit for human consumption. Of the remaining only 3%, they are freshwater, divided into 71% in the form of glaciers or polar ice caps, and the remaining 29% is subdivided into 18% of groundwater (groundwater), 7% of the water in lakes and 4% in air humidity. (Aito Victorino, 2007) and (Laura Zocolotti, 2008)

According to RAYLTON (ASCOM / ANA) (2015), a study released by the National Water Agency (ANA) points out that irrigation accounts for 69% to 70% of water consumption in Brazil - according to this study, irrigation consumes 986,4 thousand liters of water per second. It also points out that irrigation is the largest water user in Brazil, with an irrigable area of approximately 29,6 million hectares.

Thinking of this principle, it is very important to ration water, in the various sectors of its use, in irrigation for example, it is possible to mount a system that brings good results to the ground and still rationalize the water used for this purpose.

The years passed and irrigation, of rudimentary practice, was structured on scientific-technical bases to such an extent that, today, it is considered as true science, as a technique used in agriculture to control the amount of water destined for planting, in sufficient quantity and at the right moment, ensuring better productivity and survival of the plantation, and to have control over the crop throughout the growth processes, from seeds to the plant already adult, according to (Ferreira Sousa, 2011) and (Testezlaf, 2017).

Among the various forms of irrigation, dripping and sprinkling is the most widely used irrigation method in surface irrigation, in which water is discharged into the soil and infiltrates the soil by gravity (Tangerino Hernandez, 2014).

In this project was used the sprinkler irrigation techniques, with the use of rotary sprinklers. For the sizing of this system, fluid mechanics techniques were used, such as the conservation of mass for a control volume, considering permanent flow, incompressible fluid and uniform properties in each section. In sizing a pump, used the knowledge of flow machines to select it. Programming and computing knowledge was used to automate the entire system using the Arduino microcontroller.

2. OBJECTIVES

The objective of this project is the development of an automated irrigation system for the entire garden of a residential condominium, taking into account: soil moisture, the occurrence of rainfall that are captured by sensors, the time programmed to irrigate and temperature.

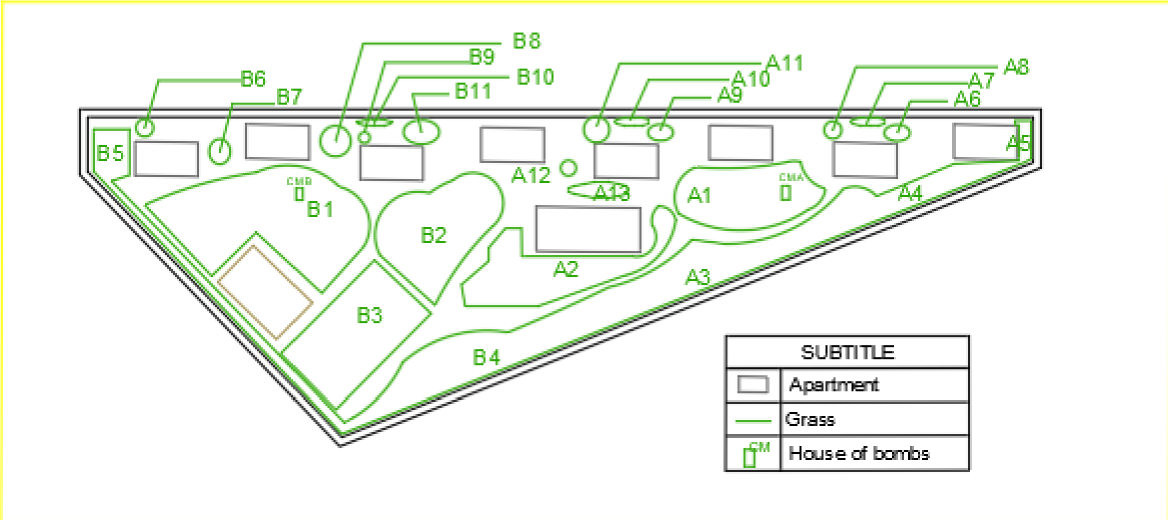

Figure 1. Schematic containing the garden areas of the residential condominium.

3. MATERIALS AND METHODS

3.1 Materials used

The materials used were: Microcontroller Arduino Uno that control the system; rain sensor LM393, when the Rain Sensor comes into contact with water droplets, it sends the information (pulses) through the module; soil moisture sensor LM393, this sensor is designed to detect soil moisture variations; temperature sensor LM35, featuring a temperature-related linear output voltage; rotary sprinkler "5004" and "van 15"; tubes and pipes; contactor switch "Siemens 220v" and a centrifugal pump "CAM W14".

3.2 Methodology

Initially the areas corresponding to the garden were measured, as shown in the diagram in Fig. 1, where CM represents the engine room and "A" the areas of sector A, which are: A1 = 682,24 m², A2 = 381,72 m², A3 = 174,72 m², A4 = 287 m², A5 = 370 m², A6 = 67,6 m², A7 = 49,92 m², A8 = 33,28 m², A9 = 131 m², A10 = 27 m², A11 = 91,5 m², A12 = 50,3 m², A13 = 78 m², resulting in a total area of 2425 m². B the areas belonging to sector B, which are: B1 = 900 m², B2 = 780 m², B3 = 150 m², B4 = 200 m², B5 = 100 m², B6 = 33,26 m², B7 = 200 m², B8 = 50 m², B9 = 50 m², B10 = 25 m², B11 = 75 m², resulting in a total area of 2663 m².

For the selection of sprinklers, the selection criterion was the price, the area of irrigation reach and the average volumetric flow required for each sprinkler used.

To calculate the number of sprinklers required for the project, simply divide the garden area analyzed by the coverage area of each sprinkler, according to the Eq. (1). The position of the sprinklers takes into consideration the distributing them along with the lawn in an equidistant and regular way.

$$\mathrm{N} = A_t / A_{asp} \qquad (1)$$

Where "N" represents the number of required sprinklers, "A_t" the total area to be designed, "A_{asp}" the sprinkler coverage area.

The calculations were done first for the main area "A1" and then the same procedures for the other areas.

The selected sprinkler was of the type "Uni-spray", with nozzle series "15 VAN", covering approximately 36,32 m² of area, in an arc of 360°, with average flow volumetric of 0,75 m³/h. (RAINBIRD, 2016).

Using Eq. (1), where "A" is the area "A1" and "A_{asp}" is 36,32 m², 19 sprayers of the type "Uni-spray" are required.

Defined the number of sprinklers, the next step is determining the length and path of the piping required for the system. From this, it was distributed according to the size of the areas, along with 5 main ways for each sector, as shown in Fig. 2, is represented by a line in blue.

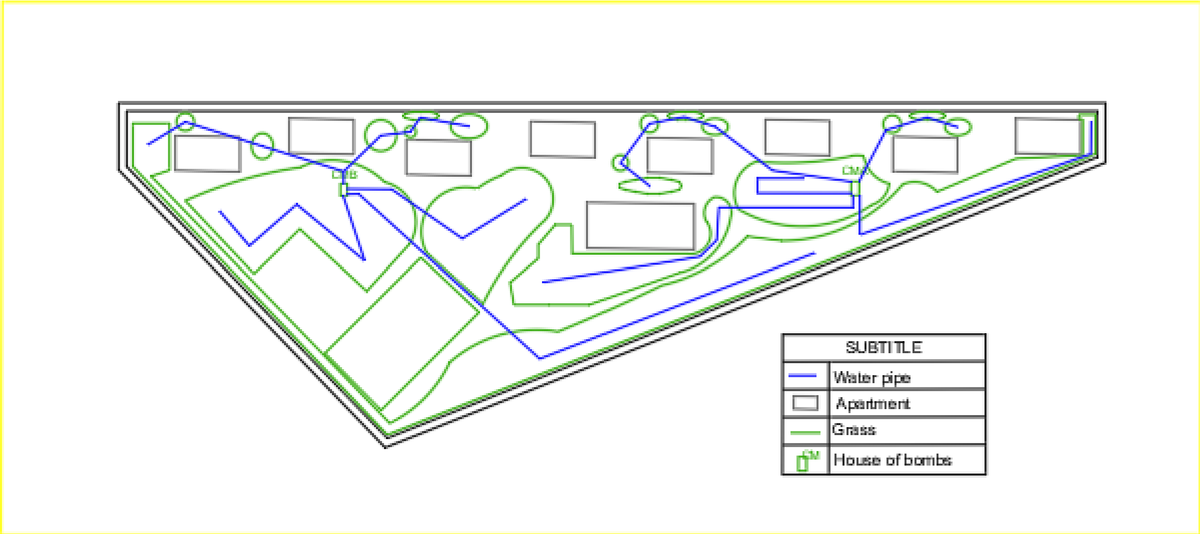

Figure 2. Hydraulic design for water pipes.

To determine the capacity required by the system, it is important to determine the flow rate required. This can be done by analyzing the control volume of the water-conducting pipes, as shown in the figure below for the main area "A1".

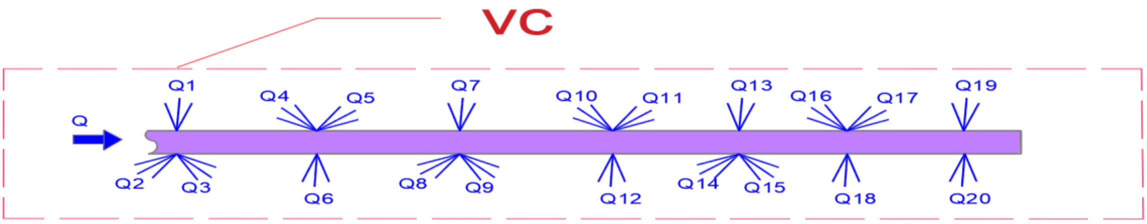

Figure 3. Schematic drawing of tubing along area A1.

Applying the conservation of the mass to the chosen control volume, considering permanent flow, incompressible flow, uniform properties in each section, results in: (FOX et al., 2006).

$$0 = \int_{SC} \vec{V} . d\vec{A} \tag{2}$$

$$\sum_{SC} V . A = \sum_{SC} Q = 0 \tag{3}$$

$$Q_{in} = \sum_{i=1}^{19} Q_i \rightarrow Q_{in} = Q_1 + Q_2 + \ldots + Q_{18} + Q_{19} = Q_t \tag{4}$$

Where "Q_t" represents the inlet volumetric flow, necessary to provide the recommended flow rate for each "Q_i" sprinkler.

As previously mentioned for area "A1", a "Uni-spray" type sprinkler was used, with a mean working flow of 0,75 m³/h. Then Eq. (4) results in a total flow Q_t of 0,003958 m³/s or 14,25 m³/h only for this main duct.

To supply the proposed volumetric flow demand, a corresponding flow pump is required. The task of selecting a centrifugal pump for the system consists of calculating the following parameters: flow volumetric and manometric height (Henrique Souza, 2014).

Due to the conditions of the pump house space, the positioning of the pump and piping positioning is designed as shown in Fig. 4.

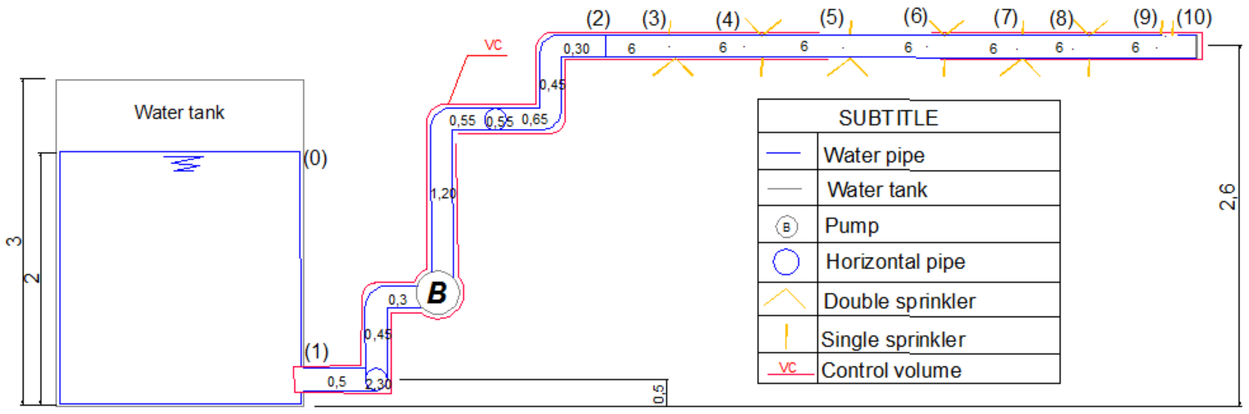

Figure 4. Schematic of the suction and discharge system.

The system was divided into numbered points as shown in Fig. 4.

The water tank is a rectangular tank of dimensions 0,60 m x 0,60 m x 2 m with apertures to the atmosphere, in the main path piping, 3 sprinklers were placed every 6 meters, was chosen the nominal diameters of 40 mm for suction and 32 mm for discharge, which are values found on the market, corresponding to an internal diameter of 38,1 mm and 31,75 mm respectively.

The value of water density (ρ) and the absolute viscosity (μ) are, respectively, 998 kg/m³ and 0,001 kg/(m.s) or Pa.s (Henrique Souza, 2014).

$$v = \frac{Q}{A} \tag{5}$$

$$Re = \frac{\rho v D}{\mu} \tag{6}$$

With a volumetric flow rate of 0,003958 m³/s, the velocity at point 1 of 3,47 m/s and velocity at point 2 and 3 of 5 m/s. Reynolds number was obtained by Eq. (6) being equal to 1,32 x 10^5 for point 1, and 1,58 x 10^5 for point 2, corresponding to the turbulent regime by Reynolds be bigger than 4000 (Çengel et al., 2007).

After point (3), there will be sprinklers that release water, the flow will change, and consequently the speed and Reynolds number as well. Thus, the new flow rate will be calculated as in Eq. (7), with "i" starting at 4, and ending at 9.

$$Q_i = Q_{i-1} - (3 * 2{,}0833.10^{-4}) \tag{7}$$

The new flow rates, speeds and Reynolds number are shown in the table below.

Table 1. New outflows for the flow, and their restraining velocities and Reynolds number.

Points	4	5	6	7	8	9	10
Flow rate (m³/s)	0,0033	0,0027	0,0021	0,0015	0,00083	0,00021	0,00021
Velocity (m/s)	4,21	3,42	2,63	1,842	1,052	0,2632	0,2632
Reynolds	1,33* 10^5	1,08*10^5	8,34* 10^4	5,84* 10^4	3,34* 10^4	8,34* 10^3	8,34* 10^3

For the pipe system involving a pump, the energy equation for the stationary flow expressed in terms of charges is given by:

$$\frac{P1}{\gamma} + \frac{{v_1}^2}{2g} + z_1 + h_B = \frac{P10}{\gamma} + \frac{{v_{10}}^2}{2g} + z_{10} + hl_{(1,10)} \tag{8}$$

In order to calculate the manometric height, we consider stationary flow and incomprehensible flow, fully developed flow, turbulent flow, manometric pressure at zero outlet.

$$h_B = \frac{{v_{10}}^2 - {v_1}^2}{2g} + z_{10} - z_1 + hl_{(1,10)} - \frac{P_1}{\gamma} \tag{9}$$

Where "h_B" is the payload of the pump supplied to the fluid and hl is the total loss of load along the pipe (including major and minor losses).

The highest load loss (distributed load loss, caused by friction along the pipes) and the lower pressure loss (local pressure loss caused by accessories) for the fully developed flow are given by Eq. (10).

$$h_l = \sum f \frac{L}{D}\frac{v^2}{2g} + \sum f \frac{L_{eq}}{D}\frac{v^2}{2g} \tag{10}$$

The friction factor can be determined using the Moody diagram in Fig. 5. To this end, the value of the relative roughness must be determined.

Using the absolute roughness of the PVC to be 0,05 mm (Marques and Oliveira, 2011), the relative roughness can be obtained, being.

$$er = \frac{e}{D} \tag{11}$$

The relative roughness of point 1 will be 0,0015, and the other points will be 0,00157.

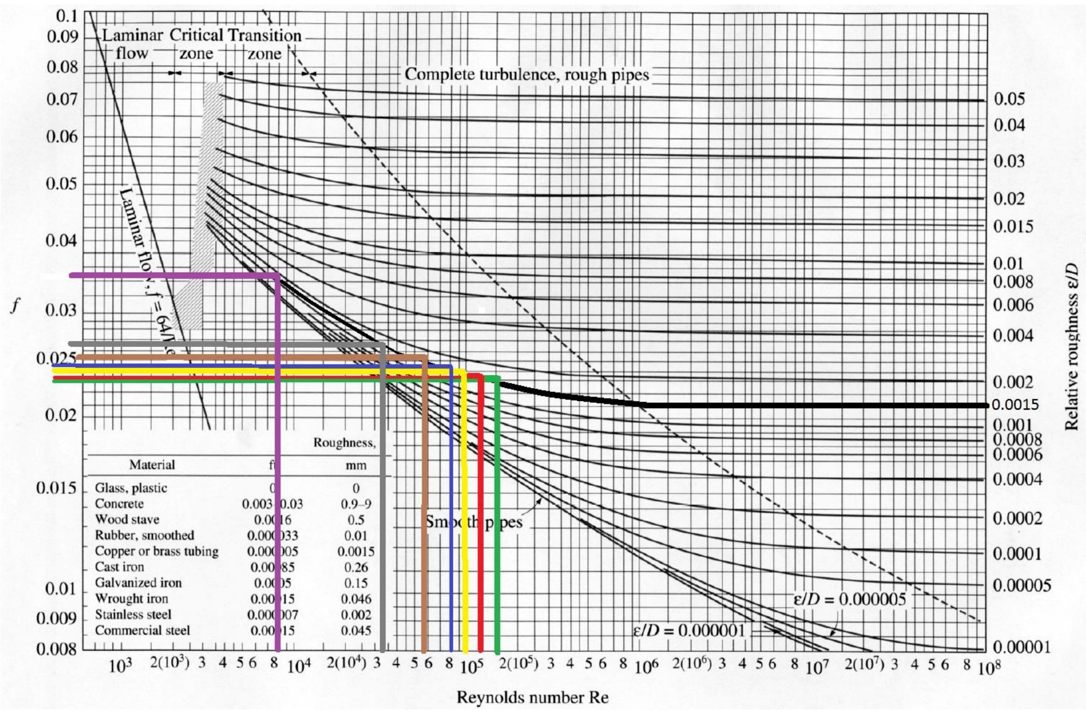

Figure 5. The Moody chart for the friction factor for fully developed flow in circular tubes.
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Using the relative roughness values and the Reynolds number, for each point, through the Moody House diagram, the determined friction factors were: $f_1 = f_2 = f_3 = f_4 = 0{,}023, f_5 = f_6 = 0{,}024, f_7 = 0{,}025, f_8 = 0{,}026, f_9 = f_{10} = 0{,}034$.

By analyzing the losses located before suction, there are 3 knees, considering the equivalent length of each knee of diameter 0,0381 m, as being 2 m (MZ, 1998), the equivalent length before the pump will be 6 m.

After pump up to point 2 were 5 knees, considering the equivalent length of each knee diameter 0,03175 m, as being 1,5 m (MZ, 1998), the equivalent length is 7,5 m.

Also between point 2 and point 10, there are 3 knees, as shown in Fig. 2, for calculation purposes, were conservatively counted at the beginning, the equivalent length is 4,5 m.

The linear length between the point 1 and the pump is 3.55 m, between the pump and the point 2 is 3.7 m; between the other points, the linear length will be 6 meters, as shown in Fig. 4.

Given the speeds, and their equivalent lengths, through Eq. (10), the total load loss for the designed system is 32,94 m.

The pressure at point (1) is calculated by the manometric equation.

$$P_1 = \rho . g . h \tag{12}$$

With "ρ" being the density of the fluid, "g" is the gravity, and "h" is the difference of height between high points (0) and (1) which is 1,5 m, the pressure will be 14685,57 Pa.

Finally, all the necessary data for the calculation of the manometric height were obtained. With Z1 = 0,5 m and Z2 = 2,6 m, the water column height required by the pump using Eq. (9) will be approximately 33 meters.

The characteristic curve of the system can be obtained by varying the flow using the same equations as above for calculating the hydrostatic water pressure. The Fig. 6, was placed in m³/h, simply to compare with the graph of the pump curve, which is given in this unit.

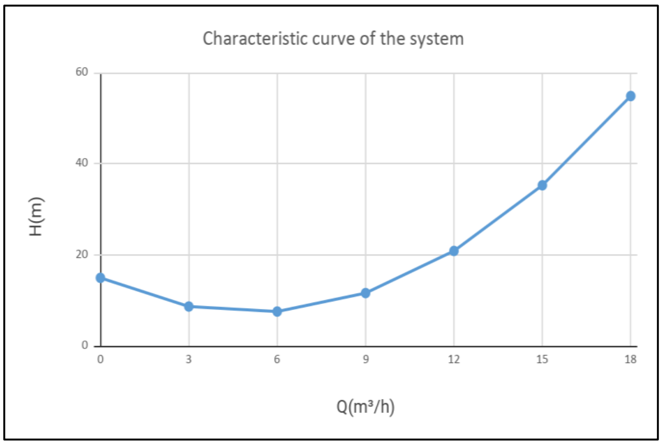

Figure 6. Characteristic curve of the system, height manometric versus flow.

For the selection of the pump, the volumetric flow "Q" and the hydrostatic water pressure "H" required by the system were used as a parameter.

As previously mentioned, the selection point was the volumetric flow rate of 0,003958 m³/s (14,25 m³/h) and a height of 33 m.

With these values, it is possible to find a suitable pump in a manufacturer's catalog.

The pump chosen was the Multi-Purpose Centrifuge W-14, 3CV of the CAM series, as it can generate a flow of 0,0041 m³/s (14,8 m³ / h) and a height of 34 m, which is an approximation of the dimensioned in this project. (DANCOR, 2009).

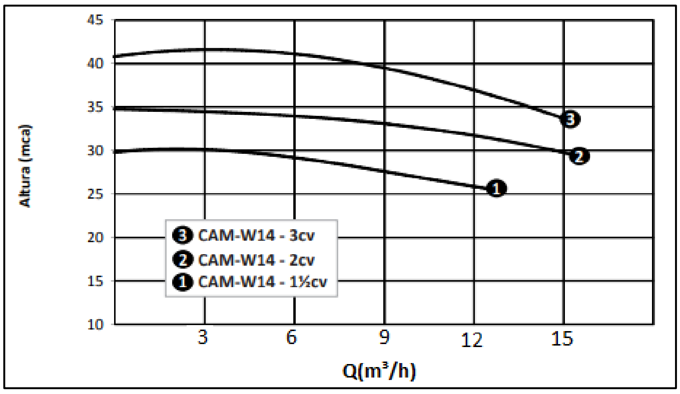

Figure 7. Characteristic curve of the pump, height manometric versus flow.
Available from: http://www.dancor.com.br/dancor-site-novo/public/uploads/produtos/centrifugas/cat%C3%A1logos/cam-w14-pbe_cat.pdf

The electronic system was mounted using a microcontroller called Arduino, which in turn will receive the information of humidity, temperature, precipitation, and time, to operate the pump in the planned circumstances.

With the soil moisture sensor positioned at the proper depth, the system will monitor the soil water indexes, and when the soil is dry the sensor output is high and low when wet. Through exams, it has been found that the analog result of the sensor being greater than 800 identifies that the soil is dry, between 500 and 800 identifies that it is partially moist, and below 500 that it is wet. For this design, when the soil moisture sensor response value is greater than 800, irrigation is important.

The Rain Sensor, as its name suggests, is a sensor used to detect the presence of rain, when the sensor comes in contact with water droplets, it sends information through the module (pulses) to the Arduino. When the sensor response is less than 800, it indicates rain. This value was established as a criterion, based on tests. For this system, when the response value of the sensor is greater than 800, irrigation is interesting.

The temperature sensor displays an analog value for the ambient temperature. For the project, it was defined as a reference point, 27 ºC. When the environment is below 27 ° C, it will be considered cold, when above 27 ° C, it will be considered hot. The environment with high temperature indicates the need for cooling, so that for the system when the temperature is above 28 ° C, irrigation is interesting.

The Real-Time Clock Module "RTC DS3231" is a real time clock with high accuracy and low power consumption, which is able to provide information such as second, minutes, day, date, month and year. It is with this module that the irrigation schedule is established.

Daily, the garden was irrigated 2 hours a day, always early in the morning to avoid the sun. For this project, the time was reduced to 30 minutes, but being twice a day in the early morning at 05 o'clock, and at night at 22 o'clock, because at these times the rate of solar evaporation is low and the movement of people as well.

The controller will be responsible for comparing the received values of soil moisture, precipitation, temperature and time, with the established standard for each parameter as explained above, so that when the four conditions are satisfied, the microcontroller sends a signal to the electronic key “relé”, triggering the coil of the contactor switch, allowing the passage of the three-phase current to the pump, according to Fig. 8.

In this way, the automated system will allow the garden to be always moist and in good condition.

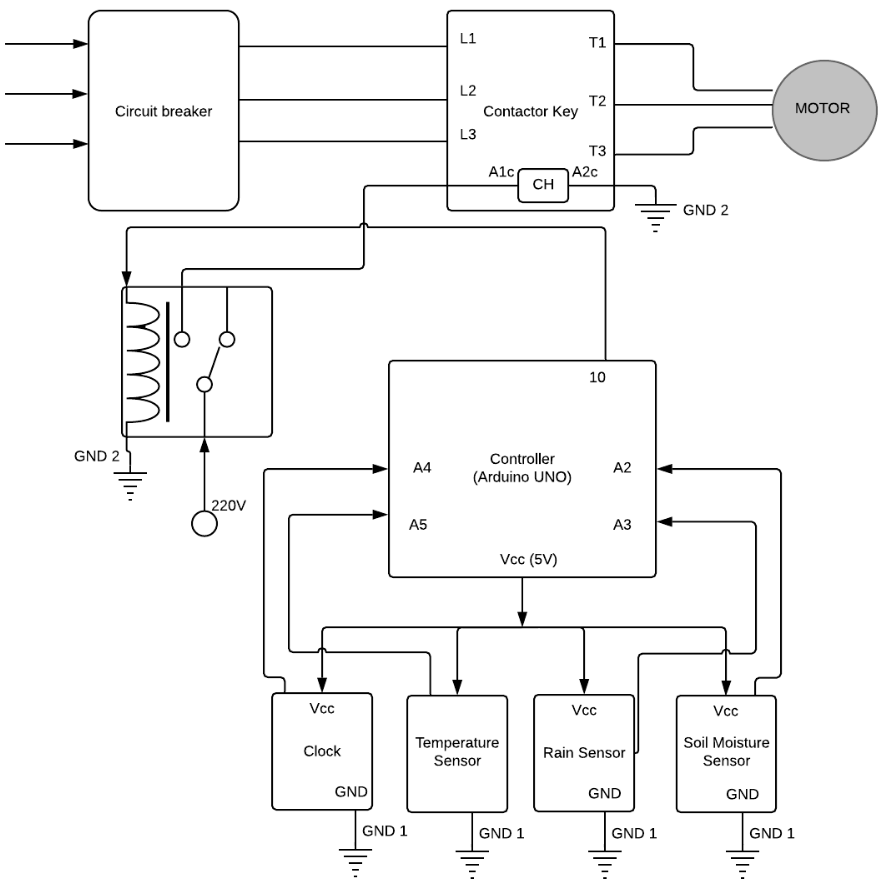

Figure 8. Electrical circuit of the whole system.

4. RESULTS AND DISCUSSION

The components that are part of the designed system have been installed. The microcontroller was placed in the engine room, the water reservoir already existed in the environment, the tubes were placed internally in the ground.

The areas were divided into two sectors (A, B) because they were very large areas. The choice facilitated the calculations and allowed the installation of a pump in each sector.

Five pipes were chosen from each pump house for logistical reasons, to be more organized, to better distribute the water in space and also so that the pump could operate efficiently for each sector, since it would not be possible to execute everything at once.

The same procedures performed for area "A1" were also performed for the other pipe paths.

Table 2. Values calculated for all waterways.

Area	Total area (m²)	Sprinkler	Amount(N)	Q (m³/s)
A1	682,24	Uni-spray van 15	19	0,0039
A2	382,72	Uni-spray van 15	11	0,00229
A3,A4,A5	831,76	Rotor 5004	4	0,00061
A6,A7,A8	150,8	Uni-spray van 15	5	0,001
A9,A10,A11A12,A13	299,865	Uni-spray van 15	9	0,001875
B1	900	Rotor 5004	4	0,000611
B2	780	Rotor 5004	3	0,000458
B3,B4	350	Uni-spray van 15	10	0,0021
B5,B6,B7	333,28	Uni-spray van 15	10	0,0021

The Tab. 2 presents the main parameters analyzed for each of the ways of each sector A and B, where "N" is the number of sprinklers required and "Q" is the required flow.

When analyzing the data presented in the tab. 2, it is possible to note that two types of sprinklers have been chosen: the "Van 15" series and the "rotor 5004". The Rotor sprinkler reaches a coverage area of approximately 254 m² with an average flow of 0,55 m³/h (RAINBIRD, 2016) and a medium price is R$ 73,79, and the Van 15 sprayer reaches a coverage area of 36,32 m², with an average flow rate of 0,75 m³/h and a medium price of R$ 18,17.

In the economic sense, the sprinkler "rotor 5004" is better because, although the unit is more expensive it needs few units because of the wide coverage; As it has a long reach, the sprinkler is suitable for large spaces. The rotor was placed in areas larger than 700 m². For small areas, the "Uni Spray-Van 15" sprinkler was chosen.

Figure 9 shows the automated drive system mounted on the wall of the pump house, containing the circuit breaker in the upper box and the contactor key in the lower box.

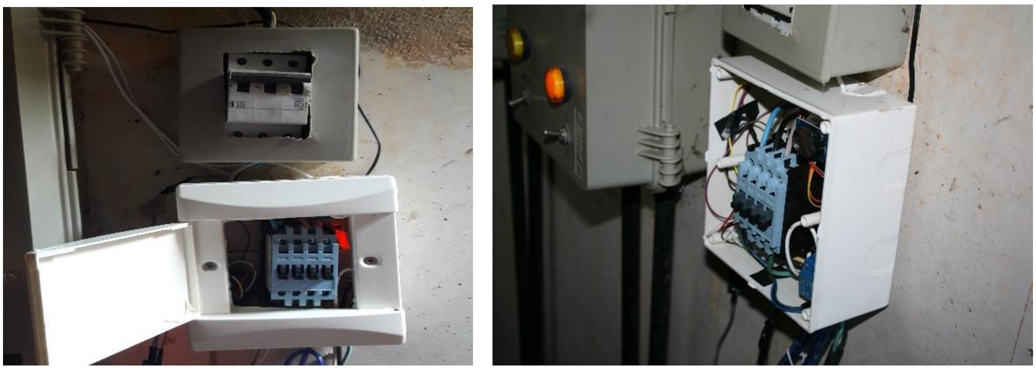

Figure 9. Electrical system mounted on pump house.

Figure 10 shows the pump (black, in the bottom of the image), installed along with the plumbing. The water is aspirated from the tank to the pump, and rises. (the red arrows show the way).

Figure 10. Pump and plumbing installed in pump house.

According to the graph of Fig. 11, it can be inferred from the month in which the project was applied there was a reduction in water consumption, this may be an indicator that the system contributed to this decrease, knowing also that other factors would have influenced the outcome.

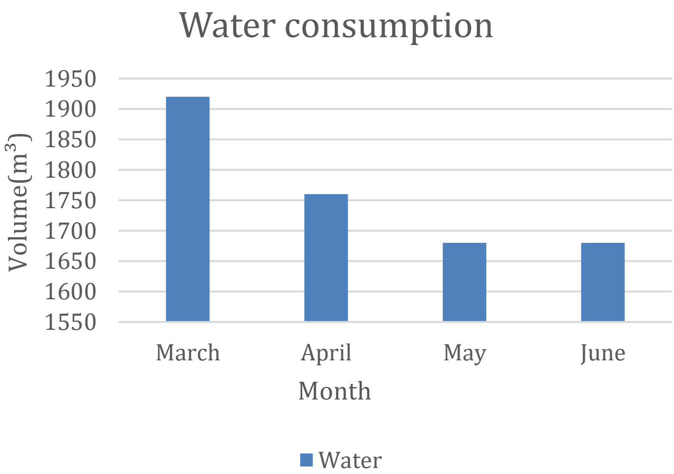

Figure 11. Graph of monthly payments paid by the condominium.

Due to reduced irrigation time, water and energy have been saved with the project implementation.

Irrigation allowed the garden to become greener, making it more beautiful, as seen in Fig. 12, after irrigation.

Figure 12. Image of the playground area "A1" before and after automated irrigation respectively.

The project can be easily applied in residential environments, providing labor-free irrigation.

Another important point is the facility of adaptation to new functions, because anytime the system can be turned off and used manually if necessary.

5. CONCLUSION

For the development of the system, it was necessary to survey the total area to be irrigated, types and quantities of sprinklers used, drive schedules, system and pump design, as well as knowledge in automation, programming, fluid mechanics and flow machines.

The irrigation project proved to be able to supply the necessary water demand for the residential condominium garden, obeying the theoretical techniques seen in the classroom.

It is interesting to note that the experience gained through this project also provided a broadening in the perspective of the designer in relation to a field of action of the Mechanical Engineering professional, where it was possible to pay attention to the existing possibilities regarding the range of solutions and interventions of Mechanical Engineering along with the existing problems in the project.

From this project it can be concluded that: Irrigation has been increasingly sought due to the need for continuous drainage of gardens, fields, lawns and plantations; The choice of sprinkler irrigation method was a determining factor for the project given the existing conditions and treated in the present work; the project generated energy savings, water savings, labor shortages and greater local beautification; The system was developed automatically without the need for manual control; The objectives were achieved through the implementation of the system.

It is suggested for the proper functioning of the system: Predictive and preventive maintenance, through the evaluation of water quality and system operation by residents and employees; Identification of water concentration points and drypoints.

For future work, it is intended to place the system monitoring through a computer by bluetooth signal, as well as activation, allowing the administrator to have control of the system while in the office.

6. REFERENCES

Aito Victorino, C.J., 2007. *Planet water dying of thirst.* EDIPUCRS, Porto Alegre, Rio Grande do Sul.

Çengel Yunus, A. and Cimbala John, M., 2007. *Fluid mechanics: fundamentals and applications*. São Paulo: McGrawHill, Bookman, AMGH, xiv, pp. 279-280.

DANCOR, 2009. “CAM Series CAM W-14 Multi-Purpose Centrifuge.” pump catalog. May. 2019 <http://www.dancor.com.br/dancor-site-novo/public/uploads/produtos/centrifugas/cat%C3%A1logos/cam-w14-pbe_cat.pdf>.

Ferreira Sousa, V., 2011. *Irrigation and fertigation in fruit trees and vegetables.* Embrapa Information Technology - Brasilia DF.

Fox, R.W., Mcdonald, A.T., Pritchard, P.J., 2006. Introduction to Fluid Mechanics. 6ª ed. Rio de Janeiro: LTC.

Hahn Aita, R., 2017. *Localized and automated irrigation system* - Completion of course work - control engineering and automation. Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre RS.

Henrique Souza, P.A.I., 2014. *Presentation of the calculations for selection of pumps for the system of reutilization of water of artesian wells*. Completion of the course.Federal University of Rio de Janeiro, Rio de Janeiro.

Laura Zocolotti, M., 2008. *Irrigation in Brazil situation and guidelines*, Ministry of National Integration. Brasília, DF.

MZ, 1998. “NBR 5626, Installation of cold water” 13 April. 2019 <http://mz.pro.br/hidraulicapredial/08-NBR_5626_Agua_fria.pdf>.

Marques, J.A.A.S. and Oliveira Souza, J.J.O., 2011. Hidráulica urbana. 3. ed. Coimbra: Universidade de Coimbra.

RAINBIRD, 2016. “Irrigation Product Catalog” Sprinkler Catalog. 10 Feb. 2019 < https://www.rainbird.com.br/upload/catalogofinal_virtual.pdf >.

Tangerino Hernandez, F.B., 2014. “*Irrigation Systems for All Purposes”.* 22 May. 2014 <http://www.agr.feis.unesp.br/sistemas.htm>.

Testzlaf, R., 2017. *Irrigation: methods, systems and applications”.* University of Campinas, Campinas.

7. RESPONSIBILITY NOTICE

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